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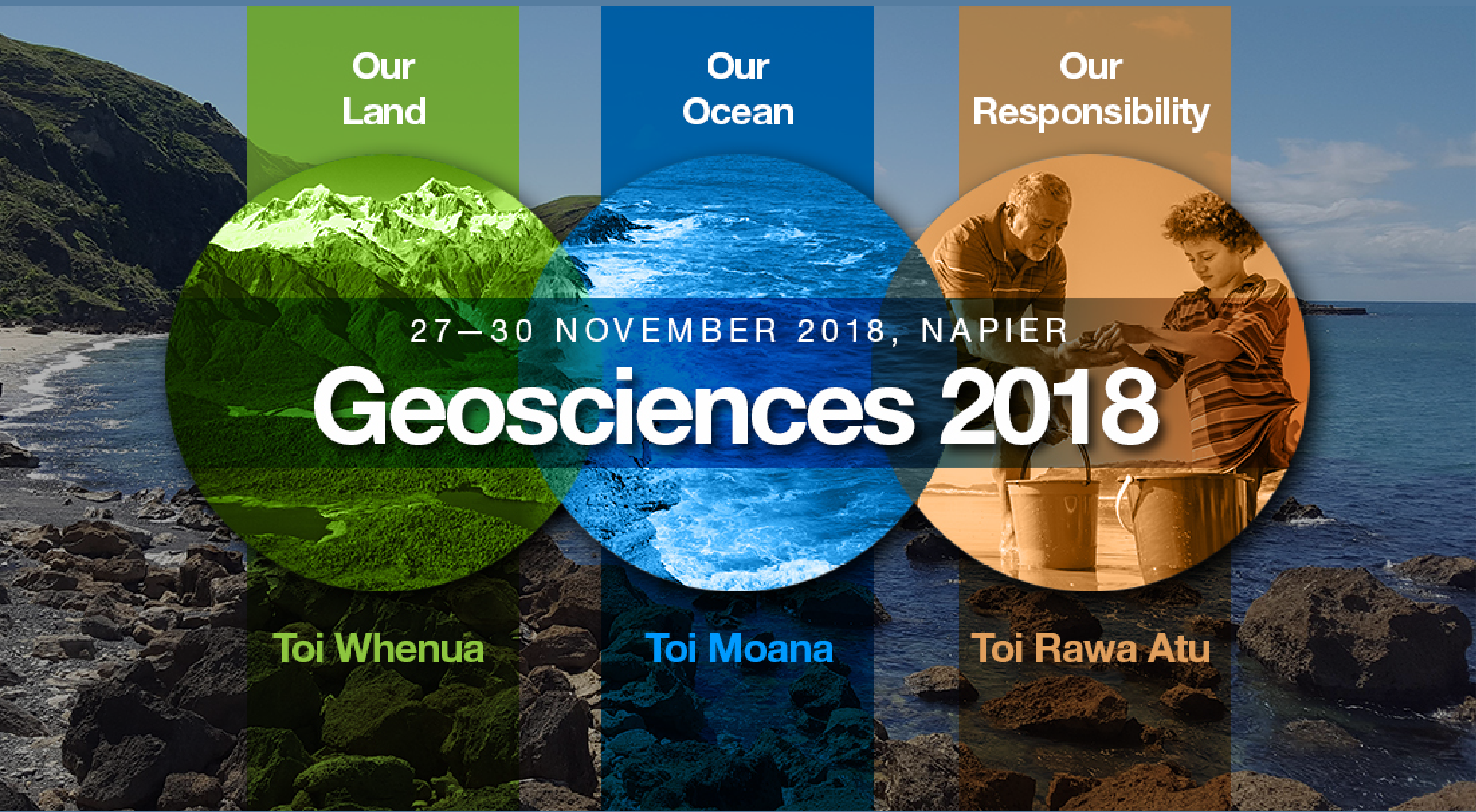

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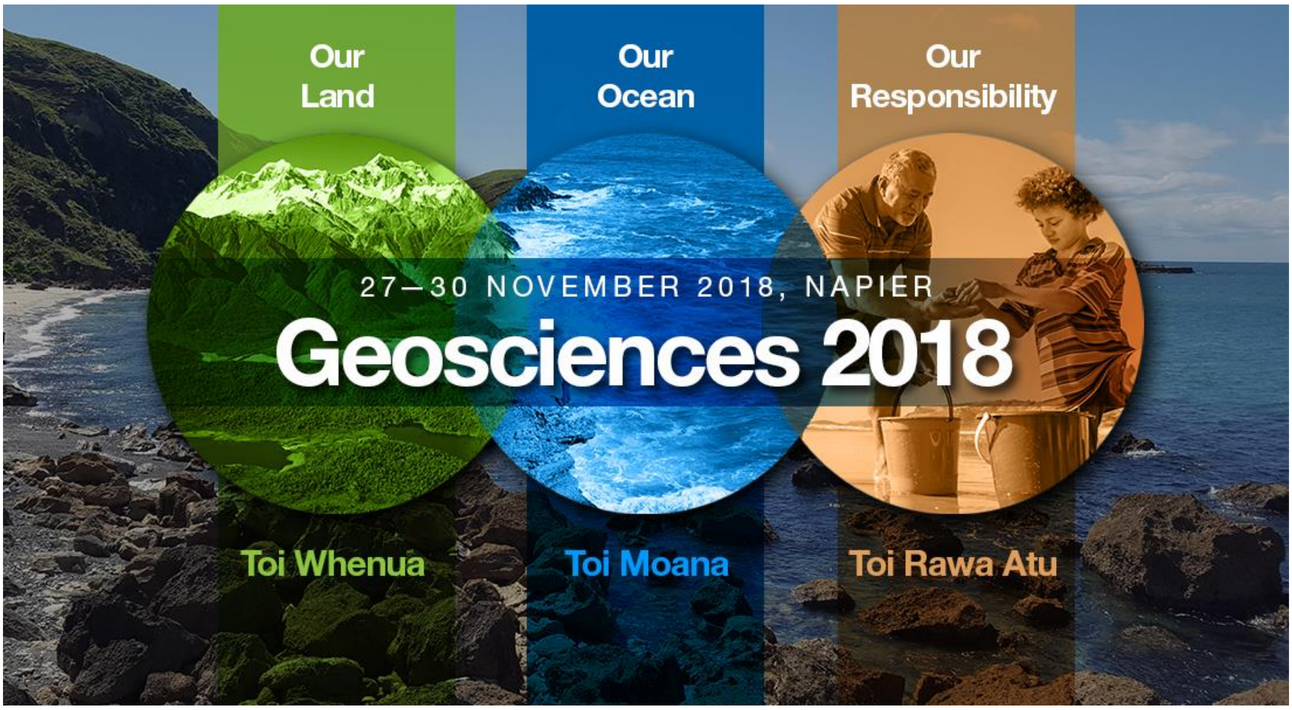

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Rupert Sutherland

THE HIDDEN CONTINENT OF ZEALANDIA YIELDS NEW EVIDENCE FOR HOW SUBDUCTION STARTS

Rupert Sutherland is a professor of geophysics and tectonics at Victoria University of Wellington. He was Co-chief Scientist of IODP Expedition 371 in July-September 2017.

THE HIDDEN CONTINENT OF ZEALANDIA YIELDS NEW EVIDENCE FOR HOW SUBDUCTION STARTS

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There are seven continents on Earth, but Zealandia is one of the least well known, because 96% of it lies submerged beneath the ocean. Northern Zealandia, a region about the size of India between New Zealand, New Caledonia, and Australia, was investigated during International Ocean Discovery Program (IODP) Expedition 371 in late 2017. The only previous expedition to sample this region to a similar depth was DSDP Leg 21 in 1971.

Subduction zones drive plate tectonics and global geochemical cycles, but little is known about how they start. The most profound subduction initiation event and global plate-motion change since 80 Ma occurred in the early Eocene, when Tonga–Kermadec and Izu–Bonin–Mariana subduction initiation corresponded with a change in direction of the Pacific plate (Emperor–Hawaii bend) at ~50 Ma.

Expedition 371 precisely dated and quantified deformation, uplift/subsidence, and volcanism associated with Tonga–Kermadec subduction initiation. Existing geodynamic models are not able to explain the range of observations we made, and a new class of model is currently under development. Our observations provide new insight into the role of subduction zone initiation as a continent-altering process.

Plenary 2:

Leanne Armand

OCEAN PLANET – ANZIC AND THE NEXT PHASE OF THE INTERNATIONAL OCEAN DISCOVERY PROGRAMME

A/Prof. Leanne Armand is the ANZIC (Australian and New Zealand International Ocean Discovery Program Consortium) Program Scientist and an ANU RSES researcher.

OCEAN PLANET—ANZIC AND THE NEXT PHASE OF THE INTERNATIONAL OCEAN DISCOVERY PROGRAMME

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The International Ocean Discovery Program (IODP), turned 50 this year. The program is recognised as the global community's longest and most successful marine geoscience program. Throughout the life of this program, the IODP scientific strategy has been to answer globally-significant research questions about the Earth's structure, and the processes that have, and continue to, shape our planet and its climatic history. The current strategic plan (2013–2023) has been shaped and delivered through international community-driven input. It is a plan that nations and other global research bodies consider when planning their own scientific plans and strategies. With the end of the current strategic plan fast approaching in 2023, the IODP Forum has opened discussion again to look at our current four themes (Climate and Ocean Change, Biosphere Frontiers, Earth Connections and Earth in Motion) and 14 challenges to decide on where our successes have been and what globally-significant research questions will next face our Ocean Planet. The Australian and New Zealand IODP Consortium (ANZIC) will again shape this future strategy with a new workshop "OCEAN PLANET—Developing the new IODP Strategic Plan 2024–2034" on April 14–16 2019. While we may reflect on how far we have come, and the successes of the past two years due to an IODP focus in our region, it is now time to think about how our nations, with support from our Universities, Government research institutions and agencies, will continue our strong collaboration and also provide input from our community (from early and mid-career through to established researchers) to ensure the global questions include those of relevance to our nations and the southern hemisphere.

Plenary 3:

Philip Barnes

DRILLING AND CORING THE NORTHERN HIKURANGI SUBDUCTION MARGIN TO UNLOCK THE SECRETS OF SLOW SLIP: INTERNATIONAL OCEAN DISCOVERY PROGRAM EXPEDITIONS 372 AND 375

Philip is a Principal Scientist in Marine Geology at the National Institute of Water & Atmospheric Research, New Zealand. His specialist interests are in active continental margins, plate boundary faulting, sedimentary systems, and marine geohazards.

DRILLING AND CORING THE NORTHERN HIKURANGI SUBDUCTION MARGIN TO UNLOCK THE SECRETS OF SLOW SLIP: INTERNATIONAL OCEAN DISCOVERY PROGRAM (IODP) EXPEDITIONS 372 AND 375

P Barnes[1], D Saffer[2], L Wallace[3], I Pecher[4], K Petronotis[5], L Levay[5] & IODP Expedition 372 & 375 scientists

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Slow-slip events (SSEs) at the northern Hikurangi subduction zone, New Zealand, are among the shallowest on Earth, and recur every 1–2 years. At depths of 2–15 km and potentially reaching the seafloor, they offer a unique opportunity to use scientific ocean drilling to investigate the processes and *in situ* conditions associated with SSEs. International Ocean Discovery Program (IODP) Expedition 375 (March–May 2018) together with part of Expedition 372 (November 2017–January 2018) were designed to address three broad scientific objectives: (1) characterize the incoming plate and shallow plate boundary fault near the trench, which represent the protolith and initial conditions for fault zone rocks hosting SSEs at greater depths; (2) characterize material and physical properties in the upper-plate above the primary SSE source further landward; and (3) install borehole observatories at two upper-plate sites to measure temporal variations in deformation, temperature, and fluid flow over multiple SSE cycles.

Preliminary results of logging-while-drilling (LWD; Exp. 372) and coring (Exp. 375) will be presented at four sites, tied to regional seismic reflection profiles. The two upper-plate sites were located within an active thrust fault near the deformation front and in a sedimentary basin above the high-slip SSE source region, respectively. Pleistocene mudstone samples and geophysical logs from the thrust fault zone provide insights into the composition, physical properties, and structure of a shallow splay fault that potentially hosts slow-slip behaviour, as well as providing constraints on the growth of the accretionary wedge. At two sites on the incoming Pacific Plate we sampled and logged the Early Cretaceous to Holocene sedimentary succession in the Hikurangi Trough and atop the Tūranganui Knoll seamount. These first drilling data from the Hikurangi Trough tied to seismic reflection profiles provide insights into the lithological and structural assemblages that may exist in the plate boundary fault zone undergoing slow-slip and other seismic phenomena.

Plenary 4:

Vaughan Stagpoole and Elana Geddis

10 YEARS OF THE NEW ZEALAND EXTENDED CONTINENTAL SHELF

Vaughan Stagpoole is Head of the Department of Marine Geoscience at GNS Science. He is a geophysicist with expertise in the application of geophysical methods to investigate the structure of the Earth. He was the compiler of the New Zealand UNCLOS submission and has provided technical advice on UNCLOS projects undertaken for several other countries.

Elana Geddis is a Wellington barrister, specialising in international and public law. She led New Zealand's submission to the United Nations Commission on the Limits of the Continental Shelf and has advised a number of countries on continental shelf issues

TEN YEARS OF THE NEW ZEALAND EXTENDED CONTINENTAL SHELF

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In September 2008 the United Nations Commission on the Limits of the Continental Shelf (CLCS) confirmed New Zealand's rights over approximately 1.7 million km^2 of seabed outside the EEZ. New Zealand now has sovereign rights over more than 5.7 million km^2 of ocean floor, about 1% of the surface of the Earth.

In 1996 New Zealand ratified the United Nations Convention on the Law of the Sea (UNCLOS) and set up the Continental Shelf Project. A multi-disciplinary and cross-governmental team was formed to carry out the project—including scientists, lawyers and administrators from GNS Science, National Institute of Water & Atmospheric Research (NIWA), Ministry of Foreign Affairs and Trade (MFAT), Royal New Zealand Navy (RNZN) and Land Information New Zealand (LINZ). The objective of the project was to define the outer limits of New Zealand's extended continental shelf—the area of seabed outside the EEZ that forms the "natural prolongation" of the landmass. From 1996 to 2004 the team planned and undertook surveys, processed and analysed the data. In 2004 New Zealand resolved our maritime boundaries with Australia, paving the way for the submission to be presented to the CLCS in 2006. After two years of close analysis, and six meetings with the New Zealand delegation, the CLCS adopted recommendations confirming the outer limits of the continental shelf. Those limits have recently been adopted in New Zealand law.

Tangible benefits from the project include acquisition of geoscientific data conclusively demonstrating the existence of the Zealandia continent, laid the foundations for new International Ocean Discovery Program (IODP) expeditions and enabled the granting of prospecting permits over the extended continental shelf. Policy regulators, explorers and the defence forces now have certainty about the rights and the obligations required for governing activities in this region. The growing global demand for resources and the development of deep-water exploration technologies offers the opportunity to discover and manage New Zealand's resources for economic, social and environmental security. There is enormous potential for New Zealand to benefit from its marine estate, and now the country has both the governing framework and the opportunity to develop a thriving marine-based economy should it wish to do so.

Plenary 5:

Ken Gledhill

ENHANCED GEOHAZARDS MONITORING FOR NEW ZEALAND

Ken Gledhill is currently on secondment from his role as Director of New Zealand GeoNet, a position he has held for more than 12 action-packed years, working as a technical advisor to the establishment of the 24/7 Geohazards Operations Centre.

ENHANCED GEOHAZARDS MONITORING FOR NEW ZEALAND

K Gledhill[1] & the wider GeoNet/EGM team[1]
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By the end of 2018, GNS Science will be operating a full 24/7 Operations Centre at the heart of GeoNet to deliver Enhanced Geohazards Monitoring (EGM). The centre will monitor and respond rapidly to all geological perils, but over time will also take on the monitoring of GeoNet's data collection systems. At launch the fundamental change will be the fully staffed 24/7 operation, with at least two people on site at all times, complementing our continuing duty system comprising subject matter experts. Over the last year GNS Science have completed a business case for EGM, recruited an Operations Centre Manager and 15 Geohazards Analysts to staff the centre, and completed the construction of the centre at our Avalon site. Our Wairakei site will serve as back-up and we are working through options for short-term and international back-up of our critical capabilities. The Geohazards Analysts have undergone intensive training for the last five months and will be ready for the launch in December after beginning "shake-down" operations in late October. This signals a new phase in the development of GeoNet, which began operation in 2001, primarily with funding from the Earthquake Commission (EQC) and Land Information New Zealand (LINZ). Now with additional funding for EGM from the Ministry of Business, Innovation & Employment (MBIE) and close engagement with Ministry of Civil Defence and Emergency Management, GeoNet is an exemplar of cross-government collaboration for the benefit of New Zealanders and is an integral part of GNS Science. Over the last decade GeoNet has demonstrated its value through numerous earthquakes, tsunami, volcanic and landslide events, most recently the Kaikōura Earthquake and tsunami in November 2016. The value of fast, reliable geohazards information for decision makers was critical during and following these events to ensure New Zealanders respond rapidly and appropriately to the natural perils we face.

Plenary 6

Nick Golledge

CAUSES AND CONSEQUENCES OF 21ST CENTURY ICE SHEET MELT

Nick is an Associate Professor at the Antarctic Research Centre, Victoria University of Wellington. His research involves using computer models to simulate the Antarctic and Greenland ice sheets in order to predict the consequences of future environmental changes. He was a winner of the 2017 McKay Hammer Award.

CAUSES AND CONSEQUENCES OF 21^{ST} CENTURY ICE SHEET MELT

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Even with government pledges to reduce greenhouse gas emissions as part of the Paris Agreement, we are likely committed to 3–4 °C surface warming above pre-industrial levels by 2100 CE, leading to enhanced ice sheet melt. The global impacts of this increasing ice sheet discharge are unclear, because the climate simulations most commonly used to inform governmental policy do not incorporate ice sheet meltwater fluxes. To address this shortcoming, we can use satellite-based measurements of recent ice mass change to constrain Greenland and Antarctic ice sheet simulations. Doing this, we predict an ice sheet contribution to sea-level of 25 cm by 2100 CE. If we then also model the environmental impacts of this melt on the ocean and atmosphere, we find that meltwater from Greenland slows Atlantic overturning circulation, whereas meltwater from Antarctica traps warm water below the sea surface, creating a positive feedback that increases Antarctic ice sheet retreat. Greenland contributes linearly to sea-level rise under a warming climate, whereas the response from Antarctica emerges mid-century once dynamic thinning outweighs increased snowfall. Using a sea-level model to predict the redistribution of meltwater, we are able to identify that central Pacific island nations will most likely experience the greatest sea-level rise.

ABSTRACTS

Abstracts are organised alphabetically by the surname of the first author. The name of the presenting author is underlined, and their email address is given immediately below the list of affiliations. Postal addresses for New Zealand-based authors are provided along with their affiliation(s), while affiliation(s) of international authors are given as provided.

Abstracts presented as part of the 7th Symposium of the IGCP 632 project “Continental Crises of the Jurassic: Major Extinction events and Environmental Changes within Lacustrine Ecosystems” bear the project logo:

SEISMIC ANISOTROPY AND ITS IMPACT ON IMAGING THE ALPINE FAULT: AN EXPERIMENTAL AND MODELLING PERSPECTIVE

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Seismic methods are used to develop our understanding of fault zone geometry and to infer its physical properties. Seismic wave anisotropy can be significant in fault zones due to structural characteristics such as the spatial distribution, texture, and crystallographic preferred orientation (CPO) of minerals (i.e., tectonite fabric tensor), as well as fractures and regional stress variation. Still, a quantitative treatment of seismic anisotropy that would allow imaging of fault zones from reflection or passive seismic data is rare. Here we combine experimental and numerical methods to establish the implications of elastic wave anisotropy in a quartzofeldspathic mylonite for seismic imaging of the Alpine Fault.

P-wave elastic wave anisotropy of the mylonite is estimated by common experimental methods, namely ultrasonic wave propagation under confining pressure and numerical modelling based on scanning electron backscattered diffraction (EBSD) data. EBSD-modelled anisotropy is estimated from the (static) effective media elastic tensor following a Voigt–Reuss–Hill averaging (MTEX) and with dynamic simulation of wave propagation using finite element modelling (FEM). The numerical results show a 16–20% anisotropy based on two EBSD sections. The FEM results show a lower slow P-wave velocity compared to MTEX as the method is sensitive to both CPO and the spatial distribution of minerals. Moreover, the dynamic nature of the FEM allows simulating scattered and guided waves. The laboratory measurements show much higher anisotropy (27% and 31% at pressures equivalent to 15 km and 5 km depth, respectively), because micro-cracks remain open at pressures representative of the Alpine Fault seismogenic zone. Our study shows wave speeds that match those from Alpine Fault Drilling Project (DFDP-2) sonic logs, providing an explanation of the identified low velocity zones. Finally, we show that in the brittle regime high seismic reflectivity at near-vertical incidence to the fault plane can be explained by accounting for elastic wave anisotropy and foliation-parallel fractures identified in our experimental study.

RESOLVING FINE-SCALE VELOCITY STRUCTURE OF THE PLATE BOUNDARY IN THE NORTHERN HIKURANGI MARGIN FROM THE NZ3D OBS SURVEY

R Arai[1], S Kodaira[1], R Kellett[2], V Stucker[2], D Bassett[2], S Henrys[2], K Obana[1], N Bangs[3], D Barker[2], R Bell[4], K Mochizuki[5], S Miura[1], B Fry[2] & NZ3D team

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To investigate physical properties and structural controls on slip processes on shallow megathrust faults, we collected 3-D seismic refraction/wide-angle reflection data in the northern Hikurangi margin, offshore Gisborne, New Zealand, as part of a community 3-D seismic project, NZ3D. Various types of slow earthquakes are known to occur in the survey area. These include shallow slow-slip events, low-frequency tremor and slow tsunami earthquakes, associated with the subduction of a large seamount. For the 3-D reflection survey, over 140,000 airgun sources were triggered every 25 m in an area of 60 × 14 km ranging from the northern Tuaheni landslide complex and the easterly forearc slope to the subduction trench. Within this rectangular area, we deployed 100 JAMSTEC ocean bottom seismometers (OBSs) with an average spacing of 2 km on 4 parallel lines, using the *RV Tangaroa,* to record airgun signals generated by the RV *Marcus G Langseth*. Ninety-seven out of 100 OBSs successfully recorded the seismic data, providing one of the largest and densest 3-D OBS datasets in subduction zones worldwide. The OBS data are of good quality and include long-offset refraction waves, which will be utilized to finely image the plate boundary structure as well as the fault structures in the overriding plate. On the other hand, the primary refraction phases are contaminated with high-amplitude direct water waves from previous airgun sources, which requires additional pre-processing. In this presentation, we describe the OBS data, preliminary P wave velocity models from travel time analyses and our future processing strategy, including application of a full waveform inversion technique to the OBS data.

ELECTRICAL SELF-POTENTIAL SIGNATURES OF HYDROTHERMAL SYSTEMS: NUMERICAL MODELING AND APPLICATION TO LUSI MUD VOLCANO

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Mud volcanoes and hydrothermal systems are potential natural hazards to environment and humans. In May 2006 LUSI mud volcano in Indonesia started to erupt in a highly populated area and displaced over 50,000 people. The eruptive behaviour and sub-surface fluid transport of mud volcanoes are still poorly understood. In order to investigate and monitor such phenomena the electrical self-potential method provides a useful tool. The naturally occurring self-potential can arise by various mechanisms, while this study focused on the streaming and thermoelectric potential resulting from fluid and heat flow, respectively.

This study is the first numerical simulation including the thermoelectric potential (TEP) at a mud volcanic complex, which is compared to the streaming potential (SP) less studied and often neglected. For the purpose of investigating the main contribution to the measurable self-potential at the surface, a model was implemented with COMSOL multiphysics.

The modelling results identify the TEP-anomaly as the main contribution to the arising self-potential signature, with values four times higher as the SP-anomaly at the crater of LUSI. The spatial pattern of the TEP exhibits a dome-like structure, collinear to the temperature distribution, while the SP shows radial structures at the bottom and top of the feeder channel. The simulated self-potential anomalies within this study are in good agreements with measured values in volcanic and hydrothermal areas worldwide.

To adapt the TEP-model of LUSI mud volcano to a more realistic state, laboratory investigations of significant thermoelectric properties, as well as examination of time-dependent eruptive dynamics are essential. In conclusion this master's thesis indicates that the electrical potential at a mud volcanic system is strongly influenced by the TEP-anomaly and should be considered at further volcanic and hydrothermal areas to explain the arising electrical anomalies and sub-surface processes.

THE CASE FOR A UNESCO CAVES & KARST GEOPARK AT WAITOMO

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The global uptake of the Geopark concept is patchy. UNESCO Geoparks are widespread in Western Europe and East Asia, but there is only one in the Southern Hemisphere. What are the purposes and benefits of Geoparks and should we participate? In New Zealand we are well-served by National Parks and reserves, but in terms of formal conservation recognition some important areas have "slipped between the cracks". Such areas include the volcanic features around Rotorua, the braided rivers of Canterbury, the Chatham Islands, karst landscapes at Waitomo, and the Bay of Islands.

Nomination of an area as a UNESCO Geopark must be a bottom-up process, because even though the geological attributes may be outstanding, the site cannot operate successfully without committed and sustained local support. A Geopark is required to showcase the relationship between the people and the land, but cultural sensitivities may constrain what is revealed. Some significant features may be on private land, so issues of privacy, personal safety, and cost of access may pose barriers.

Here we consider these requirements and the extent to which they are met by a potential Caves and Karst Geopark at Waitomo. Important considerations are: international quality geological attributes, ownership, legal status and public access to key field sites, depth of community support for the venture, assurance of on-going financial support, and facilities for and continuity of quality management. We conclude that the geological features meet Geopark requirements, in many ways the Discovery Centre (Caves Museum) already operates as a Geopark information centre, many local people welcome the initiative because of perceived economic benefits, but wider concerns amongst some farmers and tangata whenua must be resolved before a nomination can be made.

GEOPHYSICAL CONSTRAINTS ON THE RELATIONSHIP BETWEEN SEAMOUNT SUBDUCTION, SLOW SLIP AND TREMOR AT THE NORTH HIKURANGI SUBDUCTION ZONE, NEW ZEALAND

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We use a pre-stack depth migration reflection image and magnetic anomaly data across the northern Hikurangi subduction zone, New Zealand, to constrain the structure of the plate boundary and the geometry of a subducting seamount in a region of shallow slow-slip and recent International Ocean Discovery Program (IODP) drilling. Our 3-D model reveals the subducting seamount as a SW–NE striking lozenge-shaped ridge approximately 40 km long and 15 km wide, with relief up to 2.5 km. The subducting seamount is found to broadly correlate with a 20-km-wide gap separating two distinct patches of large (>10 cm) slow-slip and the locus of tectonic tremor associated with the September–October 2014 Gisborne slow-slip event (SSE). The largest slow-slip magnitudes occurred where the décollement is underlain by a 3.0-km-thick zone of highly-reflective subducting sediments. Wavespeeds within this zone are 7% lower than adjacent and overlying strata, supporting the view that high fluid pressures within subducting sediments may facilitate shallow slow-slip along the north Hikurangi margin.

ASH DISPERSAL FROM FUTURE ERUPTIONS OF TAUPŌ SUPERVOLCANO

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Hazard analysis at caldera volcanoes is challenging because of the wide range of potential eruptive sizes and conditions that can plausibly occur in any single event. Taupō volcano is one of the most frequently active and productive calderas on Earth and host to the youngest known supereruption ~25,400 ka. Over the past 12 kyr there have been at least 25 more eruptions that span 3–4 orders of magnitude in size and recent studies suggest that there is still a large magma system present. We have combined Taupō's eruptive record with one of the most advanced ash dispersal models, Ash3d, to build a better understanding of which areas of New Zealand would experience ashfall across a range of eruption sizes and wind conditions. For the smallest eruptions considered (~0.1 km^3 magma), ashfall to >1 cm thickness is largely confined to the central North Island and dispersal is dictated mostly by day-to-day weather. Only major population centres in the eastern North Island between Tauranga and Hastings can expect >1 mm ashfall at 10–30% probability. However, with increasing eruption sizes (1–5 km^3), the probability of ash thickness to reach damaging levels (10–100 mm) becomes increasingly significant. With increasing eruption magnitude, ash dispersal becomes less dependent on weather, as the formation of a major umbrella cloud may force ash upwind or cross-wind. For the largest eruptions (50–500 km^3), ash thicknesses associated with major damage (100 mm) or severe structural damage (>300 mm) can be expected at high probabilities in most major North Island towns. Particular weather conditions result in increased probabilities of ashfall in different locations. Light winds associated with a high-pressure system over New Zealand generally lead to the highest probability of ashfall at major cities. In contrast, strong dominant westerly winds lead to a significant amount of ash being distributed offshore.

DUNEDIN URBAN GEOLOGICAL MAP

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As part of the GNS Science Urban Geological Mapping project, a 1:25,000-scale geological map encompassing the Dunedin urban area has been compiled. The new GIS-based map updates previously published geological maps at 1:50,000 (Benson 1968, NZ Geological Survey Miscellaneous Series Map 1) and 1:25,000 scale (McKellar 1990, NZ Geological Survey Miscellaneous Series Map 22). Although an adjunct geomorphological map is commonly prepared as part of each GNS Science urban map project, this was considered unnecessary for Dunedin, because its combination of distinctive stratigraphic units and topographic relief makes for extensive outcrop of the various strata. Thus, Dunedin’s geological structure is generally well expressed at the surface, and the geological map alone is richly informative. This contrasts with locations such as Christchurch where most stratigraphic units are concealed under Late Quaternary deposits (Begg et al. 2015, GNS Science Geological Map 3). The Dunedin geological map is augmented by 3-D representation of the geological structure via structure contour maps on three key geological boundaries: top of the Otago Schist/base of Zealandia Megasequence; base of the Dunedin Volcanics, and base of Quaternary sediments.

The Dunedin geological map compilation has benefited from companion research on active fault hazards funded by the Natural Hazards Research Platform (Villamor et al. 2018, GNS Science miscellaneous series 124; Villamor et al., this volume), and EQC (Barrell et al. 2018, GNS Science Report 2017/035) that has improved the understanding of Dunedin’s fault and fold structures, and demonstrated that the Titri Fault has experienced at least 2 surface ruptures since ~38 kyrs ago and extends beneath Dunedin as a blind structure.

KAIKŌURA EARTHQUAKE: HUNDALEE FAULT PALEOSEISMOLOGY

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Originally mapped as a major bedrock fault, ~30 km long and with a vertical component of Late Cenozoic displacement of >1 km, the northeast-striking Hundalee Fault ruptured along at least 23 km of its length during the 2016 Kaikōura Earthquake (Williams et al. 2018, Bull. Seismol. Soc. Am. 108: 1540–1555). The 2016 surface ruptures were surprisingly diffuse and discontinuous for such a major fault, with rupture strands as much as 0.8 km off the line of the bedrock fault. The 2016 movement sense was oblique reverse-dextral on east–northeast-striking strands of the fault, and reverse-sinistral on north–northeast striking strands, consistent with the regional principal strain axes. Although not mapped from a paleoseismological perspective prior to the earthquake, post-quake field examination revealed pre-existing surface rupture traces in several locations, mostly on relatively youthful steep hillslope terrain. One pre-existing scarp, ~2 m high, that runs across an alluvial terrace of Okarahia Stream, experienced ~0.5 m of reverse-sinistral 2016 rupture and was judged suitable for trenching to determine previous rupture history. The trench revealed a ~2 m reverse-sense vertical separation of lensoidal-bedded alluvial gravel and silt focused on a thrust plane of overall dip ~30° northwest. The deformation was a combination of discrete offset as well as broad folding, and we could not differentiate how much of the folding arose from the 2016 rupture or from previous rupture. Only minor colluvial deposition followed this earlier event, consistent with minimal scarp modification. There was no evidence of more than one prior event recorded at this site. Detrital charcoal is common in the alluvial silt and two samples from the middle of the faulted sediment package were radiocarbon-dated, returning calendar ages of 3550 ± 83 and 3499 ± 68 years BP. These ages are maxima for the penultimate rupture of the Hundalee Fault at this location.

LATE CRETACEOUS-EOCENE UNDERFILLING OF THE CANTERBURY BASIN: WHAT DOES IT TELL US ABOUT EASTERN GONDWANA LANDMASS EVOLUTION?

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Extension across Zealandia from ~110/105 to ~83 Ma immediately prior to Gondwana break-up produced a widespread rift province forming several rift basins, which are now best preserved in offshore New Zealand. The Canterbury Basin, east of South Island of New Zealand, was one of these mid-Cretaceous rift basins that was part of a basin and range topography though barely filled by sediments.

The early syn-rift sedimentation was dominated by alluvial fans developed along fault scarps into braided rivers flowing along the axis of rift valleys. Downstream these rivers connected either to lakes or to the sea that was progressively transgressing inland. After the onset of eastern Gondwana break-up at ~83 Ma, sediments progressively onlapped structural highs that were acting as sediment sources. Once the marine transgression covered structural highs, and horsts no longer provided sediments to nearby areas, pelagic sedimentation dominated and draped horsts that were below wave action. During the Paleocene and Eocene, a ramp system parallel to the present-day coastline developed in the basin. More distally, deep-water fans accumulated at the toe of the ramp along the topographic depressions adjacent to the buried horst. By the end of the Eocene, sediments almost covered the entire rift paleo-topography showing that the rift topography remained dominant in the basin for a protracted period of time.

The underfilling of the Cretaceous rifting arose because fault displacement rates exceeded sedimentation rates by up to a factor of 1.5. Why could the sediment supply not keep-up with creation of accommodation space? We suggest that whether the rift basin fills with sediment depends on a number of factors such as the duration of the rifting, the paleo-climate and the topography of Eastern Gondwana landmass that controlled the sediment supply, routing pathways, and the type of drainage system present.

THE RELATIONSHIP BETWEEN FOREARC STRUCTURE AND GEODETIC LOCKING ALONG THE HIKURANGI MARGIN FROM SHIRE SEISMIC DATA

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Active source seismic data recorded by 49 Ocean Bottom Seismographs and a 12.7-km-long streamer constrain crustal structure along a 600 km margin-parallel transect of the Hikurangi subduction zone. The subducting Hikurangi Plateau exhibits crustal P-wave velocities (V_P) of 5.0–7.5 kms^{-1} over a 12 ± 2-km-thick interval and mantle wavespeeds increase from 8.0 km s^{-1} to >9.0 kms^{-1} at <30 km depth. The subduction interface is located at 10–12 km depth. We observe a sharp along-strike transition in the forearc crustal structure. The northern half of the transect is characterized by ~4 km of basin fill (<3.5 kms^{-1}) and forearc crustal wavespeeds are <5.0 kms^{-1}. The southern half of the transect is characterized by wavespeeds that are 0.5 kms^{-1} faster at all levels of the forearc crust. The transition zone is <10 km wide and is well-correlated with a sharp north-to-south reduction in water-depth across the forearc trench-slope. It is also well-correlated with the north-to-south increase in slip-rate deficit that marks the transition from a creeping megathrust in the north to an interseismically locked megathrust in the south. We will describe a range of physical and geological interpretations for the observed transition in crustal structure and its relationship to the slip-behaviour of the subduction interface.

COMPLEX RELATIONSHIPS AND COMPOSITIONAL VARIATION, AT THE ONSET OF DUNEDIN VOLCANISM

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Intraplate volcanism is common across the world, yet details of its mechanisms remain incompletely understood. Typically rocks from the earliest activity are not exposed at modern, active, intraplate volcanoes, make investigating such processes difficult. By studying the eroded remnants of ancient volcanoes, such as the Dunedin Volcanic Complex (DVC), we can learn about the initial magmatic/volcanic activity of intraplate volcanic systems. The DVC was a long-lived volcanic centre, active from 16 to 10 Ma. Allans Beach on the south-eastern coast of the Otago Peninsula is one of the oldest known exposed sections of the DVC and contains early-erupted and intruded products with a compositional range extending to phonolite. Whole-rock XRF analyses of new samples from this area have confirmed a wide compositional range from alkali basalt to trachyte. There are complex contacts of mingled dikes including alkali basalt, basalt, and trachyte, intruded near contemporaneously. Within this mingled mass of dikes, is one dated in a previous study at 16.0 Ma. The short timing between emplacement of these compositionally diverse dikes indicates that multiple magmas were active, and intruding the area, early in the history of the DVC. Cross-cutting relationships show that these rocks are not the oldest of the field site because other dikes are cross-cut by these, and all the dikes are hosted within a volcaniclastic deposit. Whole-rock major, minor and trace element patterns, along with petrographic textures and mineral data collected on electron microprobe analyser (EMPA), indicate that fractionation and magma mixing produced the range of rock types and compositions at Allans Beach. Based on field data, drone photogrammetry and paleomagnetic studies, it is shown that diatremes and the dike complex are penecontemporaneous and were emplaced into a bedded sequence of unconsolidated pyroclastic deposits of evolved composition.

INFERENCE OF HEAT AND STEAM INPUT INTO RUAPEHU CRATER LAKE FROM GEONET DATA

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Crater lakes on active volcanoes act like a filter, allowing valuable insight into the heat and steam output from the vents entering the lake. Monitoring changes in temperature, water mass and ion concentration can, therefore, serve as proxies for changes in gas-release by the melt zone beneath the volcano. While the underlying physical model of energy and mass balance for volcanic crater lakes in general and Ruapehu Crater Lake (Te Wai ā-Moe) in particular was established 30 years ago, GeoNet's latest improvements to storing and providing low-rate continuous measurements of water level and water temperature have largely facilitated automatic inference of heat and steam flux into Ruapehu Crater Lake. Our new probabilistic estimates give us an improved understanding of the behaviour of Ruapehu Crater Lake during and between heating cycles and point out necessary improvements in lake observables to further constrain the inferred results.

AN IMPROVED UNDERSTANDING OF THE CENOZOIC EVOLUTION OF THE CAMPBELL PLATEAU USING SUB-BOTTOM PROFILE DATA

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The Campbell Plateau represents ~30% of the submerged continent of Zealandia's landmass, and is an original piece of the Gondwana continent with a geologic history stretching back to the break-up of this supercontinent at ~98 Ma. The focus of this MSc thesis is to use sub-bottom profile data collected in 2017 and 2018 on Campbell Plateau to improve our understanding of the Cenozoic evolution of the region. The sub-bottom profiles show a rugged basement overlain by a variety of sedimentary structures and sub-surface features such as volcanoes, onlap and downlap surfaces, as well as multiple unconformities that can be traced across the plateau. The sub-bottom profiles are compared to two drill cores; Ocean Drilling Program (ODP) 1120 and Deep Sea Drilling Project (DSDP) 277, which indicate that the lithology from the Cretaceous onwards is predominantly biogenic sand and mud, which changes to nanofossil-rich oozes from the Miocene through to the latest Pliocene. The paleoceanography of the Southern Ocean is the main driver of these lithological, plateau-wide sedimentological structures, especially in the southern section of the plateau, which appears to be more dynamic, having more evidence of onlap/downlap surfaces, current scours, and erosional surfaces indicating the removal of sedimentary units. In contrast, the northern section of the plateau is relatively quiescent with thinner, relatively uniform horizontal strata.

THE AKAROA VOLCANIC COMPLEX: A COMPLEX MAGMATIC SYSTEM

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The Akaroa Volcanic Complex (AVC) is the younger (8–12.4 Ma) and more mafic of the two major phases of volcanism associated with the formation of Banks Peninsula. Due to a lack of exposed plutonic material, very little work has focused on the magmatic system feeding this large, long-lived volcanic complex. Plutonic lithics (erupted remnants of the magmatic system) are found throughout the lava flows, plugs, and domes of the AVC and reveal considerable variation in chemistry, mineralogy, crystallographic fabrics, and 'rheology' of the magmatic system.

A multi-method (EBSD, EDS, colour-CL, and major element XRF) approach is used to parse out the magmatic processes and conditions responsible for the variations observed. Plutonic lithics from five locations are presented here. Lithics are geochemically related to one another along the same increasing silica and alkalis trend documented for AVC volcanics. Lithic locations are often geochemically and mineralogically distinct, suggesting that these volcanic features sourced different sections of the magmatic system.

Crystallographic fabrics are dominated by plagioclase or pyroxene and, when non-random, reflect compressive forces with no evidence of tectonic overprinting. Novel colour-CL maps of full thin sections reveal the presence of frozen interstitial melt, which has considerable variation in luminescence and distribution, often with an inverse correlation between fabric strength and melt volume. Preliminary EDS results show that melt compositions are more felsic than plagioclase phenocrysts, suggesting progressive magmatic differentiation and melt extraction.

The wide variety in chemistry, fabrics, and melt distribution suggests that the AVC was a more complex magmatic system than previously reported. AVC lithics suggest that the magmatic system was varied in crustal space and time, giving rise to diverse crystallisation conditions, crystal organisation and deformation, and cooling/reheating histories. Additionally, we propose that a layered intrusive model fits the variations observed in AVC lithics across multiple locations.

MAGMA IMAGED BY ARRAY MT DATA IN THE TAUPŌ VOLCANIC ZONE

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More than 1000 broadband magnetotelluric (MT) measurements (with 2 km site spacing) have been acquired to form two arrays in the central part of the Taupō Volcanic Zone (TVZ), New Zealand. The TVZ is an actively rifting volcanic arc, with a central segment representing the largest rhyolitic volcanic system on Earth (since ~340 kya). Heat flux across the TVZ is more than ten-times the global mean for continental crust and is discharged through more than 20 high-temperature geothermal fields.

Previous results using subsets of these array MT data provide the first-ever images of connections between the shallow parts of the known geothermal fields and their deeper underlying (magmatic) heat source. Variations observed between the basement roots of the geothermal fields imply a strong connection with tectonic and volcanic structure that was not previously envisaged. The conceptual model of heat transport in the brittle crust is now advanced to a model of episodic intrusion around the geothermal fields, modulating the broad pattern of overall convective heat transport.

Recent MT measurements cover the Okataina Volcanic Centre (which has erupted 80 km^3 within the past 22 ka) and include Mount Tarawera; a series of rhyolite domes that experienced a Plinian basalt fissure (17 km long) eruption in 1886. 3-D resistivity inversion models of MT data in the Okataina Volcanic Centre suggest that Mount Tarawera straddles the eastern margin of a large basement low-resistivity zone. Global Positioning System and InSAR observations of subsidence (up to 2 cm/yr) located above this low resistivity zone support interpretation as a body of magma, cooling-off (and contracting) within the upper crust.

NATURAL AND HUMAN ENVIRONMENTAL IMPACT FROM LAKE HOROWHENUA

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A record of natural variability and human-induced environmental change has been reconstructed from Lake Horowhenua; a turbid hypertrophic dune lake on the west coast of the lower North Island. A range of proxies (palynology, charcoal analysis, sedimentology/grainsize, XRF geochemistry, radiometric dating (^{14}C, ^{210}Pb and ^{137}Cs) have been used to track how the lake catchment responded to natural and anthropogenic events over its lifetime. This work represents one of the first comprehensive multiproxy studies from lakes of the Manawatu–Horowhenua sand country. 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. Prior to human arrival, sedimentological, pollen, charcoal, and algal data indicate a stable environment with a dense podocarp–hardwood forest dominated by *Dacrydium cupressinum,* little catchment disturbance, and high water quality. Pollen and charcoal data support arrival of Polynesians to the area at 1431–1464 AD at the latest. Two phases of European impact are captured within the sediments. Phase one comprises a decrease in tall forest taxa, the appearance of introduced grass species, and *Pinus radiata,* and increased sedimentation rates. Phase two begins with increase of nutrients into Lake Horowhenua evidenced by *Pediastrum*, and a further increase in sedimentation rates. The archive of information retrieved from the sediments of Lake Horowhenua will be a key resource informing lake restoration efforts currently underway.

CHARACTERISATION OF A MIDDLE MIOCENE BURIED VOLCANIC FIELD IN THE CANTERBURY BASIN, EASTERN ZEALANDIA

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Many buried volcanoes occur within New Zealand offshore sedimentary basins. Here we study the formation of the Maahunui Volcanic Field (MVF), a cluster of buried monogenetic middle Miocene volcanoes in the offshore Canterbury Basin. To characterise igneous processes in the MVF, which is 40 km south of Banks Peninsula, we use bulk geochemistry, optical petrology, XRF and SEM–EDS analysis of volcanic fragments, interbedded with bathyal siltstones, and a monzogabbro recovered from the Resolution-1 well at depths of 1103.5 to 1200 m, and 1963 m, respectively. Volcanic rocks comprise altered, very fine to granule size fragments of vitreous to microcrystalline basalts. Less altered fragments show primary mineralogy with interlocking microcrystals of plagioclase and pyroxene. Shard fragments with blocky shapes are common and could indicate phreatomagmatic eruptions and/or quenching fragmentation. Shards with cuspate and cuneiform shapes have also been identified, suggestive of explosive eruption styles. Pelloital aggregates of altered glass, plagioclase and pyroxene, and spherulitic textures were also observed and may suggest H_2O–magma interaction. The monzogabbro was emplaced in a sequence of paralytic to deep-marine strata and shows ophitic texture and miarolitic cavities, which indicates an intermediate magma cooling rate and that the magma was injected at shallow depths in the basin. XRF results indicate an average bulk composition of 50 wt% SiO_2, 5 wt% MgO, and high Fe, Mg, K, Ca and Ti contents for the monzogabbro. The volcanic fragments have similar compositions. Seismic reflection lines with geochemical and petrologic data support the notion that the monzogabbro and the basalts were produced during the same magmatic event, which formed a tuff cone volcano at 1000 to 1500 m water depth.

ARSENIC REDISTRIBUTION IN LOESS ABOVE THE HYDE-MACRAES SHEAR ZONE, OTAGO, NEW ZEALAND

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Loess overlies portions of the Otago Schist in the vicinity of the Hyde-Macraes Shear Zone, which is a major orogenic gold producing region of New Zealand with >10 Moz of gold. The overlying loess forms a mantle 0.5 to 7 m thick and makes surface identification of hard-rock zones of mineralization difficult to impossible on a local and regional scale. Known gold ore deposits in the Hyde-Macraes Shear Zone are typically accompanied by high concentrations of arsenopyrite in surrounding schist at the 1 to 10 m-scale, allowing the use of arsenic as a potential pathfinder element for zones of gold mineralisation. Oxidation of arsenopyrite from primary mineralised zones leads to mobilisation of arsenic, which has infiltrated overlying loess at the recently exposed Hoopers outcrop in the southeast part of the Hyde-Macraes Shear Zone, creating a spatial footprint of at least 90 cm of arsenic enrichment where loess overlies mineralised structures in the schist. Identifying changes in the mineralogy and mobility of arsenic from sulphides in mineralised schist, to secondary arsenic minerals in loess and the resulting footprint of enrichment, can have significant implications for its use as a geochemical indicator of gold ore zones obscured by the loess mantle in Otago.

PALEO-PRODUCTIVITY IN THE SW PACIFIC OCEAN DURING THE EARLY HOLOCENE CLIMATIC OPTIMUM

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The oceans are warming, but it is unclear how marine productivity will be affected under future climate change. In this study we examined a wide range of paleo-productivity proxies along a latitudinal transect (36–58°S) in the SW Pacific during the early Holocene climatic optimum, to explore regional patterns of productivity in a slightly warmer-than present world. In agreement with the modern biological oceanography, the majority of the proxies in the late Holocene show that the highest overall productivity is at, or immediately adjacent to the Subtropical Front (STF). During the early Holocene there is a small increase in productivity in the subtropical waters (STW), no change at the STF, and conflicting evidence in records immediately south of the STF, where an increase is inferred from one core site, but not at the other. Evidence for an increase in productivity in Antarctic Surface Waters (AASW) south of the Polar Front (PF), is also equivocal. We infer the increase in productivity in STW and the ocean just south of the STF was associated with changes in the ocean circulation of the SW Pacific, driven by changes in the Southern Hemisphere Westerly Winds (SWW) split jet structure in this region. The relatively modest warming during the early Holocene climatic optimum suggest that this time period may provide an analogue for future productivity for the SW Pacific for the mid-century (2055) under IPCC Representative Concentration Pathway (RCP) 8.5, business as usual, or for the end of the century (2100) under RCP 4.5.

EPISODIC FRACTURE AND CREEP AT SHALLOW CRUSTAL LEVELS, HUNGAROA FAULT ZONE, HIKURANGI SUBDUCTION MARGIN, NEW ZEALAND

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Faults and folds exposed along the Hikurangi Subduction Margin (HSM) reflect the onset of subduction in the early Miocene (~25 Ma). One such structure, the inactive Hungaroa Fault Zone (HFZ) on the Wairarapa coast, accommodated large displacements (~4–10 km) as a thrust fault developed in Paleogene hemipelagic sediments of the Wanstead Formation. Spectacularly exposed in an uplifted shore platform, the HFZ is a mélange comprising deformed calcareous mudstones and marls (27–58% phyllosilicates; 7–56% calcite). The mélange experienced up to four stages of deformation, possibly as part of a continuum evolving towards higher strain: (1) tight to isoclinal, asymmetric to overturned folding of bedding; (2) transposition of the folds along a spaced tectonic foliation, S (or P), that is locally cut by C (or Y) shear bands within a high-strain zone ~40 m wide; (3) cross-cutting of the S fabric by C′ (or R_1) shears; and (4) cross-cutting of these fabrics by discrete brittle faults oriented sub-parallel to the shear zone boundaries. Finally, rotation and overturning of the HFZ took place in the younger regional Coastal Anticline. Within the high-strain zone, marls form lozenges embedded in the foliated, calcareous mudstone matrix. The lozenges and matrix contain the following microstructural evidence for fracture, creep, and dissolution–precipitation processes: discrete faults, veins containing stretched calcite fibres, veins with calcite slickensides, calcite foliation–boudinage structures, calcite pressure fringes, dark dissolution seams, stylolites, embayed calcite grains, and an anastomosing (scaly) phyllosilicate foliation. Raman spectroscopy of carbonaceous material, calcite twin thermometry, and the ubiquitous presence of montmorillonite indicate that deformation took place at shallow crustal conditions (<120–150 °C, <5–6 km depth). At shallow depths and low temperatures, calcareous sediments typical of those found throughout the HSM deform by a combination of frictional sliding and pressure solution creep and exhibit evidence for both localized and distributed deformation.

ALONG- AND ACROSS-ARC VARIATIONS OF VOLATILE CONTENTS AROUND AN ARC–ARC COLLISION SETTING

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Volatiles have a preponderant role in arc magma genesis. The interplay between slab and mantle wedge conditions controls the volatile release from the slab and affects the degree of melting of the mantle, which in turn controls the volatile composition of the primary magma.

We analysed the volatile composition of olivine-hosted melt inclusions of basaltic tephras from several volcanoes of NE Japan. The NE Japan arc and the Kurile arc meet at Hokkaido Island, where the orientation of subduction changes. This particular setting provides an opportunity to study the relationship of volatile abundances in arc magmas with changes in subduction zone architecture (slab, mantle wedge and overriding crust). To date, melt inclusion studies in NE Japan are scarce, and this study will yield new insights into arc magmatism there.

Analysis by ion microprobe equipped with a SCAPS detector allows high-resolution mapping of volatile contents in melt inclusions. Preliminary results of S, Cl and F show distinct compositions for melt inclusions in five volcanoes (Akita-Komagatake, Hakkōda-san, Ōshima-Ōshima, Tokachi-dake and Tyatya-dake). Volatile contents are lower in the NE Japan arc (S = 80–260 ppm, Cl = 410–790 ppm and F = 190–250 ppm) and higher in the Kuril arc (S = 100–460 ppm, Cl = 820–1320 ppm and F = 230–400 ppm), increasing towards the arc-arc junction. This agrees with a model of slab thinning or cracking, caused by bending of the slab, which would favour heating and volatile release. Interestingly, the highest volatile concentrations were found in the back-arc of the NE Japan arc (S = 170–490 ppm, Cl = 1240–3390 ppm and F = 260–540 ppm). CO_2 and H_2O contents were low throughout. Future work will extend this dataset to additional volcanoes in the area and include the quantification of CO_2 and H_2O compositions through SIMS spot analyses.

ALPINE SCHIST PETROCHRONOLOGY RECORDS PLATE BOUNDARY METAMORPHISM DURING GONDWANA BREAKUP

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The Alpine Schist represents some of the youngest metasedimentary rocks accreted at the Pacific–Gondwana subduction margin during Cretaceous orogenesis. Enigmatically, the metamorphic record preserved in the Alpine Schist suggests that metamorphism post-dated the widely accepted estimate for the end of subduction along this section of the Gondwana margin (~105 Ma) and was synchronous with the final stages in the breakup of Gondwana. Here we present new evidence for the timing and duration of metamorphic mineral growth and partial melting in the Alpine Schist using a combination of Lu–Hf garnet geochronology and U–Pb monazite, zircon and xenotime petrochronology. Garnet ages are diachronous and range from 97.3 ± 0.3 to 75.4 ± 1.3 Ma. Metamorphic zircon rim ages were acquired by depth profiling using laser-ablation split stream (LASS)–ICP–MS and range from 84 to 50 Ma. U–Pb monazite, zircon and xenotime petrochronology and whole-rock geochemistry of granitic pegmatites indicate that partial melting of the Alpine Schist occurred repeatedly over a period of ~30 Ma, from 85 to 49 Ma. In combination, these results provide strong evidence that burial, metamorphism and partial melting of the Alpine Schist accretionary complex occurred concurrently with regional extension and rifting of Zealandia from East Gondwana. These young ages justify a reassessment of the drivers of metamorphism in the Alpine Schist and the Cretaceous tectonic history of New Zealand.

TURBULENT OSCILLATIONS CONTROL HAZARD IMPACT IN PYROCLASTIC SURGES

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Pyroclastic surges are one of the most violent phenomena associated with explosive volcanism. Their high velocities, dynamic pressures and temperatures make direct probing impossible. Hence only limited observations and deposits provide clues of their internal dynamics and associated hazard mechanisms. Here, we provide first internal views inside surges generated at the large-scale eruption simulator PELE. Characterisation of time and space variant velocity, concentration and density structure of surges reveal regular pulsing during flow propagation. Associated with these pulses are characteristic low to high frequency oscillations related to the passage of coherent large-eddy structures in these highly turbulent flows.

Here we reveal three new mechanisms that lead to the destructiveness of surges: First, the low frequency oscillations in velocity and density result in a succession of dynamic pressure pulses throughout the entire passage of the flow. These pulses of up to 1 kPa in experiments occur at regular intervals and translate to several tens to hundreds of kPa in real-world flows. The repeated impact of pressure pulses increases the destruction potential of surges similar to repeated aftershocks during earthquake events. Second, turbulent fluctuations in dynamic pressure exceed the mean pressure by a factor of three. This discovery is highly alarming because our existing procedures of estimating dynamic pressure and flow destruction are only based on rough estimates of the mean flow velocity and density. We suggest that these experimentally determined excursions in turbulent fluctuations are applied to hazard estimates. Third, for a wide range of flow conditions the typical frequencies of turbulent oscillation can coincide with the eigen-frequencies of infrastructure. This means that in addition to mechanical loading the hazard potential can multiply when surges bring man-made structures into resonance. These findings will have implications for defining new and updating existing hazard models.

TECTONIC GEOMORPHOLOGY AND PALEOSEISMOLOGY OF THE HUMPS FAULT WHICH INITIATED THE M_W 7.8 2016 KAIKŌURA EARTHQUAKE

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The November 2016 M_w 7.8 Kaikōura Earthquake initiated beneath the north Culverden basin on The Humps Fault and propagated northeastwards, rupturing at least 17 faults along a strike length of ~180 km. The geomorphic expression of The Humps Fault across the Emu Plains, along the NW margin of Culverden basin, comprises a series of near-parallel strands separated by up to 3 km across strike. The various strands strike east to east–northeast and mainly dip steeply to the south (~80°). In this area, the fault predominantly accommodates right-lateral slip, with uplift and subsidence confined to releasing and restraining bends and step-overs at a range of scales. Maximum horizontal and vertical displacements during the 2016 earthquake are 3.9 ± 0.4 m and 1.2 ± 0.2 m, respectively, with variations in the components of slip being closely linked to corresponding strand orientation. The Kaikōura event ruptured a pre-existing fault scarp along the Emu Plains, which had been partly identified prior to the earthquake. To constrain the slip related to the 2016 event, and the timing and slip of paleoseismic events, a trench was excavated across the fault where it crossed a late Quaternary alluvial fan. Mapping of stratigraphy exposed in the trench walls, and dating of variably deformed strata, constrains the event history at the trench site. The available data provides evidence for at least three paleoearthquakes within the last 15.1ka. These events are estimated to have occurred at 2016–7.7ka, 7.7–10.3ka, 10.3–14.8ka, with a further poorly constrained event which is older than ~15.1ka. Given the available age data, earthquake recurrence intervals for the fault may not have been uniform. The low slip-rate on the fault (which we estimate to be 0.20.6 mm/yr) may help explain why the fault expression was poorly resolved prior to the 2016 event.

FLUVIO-DELTAIC AND LACUSTRINE ROCKS OF THE MURIHIKU SUPERGROUP IN SOUTH AUCKLAND

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Latest Jurassic and earliest Cretaceous siltstones and sandstones are described from the youngest outcropping portions of the Murihiku Supergroup in South Auckland. Three prominent lithofacies occur: 1) trough cross-bedded sandstone in fining-upward cycles, capped by siltstone with rootlet horizons, 2) well-bedded siltstone with thin intercalated sandstone and, 3) trough-cross bedded sandstone with minor conglomerate and siltstone. Lithofacies 1 and 2 constitute the Matira Siltstone and Lithofacies 3 the Mangatara Measures, collectively over 700 m in thickness, and comprise the Huriwai Group. U–Pb zircon geochronology indicates ages in the range 149–139 Ma (latest Jurassic–earliest Cretaceous). The younger Matira Siltstone contains a rich but relatively low-diversity fossil leaf assemblage of ferns and gymnosperms similar to the well-known macroflora from the lower part of the Huriwai Group at Waikato Heads. The formation also contains diverse miospore palynofloras, with fair to good preservation, and sporadic occurrences of bivalve and gastropod faunas.

The sedimentology and fossil content of the Matira Siltstone is interpreted as a fluvial to deltaic succession that prograded into lacustrine and paludal environments in the central and northern parts of the outcrop area. Although earliest Cretaceous and non-marine Murihiku sediments are known elsewhere in the North Island, this is the first recognition of lacustrine sediments from outcrop (although small ponds or oxbow lakes have been interpreted in the past by others in parts of the Murihiku Supergroup). This work raises the possibility that present-day offshore areas in the Reinga and Great South basins where Murihiku rocks occur may also have fluvio-deltaic and lacustrine lithofacies in the stratigraphically younger parts of the supergroup.

FAULT RUPTURE PATTERNS COMPLEXITY AND SLIP TRANSFER DURING THE M_W7.8 2016 KAIKŌURA EARTHQUAKE IN NORTH CANTERBURY, NEW ZEALAND

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The M_w7.8 Kaikōura earthquake of the 14th of November 2016 produced a complex series of fault ruptures, which propagated northeastward for about 180 km from an epicentre on the Waiau Plains in North Canterbury. The factors that control the rupture and transfer of slip between intersecting faults are poorly understood. This study focuses on the interaction between two previously largely unknown fault systems, the west to southwest striking The Humps Fault, and the segmented, south to southwest striking Leader Fault. In the study area The Humps Fault dips ~60° to the NW, and 80% of the primary fault trace along the base of the Mt Stewart range occurs within 500 m of the contact between the Torlesse basement and the overlying Miocene Greta Formation. Vertical and lateral separations of up to 5 m and 1 m, respectively, were measured on the eastern section of The Humps Fault following the 2016 earthquake. These vertical separations are in accord with uplift of the Mt Stewart range, with the far-field deformation suggesting up to 5 m of vertical displacement on the fault at depth. The Leader Fault comprises four sections ranging in strike from south to southwest and separated by up to 3.5 km across strike. The Leader Fault produced maximum vertical and left-lateral separations of 3.5 m and 2.7 m, respectively. South of the Leader–Humps intersection, the main surface rupture on the Leader Fault coincides with the contact between Torlesse basement and ~10–30° westward dipping Cretaceous cover rocks, and with the contact between the Muzzle and Eyre groups in the cover sequence. North of the fault intersection the main ruptures are contained entirely within Torlesse basement and strike sub-parallel to basement bedding. Therefore, we infer that at the ground surface the orientation and spatial distribution of surface rupture during the earthquake was locally controlled by the geometries and orientations of basement and cover strata bedding. These bedding surfaces may represent planes of weakness, which promote distributed deformation and rupture complexity. Collectively the faults produce a kinematically coherent network for which fault intersections promoted the northeast transfer of slip during propagation of the earthquake.

JURASSIC BIOSTRATIGRAPHIC ZONATION OF ZEALANDIA'S MURIHIKU TERRANE (NEW ZEALAND) AND TEREMBA TERRANE (NEW CALEDONIA): WHAT DOES IT TELL US ABOUT CONTINENTAL CRISES?

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Zealandia rifted away from Gondwana with formation of oceanic crust in the Tasman Sea during Late Cretaceous to Paleogene time (83–53 Ma). In this context, Zealandia is the third youngest continent. Australia and Antarctica are younger and represent the last continental products of Gondwana break-up.

From a global perspective, what makes the Zealandian Jurassic sedimentary record really interesting is that at least two conjugate basins (Murihiku and Téremba) developed marginal to a substantial length (2–3,000 km) of the elongate long-lived active subduction margin of SE Gondwana in latitudes within 20 degrees of the South Pole. This is based on sea-floor spreading data. The Jurassic fossil biotas preserved in Zealandia are, therefore, best regarded as Nothal, pertaining to the South Pole, as opposed to Boreal (North Pole).

The sedimentary rock sequences preserved within these basins are referred to as the Murihiku Terrane in New Zealand, and the Téremba Terrane in New Caledonia. These sequences are of regional extent but in general are poorly exposed. Fortunately, they are well-exposed in coastal sections. They consist of relatively thick, largely shallow marine, weakly metamorphosed, relatively undeformed and fossiliferous volcanogenic clastic lithologies (siltstone, sandstone, conglomerate). They are characterised by distinctive shellbeds dominated by opportunistic molluscan faunas, and tuffs (vitric, crystal and lithic). They appear to be devoid of limestone, black shale and biogenic chert.

The question is: do they preserve an archive of known Jurassic events (continental crises) that are interpreted from Tethyan (equatorial) latitudes? To try and answer this question, this paper will explore aspects of the established shelly marine biostratigraphic record. In so doing, it will address the basis for the regional Zealandian stage scheme as presented in the New Zealand Geological Timescale. Six stages are recognised: Aratauran, Ururoan, Temaikan, Heterian, Ohauan and Puaroan. Ammonites and belemnites enable correlation with international stages.

EXAMINATION OF THE RELATIONSHIPS BETWEEN FRACTURES AND MINERALOGICAL VARIATION IN DFDP CORES FROM CT AND HYLOGGER DATASETS

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Fractures can affect petrophysical and geochemical properties of their host rock masses, as well as fluid transport and storage, so characterization of them is important to many industries. We have extracted information about fracture intensity and orientation from CT scans of rock cores collected during the Alpine Deep Fault Drilling Project (DFDP). The same cores have also been scanned using the HyLogging technique for mineral information, which measures spectra of light scattered from the core surface within different wavelength ranges (Hancock and Huntington 2010, Geological Survey of Western Australia). Variations in these spectra are linked to mineralogical variations, so that we can estimate the type and quantity of the minerals present along a scanned surface.

We expect that mineralogical variation in these drillcores might reflect either (1) primary lithological variation, (2) alteration related to fluid that passed through fractures, or (3) alteration related to disseminated fluid transport (not in fractures). We would expect systematic relationships between mineralogy and fractures only in case (2). We will present comparisons of our measurements of fracture intensity to the HyLogger-derived mineralogy of several cores using Fast Fourier Transforms (FFT), Power Spectral Density (PSD), Recurrence Plots, and Multifractal analysis, in order to establish if systematic relationships exist between these datasets. For example, in a 0.6 m length of DFDP core, we have compared fracture intensity to quartz content. A simple comparison of normalized versions of these datasets against position in the core demonstrates similar fluctuations over only approximately half of the depth range. The FFT analysis displays little correlation between dominant frequencies. In cross recurrence plots we observe patterns indicative of deterministic relationships between these datasets, but also that there are some very atypical values in one of the datasets. We conclude that at this scale of observation a hypothesis of fracture-related alteration of quartz content is not supported.

RESULTS OF NEAR-SEAFLOOR GEOPHYSICAL SURVEYS AT BROTHERS VOLCANO

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Brothers volcano is arguably more hydrothermally active than any other volcano along the Kermadec arc, with three hydrothermal fields located on the caldera walls and two hydrothermal fields on the Upper and Lower cones, respectively. These sites show different types of hydrothermal activity in terms of temperature, chemistry and associated mineralization, representing windows into the complicated hydrothermal systems that are associated with submarine arc volcanoes. Joint interpretation of near-seafloor magnetic data and heat-flow surveys at Brothers volcano provide a unique model of the hydrothermal system, which is essential to place the recent results from the International Oceanic Discovery Program (Leg 376) results in the right context.

DETECTION OF TRIGGERED TREMOR AND ASSOCIATED SLOW SLIP IN NEW ZEALAND FROM TRANSIENT TELESEISMIC SURFACE WAVES

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Tectonic tremors and slow-slip events (SSEs) have been widely documented in subduction zones around the world; the temporal correlation of these two phenomena have been given the name episodic tremor and slip. In New Zealand's Hikurangi subduction margin however, there has been a lack of definitive evidence for simultaneous occurrence of tectonic tremors and SSEs. Previous studies have reported increased seismicity associated with SSEs, as well as dynamic triggering of deep tremors due to teleseismic surface waves from a 2010 M_w8.8 earthquake. However, the detection of tectonic tremors accompanying SSEs in the Hikurangi margin has been challenging, due to highly attenuating sediments and relatively high ambient noise. In this study, we apply a modified frequency scanning method to search for tremor signals on a temporary seismic network deployed in the southern Hawke's Bay region. Initial findings have identified potential triggered tremor signals following the 2017 M_w8.2 event near Chiapas, Mexico. Preliminary study of continuous GPS data also hint at small associated SSEs during this time period. We present our ongoing efforts towards capturing and locating triggered tremors, and associated SSEs, in the North Island of New Zealand.

PROBABILISTIC ERUPTION FORECASTING WITH BAYESIAN NETWORKS AND EXPERT ELICITATION: A PILOT STUDY FOR WHAKAARI/WHITE ISLAND

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Bayesian Networks (BNs) are probabilistic graphical models that provide a robust and flexible framework for understanding complex systems. Even though BNs have been applied successfully to model multiple data streams for eruption forecasting and volcanic hazard assessment, they are not widely employed in volcano observatories. We have worked closely with the GeoNet volcano monitoring team to explore the usefulness of BNs for probabilistic eruption forecasting in New Zealand. We adapted a previously published BN for a pilot study to forecast volcanic eruption on Whakaari/White Island. Developing the model structure provided a useful framework to share knowledge and interpretation of the volcanic system. The BN structure aimed to capture the conceptual understanding of the volcanic processes and represent all observables that are regularly monitored. The pilot model has a total of 30 variables, four of them describing the volcanic processes that can lead to three different types of eruptions: phreatic, magmatic explosive and magmatic effusive. The remaining 23 variables are grouped into observations related to seismicity, fluid geochemistry and surface manifestations. To estimate the model parameters, we held a workshop with eleven experts, including two from outside the monitoring team. To reduce the number of conditional probabilities that the experts needed to estimate, each variable is described by only two states. However, the volcano monitoring team members were concerned about this limitation, particularly for continuous data. Therefore, they were reluctant to define thresholds to distinguish between states. We conclude that volcano monitoring requires BN modelling techniques that can accommodate continuous variables. Here we use the pilot model to illustrate the benefits of BN modelling to understand complex systems.

PROGRESS TOWARD A LOCALLY-DERIVED RADIOCARBON MARINE RESERVOIR CORRECTION ALONG THE HIKURANGI MARGIN AND IMPLICATIONS FOR COASTAL PALEOSEISMOLOGY

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The timing of past earthquakes and tsunamis is a key parameter for understanding the hazard of the Hikurangi Margin and radiocarbon dating is the most common technique for dating Holocene earthquakes and tsunamis along the Hikurangi Margin. Calibrated radiocarbon ages derived from marine shells have a ~400-year reservoir correction applied to account for the fact that marine carbon is isolated from the atmosphere by ocean currents and, therefore, appears slightly older than the atmosphere. The 400-year correction is a global average but there are regional and local deviations driven by local ocean currents and quantified by the localised reservoir correction (ΔR). The localised reservoir correction is particularly variable along coastal margins that can be influenced by local currents and terrestrial outflow.

New Zealand has relatively few locally derived ΔR values and notably none currently published from along the Hikurangi Margin north of Cook Strait. Past studies of paleoearthquakes along the Hikurangi Margin have typically used "New Zealand average" ΔR values of -30 ± 13 years or 3 ± 14 years. Over the past year, we have dated a small number of pre-AD 1950 shells from four locations along the Hikurangi Margin and obtained ΔR values that range from 189 ± 60 to 75 ± 46 years. These preliminary ΔR values highlight two relevant points: (1) appropriate ΔR values for the Hikurangi Margin are likely to be significantly different from the New Zealand-wide values that are currently in use; and (2) values along the margin appear to be spatially variable.

The larger ΔR values that we obtain from sites along the Hikurangi margin have varying impacts on the ages of paleoearthquakes along the margin. When earthquake and tsunami ages have broad ranges (>100 year-scale) due to factors such as radiocarbon measurement uncertainties, poor quality organic material with inherited ages or modern contamination, or lack of material close to an event horizon, then the ΔR value matters less in comparison to the other sources of uncertainty. Conversely, as the precision (currently ≤ ±20 years) of radiocarbon dating and statistical event-age modelling techniques have improved in recent years, we are able to obtain tighter age ranges for past earthquakes and tsunamis and, therefore, the relative importance of the ΔR uncertainty increases.

EXPLORING LABORATORY SCALE, FLUID-INDUCED VOLCANIC EARTHQUAKES

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Volcano seismicity is inextricably linked to the movement of pressurised fluids (gases, brines and magmas), yet the relationship between fluid type and induced seismic signals is not well understood. To increase this understanding, which has important implications for hazard analysis, we report on laboratory experiments in which acoustic emissions (AEs) are induced by rock fracture and subsequent depressurisation of fluids through the damage zone. These processes have long been known to be associated with Volcano-Tectonic (VT) and Long-Period (LP) seismicity. Additionally, we use active source surveys to investigate the role of path effects on volcanic earthquakes by calculating attenuation for different volcanic rocks and pore fluids.

The viscosity of our experimental fluids is varied and scales to represent volcanic fluids. The relationship between fluid viscosity and seismic signals is important to understand because viscosity represents a key influence on eruptive behaviour. While fracturing AEs predominantly resemble VT seismicity, fluid induced events model VT, LP and hybrid seismicity. Long duration signals resembling volcanic tremor is only observed in the early stages of nitrogen venting, suggesting tremor may be more often associated with gases than magma.

The viscosity of the venting fluid correlates inversely with the number and initial rate of induced events. A decrease in peak spectral frequencies of events is associated with increasing viscosity, which may be due to increased attenuation. The effect of wave speeds and seismic attenuation is explored using active source surveys with known source signal. Wave speed is highly sensitive to the saturating fluids for fractured granites and high-porosity tuff samples. Wave attenuation is highest for gas-saturated samples, with tuffs showing the highest attenuation of the samples measured. By comparing low porosity, fractured granites and high porosity ash tuffs at geologic pressures we provide wave speeds and attenuation data representative of shallow and deep volcano facies.

LARGE-AMPLITUDE INTERNAL SOLITARY WAVES ON THE SOUTH ISLAND'S CONTINENTAL MARGIN

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Internal solitary waves (ISWs) occurring at the boundaries between horizontally stratified water masses have been observed in many parts of the world's oceans. They play an important role in vertical mixing of water masses on continental margins and can also pose a risk to man-made structures. Although they propagate along pycnoclines in the interior of the ocean, ISWs alter the sea surface roughness, making them readily detectable in satellite imagery. Additionally, in recent years, multi-channel seismic reflection data (commonly used for seismic investigations of sub-seafloor geology) have been used to extract ISW parameters like their maximum displacement amplitude.

Here we present first seismic reflection images of large-amplitude ISWs approaching the shelf break on the continental margin of the southeast South Island. We examine coincident synthetic-aperture radar (SAR) satellite data and compare our observations to those from other locations, especially from the South China Sea, an established hotspot for ISW research. Correlations of our observations with tides, wind patterns, and variations of the Subtropical Front off the southeast coast of the South Island contribute to discussions of the formational processes and extent of ISWs in the region.

SEA-LEVEL IS NOT LEVEL: WORKING TOWARDS A BETTER UNDERSTANDING OF POST-GLACIAL RELATIVE SEA-LEVEL CHANGE AROUND NEW ZEALAND

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Relative sea-level (RSL) is not level but varies over time and space. In an ongoing Marsden-funded project, we aim to understand the forces driving variability in RSL changes around the New Zealand coast during the post-glacial period.

The broad pattern of RSL change around New Zealand during this period reflects changes in sea-surface height (SSH), which was broadly spatially uniform. Relative sea-level rose rapidly between 21,000–8,000 years BP due to the melting of continental ice sheets; RSL peaked ~8,000–5,000 years BP in a sea-level highstand; RSL fell after ~5,000 years BP due to equatorial ocean siphoning.

Variations to this pattern are hypothesised to be the result of two processes driving variations in solid Earth elevation (E) around the New Zealand coast: meltwater loading on the continental shelf; and postglacial melting of the Southern Alps icefield. These processes are hypothesised to drive spatial variations in the timing and magnitude of the highstand, and the magnitude of the post-highstand fall in RSL.

To investigate these drivers, we will use fossil shells preserved in coastal environments to construct records of RSL changes for targeted sites in Northland, Tasman–Nelson, and Otago–Southland. To resolve our hypotheses, we will analyse these records using a model of the Earth's response to changes in ice and meltwater loading during the postglacial, tuned for New Zealand using a time-varying model of the mass of the Southern Alps icefield. In addition, we hope to contribute to questions that have recently emerged: Was RSL uniformly below present around New Zealand during the Little Ice Age? Did RSL oscillate as it fell following the highstand? This work will provide new insights into the postglacial development of New Zealand's coastal environments, informing studies of coastal tectonic movements, predictions of future coastal change, and global research into the melting of continental ice sheets.

LATE QUATERNARY GEOMORPHIC EVOLUTION OF THE MANAWATU VALLEY: A RAPIDLY-INFILLED INCISED-VALLEY ESTUARY, NORTH ISLAND, NEW ZEALAND

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The geomorphic evolution of the Manawatu valley has been reconstructed for the past ~30,000 years. The valley was incised during the Last Glaciation, when the Manawatu was a braided gravel-bed river. The valley mouth was first inundated by rising sea-levels ~14,000 years BP. During early stages of the marine transgression fluvial sediment input to the valley postponed establishment of an estuary. Transgressive sedimentation by the river drove a change in channel behaviour to a meandering, low-gradient, silt-bedded river.

At the valley mouth barriers provided protection from marine incursions during the marine transgression. A low-energy intertidal estuarine environment was established in the lower valley ~8,200 cal. yr BP. As sea-levels rose the intertidal zone migrated up-valley, with the estuary's maximum extent achieved between 7400–6700 cal. yr BP, coincident with the peak of the sea-level highstand on the Manawatu coast.

The coast began prograding and parabolic dune-building was initiated at the onset of the sea-level highstand ~7,500 cal. yr BP. Dune-building and coastal progradation were initially fed by transgressive marine sands and sustained through the Holocene by longshore drift. The estuary infilled rapidly due to high sediment inputs from fluvial and marine sources. Between 7,100–6,800 cal. yr BP the estuary margin advanced 2–3 km down-valley, driven by fluvial sediment inputs. By ~6,300 cal. yr BP the estuary's extent had reduced by 40 percent. By ~6,000 cal. yr BP the estuary extent had halved, and by ~4,700 cal. yr BP the estuary was infilled. Throughout the valley the transition from estuary to floodplain was almost instantaneous. Post-4,700 cal. years BP limited data shows that the coast prograded at a long-term average rate of ~0.85 m/yr, sustained by longshore drift and fluvial sediment by-passing the Manawatu valley.

WHAT'S SIZE GOT TO DO WITH IT? NEW ZEALAND'S UNIQUE BIVALVE-BRACHIOPOD MARINE ECOSYSTEM IN THE LATE TRIASSIC

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Late Triassic–Early Jurassic shell beds from New Zealand are unique not only for their paucispecific fossil densities but also for the large population sizes of the fossil shells. However, less dense shell beds display a complex body size and diversity relationship. Here we explore the nature of these differences and provide preliminary paleoecological and geochemical data to elucidate the causes for New Zealand's unique benthic ecosystems of the Early Mesozoic.

In deposits of the Taringatura Group in the South Island, which record deposition of a high-latitude volcaniclastic marine shelf in the Late Triassic, fossil assemblages from the Oretian–Warepan (Norian) interval are analysed and compared to Norian assemblages from Nevada, USA. Fossil assemblages from both regions undergo a significant faunal turnover between the early and late Norian, but notable differences in body size and paleoecological selectivity suggest that these taxonomic changes may have complex causes. At these localities, the Oretian (early Norian) benthic taxa are significantly smaller than those from lower latitude deposits. A taxonomic shift occurs during the Warepan stage when dominant bivalve taxa are replaced, and newly dominant taxa are significantly larger than low-latitude taxa, which do not exhibit a size increase. Late Triassic shelly assemblages from New Zealand also present a far more limited range of ecological life modes and behaviours than lower latitude deposits of the same age.

While predation has been proposed for the faunal changes in Late Triassic Nevadan samples, several mechanisms may play a key role in explaining the initial assemblages and faunal changes in the Warepan deposits. The absence of infaunal bivalves suggests potentially acidic pore waters in the volcaniclastic sediments of the Taringatura Group. The late Warepan transition to an abundant *Inflatomonotis*, an epifaunal bivalve, also suggest assemblages may be responding to pressures other than predation.

GIANT PUMICE AND ASH DEPOSITS FROM AN EXPLOSIVE SUBMARINE ERUPTION ON THE GREEK ISLAND OF MILOS

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The uplifted Pliocene submarine volcanic succession at Filakopi on Milos Island, Greece, is one of the best-preserved sequences of its kind. The felsic eruption produced pumice breccia and ash, reversely graded in sections up to 20 m high. Giant ash-supported pumice clasts up to 7 m in size can be seen in the upper 6 m. The mechanisms of such eruptions are poorly understood and analysis of this deposit on Milos island will allow us to better understand the eruption dynamics and processes involved. The eruption on Milos will also provide a comparison model to the Havre seamount eruption of 2012, where similar eruptive products formed. Constraining the environments in which these deposits are found will allow further insight into these submarine volcanic systems.

Analysing palaeomagnetic orientations and thermal-demagnetisation data from orientated samples collected from giant pumice clasts in the field will allow us to look at clast cooling histories. Blocks will have required time to water-saturate before being emplaced on the sea floor. If large blocks rotated during transport their cores will have different magnetic orientations than the earlier-cooled rims. Thermal information and vesicle population studies of the bounding units will also provide information of conditions over a longer timeframe and their relationship to the Filakopi eruption. Characterisation of the morphology and textures of ash particles and pumice vesicles using microtomography and SEM will aid in determining fragmentation energy and allow interpretation of the effects of the water column on dynamics of the eruption.

GRAPTOLITE EVOLUTION AND PALEOCLIMATE: HOW THE COURT JESTER MANIPULATES THE RED QUEEN

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Two competing theories about what drives macroevolutionary change have been debated for many decades. The Court Jester hypothesis invokes environmental influences, such as volcanic or climatic events, whereas the Red Queen hypothesis implies that species diversity remained at near-saturation levels causing fierce inter-species competition, such that a new species lineage could not arise unless an existing lineage became extinct. All lineages had to keep evolving to avoid being left behind in the competition for the available resources.

Using an exceptionally high resolution global data set of graptolite evolutionary rates, we show that, through most of the 74 Ma history of the graptolite clade, 10–16% of the variance in macroevolutionary rate in this ancient marine plankton clade is explained by environmental factors (Milankovitch Grand cycles and glacial events) in accordance with the Court Jester hypothesis. These are inferred to have temporarily reduced the available ecospace and food resources thereby forcing Red Queen inter-species competition which, in turn, explains a further 12% of the variance. This scenario suggests that the primary driver was climatic change, probably operating through the marine microphytoplankton food resource for graptolites, and temporarily creating conditions for Red Queen processes to apply.

UNDERSTANDING THE FLOW DYNAMICS OF PYROCLASTIC FLOWS: FROM ANALOGUE EXPERIMENTS TO SUPER-VOLCANO ERUPTIONS

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Pyroclastic density currents (PDCs) are hot flows of gas and particles from volcanoes that destroy everything in their path. For ash-poor and coarse-grained PDCs, particularly during late-stage flow, effects of the gas phase on flow behaviour become reduced and flow dynamics are governed by grain interactions. To better understand the frictional behaviour of these dry granular flow situations in PDCs, we studied them experimentally. We initiated wall-bounded avalanches of glass beads along a smooth incline (varied between 15–83 °) and measured the forces at the flow base using a three-axis loadcell. Experiments showed a drop in the basal friction coefficient (1) by increasing flow thickness and (2) when their speed is very high. Lateral wall effects, shearing at the base of the flows and their density are probably responsible of these behaviours. These results provide complexity to the known problem of quantitatively explaining the long runout behaviour of PDCs. However, they also point to the usefulness of three-axis force sensors to study the rheology of geophysical mass flows.

Moving on from these simplified benchtop-scale test experiments, we are now seeking to explore the processes behind the enigmatic long runout behaviour in real-world flow situations. As part of a new PhD research project, we will use reconnaissance mapping of the 232 AD Taupō ignimbrite to correctly scale and reproduce flow behaviour of hot gas–particle flows of natural pyroclastic material in large-scale experiments using the eruption simulator PELE. We here present the project outline of this research, which seeks to address two main challenges in volcanology: What are the fundamental transport mechanisms of PDCs produced in high-magnitude super-volcano eruptions, and do they differ from those in smaller-volume types? How can we quantitatively model PDC transport and deposition processes for these high-magnitude eruption situations and, thus, forecast hazard impacts of future eruptions?

SYNTHESIS OF SPINEL SERIES MINERALS IN THE PRESENCE OF D_2O: EXPERIMENTAL STRATEGY TO ASSESS THE PARTITIONING BEHAVIOUR OF WATER BETWEEN MELT AND NOMINALLY ANHYDROUS SPINEL-STRUCTURED OXIDES

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Knowledge of the nature and distribution of water in a magmatic system is an important part of petrologic research. Water influences rock melting systematics and, when dissolved in magma, it affects the physio-chemical properties of that magma during evolution, ascent, and eruption. Silicate minerals within the upper mantle commonly contain trace amounts of water, and within the mantle transition zone, minerals such as wadsleyite and spinel-structured ringwoodite have been shown to potentially contain up to weight percent concentrations of hydrogen. It is currently unknown if non-silicates such as spinel-structured oxides contain measurable quantities of water. Because these oxides commonly crystallize from mantle-derived magmas, it may be possible to measure magmatic hydrogen trapped in their crystal structures. This potentially provides an opportunity to use spinel-structured oxides, which are resistant to alteration, for estimating the water contents of primitive magmas.

We have performed a series of experiments to synthesize spinel-structured oxides in the presence of deuterium, which is easier to analyse by ion microprobe than hydrogen. Our goal is to determine if water partitions into the spinel structure and how partitioning behaviour may change as a function of temperature and oxygen fugacity. We used an internally heated pressure vessel and an $Ar–H_2$ gas mixture to simulate magmatic temperatures (1100, 1150, and 1200 °C) and pressures (2 kbar), and to impose variable redox conditions (log fO_2 ~NNO+1 and NNO+3) during spinel crystallisation experiments. Two natural samples were used to grow spinel under these conditions. Basalt from Taranaki was used to grow magnetite, and high-silica boninite from the forearc region of Guam was used to grow chromite. Preliminary data show that we have successfully grown magnetite and iron-rich chromite under these conditions. Future secondary ion mass spectrometry analyses will elucidate the partitioning behaviour of added deuterium during the crystallization of these spinels.

THE GEOMAP DATASET OF ANTARCTIC ROCK EXPOSURES

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The Scientific Committee on Antarctic Research (SCAR) GeoMap Action Group (www.scar.org/ssg/geosciences/geomap) has been building a detailed digital geological dataset of Antarctica. We have been capturing existing geological map data, refining its spatial reliability, improving representation of glacial sequences and geomorphology. The initiative is aimed towards continent-wide perspectives and for cross-discipline use. Our international team of over 40 people representing 15 different nations is collaboratively classifying and describing around 72,000 distinct areas that cover 51,000 km^2.

The dataset will describe "known geology" of rock exposures rather than "interpreted" sub-ice features. Glacial deposits are an important focus for their potential to contain records of ice fluctuations of relevance to climate change. Here we present background on: (1) Completion, or very near-completion, of the first version of a continent-wide dataset. (2) The large number of hard-copy geological maps and data sources, which range in scale and quality. (3) Development of local legends, which highlight geological variation across the region. (4) Progress towards a unified classification scheme. (5) Bibliographic links referencing authors of key original work. (6) Potential for the dataset to provide fresh perspectives, for example, through combined geological legends and interrogation of continent-wide time–space plots.

We are pleased to announce that the majority of the continent's rock outcrops have now been classified with some form of digital representation of geology suitable for use at 1:250,000 (or smaller) scale. Work continues to translate data attributes and harmonise them into a standard GeoSciML format. Release of a beta test version for review is expected in early 2019.

TOWARDS UNDERSTANDING THE EFFECTS OF SEA-LEVEL RISE ON GROUNDWATER

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The picture of climate change and global sea-level rise is becoming much better-established, albeit with a wide range of uncertainties. But the exact nature of local effects is far less clear. Increased frequency of events such as drought, wildfire, flooding and coastal surge are perhaps most commonly considered. Less-obvious, yet equally important, are changes to groundwater and associated natural hazards, such as land inundation. Understanding of the impacts and risks of sea-level rise is a key objective of the NZ SeaRise programme. Research Aim 3.3 is investigating some high-vulnerability urban areas constructed on land with shallow groundwater.

Downscaling to regional or local models and shifting from general probabilistic scenarios to a deterministic understanding of where and how often the effects will be felt, involves significant challenges. Downscaling requires holistic understanding of natural systems and processes that can perturb their present state. Local (cf. global) processes and impacts of climate change and sea-level rise are for the most-part still poorly quantified/understood, with significant temporal (frequency) and (perhaps more importantly) spatial uncertainty in the hazards faced across our communities. Definition of the spatial reach of hazards, and how various hazards interplay, are becoming an expectation for future planning and mitigation.

Here we report on progress in South Dunedin and Christchurch. We outline new monitoring and data-processing to constrain both spatial and temporal uncertainties. A series of water table maps and movies provide a unique and unparalleled visualisation of local groundwater systems. Vulnerability to groundwater inundation and increased surface flooding is clearly not a simple function of land elevation. Instead, hazards are strongly dependent on local permeability and hydrogeology. To make decisions around investment for mitigation, zonation or managed retreat, both cities need clarity about sub-surface hydrological processes. Steps are now in place to begin addressing such knowledge gaps.

WHEN DID CRETACEOUS SUBDUCTION END AT THE MARGIN OF ZEALANDIA?

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During the Permian to Cretaceous, Zealandia lay on the proto-Pacific-facing, convergent margin of Gondwana. Subduction on this margin ended somewhere between ~105 Ma and perhaps 70 Ma. The timing of this transition remains controversial, but resolution of this uncertainty is important for plate-tectonic models of the southwest Pacific. Here we re-examine this problem using a synthesis of diverse existing information from across Zealandia along with new data from the East Coast Basin, which lay atop the relict Cretaceous accretionary prism and is expected to preserve direct structural and stratigraphic evidence for Late Cretaceous subduction.

Within the East Coast Basin, we find no unequivocal evidence for Late Cretaceous extensional structures, although they may exist, but there is basin-wide evidence for Late Cretaceous compression lasting until ~86 Ma. The youngest undoubted outcropping rocks of the Cretaceous accretionary prism are 100 Ma, and in most places, these are overlain with marked unconformity by less indurated and deformed "cover" strata. Locally, basal cover comprises highly distinctive, thick, olistostrome deposits. Cretaceous strata of the East Coast Basin record a series of discrete tectonic and magmatic events at ~110–100 Ma, 96 Ma, ~86–83 Ma, and ~83–81 Ma. Importantly, these events can all be recognised elsewhere across Zealandia, suggesting that the (relict) Cretaceous accretionary prism shared a common Cretaceous tectonic history with the rest of the continent.

Combining observations from the East Coast Basin with structural, magmatic, metamorphic and stratigraphic data from the wider Zealandia, we infer that there is diverse evidence to indicate that subduction finished along the New Zealand segment of the Gondwana margin by 100 Ma. The causes of Late Cretaceous compression are not well understood but may reflect Late Cretaceous oblique or strike-slip deformation and/or compression outboard of the collapsing, elevated Median Batholith.

THE RESILIENCE CHALLENGE 2015–2024—INCREASING INVESTMENT INTO GEOLOGICAL HAZARDS

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The Resilience Challenge (RC) is one of 11 National Science Challenges funded by the Ministry for Business Innovation and Enterprise and is the most closely aligned with the geological sciences. In the first phase of the Resilience Challenge, from 2015 to 2019, we operate alongside the Natural Hazards Research Platform, so that our additional geological research related mainly to developing large-scale earthquake hazard scenarios for an Alpine Fault earthquake (both region wide and localised to a Franz Joseph case study). In addition, we developed research into mathematical approaches to link earthquake causes into chains of cascading hazards (landslide, river dams). The 2016 Kaikōura earthquake provided an opportunity to test some of these tools and develop further research in collaboration with other agencies. From mid-2019 the second phase of the Resilience Challenge is integrated with the Natural Hazard Research Platform and, thus, a much greater scope and depth of geological research will be undertaken. While specific details of the research programs are still to be confirmed by the outcome of MBIE reviews and the Challenge Governance Group, we can signal clear intentions in the following new research areas: (1) evaluating the large-earthquake record in NZ via virtual earthquake simulation tools; (2) coupled ground–earthquake response to earthquakes; (3) understanding short (syn-crisis) and long-period cycles of volcanism; (4) an NZ-wide evaluation of coastal geomorphic change in relation to climate change/wave changes; (5) modelling the impacts of distal and far-field tsunami. In addition to these areas a major investment will go into understanding weather impacts from new down-scaled models. The hazard research will be integrated within a new multi-hazard risk model that will attempt to combine the diverse type, scale and interrelation of hazards within a socio-economic framework. Ongoing research will also target the development of resilience practice in the light of our new hazard/risk research and work with communities, businesses and governance in New Zealand to mainstream resilience-based decisions. The second phase of the Resilience Challenge presents an exciting opportunity for a large portion of New Zealand's geohazard research to be under a single central organisation and paves the way for coordinating and collaborating with the geoscience community (and metrological, engineering, social science, etc.) to support new MBIE Endeavour, Marsden and other research agencies.

HYDEE VOYAGE I: FIRST RESULTS OF A GAS HYDRATE RESEARCH VOYAGE ABOARD RV TANGAROA, SEPTEMBER 2018

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Gas hydrates represent a large reservoir of methane that has the potential to act as a bridging fuel as the world moves towards cleaner energy sources. However, producing methane from gas hydrates is not trivial and may have significant impacts on seafloor stability, marine biology and ocean biogeochemistry. During a four-week voyage aboard RV Tangaroa we used a variety of scientific methods to improve our understanding of natural gas hydrate systems within New Zealand's southern Hikurangi subduction zone. We collected a network of high-resolution, two-dimensional seismic reflection profiles that give insight into sub-seabed fluid flow and gas hydrate formation. These data allow us to map out the extent and character of gas hydrate accumulations. We also collected high-frequency singlebeam data, as well as multibeam imagery of the seafloor and water column, to investigate shallow gas migration and escape into the ocean. Finally, we carried out targeted seabed sampling to characterise (1) microbial activity at productive gas hydrate systems and (2) seafloor sediment composition and grainsize. This poster presents examples of data and samples we collected during the voyage. Ongoing work on these data will enable us to understand the types of settings that might be targeted for gas hydrate production in the future and explore environmental impacts that could be associated with such activities.

THE COMPOSITION AND EVOLUTION OF THE MARTIAN CRUST

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What is the composition of Mars's crust? As a sample-return mission has yet to be completed, the composition is generally inferred through measurements from orbiting spacecraft and landers/rovers on the surface. These indirect measurements are restricted to the near surface and cannot achieve the precision and accuracy of analyses conducted in laboratories. However, samples of Mars occur on Earth as meteorites that were ejected from the red planet during violent meteorite collisions, as a result of a low escape velocity.

Here, we will provide a general introduction to Martian meteorites and then discuss our results from an investigation into three samples. The analysed samples have tholeiitic basaltic compositions (shergottites) and comprise pyroxene ± olivine + maskelynite ± plagioclase (as well as various sulphide, oxide, and calcium phosphate minerals). The elevated Mn/Fe in pyroxene and olivine, compared to Earth minerals, confirm a Martian origin and relates to there having been only a small degree of melt extraction from the Martian mantle.

Most Martian meteorites examined have been shock metamorphosed and contain maskelynite, a type of glass that replaces igneous plagioclase grains at the time of target impact. Such events also generate high-pressure phases (e.g., ringwoodite) that are stable on Earth only in the mantle transition zone or lower mantle. The analysed samples contain symplectites of glasses with compositions of feldspar and pure silica, which, in one sample, displays a texture consistent with a post-stishovite polymorph, recording shock metamorphic pressures of >40 GPa (in comparison, the deepest exhumed rocks in New Zealand reached only 2 GPa). We propose that their formation may record metasomatism facilitated through reaction with a Si-, Na-, and K-enriched fluid in the seconds after meteorite impact. The impact process disturbs the Ar/Ar system, resulting in anomalously young ages for the Martian crust, which is probably mostly Proterozoic or older.

JURASSIC BIVALVES, CONTINENTAL CRISES, AND BIOSTRATIGRAPHY IN SOUTHERN GONDWANALAND

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Bivalves are abundant and diverse Jurassic macroinvertebrate fossils worldwide, and as such they are key to understanding paleoenvironmental crises, either as source of significant data or indirectly as correlation tools. The Toarcian Oceanic Anoxic Event (T-OAE) was one of the major environmental perturbations of the Mesozoic, and it has been chemostratigraphically identified in southern Gondwanaland in the Neuquén Basin (Argentina) in bulk rock and fossil wood samples. At the same time, the variations in abundance and body size of the dominant bivalve species during that interval, the paper clam *Posidonotis cancellata* (Leanza), were analysed. The species disappeared just before the minimum negative carbon-isotope value (OAE *sensu stricto*). In fact, the probably related Late Pliensbachian–Early Toarcian biotic crisis, with a peak at the *tenuicostatum/falciferum* ammonite zone boundary, was particularly evident for marine bivalve species, and meant the extinction of both previously successful taxa and survivors from the Triassic–Jurassic extinction event. In southern Gondwanaland it involved many bivalve species and several genera (e.g., *Ryderia, Asoella, Posidonotis, Agerchlamys, Weyla, Cardinia, Kalentera*, and probably *Pseudaucella*). Additionally, although bivalves are not generally regarded as biostratigraphically useful due to their long species turnover rate, they have proven to be especially valuable in southern Gondwanaland for recognition, correlation and dating of local stratigraphic units and continental crises. In New Zealand most of the bases of local Jurassic stages and sub-stages where originally defined (and are still characterized) by the lowest occurrence of certain bivalve species. In the Neuquén Basin the proposed regional biostratigraphic zonation based on bivalves is closely linked to a detailed ammonite zonation soundly correlated with international standard zones. Some of the key bivalve species are shared between these two regions, and thus they become significant for discussing the adjustment of the chronological equivalence of events along the southern Gondwanaland margin.

UTILIZATION OF GEOCHEMICAL TECHNIQUES TO UNDERSTAND THE LONG TERM WEATHERABILITY OF RECYCLED RD AGGREGATE

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The geochemical behaviour and weatherability of premium and recycled base-course aggregate sourced from the Auckland region has been investigated. The current specifications assess aggregate performance at the onset of use, failing to accurately encapsulate the aging characteristics of the geomaterial. To address the rapidly depleting local resources of premium natural aggregates, recycled materials need to be utilised in a greater capacity. This research presents a comparison between recycled aggregate products available within the Auckland region to premium natural aggregates in terms of geochemical behaviour and subsequent degradation in mechanical properties. Soaking experiments have been employed to simulate *in situ* conditions, and the ensuing geochemical behaviour of this material has been analysed. Both the mechanical and geochemical properties have been investigated pre- and post-soaking, allowing the relationship between the nature of the chemical degradation and the changes in the mechanical behaviour to be assessed. Weathering products have been identified using XRD techniques, and bulk chemical changes have been assessed through XRF analysis. Solution ICP–MS has been utilized to analyse the elemental concentrations within the soaking fluid, providing a method for monitoring the progressive chemical alteration and exsolution occurring from vulnerable mineral phases. The UCS and durability of each aggregate composition was determined, with the results indicating that crushed concrete material shows the most marked decline in mechanical performance compared to traditional premium aggregates. Additionally, acidic conditions have shown to accelerate the rate of clay formation, which in turn had a negative impact on the durability of the aggregates. This research provides a methodology for investigating the long term chemical behaviour of aggregate material and identifies inherent vulnerabilities of differing compositions through the use of geochemical techniques. Modifications to the current specifications are required to accommodate recycled aggregate material, particularly to mirror the growing international trend towards recycling premium construction materials.

CONJUGATE STRIKE SLIP FAULTING ASSOCIATED WITH SEAMOUNT SUBDUCTION AT THE HIKURANGI MARGIN DEFORMATION FRONT, NEW ZEALAND

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Subducting seamounts may have a profound impact on the structure and morphology of the frontal accretionary wedge. Along the offshore northern Wairarapa section of the obliquely convergent Hikurangi subduction margin, where incoming sediment is about 4 km thick, subduction of the largely buried Bennett Knoll seamount is at an incipient stage. Using high resolution, 30 kHz Kongsberg EM302 multibeam swath bathymetry, TOPAS PS18 sub-bottom profiles, and regional seismic reflection data, we document a peculiar style of coeval thrust and strike-slip faulting in association with seamount collision. The strike-slip faults observed are not deforming the immediate hangingwall overriding the incoming Bennett Knoll seamount, but are conjugate faults up to ~30 km in length that straddle the buried flanks of the seamount, offset the frontal thrusts and proto-thrust zone, and extend significantly across the Hikurangi Trough basin floor.

The conjugate strike-slip faults are steeply dipping and have propagated approximately parallel and normal, respectively, to the present-day plate convergence vector. They are expressed clearly in the geomorphology, with evidence for dextral and sinistral displacements on the respective conjugate structures. In comparison with published analogue and numerical models and other marine field observations of subducting seamounts elsewhere, the Hikurangi margin conjugate faults appear to be unusual. We discuss the kinematic controls that may influence their formation.

POLYMETALLIC NODULE GEOCHEMISTRY: THE INTERPLAY BETWEEN SEDIMENTOLOGY AND OCEANOGRAPHY IN THE SW PACIFIC OCEAN

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Polymetallic nodules are authigenic marine sediments that form slowly over millions of years from the precipitation of iron and manganese (hydroxy)oxides from seawater and sediment pore waters. These deposits, commonly enriched in metals such as copper, nickel and cobalt, and the rare earth elements, are of interest both as long-lived records of changing oceanic environmental conditions and potential economic resources. The incorporation of trace elements and metals into polymetallic nodules reflects their growth mechanism and environmental conditions, and their chemistry is thus dependent on the sedimentology and oceanography of the region in which they are forming.

This study presents the chemical composition of the outermost rims of 77 polymetallic nodules and associated sediment from locations in the Campbell Nodule Field, Tasman Sea and Southern Ocean. Although the sample locations lie several thousand kilometres apart, they are all overlain by Lower Circumpolar Deep Water, but with varying water depth, current velocity, and sediment type. The Campbell Plateau nodule field is sampled across two transects perpendicular to the Subantarctic Slope with varying degrees of influence from the Deep Western Boundary Current across the transects, whereas samples from the Tasman Sea represent a more quiescent environment.

Nodule and sediment trace element and sediment grainsize data provide insights into nodule growth mechanisms in the Southwest Pacific Ocean. Whilst the nodules overall are dominated by hydrogenetic growth mechanisms, the Southern Ocean and Tasman Sea nodules define distinctive trace element signatures that can be attributed to hydrogenetic (seawater) and diagenetic (sediment pore water) growth mechanisms, respectively. The Campbell Nodule Field transects show systematic variations in mixed hydrogenetic–diagenetic contributions, with increased diagenetic influence with greater distance from the Subantarctic Slope. This reflects variations in the underlying sediments (grainsize, geochemistry and calcium carbonate content), which in turn is influenced by the regional oceanography of the sites.

THE PAHAU/RAKAIA TERRANE BOUNDARY OF THE NORTHERN CHATHAM RISE AND IMPLICATIONS FOR THE 2016 KAIKŌURA EARTHQUAKE SEQUENCE

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A major fault, often with an associated seafloor displacement, and separating zones of differing deformation patterns is traceable, in seismic reflection data, the entire length of the northern Chatham Rise. Contrasts in density across the fault result in a matching horizontal gravity gradient peak are also traceable most of the length of the Chatham Rise.

The major fault above is interpreted as the terrane boundary, along the Chatham Rise, between the Pahau and Rakaia terranes. Cretaceous collision and flat-subduction of the Hikurangi Plateau with the Chatham Rise is interpreted to have underplated much of the Pahau Terrane beneath the Chatham Rise along the identified terrane boundary with the Rakaia Terrane.

Within the Pegasus Basin region southward-directed compression interpreted on seismic data has fault-uplifted both the remaining Pahau Terrane and the underthrust Rakaia Terrane. Some of this compression appears to be recent.

The talk will discuss the relationship between uplift interpreted offshore and uplift patterns that occurred onshore during the 2016 Kaikōura Earthquake sequence, as well as discussing the relationship between the Kaikōura Earthquake sequence fault pattern, seismicity and the Cretaceous offsets in Pahau–Rakaia terrane boundary.

EVOLUTION AND ERUPTION OF GEOTHERMALLY COOLED MAGMA BODIES

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Magmatic geothermal systems extract heat and volatiles from deep magma bodies and transport these upward through the brittle crust. Sometimes, these same magma bodies evolve toward an unstable, overpressured state, precipitating a catastrophic caldera eruption. Understanding the deep coupling between magmatic and geothermal systems can help contextualise our near surface observations and plan for utilisation of the deep resource. In addition, insight into how the system transitions between convective and eruptive phases has implications for our understanding of volcanic hazard.

We have developed a lumped parameter thermomechanical model of a magma body that is being cooled from above by geothermal systems and recharged from below by deep magma sources. The model tracks the evolution of temperature, pressure and magma composition, and includes parameterised descriptions of eruption, volatile leakage across a viscoelastic shell, and overlying geothermal systems. We have used this model to explore generic eruptive styles and to develop an approximation of the eruptive record of the modern Taupō Volcanic Zone (TVZ).

Our modelling suggests that magma bodies at 4–5 km depth in the TVZ are overlaid by a 500 m-thick, permeable, viscoelastic shell. The timing and volume of eruptions are dominated by short intervals of sporadic magma recharge originating deeper in the crust. Long-term climatic modulation of rainfall driven geothermal systems has minimal impact on eruptive timing. However, under certain conditions, efficient geothermal systems can trigger an eruption by cooling a magma body too rapidly, resulting in gas exsolution that builds to a critical overpressure. These insights highlight the value of coupled magmatic–geothermal models and suggest development of a magmatic reservoir simulator could shine new light on the complex physical interplays occurring deep in the TVZ.

A POSSIBLE TOARCIAN FLORA FROM JUNGGAR BASIN, XINJIANG, NW CHINA AND ITS PALEOCLIMATE IMPLICATIONS

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The flora from the Sangonghe Formation of the Haojiagou-Toutunhe section in the Junggar Basin, Xinjiang, NW China, consists of ~21 taxa, including *Neocalamites hoerensis* (Schimper) Halle, *Equisetites lateralis* Phillips, *Todites* sp, *Marattiopsis asiatica* Kawasaki, *Phlebopteris polypodioides* Brongniart, *Dictyophyllum* sp, *Coniopteris bella* Harris, *Coniopteris* sp, *Cladophlebis argutula* (Heer) Fontaine, *Cladophlebis* sp, *Sphenopteris* sp, *Otozamites leckenbyi* Harris, *Otozamites* sp, *Zamites* sp, *Dictyozamites* sp, *Ginkgo* sp, *Czekanowskia setacea* Heer, *Brachyphyllum* (*Hirmeriella*?) sp, *Pityostrobus* sp and *Cadmisega ephedroides* Krassilov et Bugdaeva, *Carpolithus* sp. This floral assemblage suggests a late Early Jurassic, and most probably the Toarcian, age based on the known ranges of the species and correlation with contemporaneous floras in Eurasia. The assemblage is extraordinary due to the very high proportion (40%) of thermophilous or arid-tolerant (Xerophilous) taxa compared to the underlying and overlying beds. These taxa include the thermophilous plants, matoniaceous fern *Phlebopteris polypodioides*, dipteridaceous fern *Dictyophyllum* sp, marattiaceous fern *Marattiopsis asiatica*, bennettitaleans *Otozamites leckenbyi*, *Otozamites* sp, *Zamites* sp and *Dictyozamites* sp, and arid-tolerant plants, gnetalean plant *Cadmisega ephedroides*, and cheirolepidiaceous conifer *Brachyphyllum* (*Hirmeriella*?) sp. The leaves of the ferns are much smaller than those from the older and younger strata in the same section. Besides it is accompanied by an abrupt increase of the cheirolepidiaceous conifer pollen *Classopollis*. Together these indicate that the climate in the Junggar Basin area changed to warm and arid during the late Early Jurassic. This climatic event in terrestrial ecosystems could be linked to the Toarcian Oceanic Anoxic Event (T-OAE) recognised in oceanic settings.

SBAS: SATELLITE BASED AUGMENTATION SYSTEM AN EMERGING TECHNIQUE FOR GEOSCIENTISTS?

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The prototype implementation of a Satellite-Based Augmentation System (SBAS) for the Australasia region, sponsored by Geoscience Australia and Land Information New Zealand (LINZ), is designed to overcome the current gaps in cellular (mobile) and radio communications to ensure that accurate and reliable positioning information can be received anytime and anywhere within Australia and New Zealand. As part of the development of this project, the University of Otago in collaboration with Trimble New Zealand, has conducted one of the testbed projects focusing on survey applications.

Legacy SBAS, which is based on single-frequency single-point positioning and is primarily used by the aviation industry, has a typical positioning accuracy of ± 1–3 m. The prototype SBAS has the potential to deliver low centimetre (± 1–5 cm) positioning accuracy using the satellite-delivered SBAS Precise Point Positioning (PPP) and decimetre (< ± 50 cm) using Dual-Frequency Multi-constellation (DFMC) services.

The purpose of this project is to evaluate the effectiveness of using the prototype SBAS positioning services (PPP, DFMC) to conduct low-accuracy rural surveys to the LINZ Class C standard (i.e., rural surveys). We present our experience using SBAS to conduct surveys in Otago, benchmarked against conventional single-base RTK and Trimble’s RTX positioning service. We show the advantages and limitations of using SBAS and the results achieved in a variety of different environments ranging from an easy site with no sky occlusions (e.g., vegetation, topography) to sites with significant bush cover and steep mountainous topography. One of the critical issues turned out to be the ability of both SBAS and RTX to correct effectively for crustal motion, both in New Zealand and the wider Asia–Pacific region.

LARGE-SCALE TRANSPORT OF METALS AT BROTHERS SUBMARINE ARC VOLCANO: EVIDENCE FROM MASSIVE SULFIDE STOCKWORK ZONES

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Brothers volcano of the southern Kermadec arc, New Zealand, is host to extensive hydrothermal activity, including two prominent hydrothermal vent fields: the NW Caldera and Upper Caldera sites. Where demarcated by a magnetic low, the boundaries for these sites have an hour-glass shape in plan view, with a bulbous, open top section ~1 km wide near the Upper Caldera walls, which extends ~800 m to the SE where it narrows to 400 m at the NW Caldera rim, occupying an area ~0.68 km^2 (Upper Caldera site). This alteration zone then widens again to ~1 km and extends a further ~700 m towards the SE, encompassing an area of ~0.76 km^2 that includes all of the NW Caldera walls, and which extends onto the caldera floor (NW Caldera site). The Upper Caldera vent field is host to numerous black smoker chimneys up to 20 m tall expelling fluids up to 320 °C. Only minor, diffuse venting occurs across the caldera rim. Hundreds of both active and inactive chimneys are perched on benches that cut across the NW Caldera walls, reaching heights of ~15 m and discharging fluids up to 311 °C. No present-day venting occurs on the caldera floor. The top of the Upper Caldera wall occurs at ~1300 mbsl and the caldera floor is at ~1800 mbsl, ensuring ~500 vertical meters of seafloor hydrothermal activity in this sector of Brothers volcano today. The NW Caldera walls are characterized by normal faults, which are associated with caldera collapse. Extensive stockwork veining is exposed in the faces of several of these faults, with three examples occurring at ~1600, ~1655 and ~1685 mbsl. The faults strike between 037° and 057° and extend for up to 210 m, typically ~150 m. The throw on the faults is commonly ~15 m, though can reach up to 20–30 m. An anastomosing network of sulphide veins cut highly-altered wallrock with the veins ranging between mm to >10 cm wide. Pyrite is the most dominant sulphide seen macroscopically, although Cu is likely present given the green staining of the adjacent wallrock. Extensive stockwork mineralization exposed at the NW Caldera vent field is testament to mobilisation of metals that occurred prior to caldera collapse.

CONTROLS ON WEATHERING INDUCED STRENGTH DEGRADTION WITH IMPLICATIONS FOR BRITTLE ROCK SLOPE FAILURES

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Triggers of rock slope failures are often ambiguous and can be undetectably small. For failure to occur under such conditions, weakening of the rock mass through time, commonly lumped into the all-encompassing term weathering, must occur. Recent research has suggested that the quasi-constant stress experienced by a rock mass, as determined from overburden loading and slope morphology, may influence weathering intensity, with areas of higher or lower stress experiencing different rates of strength degradation. Additionally, the links between weathering, micro-crack damage and rock strength are not well-constrained, including not only the potential for strength reduction but the broader geotechnical response of intact rock to weathering, which is important for determining failure style.

We conducted experiments using sedimentary rock samples to determine the influence of gravitational stress, local slope geometry and existing micro-crack damage on weathering and subsequent changes in rock strength. We placed samples under a constant compressive stress using a novel experimental set-up and subjected samples to either intensive short-term laboratory-based conditions, or field based long-term coastal conditions. At the end of the tests, geotechnical behaviour and rock strength were determined via unconfined compression testing and compared with baseline values. Our analysis reveals that compressive stress conditions alongside sample modifications do not influence weathering intensity, with the stresses imparted by weathering processes equal to or greater than the stresses imposed by our experimental set-up. Weathering does, however, significantly reduce intact rock strength, which results in a change in macro-scale failure style, with samples displaying multiple stages of brittle failure before residual strength is reached. This holds implications for interpretation of rock slope pre-failure deformation data as well as the sequence and magnitude of triggering events required to promote total failure of rock slope.

FLOW MAPPING OF MT TARANAKI THROUGH AERIAL PHOTOGRAPHY: CONSTRAINING SAMPLING SITES FOR PETROGRAPHIC AND GEOCHEMICAL WORK

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Mt Taranaki/Mt Egmont is an active stratovolcano that last erupted in ~1854. It is located in the western part of the North Island in New Zealand. The Egmont National Park is a 335 km^2 region covered by thick native rainforests. The densely vegetated lower flanks and the steep faces of the upper cone of Mt Taranaki make it difficult to access all locations for field mapping. Recently, we have completed a low-flying airborne hyperspectral and digital photography survey using a Cessna 185 aircraft. The airborne GPS-tagged photographs were used to construct a Digital Surface Model (DSM) using the structure-from-motion technique. This resulted in true-coloured mosaicked imagery and a DSM with a spatial resolution of 0.3 m. We used this DSM and photo mosaic to trace the deposits of effusive activity of Mt Taranaki. The high-resolution image data made it possible to identify individual lava flows and lobes from previous eruptions and to trace their extent and morphology. This mapping project on effusive activity is key to understanding the recent eruptive history of the volcano and contributes to hazard mitigation. The DSM will be used to calculate thicknesses and volumes of lava flows to gain insights into the magma extrusion rates during each effusive period, thereby constraining magma supply from the plumbing system beneath Mt Taranaki. The data inform updated geological maps of the lava flows, which will be used to select sites for field mapping to determine the stratigraphic correlation of the lava flows and intercalated tephra fall deposits. These maps will also form the basis of sampling of Mt Taranaki's recent effusive events for petrographic and geochemical work. Preliminary petrographic data of recent deposits and analytical methodologies to constrain pre-eruptive processes will be discussed.

THE HIKURANGI MARGIN COASTAL RADIOCARBON AGE DATABASE

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The Hikurangi Margin Coastal Radiocarbon Age Database is a GIS database containing published and unpublished radiocarbon ages from coastal sites along the Hikurangi Margin. All radiocarbon age and contextual information complied in the database was retrieved from paleoseismic and paleoenvironmental studies along the coastline from Kaikōura Peninsula to East Cape, New Zealand. The primary purpose of compiling the radiocarbon dates in the database is provide an underpinning chronology for the timing of subduction zone and upper plate fault earthquakes and tsunamis along the Hikurangi Margin. The database has been designed to allow easy extraction of conventional radiocarbon ages to facilitate the recalibration of ages as updated calibration curves and/or marine reservoir correction values become available. Currently the database has 701 entries from 369 locations. It is intended that as new radiocarbon ages are acquired they will be routinely added to the database. The database consists of three ArcGIS shapefiles that relate to (1) marine terraces, (2) coastal waterbodies and (3) transgressive deposits. Along with the age, fraction dated and locational data of each entry, we include as much contextual information as possible about radiocarbon age. For example, where possible we include the preferred paleoenvironment of the shell species dated (e.g., estuarine, rocky shore or beach environment), the depositional zone the sample was collected from, and notes on the likelihood that the sample was collected from a paleotsunami deposit. Although the primary purpose of this database is for paleoseismic studies, the information may be of use for calculating Holocene vertical deformation rates, and for sea-level and archaeological studies.

PLIOCENE–PLEISTOCENE PALEOPRODUCTIVITY ON THE WILKES LAND MARGIN, ANTARCTICA

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Although the East Antarctic Ice Sheet (EAIS) is considered relatively stable, the Wilkes Land Margin (WLM) is susceptible to global warming because its marine-based glaciers are at risk of contact with warm mid-depth waters. Unstable ice sheets cause sea-level rise that threatens coastal communities, but our understanding of ice variability and response to climate change is poorly constrained due to a lack of data. We present a Plio-Pleistocene biogenic silica (wt% BSi) stratigraphy and diatom assemblage from a marine sediment core collected from International Ocean Discovery Program (IODP) site U1361A, located on the WLM continental rise. Characterizing Southern Ocean conditions from 3.8–1.8 Ma allows us to examine the shift from the warm Pliocene, which is an analogue for future warming conditions, to the cooler Pleistocene, and may improve the parameterization of EAIS response to climate forcings. High wt% BSi intervals are interpreted to reflect interglacial episodes of elevated diatom productivity, while lower wt% BSi intervals are interpreted to reflect glacial episodes of decreased productivity and/or increased terrigenous input. Diatom assemblages from mid- and late-Pliocene interglacial intervals indicate the onset of cooler interglacial surface ocean temperatures around 3.6 Ma, punctuated by short-lived warm water incursions.

A CENOZOIC RECORD OF OCEAN TEMPERATURE FROM ANTARCTICA

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The long-term climate evolution of Antarctica is largely derived from records of benthic foraminiferal $\delta^{18}O$ far removed from the continent. Benthic $\delta^{18}O$ incorporates a signal that reflects both shifts in ice volume and deep-sea temperature. Attributing the relative contribution from each of these two factors is challenging, making it essential to investigate temperature changes at the high southern latitudes where much of the global ocean deep water is formed. Evidence from the past and present day also indicate that temperature changes at the poles are amplified relative to the global mean. However, there are few high latitude reconstructions of past temperature, limiting our understanding of the constraints on the magnitude of polar amplification during warm periods in the geological past. Here, we present the first Cenozoic compilation of ocean temperature from the Ross Sea, using proxies based on isoprenoid glycerol dialkyl glycerol tetraethers (GDGTs) sourced from marine archaea. Reconstructed temperatures from TEX_{86}^{L} (0–200 m water depth) and BAYSPAR in standard sub-surface mode indicate cooling prior to the Eocene–Oligocene boundary. Temperatures remain relatively cool for much of the Cenozoic, with the exception of short periods of warmth during the late Oligocene and Miocene Climate Optimum, with modern polar temperatures reached by the mid-Pleistocene. The temperature trends in the Ross Sea, the key source region for Pacific bottom water, are broadly comparable to the lower latitude deep Pacific $\delta^{18}O$ record. Isoprenoid GDGT distributions through the Cenozoic indicate a shift in the Ross Sea marine environment towards a more oxygenated seafloor as the continental shelf deepened and ocean bottom currents became more active. The transfer of terrestrially sourced branched GDGTs declines over the Cenozoic, reflecting increasingly less active glaciofluvial systems and limited soil development on less ice-free land.

DEEP SUBMARINE ASH DEPOSITS: EXPLOSIVE ERUPTION, EXTREME QUENCH FRAGMENTATION, OR BOTH? FINGERPRINTS OF ASH-FORMING PROCESSES DURING THE ~1 KM-DEEP ERUPTION OF HAVRE, KERMADEC ARC

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Havre volcano erupted in 2012 from about 1 km depth to produce a ~400 km^2 pumice raft, and a plume of vapour at the surface that extended ~80 km. Focused heat delivery to the surface is inferred from the latter, requiring some form of narrow thermal plume. A 1 m^2 resolution bathymetric map of the volcano, observations from ROV Jason, and systematically sampled ash from the seafloor reveal a multi-layered deposit of dominantly fine ash. One layer shows no clear thinning or fining trends across the whole of the caldera floor and shoulders. Both raft pumice and giant pumice blocks on the seafloor are texturally distinct from the ash, which we are analysing to determine the driving mechanisms for ash production. We have also produced ash experimentally from re-melted Havre rhyolite to help assess heat transfer to the ocean. Fragmentation at Havre helped transfer heat to the water but requires process-specific energy to produce the new fresh surfaces. In subaerial eruptions, heat transfer from ash strongly controls generation of buoyant plumes. Experimental data in combination with 2-D and 3-D shape analyses of both lab-generated volcanic particles and natural volcanic ash are beginning to reveal the dominant ash generation mechanisms involved in the 2012 Havre eruption. We describe our experimental setups and analytical techniques, and discuss eruptive scenarios based on initial results.

HETEROGENEOUS DISTRIBUTION OF SLAB FLUIDS INFLUENCES ALONG-ARC VARIATION OF SUBDUCTION PROCESSES IN THE HIKURANGI SUBDUCTION ZONE

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Seismicity distribution and 3-D models of P- and S-attenuation (1/Q) in the Hikurangi subduction zone, North Island of New Zealand, show large variation along-arc in the fluid properties of the subducting slab. Volcanism is also non-uniform, with extremely productive rhyolitic volcanism localized to the central Taupō Volcanic Zone, and subduction without volcanism in the southern North Island. Plate coupling also varies, with heterogeneous slip deficit in the northern section, low slip deficit in the central section, and high slip deficit (strong coupling) in the south. Subduction zone fluid comes into the system from hydration of the crust and mantle in the outer rise bending zone. Thus, heterogeneous initial hydration and varied dehydration history of the subducted slab are inferred to play a role in along-arc variation. Parts of the Hikurangi Plateau large igneous province have been subducted beneath New Zealand twice, and it has an uneven downdip edge, which has stalled the subduction rate for some sections during impact. The mantle wedge beneath the region of rhyolitic volcanism has a very low Q feature centred at 50–125 km depth, directly overlying a 150-km long zone of dense seismicity in the subducted plate. This seismicity occurs below a sharp transition in the downdip extent of the Hikurangi Plateau, where difficulty subducting the buoyant plateau would have created a zone of increased faulting and hydration that spent a longer time in the outer-rise yielding zone, compared with areas to the north and south. The locally abundant slab fractures and hydration may provide high fluid flux under Taupō. Additionally, since fluid can migrate within the slab, the consumption of released water by rising melt may encourage continued high slab fluid release under the Taupō centre. Where the plate interface is at depths less than 50 km, the central section of the subducted plateau has low Q in the slab crust, indicating that it is extremely fluid rich, exhibiting weak plate coupling with both deep and shallow slow-slip events. The upper plate faulting and fluid flux may also encourage underlying slab fluid flux, enabling continued interaction between upper and lower plate fluid processes.

ICE SHELF CRYOSEISMOLOGY

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Climate and oceanographically motivated hot water drilling through the McMurdo and Ross ice shelves as part of the Aotearoa New Zealand Ross Ice Shelf Programme has provided a novel opportunity for cryoseismology investigating the manifestations of ice shelf structure, inherited fabrics and intra-shelf deformation. The 2016 pilot study at Windless Bight on the 220-m-thick McMurdo Ice shelf has confirmed the viability and seasonal survival of borehole seismometers frozen into the ice shelf and improved resolution of ice fabric anisotropy sensitive active source S-wave phases via this approach. Surface hammer driven P- and S-wave seismic sources provided signal propagation to >240 m and produced reflections from the basal ice surface and seafloor. In this high snow accumulation area firn, with a low P-and S-wave velocities, transitions to ice at ~34 m depth. Glacial ice, derived from the Terror Glacier, Ross Island, has indications of complex anisotropy associated with glacial flow. Such seismic anisotropy indicates mechanical anisotropy that will influence continued glacial flow dynamics. Over autumn passive seismic recording reveals strong tidal control on ice deformation associated with flexure.

The 2017 HWD-2 drilling of the central Ross Ice Shelf penetrated 370 m of ice thickness at two sites 560 m apart. A rich multi-disciplinary dataset was successfully acquired. Eight levels of 3C, 15 Hz borehole seismometers were deployed through the ice shelf recording events from a borehole sparker source deployed in the second hole and multi azimuth and offset surface P- and S-wave sources. This “ground truthed” site provides a valuable opportunity to calibrate seismic velocity to temperature, seismic reflectivity to complex basal ice conditions optically imaged and explore ice structure and deformation of the central Ross Ice Shelf area.

CHANGING ROSS SEA CLIMATE ~8900 YEARS AGO—A REGIONAL OR CONTINENT-WIDE SIGNAL?

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To improve our understanding of the stability of the Ross Ice Shelf (RIS) in a warming world, the Roosevelt Island Climate Evolution (RICE) project recovered a deep ice core from Roosevelt Island (RI), an independent ice rise at the northeastern edge of RIS. The Holocene epoch is an interesting time period for comparison as it represents the current interstadial with similar sea-level and temperature conditions.

Here, we present high-precision (low to sub-ppb concentrations) Ion Chromatography (IC) data from discrete samples of the RICE ice core in high-resolution (sub-annual to 5 years) covering the Holocene from ~10.5 to 7.3 ka BP. Our reconstruction of open ocean area/sea ice extent (SIE) and marine primary productivity is based on MSA^- and the ratio of Na^+/SO_4^{2-}, which is used to quantify the frost flower contribution. To infer changing atmospheric circulation patterns, we use varying concentrations of ions with different sources: While the crustal/continental ions K^+, Mg^{2+} and NO_3^- are linked to katabatic winds, sea salt ions as Na^+, Cl^- and Ca^{2+} are associated with cyclonic activity.

The early Holocene is characterised by increasing productivity and cyclonic activity trends between ~10.5–7.3 ka, while the RICE stable water isotopes indicate a temperature shift from warm conditions during the early Holocene (11–10 ka) to colder conditions between ~9.6–8.5 ka. Iceberg-rafted debris (IBRD) records from the Scotia Sea are interpreted to reflect Antarctic Ice Sheet (AIS) discharge variability. A decrease in AIS discharge from ~9.5–8.9 ka BP is synchronous with the temperature shift at RI. Wavelet analysis of the IBRD and RICE records suggests a concurrent frequency shift. We interpret these changes to reflect a climatic event of Antarctic-wide impact around 8.9 ka BP.

"WEAK BUT STRONG"—INVESTIGATING HETEROGENEOUS AND TRANSIENT STRESS STATES IN NEW ZEALAND'S SHEAR ZONES

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The deep parts of crustal faults often consist of irregular, branching, or anastomosing strands of weak and deforming matrix material, surrounding dismembered competent lenses. With increasing strain, the competent lenses mechanically interact with each other and the surrounding matrix, rotate, internally deform, and can ultimately disaggregate. Such a fault is better described as a tabular shear zone with a finite thickness determined by geometry, composition, and deformation mechanisms. For example, a subduction interface can range in thickness from metres to kilometres, depending on subducting relief, incoming sediment properties, strain, and depth. Many of New Zealand's exhumed terrane boundaries are also separated by wide shear zones and mélanges.

Numerical modelling of outcrops such as the Chrystalls Beach Complex, an inferred ancient exhumed subduction mélange, reveals that a shear zone comprised of two or more rock competencies can exhibit substantial changes in stress orientation, failure mode, and bulk shear strength over timescales of years to centuries. This temporal variability may cause the juxtaposition of weak shear deformation with high-stress fractured rock. Significant stress rotations may occur, with changes from local tension to compressional shear failure over short length scales, even when bulk fluid pressures are held constant. Temporal cycling in stresses and strain-rates due to progressive geometric reorganisation and the forming and breaking of force chains can result in simultaneous brittle and ductile deformation. Unintuitively, the shear zone may deform at low stresses while clasts within it experience much higher stresses. Models also show that clast stresses increase and force chains form for a range of volumetric clast proportions and shear zone widths, indicating that stress heterogeneity is ubiquitous in shear zone mélange.

We summarise some of these model results and their extrapolation to larger spatial scales. More broadly, we discuss the implications for the present-day Hikurangi subduction interface and other crustal-scale faults.

INTERACTIONS BETWEEN MAGMA AND MECHANICS IN AN ACTIVE VOLCANIC RIFT—WHICH FACTORS PROMOTE TENSILE AND SHEAR FAILURE ABOVE AN EVOLVING SHALLOW MAGMA CHAMBER?

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The stability of a shallow magma body in an extensional environment such as the Taupō Volcanic Zone (TVZ) depends on its evolving rheological properties and the mechanical, thermal and hydrological state of the surrounding crust. These in turn are affected by the competition between melting and cooling rates, the response to magma inflow from the surrounding crystal mush, and the response to tectonic, buoyancy and inflation forces. We outline an improved thermomechanical model to evaluate the relative importance of these factors in controlling the stress and failure regimes around a hypothetical evolving magma body in the TVZ. We include ductile creep, elastic, tensile and brittle shear failure mechanisms for the country rock surrounding the intrusion. Rock pressure and stresses in the model evolve naturally with strain-rate, thermal and fluid states and magma viscosity. Preliminary tests modelling extension around a thin dike growing from a magma reservoir emphasise the importance in magma geometry in perturbing stresses in the surrounding country rock. The style of faulting (and amount of tensile yield) depends on the relative influence of tectonic extension versus magma forcing from buoyancy and inflation. Regions of tensile extension preferentially form in the top 1–5 km within faults activated above a dike, but with increasing inflation stress and/or density contrast between magma and country rock they will also form at the dike tips, thereby enhancing dike propagation. The complex zone of shear and tensile failure above a magma body is predicted to enable hydrothermal/meteoric fluid circulation, increasing the rate at which the magma body cools through thermal convection.

MULTI-COMPONENT AMBIENT NOISE TOMOGRAPHY OF THE AUCKLAND VOLCANIC FIELD, NEW ZEALAND

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For the active Auckland Volcanic Field, low earthquake-generated seismicity and a high ambient seismic noise level have, until recently, hindered the investigation of structural eruption controls by passive seismic imaging. To improve on this state of knowledge, we determined crustal shear-wave velocities in the Auckland Volcanic Field by ambient seismic noise tomography using seismic noise recorded on the vertical components. Ambient seismic noise tomography involves retrieving surface wave information from seismic noise and inverting for shear-velocity structure. The resulting overall shear velocity variations in the crust correspond well with major known surface geological features, and tectonostratigraphic terranes at depth, such as the semi-continental Murihiku and Waipapa terranes and oceanic Dun Mountain–Maitai Terrane. Analysis of the shear velocity structure along individual paths between station pairs also reflects, to some degree, the influence of these features.

In addition to ambient seismic noise tomography using seismometer vertical component data, using multi-component ambient seismic noise can increase the resolution and robustness of models of the crust. To do this, we need to know the orientation of borehole seismometer sensors. We estimate the orientations using polarisation analysis of Rayleigh wave signal retrieved from ambient seismic noise and earthquake sourced P-waves. Based on the elliptical Rayleigh wave particle motion, we maximize the correlation between the radial–vertical component and the (phase-shifted) vertical–vertical component of the Rayleigh wave signal extracted from the seismic noise. We then evaluate which multi-component estimate of the Rayleigh wave signal contains the most robust, most accurate, and most dispersion information. We will present our first attempts at inversion of the best estimates of the Rayleigh wave signal for crustal shear velocity structure in the Auckland Volcanic Field.

THE VANISHED WORLD TRAIL TO A WAITAKI WHITESTONE GEOPARK

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Vanished World Incorporated (VW) is a community-supported society that promotes the geology of North Otago and now, in 2018, is contributing to the proposal for a formal UNESCO Waitaki Whitestone Geopark. VW was established in the early 2000's, to encourage education, promotion, conservation and appropriate use of the geological materials and features in the district. Vanished World Incorporated maintains a Visitor Centre in Duntroon (shop, gallery, preparation room and rock room), mostly with voluntary staffing, and has over 20 geological sites on its VW Trail. The Centre and Trail have functioned as an informal geopark. Ewan Fordyce is scientific adviser, involved in choosing field sites, providing display items (original fossils, and high-fidelity fossil replicas) for the VW Centre, and producing signage for sites and the Centre. A folding colour A3 brochure with a map and graphics has been an important fundraiser. Sponsors have helped to fund individual projects.

Vanished World sites range from Moeraki to Oamaru, and inland beyond Duntroon. Sites are public, or private and developed by agreement, offering free access to metamorphic, igneous, and sedimentary rocks and landforms. Fossil collecting is generally discouraged. Each site has a fingerboard, and/or an explanatory plaque. Large information boards for roadsides and sites provide maps, photographs and explanation of locations.

Internationally-significant fossils from the district include sharks, bony fish, giant penguins, whales and dolphins. Sites at Anatini and “The Earthquakes” show fossil baleen whales that have been partly excavated from the encasing Otekaike Limestone behind protective covers. Anatini has open private access; The Earthquakes was recently purchased by DOC, with access maintained. The fossils are important in the proposal for a UNESCO Waitaki Whitestone Geopark currently being developed by Waitaki District Council.

FINITE-DIFFERENCE MODELLING OF GAS HYDRATE DEPOSITS IN THE URUTI BASIN ON THE HIKURANGI ACCRETIONARY MARGIN, NEW ZEALAND

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Gas hydrates are ice-like, clathrate solids trapping natural gas molecules inside a lattice of water molecules. They are common constituents of continental margins, leading to extensive studies exploring their resource potential, role in the climate cycle, associated slope stability and geohazard considerations.

Hydrates are commonly inferred within the Pegasus sub-basin, which lies at the southwest end of the East Coast Basin off the east coast of the North Island, New Zealand. Lying at the transition from subduction to strike-slip on the plate-boundary system, deformation within the sub-basin forms conduits allowing focused fluid flow, leading to high-concentration gas hydrate deposits. The host rocks in the sub-basin are presumed to consist of high-permeability sands and fractured mudstones.

A method of viscoelastic, finite-difference modelling has been established producing synthetic seismograms. This enables the determination of the theoretical seismic response of stratigraphic and structural features present within a geological model. The 2-D geologic model was built using horizons from the PEG09-25 (a conventional petroleum industry data set) and HKS02-01 (a high-resolution shallow penetration data set) seismic reflection lines defining the seabed, bottom-simulating reflections and dipping sedimentary layers infilled with gas hydrate or free gas. Synthetic seismograms are produced by simulating the propagation of seismic energy from a series of sources through the model, recorded at regularly sampled locations, using the viscoelastic, finite-difference routine. A series of finite-difference models have been created to test material properties of stratigraphic units within the Pegasus sub-basin by varying geological and acquisition parameters. These include bed thickness, host lithology, porosities, source bandwidth and sampling rate.

The synthetic seismograms are compared with the real data, validating their results and allowing improved quantification and characterisation of gas hydrates. The finite-difference models provide ratification of the existing shallow sub-surface and velocity models.

ECOTOXICITY TESTING IN THE MARINE ENVIRONMENT: A NEW SEDIMENT LEACHING COLUMN APPARATUS

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The marine environment is constantly subjected to anthropogenic influences such as pollution runoff and sediment disturbance. These types of activities have the potential to harm the environment and impact the food-chain and kaimoana (seafood). Standard methods such as elutriate experiments are available for assessing the short-term chemical release (1–2 hours) from contaminated sediments. However, long-term (weeks to months) observation of chemical release and dissolution after sediment disturbance is important as sustained higher elevations of potentially ecotoxic elements could bioaccumulate and affect local marine fauna. A reproducible and reliable method of quantifying long-term chemical release specifically from marine sediments has yet to be established.

A recirculating sediment leaching column has been developed to address this gap. Site sediment and seawater (1:4 ratio) are agitated and leached after settling in a column. A peristaltic pump is used to circulate water through the sediment to ensure equilibrium is reached. Results of preliminary experiments using a prototype design and Chatham Rise sediment and deep bottom water alongside standard elutriate experiments, will be presented. These experiments were run as part of the now completed Ministry of Business, Innovation and Employment (MBIE)-funded programme, Enabling Management of Offshore Mining (EMOM).

Atmospheric CO_2 fluctuations and associated pH changes were observed to affect the chemistry of the leachate over time in the first experiments. Therefore, the prototype design has been designed with a precision CO_2 management system for pH control. This not only enables more accurate quantification of long-term chemical release under steady-state conditions but enables insights into the timeframes of dissolved metal exposure to local fauna, and the potential to assess the effects of ocean acidification on dissolution of exposed seafloor sediments. The new design will be implemented as part of a MBIE Endeavour Smart Ideas grant.

MOLLUSCAN FAUNA OF THE OLIGOCENE POMAHAKA FORMATION: TROPICAL ESTUARINE AND BRACKISH-WATER TAXA IN OTAGO

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Thirty-four species of estuarine and brackish-water Mollusca, including three new genera and 17 new species are reported from several localities of late Oligocene age (Duntroonian) along the Pomahaka River and tributaries, Otago, southern New Zealand. *Hinemoana*, *Batillona*, *Pomahakia* and the new venerid genus are only known from the Pomahaka Formation; seven other genera (marked with an asterisk below) are the only records from New Zealand.

The Pomahaka Formation was deposited in an extensive microtidal estuarine paleo-environment similar to the present upper reaches of Moreton Bay, southern Queensland. Tropical groups such as *Modioliformia*, *Circe*, *Potamocorbula*, *Clithon* and Thiaridae, along with *Terebralia* from nearby sites of similar age, indicate that sea surface temperatures were considerably warmer than at present; the “mudwhelks and mangroves” association extended to southern Zealandia (paleolatitude ~46°S) during the late Oligocene to early Miocene.

Taxa present include **Modioliformia* n. sp., *Brachidontes* n. sp., *Xenostrobus*? sp., *Ctenoides*? sp., *Saccostrea* n. sp., *Flemingostrea wollastoni* (Finlay), Hyriidae (genus unknown), *Arthritica* n. sp., *Spisula* (Spisulona) n. sp., *Tellinota*? sp., *Hinemoana acuminata* (Hutton), Veneridae n. gen., n. sp., *Tapes* sp., **Circe* n. sp., **Potamocorbula* n. sp., *Periploma* sp., *Martesia concentrica* Suter, **Clithon pomakahaense* (Finlay), Batillariidae n. gen. *pomahakensis* (Harris), *Batillona amara* Finlay, **Melanoides* n. sp., *Zemelanopsis pomahaka* (Hutton), *Grandicrepidula salebrosa* (Marwick), *Potamopyrgus* two n. spp., *Halopyrgus* n. sp., **Hydrococcus* n. sp., *Onoba* n. sp., *Euspira* n. sp., *Pomahakia aberrans* Finlay, *Vesanula* n. sp., *Xymene*? sp., *Murexsul*? sp. and **Salinator* n. sp. (earliest record of Amphiboloidea).

ENERGY AND RESOURCE MARKETS KNOWLEDGE INVESTMENT ROADMAP—A PATHWAY TOWARD A NATIONAL GEOSCIENCE INFORMATION FRAMEWORK?

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The Energy and Resource Markets branch (ERM) of the Ministry of Business Innovation and Employment (MBIE) incorporates the regulatory functions of New Zealand Petroleum and Minerals and is responsible for significant holdings of geoscience information submitted to government by explorers under the Crown Minerals Act. The information is fundamental to understanding and managing New Zealand's petroleum and mineral economic potential and has broad application across the earth sciences. It includes physical samples and vast digital data which together represent a significant national knowledge asset.

ERM sought collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to facilitate development of an investment roadmap to support the ongoing stewardship of these assets. The roadmap aims to inform investment in knowledge and knowledge management systems to improve the availability and accessibility of ERM's geoscience information. Commonwealth Scientific and Industrial Research Organisation, drawing on their experience in the development of national geoscience and environmental information systems in Australia and internationally, facilitated workshops, interviews and undertook an extensive review of ERM's background material and current context. This consultation provided insight of how external entities interact with ERM's information and how ERM could improve information access and customer experience.

The roadmap identifies core challenges and recommends alternative information management approaches to transform data services. Doing so will improve the agility and efficiency of business systems and provide fit-for-purpose and discoverable data that is ready for downstream analysis. Current systems and processes simply cannot meet the needs of today's consumers, nor meet the national challenges in Earth resource management. Recommendations include adopting a Notional Information Systems Architecture that treats technical data and documents equally and provides a world-class geospatial infrastructure for the sharing of data across business functions. Such an infrastructure could form the basis of a national geoscience information framework with broader benefit to industry and research organisations.

A DIVERSE ASSEMBLAGE OF PLIOCENE MOSS MACROFOSSILS FROM THE AUCKLAND REGION

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An exceptional assemblage of fossil mosses (Bryophyta) has been recovered from several mid-late Pliocene (Waipipian, 3.7–3.0 Ma) localities around Auckland. These estuarine, fluvial and near shore sediments of the Tauranga Group have also yielded important plant and fungal macrofossils. Close inspection of the finer-grained, leaf-bearing sediments has revealed a diversity of exquisitely-preserved mosses. Moss macrofossils are uncommon globally and New Zealand has just two prior records, both of Mesozoic age. These newly discovered mosses represent the first Cenozoic specimens from New Zealand and the first fossil moss flora.

The moss fossils are organically-preserved gametophyte (leaves and stems) fragments commonly just one cell thick. Specimens are soft but resilient and tolerate mechanical extraction and cleaning, making them well-suited to traditional identification methods using transmitted light microscopy. To date, no sporophytes (reproductive structures) have been recovered, although the gametophytes are proving highly diagnostic and more than 15 fossil moss morphotypes are currently recognised, including *Homalia*, *Fissidens*, *Pyrrhobryum*, *Wijkia*, *Papillaria* and Hypnodendraceae. Several morphotypes resemble extant New Zealand species such as *Calyptrochaeta cristata* and *Ptychomnion aciculare*. Mosses are thought to be long-lived at the species level and Miocene specimens elsewhere are often identified as modern species. Therefore, it is not surprising that some of these Pliocene fossils share affinities with, or are morphologically indistinguishable from, gametophytes of extant species.

The fossil mosses co-occur with a diverse vascular flora characteristic of a warm temperate to sub-tropical climate that has experienced high rates of floristic turnover in some groups since the late Pliocene. The mosses complement other fossils from these localities by providing unique insights into the relatively recent, but very different terrestrial forest ecosystems of pre-Pleistocene northern New Zealand and the species that lived there.

LATE PLIOCENE MACRO- AND MICROFOSSIL PLANTS AND FUNGI FROM THE AUCKLAND REGION

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A suite of well-preserved mid-late Pliocene (Waipipian, 3.7–3.0 Ma) fossil plants and fungi are relatively common in Tauranga Group sediments exposed at various coastal sites around Auckland. Fluvial, estuarine and near-shore sediments yield organically preserved fossil fruits, seeds and cones, vascular and non-vascular leaves, wood, amber, pollen, spores, bracket fungus basidiocarps and arthropods such as mites.

Fossils of mosses and bracket fungi are uncommon globally and few records are known from New Zealand. Many of the fossil mosses have been preserved in exquisite detail and include taxa such as *Calyptrochaeta*, *Pyrrhobryum*, *Fissidens*, *Ptychomnion*, Hypnodendraceae, Neckeraceae and Sematophyllaceae.

The fossil fruit and leaf assemblages indicate a diverse vascular plant flora. The majority of fossil fruits belong to locally extinct groups, such as a genus of Cupressaceae, Vitaceae, Menispermaceae, Casuarinaceae, *Brassospora*-type *Nothofagus*, and several large-fruited species of *Elaeocarpus*. Other fossil fruit morphotypes share affinities with extant groups such as *Prumnopitys*, *Passiflora* and *Elaeocarpus*. Many fruit morphotypes remain unidentified at present and almost certainly represent groups now extinct in New Zealand. The fossil leaf flora includes diverse conifers that resemble *Prumnopitys*, *Libocedrus*, *Podocarpus*, *Dacrycarpus*, *Dacrydium* and *Phyllocladus,* and flowering plants include species of Lauraceae, Myrtaceae, Proteaceae, Fabaceae, *Nothofagus* and *Rubus*.

These fossil plants and fungi provide an unparalleled glimpse into the terrestrial ecosystems and plant species living in northern New Zealand towards the end of the Pliocene. High post-Pliocene turnover rates are indicated by a strong dissimilarity between the fossil fruits and New Zealand's modern flora and these can probably be related to the general cooling and/or climatic fluctuations of the Pleistocene.

STRUCTURAL RECONSTRUCTIONS OF THE WAIMEA-FLAXMORE FAULT SYSTEM IN THE NELSON–RICHMOND URBAN AREA: IMPLICATIONS FOR SEISMIC HAZARD

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The Waimea-Flaxmore Fault system (W-FFS) comprises NNE-oriented, E-dipping reverse faults that superpose the Eastern Province terranes above the sedimentary units of the Moutere Depression. In the Nelson–Richmond urban area Holocene activity with earthquakes of magnitude 6.5–7.4 is estimated to have occurred at intervals of ~6 ky (Johnston and Nicol 2013). The W-FFS is interlinked offshore to the Manaia and Taranaki faults, suggesting that it belongs to a set of crustal discontinuities along the suture zone between the Median Batholith and Eastern Province terranes.

The exposure of new outcrops in the rapidly growing Nelson–Richmond urban area and the analysis of LiDAR data provided by the Nelson and Tasman city councils have been used for the ongoing revision of the Nelson city geological map (Johnston 1979). The revised map, the associated reconstruction of the top basement unconformity, and regional geological transects provide the basis for reconstructing the progressive deformation history of the W-FFS during multiple phases of Neogene to Quaternary reactivation.

Progressive retro-deformation of the geological transects and development of simplified forward models show the inferred inversion from an original set of Late Cretaceous–Eocene normal faults of the proto-W-FFS to a system of reverse faults that propagated into the cover sequence during deposition of late Miocene terrestrial units (Port Hills Gravel). Continuous activity through mechanisms of fault-propagation folding persisted during sedimentation of the Pliocene–Quaternary Moutere Gravel, with breaching of the fault tip to the surface, and strong morphological control with associated processes of surface instability.

The orientation of the W-FFS in the present-day stress field and the ongoing crustal shortening associated with the Pacific–Australia plate boundary in the northern South Island create conditions favourable to reactivation of this long-lived fault system with modes of rupture that are likely to mimic its long-term evolution.

THE INCEPTION, EPISODIC GROWTH AND DEPOCENTER MIGRATION OF A FOREARC BASIN IN AN ACTIVE ACCRETIONARY WEDGE, NORTH ISLAND, NEW ZEALAND

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Forearc basins are sensitive to changes in tectonism along the plate margin, and therefore potentially record information regarding uplift–subsidence events, basin inversions, rates of sedimentation, and the broader tectonic regime. To understand the architecture of a forearc basin alongside an actively deforming plate boundary, it is important to consider the deformational history of the sediments within it, the evolution of the structures bounding it, and the relationship between the tectonic plates. The focus of this research is to provide a better understanding of the geometry and style of sedimentation related to forearc basins forming on active accretionary wedges, how this relates to progressive regional tectonics, and the evolution of the Australia–Pacific plate boundary.

The forearc basin, situated on the southeast of the North Island of New Zealand, provides a good case study as the basin succession, including the bounding structures, are entirely emergent. It has been possible to study the region by field-mapping and to compare the results with off-shore seismic data. During fieldwork in the Wairarapa region, a detailed geologic map of the early–middle Miocene basin succession, as well as the intensely deformed coastal ranges, has been compiled. The drafting of associated cross-sections and stratigraphic analysis has made it possible to refine the end of subduction during the Cretaceous, and its re-initiation at the beginning of the Miocene.

Discoveries in the Pakowhai and Mataikona rivers has given exciting insight into the Cretaceous basement–cover relationship and the magnitude of Neogene deformation. Detailed structural and stratigraphic mapping within the adjacent early–middle Miocene basin has provided evidence for a close connection between the actively uplifting wedge and the westward migration of the sedimentary successions.

Early Miocene re-initiation of subduction manifested as broad scale uplift of pre-Miocene sediments by regional trench-ward verging thrust faulting. The previously identified "Wairarapa Allochthon" (Delteil et al. 1996, NZJGG 39: 271–282; Adams et al. 2013, Geol. Mag. 150: 455–478) is interpreted as a thrust-sheet accommodating regional shortening and repetition of pre-Miocene rocks, along with accommodating progressive wedge deformation and the subsequent syn-kinematic deposition of early–middle Miocene turbidite sequences.

IDENTIFYING PYROCLASTIC DENSITY CURRENTS FROM PARTIAL OUTCROP EXPOSURES ON MT RUAPEHU, NEW ZEALAND

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Mt Ruapehu is one of New Zealand's most active volcanoes, last erupting in 2007. There have been few studies investigating the pyroclastic density current (PDC) hazard for Mt Ruapehu, despite being a popular tourist attraction. Due to the unpredictability of this hazard, it is crucial to be aware of past events in order to produce an effective plan for future PDCs.

On Mt Ruapehu, poor preservation of pyroclastic material due to past glaciations, erosion, and poor consolidation has led to significant uncertainty in distinguishing PDC deposits. Multiple techniques in the field and laboratory have been used in an attempt identify and characterise these deposits, and to address hazard frequency and magnitude. Comprehensive field-mapping over three months formed the basis for this study by identifying potential PDCs from partial exposures. A confidence-based pyroclastic identification chart previously developed by the first author was used to support interpretations based on diagnostic textures of PDCs. Grain size distribution, vesicularity, geochemical and thin section analyses of samples have been used to correlate deposits and infer the eruption style. The magnitude and volume of flows have been approximated using a digital elevation model (DEM) and estimated flow paths.

Approximately 25 PDCs have been identified from this study, adding to the 12 previously characterised by the first author. Most flows were formed during plinian to sub-plinian eruptions based on the deposit sizes and textural properties. An event tree for PDC occurrence at Mt Ruapehu was created based on previous eruptions and the frequency of PDCs in the past. The results from this study have been integrated into a map with the identified PDC deposits and an updated account of PDC occurrence for Mt Ruapehu. Increasing the awareness of past PDCs can help inform hazard management and provides a foundation for subsequent studies to investigate future PDC scenarios on Mt Ruapehu.

EARLY HOLOCENE OCEAN AND ATMOSPHERE INTERACTION IN MOUBRAY BAY, ANTARCTICA

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A unique marine sediment core (LC62) was collected from an isolated basin in Moubray Bay, Northern Victoria Land (72° 04.5'S, 170° 27.4'E) by the R/V *Araon* during the 2015 ANA05B expedition. Bulk carbon isotope ($\delta^{13}C$) values, biogenic silica and diatom species assemblages are used to reconstruct ocean–atmosphere variability and environmental conditions. LC62 is 4.7 m long and contains a 3,000-year record from the early Holocene. The core is composed of horizontal- and wavy-laminated diatom ooze. Laminations are differentiated by changes in colour (light, dark, orange and olive), texture (fluffy and massive) and density. Overall, $\delta^{13}C$ values in LC62 are more negative than typical Antarctic values (−24–25‰). At the base of the core $\delta^{13}C$ is very negative (−33‰) but becomes more positive up core (−27 to −30‰). Negative $\delta^{13}C$ values could be caused by one, or a combination, of several different environmental factors including changes in deep water upwelling, water column stratification, and high productivity. Biogenic opal is 60% at the base of the core but decreases to a plateau of around 45% up-core. The horizontal laminations are dominated by light–dark laminae pairs. The diatom assemblage observed in the laminae pairs reflects rapid export and burial of early season bloom events in a well-stratified water column, followed by late season productivity adjacent to the sea-ice edge. Occasional olive and orange laminations are dominated by *Chaetoceros* resting spore and could represent intense spring bloom events. This record provides a new point of comparison to high-resolution ice and sediment cores from Antarctica, and sediment cores from the mid-latitudes of the Southern Hemisphere.

POST-GLACIAL ENVIRONMENTS AT THE SUBANTARCTIC AUCKLAND ISLANDS, NEW ZEALAND

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New Zealand's subantarctic Auckland Islands (50°S) lie at a key latitude for reconstructing ocean and atmosphere links between Antarctica and the middle latitudes. In the vast expanse of Southern Ocean, they provide a variety of environments from which paleoclimate records can be collected. These include peatlands, lakes and fjords.

Here we present the results of a multi-proxy reconstruction of postglacial climate using a well-dated sediment core collected from Norman Inlet, Auckland Island. This record complements existing terrestrial records and constrains the timing of deglaciation, climate and sea-level rise at Auckland Island during the Holocene. Bathymetric and seismic surveys show that Norman Inlet has a seaward sill that encloses an ingression basin, which is a marine basin formerly isolated from the sea. Using physical property data, stable isotope geochemistry, and Itrax XRF element counts we identify four different sedimentary facies that have been deposited in the basin. These are: (1) deglacial, (2) lacustrine, (3) brackish/lagoon, and (4) marine facies. Deglacial sedimentation was underway in the basin by 19,000 cal. yr BP. This was followed by organic-rich deposition in a freshwater lake, but as sea-level rise began to have an influence on the depositional basin a brackish water environment formed. Lastly, around 6,400 cal. yr BP full marine flooding of the basin occurred and the modern marine depositional environment was established. The timing of deglaciation and marine inundation corresponds with terrestrial records from Auckland Islands, and paleoclimate records from other subantarctic islands and New Zealand.

MICRO-ONCOIDS FROM THE LOWER CRETACEOUS YIXIAN FORMATION IN WESTERN LIAONING, CHINA

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A large number of oncoids have been found in the lacustrine facies of Early Cretaceous Yixian Formation in the Western Liaoning, but these oncoids are significantly smaller than common oncoids, and are referred to as micro-oncoids. The micro-oncoids in Western Liaoning are preserved in many sections of the Yixian Basin and occur as particulate matter in carbonate rocks. The abundance of these micro-oncoids varies greatly from different carbonate strata. These micro-oncoids are generally smaller than 500 µm in diameter and have one to two layers of coatings.

Various morphological characteristics can be used to divide the formation of micro-oncoids into four main processes: (1) Under moderate hydrodynamic conditions, microbes begin to grow on the surface of particles. The microbes preferentially grow in divots in the surface of these particles due to the reduced friction between the substrate and other particles; (2) When the divots are filled, microbial action begins to expand until the whole particles are covered; (3) The periodic change of physical and chemical properties of water, generally caused by season changes, controls the structure of micro-sparite and micrite coating layers; (4) When hydrodynamic conditions are not strong enough to transport these particles, they are deposited and fine granular carbonate minerals form rapidly during diagenesis, thus destroying evidence of microbial activity.

LIVING WITH RIVERS CASE STUDY: WAIHEMO AND WAIANAKARUA RIVERS, OTAGO

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Understanding a river system, its changing morphology, impacts, what is valued about it, how its resources are used and how best to manage all these aspects is very important. There is no straightforward process for considering all these components in guidance, decision making, and work programmes. Otago Regional Council (ORC) has attempted to do this through the establishment of “River Morphology and Riparian Management Strategies”. These strategies aim to connect with communities, identify key aspects of the rivers and propose management options that protect the recreational, cultural and ecological values of the riverbed, and enable long-term sustainable use of the land that borders the river. The most recent of these strategies have been prepared for the Waihemo and Waianakarua rivers.

The strategies have focused mainly on the downstream reaches of the rivers to address concerns previously raised by the community, such as areas of gravel accumulation and bank erosion. The strategies include; characterisation of the river catchment and environment, assessment of the river morphology, identification of channel migration, and identification of reaches of the river experiencing aggradation, degradation and erosion. Location and width of the active fairway has been identified as well as appropriate buffer zones, which together form a corridor within which the river would naturally lie. Workshops were held with the community to collect and identify values of the rivers and we worked in partnership with local iwi to ensure their values were represented.

The outcome is a strategy tailored for each river that outlines possible methods to ensure sustainable river management. The dynamic nature of rivers, development of communities and changing climate necessitate the strategies undergo regular review and that updates are documented. The on-going challenge is to implement the guidance and river work with community input to improve how we live with our rivers.

WHAT MECHANISMS AFFECT SHEAR WAVE SPLITTING MEASUREMENTS: AN ACCOUNT FROM EMPIRICAL AND NUMERICAL STUDIES

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We use numerical modelling and empirical seismic waveforms to investigate the variations in Shear Wave Splitting (SWS) measurements. The measurement of seismic anisotropy through SWS, has widely been used by seismologists for the past three decades as a technique to characterise spatio-temporal variation in the stress fields and understand crack orientations. But, measurements on local earthquakes have often shown variations making interpretation difficult. Many studies have attributed these variations to physical mechanisms, such as scattering of seismic waves (caused by scatterers along wave propagation paths), irregular surface topography and different earthquake source mechanisms. In this study, we examine how these mechanisms affect SWS measurements with the aim of improving the technique. The Kaikōura (2016) and Seddon (2013) earthquake sequences provide a unique dataset to test how these mechanisms affect SWS measurements. We use a 3-D seismic simulation waveform algorithm (SpecFEM3D) that accounts for anisotropy, topography and heterogeneity to simulate waveforms in order to understand the effect of these mechanisms. Results from empirical studies using two permanent GeoNet stations reveal a possible temporal variation in SWS measurements for a cluster of earthquakes before and after the Kaikōura main shock. The mean fast orientation at both stations for events before the main shock aligns with the NE–SW tectonic structures in the region. Analysis of events after the main shock show a bimodal (NE–SW and NW–SE modes) fast orientation distribution at a station away from the Awatere Fault and a NE–SW fast orientation at a station close to the Awatere Fault. This variation is examined using families of earthquakes (events with similar source mechanism) to understand how different earthquake source mechanisms affect our results. We also present an account of simulated SWS measurement.

SEA-LEVEL, POLAR ICE SHEET VARIABILITY AND CLIMATE FORCING: PRESENTING A NEW SEA LEVEL RECORD (3.3–1.7 MA)

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A new mid-Pliocene to early Pleistocene (3.3–1.7 Ma) direct and continuous sea-level record has been developed from the shallow-marine stratigraphy of Whanganui Basin, New Zealand. A novel approach to reconstruct paleobathymetry utilises a sediment grainsize–water depth relationship, with an integrated age model, independent of the global benthic $\delta^{18}O$ stack. The paleobathymetry was back-stripped to remove the effects of subsidence and loading to resolve a relative sea-level record, which is modelled for glacio-isostatic adjustment.

The resulting relative sea-level record is characterised by glacial–interglacial precession-paced fluctuations of ~15 ± 12 m during the mid-Pliocene, and obliquity-paced cycles of ~20 ± 12 m for the late Pliocene, and obliquity-paced ~60 ± 12m cycles of the early Pleistocene. Phasing at three paleomagnetic reversals demonstrates sea-level fluctuations in phase with southern high-latitude insolation, implying an Antarctic-dominated meltwater source for eustatic sea-level during the mid-Pliocene, supported by the East Antarctic ice-rafted debris record. The emergence of obliquity in the record from 2.9 Ma is interpreted as a response to the intensification of Northern Hemisphere ice sheets outside of the Greenland Ice Sheet.

The mid-Pliocene (3.3–3 Ma) has long been considered an analogue for future global warming with an atmospheric CO_2 concentration of 400 ppm, average surface temperatures 2–3 °C higher than pre-industrial and a lack of large continental ice sheets in the Northern Hemisphere. This period of equable climate was terminated by global cooling coincident with a ~100 ppm drop in CO_2 and the development of Northern Hemisphere continental ice sheets during the late Pliocene (3.0–2.6 Ma).

Here, the relative sea-level record is discussed with regard to (1) implications of the sensitivity of the marine-based sectors of Antarctic Ice Sheet, (2) a reassessment of the benthic $\delta^{18}O$ proxy record for global ice volume, and (3) insights on the complexity of orbital forcing on climate.

THE GHOSTS OF OLD VOLCANOES: APPLYING GEOSITE EVALUATION METHODOLOGY AND FRAMEWORK FOR GEOHERITAGE TRAIL DEVELOPMENT FOR THE KUAOTUNU PENINSULA, COROMANDEL

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Coromandel Peninsula is a popular and well-utilised tourist destination, both at a regional and international level. It is renowned for white sand beaches, native bush walks and mining history. However, despite the presence of significant geological features, current promotion of the area does not highlight this aspect of the landscape, its significance or the story of Earth processes told by these features. We see this as an ideal area for developing a methodology and framework for establishing a geoheritage trail. Here we use the broad term geoheritage trail, and place equal weighting on Earth processes visible in the landscape, ecology, and human occupation history told in the landscape.

To date, geotourism ventures in this country have developed in a somewhat ad-hoc manner, largely reliant on the work of volunteers, non-government organisations (NGOs), local community groups, and education institutions. Most regional councils have an inventory of Significant Natural Features (SNF), yet this does not necessarily equate with preservation or promotion of geoheritage values. We aim to develop a systematic methodology, timeline and budget, based on current international best-practice, which can then be accessed by a range of stakeholders, such as local and regional community groups, NGOs, local government agencies, iwi and private landholders. Establishment of stand-alone trails, or networks of trails, provides a firm foundation on which to expand the scope of the asset in parallel with current promotion of the concept of UNESCO Global Geoparks in New Zealand.

The initial study area for this project incorporates geological, ecological and archaeological sites. Volcanoes in the Coromandel Peninsula are no longer active, but their eroded remnants are still significant landscape features, reflected in the title of the proposed geoheritage trail “Ghosts of old Volcanoes”. With ever-increasing tourist numbers visiting the Coromandel, we aim to facilitate sustainable, low-impact tourism, utilising digital resources, high-quality unmanned aerial vehicle (UAV) photography and virtual engagement.

THE FIRST REPORT OF PETROXESTES FROM WESTERN LIAONING, CHINA

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Petroxestes fossils have been found from two sites from Western Liaoning, China. One is located 4.8 km northeast of Sihetun village, where there trace fossils were discovered in the lowermost portion of the Yixian Formation. The other is located 9 km west of Yixian county, here the trace fossils were preserved in the middle portion of the Yixian Formation. The former one belongs to the Jin–Yang Basin, and the latter one belongs to Yixian Basin. All *Petroxestes* were discovered *in situ*, on the surface of carbonate rocks from the Yixian Formation.

Petroxestes from these two sites are vertical shallow borings with similar morphology. In plan view, they are elongate with straight or slightly-curved parallel sides and rounded ends. They show no preferred orientation. These borings have a round bottom in both longitudinal and transversal sections. Except for a rare few traces, most are close to each other. No intersecting structures have been observed. These traces have a high density, up to 50 counts per square meter. There are no bioglyphs distributed on the inside surface of these traces. There is a slight difference in the size of *Petroxestes* between the two areas. *Petroxestes* from the Jin–Yang Basin are 9–21 mm long and 1–3 mm wide. In the Yixian Basin, the length and width of Petroxestes are 11–20 mm and 2–4 mm, respectively. In the two areas, the depth of traces is similar, both varying from 1.5 to 3 mm. Generally, the width/length ratio of these *Petroxestes* is less than 0.2. This is the first report of Petroxestes from China and indeed the first report from a terrestrial environment.

ENGINEERING GEOLOGY OF THE WALLIS RD LANDSLIDE, GISBORNE

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Instability at the eastern end of Wallis Rd (80 m asl) landslide, Gisborne city, has been recognised for several years, resulting in the house at no. 1 Wallis Rd being demolished in 2015. Significant slope failure has occurred since then, particularly during the winters of 2016 and 2017, culminating with runout from a channelised earthflow onto the beach below. The upslope extent of the landslide is characterised by rotational slumping bounded by a broad headscarp. Lateral scarps, back-tilted blocks and ponded surface water are also present. Below the upper area, a transition zone occurs, and below this, is the channelised earthflow, bounded by levees, and smoothed internal surfaces caused by scouring from rapid sediment discharge. At present, incipient slumping is evident at the southern boundaries of nos. 3 and 8 Wallis Rd, where minor ground subsidence has begun at no. 3, and a small tomo has formed at no. 8. Cone penetrometer testing and boreholes indicate the slip base is at ~6 m depth in the upper section, marking the boundary between the surficial early Pleistocene non-welded ignimbrites and paleosols of the Mangatuna Formation and underlying impermeable mudstone of the Tunanui Formation. Unmanned aerial vehicle (UAV) imagery taken in August of 2018 shows significant re-vegetation of the landslide, compared with late 2017, indicating apparent stabilisation since the previous year. Monitoring during the 2018 winter with a time-lapse camera, a network of survey pegs and a piezometer, all indicate that deformation occurs in response to heavy rainfall. Nevertheless, deformation during the 2018 winter is more subdued compared with the corresponding period in 2017. This supports the hypothesis that the underlying Miocene Tologa Group mudstones are an impermeable barrier to groundwater infiltration through the overlying (deforming) Mangatuna Formation. An additional landslip failure surface is likely positioned along a polished surface within the siltstone of the Mangatuna Formation soils. Permeability testing and electromagnetic conductivity surveys indicate that soils in the base of the gully are reasonably saturated, while the upper slopes are relatively dry, further suggesting stabilisation has occurred during 2018.

TWO INDENTICAL TSUNAMI EARTHQUAKES IN THE KERMADEC RIDGE

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On December 8th, 2017 at 2:09:57 UTC, an abnormal earthquake with a moment magnitude (M_w) of 5.9 occurred south of Raoul Island on the Kermadec Ridge at 30.555° S, 178.492° W (USGS) and 17.5 km of depth. The focal mechanism for the earthquake is known as compensated linear vector dipole (CLVD) with vertical T-axis, which is a type of non-double-couple earthquake. Small but clear tsunami signals of the earthquake were recorded at six tide gauges in New Zealand. Another earthquake with similar M_w (6.0) and focal mechanism occurred at the same place (30.724° S, 178.617° W) on February 17th, 2009 at 3:30:53 UTC. The tsunami waveforms of the two earthquakes at these tide gauge stations are strikingly identical. A model (JAGURS) that solves the non-linear shallow water and Boussinesq equations is used in a tsunami waveform analysis to estimate the tsunami source model of the 2017 Kermadec earthquake using the tide gauge records. The estimated sea surface displacement in the source area has a maximum uplift of 45 cm and a diameter of 15 km. The estimated sea surface displacement is then used to estimate the earthquake fault model. This estimates that the inner ring diameter is 4 km and the diameter of the outer ring is 8 km. Slip of 3.7 m on this fault is required to reproduce the estimated simple sea surface displacement. The calculated seismic moment by assuming a rigidity of 2.7×10^{10} N/m^2 for a crustal fault is 6.5×10^{18} Nm, which is equivalent to M_w 6.5. This indicates that the tsunami was much larger than that expected from the earthquake magnitude, which is why the earthquake can be categorized as a tsunami earthquake.

TEN YEARS OF CONTINUOUS GPS IN THE HIKURANGI MARGIN: 2006–2016

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The Vertical Derivative of Horizontal Stress (VDoHS) method of analysis for GPS data (Haines et al. 2015, SpringerBriefs in Earth Science) proves to be excellent for elucidating temporal behaviour in the Hikurangi Margin. We present results using 10 years of continuous recordings for the period 2006–2016. The region covered is the North Island and northern South Island. Snippets will be shown from movies of horizontal and vertical velocities, strain rates and VDoHS rates at the Earth's surface, plus inferred slip-rates at the subduction interface. Full versions of the movies will be made available for download from GNS Science.

For movie connoisseurs after something different, features include Tongariro National Park going up and down, Taupō expanding, the Taupō Volcanic Zone (TVZ) north of Taupō contracting, extension in the Bay of Plenty, zippy slow-slip events along the east coast of the North Island, contrasting with ponderous slow-slip events in the Manawatu and Kapiti areas, episodic straining of the Marlborough faults between Cloudy Bay and Cape Campbell, and intimate connection between the TVZ and the Hikurangi subduction zone. Action packed, with highlights to tickle all attention spans.

For those who are more studious, and followers of David Attenborough, the movies provide a wonderful glimpse into the intricacies of our pulsating Earth. From the timescale of the lunar orbit, to the seasons, and gigantic tectonic forces, everything is intertwined. Who could imagine how many processes come together. To crown it all, we capture one of the greatest marvels of nature: the unlocking of the subduction in slow-slip events and its subsequent relocking is truly elevating to behold.

ARE CHILLED BASALTIC MAGMAS MORE SUSCEPTIBLE TO EARTHQUAKE TRIGGERING? EVIDENCE FROM THE 2015 AMBRYM, VANUATU DYKE INTRUSION

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Despite the growing number of observations that indicate a correlation between the occurrence of volcanic eruptions and moderate to large earthquakes, the reason why only some volcanoes seem affected remains an enigma. Here we use synthetic aperture radar data to analyse the deformation associated with a previously unreported 3-m-wide dike intrusion at Ambyrm Volcano, Vanuatu, in 2015 that was preceded two days earlier by a moment magnitude (M_w) 6.4 earthquake. Modelling suggests that the stress change induced in the source region was likely too small to account for the expected overpressure in the dike. To generate a sufficient volume to feed the eruption, decompression models indicate that the magma must be both H_2O-saturated and cooler than a typical basaltic melt. These observations suggest that fresh basaltic material intruded into shallow magmatic systems may be too hot to generate significant volume increases for low pressure drops, implying that partially cooled and crystallised basalts are more susceptible to eruption triggering by earthquakes.

EVIDENCE FOR ASEISMIC SLIP DRIVEN BY PORE FLUID PRESSURE FOLLOWING THE 2016 KAIKŌURA EARTHQUAKE

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Pore fluid pressure plays a critical role in the failure of a rock mass. As a result of an increase in pore pressure, the effective normal stress is reduced leading to a drop in the shear resistance and fault stability. Here we document a short lived aseismic-slip episode along a ~14 km-long unmapped fault following the 2016 Kaikōura earthquake, which was likely triggered by a localised pore pressure increase within a shallow fluid trap. Using SAR data acquired by the European Space Agency's Sentinel-1 satellites, we form a post-seismic timeseries over the epicentral region of the Kaikōura mainshock. Immediately following the earthquake, we observe ~15 cm of uplift localised within a local sedimentary basin. The observed uplift rapidly dissipates with deformation becoming focused along a NE–SW trending discontinuity that cuts through the uplifted region. Due to its poor orientation with respect to the coseismic rupture, slip along the fault should have been inhibited based on the estimated coseismic stress change. However, a reduction in the effective normal stress caused by the local pore pressure increase was sufficient to induce a short lived aseismic-slip episode. The subsequent diffusion of pore pressure explains the observed decay in ground deformation and points towards a rapid relocking of the fault.

THE JOURNEY IN CREATING THE TE PATAKA O RAKAIHAUTU/BANKS PENINSULA GEOPARK

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Te Pātaka o Rākaihautū/Banks Peninsula has a complex and varied history, with respect to its geology, flora and fauna, along with unique climatic, cultural and historical features. With these aspects framed in and around the Papatipu Rūnanga driven concept for the project, we believe Banks Peninsula can be developed into an internationally significant Geopark, celebrating distinct indigenous values, the land itself and all our Banks Peninsula stories. Te Pātaka o Rākaihautū (and Aotearoa) has the uniqueness of having a living indigenous people and their culture. Internationally this is significant, and a Geopark provides a platform to represent, present, and engage in Matauranga Maori (indigenous knowledge), korero (narrative), pakiwaitara (legend/stories), pūrākau (thought, codes, world views). Te Rūnanga o Koukourarata are a primary driving force behind the project, and has brought together Ōnuku Rūnanga, Wairewa Rūnanga, Te Hapū o Ngāti Wheke, and Te Taumutu Rūnanga (the Te Pātaka o Rākaihautū Papatipu Rūnanga) in an MOU with Te Rūnanga o Ngāi Tahu, to establish a UNESCO Geopark. Banks Peninsula is being developed under a holistic model, which follows Geoparks established in Asia, where one views the landscape and how that has influenced our culture, ecosystems, and environments, and develops a Geopark from and into that landscape to benefit its local communities. A Geopark on Te Pātaka o Rākaihautū/Banks Peninsula would provide organisations and communities advantages and benefits under the umbrella of a Geopark.

TRACE METALS IN CRUSTACEA: BIOMONITORING OF THE MARINE ENVIRONMENT

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Biomonitors provide a mechanism for evaluating the chemical health of the marine environment. 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. Importantly, they reflect the bio-available fraction of metals in the environment and trace their uptake into different levels of the food chain. We will present trace element data for marine amphipod and decapod specimens from several New Zealand locations, as part of a wider Ministry of Business, Innovation and Employment (MBIE) Endeavour-funded programme to investigate the use of Crustacea as biomonitors of the New Zealand marine environment.

Thirty trace elements have been analysed in the marine amphipod species *Ampelisca chiltoni*, and in the decapod species *Munida gracilis* (squat lobster). The trace element data allow us to evaluate natural variations among specimens from single localities and effects of parameters such as specimen size on accumulation of metals. Specimens from different localities show distinct trace element accumulations reflecting regional (local) differences in their chemical and geological environment, suggesting that point sources of metal contamination may be identifiable.

MAGMA MIXING AND CRUSTAL–MANTLE INTERACTION IN THE EASTERN KUNLUN OROGENIC BELT, NORTHERN TIBET: IMPLICATIONS FOR THE TECTONIC SWITCH FROM SUBDUCTION TO POST-COLLISION

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Widespread Triassic hybrid granites, mafic microgranular enclaves and syn-plutonic dyke swarms in the Eastern Kunlun Orogenic Belt, northern Tibet, are the expression of crust–mantle interaction and magma mixing. We present data ranging from the outcrop scale (field) to mineral scale (thin section) that was obtained during regional geologic field mapping, petrographic analyses, mineral geochemistry and geochronology, whole-rock geochemistry, and conventional geothermobarometry to unravel the petrogenesis and petrochronology of rocks generated through multiple episodes of magma mixing. The minerals in these hybrid rocks can be divided into xenocrysts, residual crystals, phenocrysts, antecrysts and hydrothermal crystals based on their microstructural, geochemical and isotopic characteristics. Eight genetic stages can be recognised using zircon Lu–Hf isotopic data. Zircon cores have high $\varepsilon Hf_{(t)}$ values that are similar to depleted mantle, while the rims have a larger range and lower average $\varepsilon Hf_{(t)}$. Migration of pre-existing crystals and melt–crystal interactions together reveal that accumulation of hot mafic magma occurred in batches that were injected into a magma chamber at depths 5–20 km. Radiometric dating of minerals suggests that crust–mantle interaction and magma mixing occurred during three short periods: 254–245 Ma, 237–235 Ma and 230–221 Ma. Whole-rock Sr–Nd–Pb and zircon Lu–Hf isotopic data indicate that the magmas generated during these three periods had different sources. This suggests that magma was generated at 254–245 Ma in a back-arc extensional setting during the oceanic subduction stage, the break-off of the subducted slab during the continental collision stage may have facilitated melting at 237–235 Ma, and detachment of the lower crust during the post-collision stage may be responsible for magma generation at 230–221 Ma.

GEOLOGY OF THE WEBER REGION, EAST COAST BASIN, NEW ZEALAND

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East Coast Basin is a large sedimentary basin in a complex accretionary geological setting. Late Cretaceous to late Miocene units crop out widely in the Weber District, 35 km southeast of Dannevirke. Local unconformities, and faults and associated folding have resulted from regional uplift and deformation associated with the nearby present-day subduction margin. Two series of 1:250,000 geological maps cover the basin; the most recent (Lee and Begg 2002, Institute of Geological and Nuclear Sciences 1:250,000 geological map 8) incorporates all available published and student thesis mapping up to 2002. As part of this project an updated 1:20,000 geological map and detailed stratigraphy of the Weber area will be produced to examine the evolution of this part of the basin.

The Late Cretaceous to Oligocene units are dominantly fine-grained mudstone indicating a period of relative tectonic quiescence and low rates of sedimentation at a passive continental margin. Marine deposition prevailed in the Weber area as indicated by the presence of marine foraminifera preserved within the Weber and Ihungia formations. A general coarsening upward trend in the Tutamoe and McCartie formations is interpreted to represent a general shallowing within the basin. Sediment is interpreted to have been derived from exposed Torlesse Composite Terrane eroded and transported along sub-marine canyons to the continental slope and abyssal plain by periodic landsliding. We interpret multiple interbedded sandstone and mudstone layers to have been formed by individual turbidity current events, characterised by coarse basal horizons representing the front of the flow path with overlying fine-grained units deposited as fine material settled from the suspension column. Abrupt changes are observed in the early Miocene Tutamoe Formation, including a change to litharenite sandstones, representing the transition from a passive margin to renewed convergence and initiation of subduction along the Hikurangi margin.

USING THE RESOURCE MANAGEMENT ACT TO PROTECT NEW ZEALAND'S GEOHERITAGE

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UNESCO Global Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development. The geological sites are required to be "protected by indigenous, local, regional and/or national law and management authorities". At present many of the geosites in the proposed New Zealand Geoparks lack any specific legal protection. The proposals and potential establishment of a Geopark will raise the profile of geosites among the local community who may have had little appreciation of their geoheritage values previously. This should result in increased local acceptance (especially in rural communities) of the need for some form of long-term protection. The most secure protection for geosites is through inclusion in publicly-owned reserves but this is expensive and requires the landowner to want to sell. Other cheaper alternatives retain the geosite in private ownership while providing for its protection. A QEII National Trust covenant is legally binding and protects the heritage values forever no matter who owns the land. The most used method for achieving protection of geoheritage features on private and publicly-owned land is through scheduling as Outstanding Natural Features (ONFs) under the Resource Management Act (RMA) in District Schemes. This method can be relatively quick and cost effective, but the resulting level of protection varies because of different rules in district schemes. Another downside is that it relies on council staff to implement, which has variable success and is often not actioned through lack of staff understanding. In recent years a number of northern councils have scheduled nearly 500 geosites that have been assessed as reaching ONF standard using the following criteria: geological significance; rarity; representativeness; aesthetic value; community association with the site; potential for public education; future research value; state of preservation; and historical association.

INSIGHTS INTO PROCESSES DRIVING THE MOST EXPLOSIVE ERUPTIONS OF MT. TONGARIRO BASED ON PYROCLASTIC TEXTURES

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The Tongariro Volcanic Complex is unusual in comprising many widely dispersed eruptive centres within an active graben structure. It has a history of isolated "flare-up" episodes with several clustered large explosive eruptions (0.5–1 km^3) interspersed with a background of more regular small-scale events (<0.01 km^3). In this study we examined the pyroclastic deposits of the Mangamate Formation, representing five sub-Plinian to Plinian eruptions produced ~11,000 years ago. These eruptions generated up to 6 km^3 of pyroclastic deposits that draped hundreds of square kilometres around the volcano in less than 400 years. Such events were attributed to tectonic drivers, but firm evidence on the triggers and dynamic processes controlling these explosive eruptions remains unclear. Here we present data from 2-D and 3-D textural analyses of juvenile lapilli clasts from all five Mangamate eruptions. Pyroclastic textures provide information about the mechanisms of magma ascent, degassing, and recycling, that provide information on the physical parameters influencing eruption styles, magnitude and intensity.

Our results indicate that pyroclasts produced by the Mangamate eruptions have extremely high microlite contents (~30 vol%) inside a bimodal vesicular groundmass (i.e., pores of 0.3 mm in diameter, and microvesicles of 1.5 µm). Microlites have well-defined tabular to acicular shapes with common reabsorption textures. Pores range from sub-spherical, through to complex shapes related to restricted growth between crystals and coalescence, along with spherical isolated microvesicles. These evidences suggest that, before erupting, the Mangamate magmas degassed and stalled in shallow conduit levels, leading to microlite crystallisation. Subsequent degassing, possibly driven by second boiling, is supported by microvesicles forming on and interstitially between microlites. Our results suggest that the Mangamate explosive eruptions were driven by stepwise magma plug decompression and shearing, characterised by effusive to explosive style transitions. This work will lead to new eruption scenarios for hazard managers at Mt Tongariro.

IMAGING THE TRANSITION FROM WEAKLY TO STRONGLY COUPLED PLATE INTERFACE AT THE HIKURANGI MARGIN, NEW ZEALAND

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Along the Hikurangi subduction margin on New Zealand's east coast, plate-coupling changes from weakly coupled in the north to strongly coupled (or locked) in the south.
Previously, magnetotelluric (MT) measurements from the northernmost part of the margin (Raukumara Peninsula) have shown a good correlation between resistivity variations and the pattern of areal strain rate derived from Global Positioning System (GPS) data providing evidence that the fluid and sediment content of the interface shear zone plays an important role in the degree of inter-plate coupling.

We have collected 160 new MT measurements covering the coupling transition. Here, the 3-D resistivity model shows that the upper-plate is more conductive where the strain is extensional and resistive where contraction is occurring. This correlation is seen in both the along-strike and down-dip directions of subduction. The distribution of seismicity in the upper 5 km of the subducting plate shows a similar change, with a greater concentration of near-interface seismicity below the conductive part of the upper plate. We interpret these correlations to show that in the more conductive region, interconnected fluids sourced in the subducting plate are escaping upwards into the extensional part of the upper-plate. Where the upper-plate is contracting and resistive, we interpret upper-plate permeability and fluid interconnectivity to be lower. Decreased near-interface seismicity seen beneath the resistive region can be interpreted to be a consequence of reduced lower-plate fluid availability and/or decreased upper-plate permeability preventing upward fluid escape.

ALONG-STRIKE VARIATIONS IN THE HIKURANGI SUBDUCTION ZONE: LAND-BASED SEISMIC OBSERVATIONS DURING THE 2017–2018 SHIRE SEISMIC ONSHORE–OFFSHORE IMAGING PROJECT

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Slip along subduction zone slab interfaces exhibit a range of styles, including destructive coseismic earthquakes, slow-slip events, tremor and aseismic creep. These slip processes are influenced by factors such as local stress state, physical properties (e.g., friction and elastic properties), presence of fluids, and mineral composition of rocks comprising the fault zones where the slip occurs. Estimations of these factors can be made using geophysical and geological methods. The Hikurangi subduction margin at eastern North Island, New Zealand, represents an excellent system to examine these physical processes that govern slip. Significant along-strike variation is present with largely stick-slip (coseismic earthquakes) observed in the southern portion of the system and dominantly aseismic creep (slow-slip events) observed to the north. Several other major earthquake and tectonic factors also vary from south to north, either influencing the change in slip behaviour or being the result of this lateral change.

The multi-disciplinary, multi-national SHIRE (Seismogenesis at Hikurangi Integrated Research Experiment) project examines these factors that influence slip plus the relationship between this slip and long-term deformation. SHIRE includes research activities in active and passive source seismology, paleoseismology and geodynamics. SHIRE carried out a large seismic onshore–offshore experiment of the Hikurangi margin during October 2017–February 2018 with international partners from New Zealand, USA, Japan and UK. This experiment involved (1) the USA R/V Langseth to collect 4046 km of MCS profiles, (2) OBS instruments to acquire airgun refraction/wide angle reflections, and (3) portable short-period land instruments to record the same airgun sources plus four months of local earthquakes. Besides being studied using active-source seismic techniques, the continuous SHIRE land data is being analysed using earthquakes for structural imaging of the slab and ambient noise for velocity structure and anisotropy. We describe the land-based field operations and present examples of these data and their early results.

CRUSTAL AND UPPER MANTLE STRUCTURE OF SOUTHERN HIKURANGI MARGIN FROM ONSHORE-OFFSHORE ACTIVE-SOURCE SEISMIC DATA

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Onshore–offshore, active-source seismic data along two transects perpendicular to the Hikurangi margin in the southeastern North Island are used to constrain the crustal and upper mantle structure of the Hikurangi Plateau. The oceanic crust of the Hikurangi Plateau is ~12 ± 1 km thick and its highest P-wave speed is determined from long offset refracted waves to be 7.2 km/s. A fast upper mantle layer of P-wave speed ~8.8 km/s is observed to underlie a regular mantle of P-wave speed ~8.0 km/s. The depth below the Moho to the high-speed mantle varies, from ~6 km under the eastern North Island, ~20 km at the Hikurangi Trench and from 1 to 10 km at ~100 km east of the trench. Previous seismic experiments conducted onshore within the eastern North Island along margin-parallel directions also indicate the presence of the fast upper mantle layer underlying the regular upper mantle layer. Although azimuthal anisotropy created by the flow-induced orientation of mantle olivine crystals was initially an obvious interpretation of the ~8.8 km/s P-wave speeds, the results from this study, show the same high speeds along a margin-perpendicular direction. This implies that the upper mantle is either isotropic or radially anisotropic. We explain the variable depths to the high-speed mantle as being due to increased bending, normal faulting and serpentinisation, which all decrease the P-wave speeds in the upper layer. The largest zone of decreased P-wave speed occurs beneath the trench. An increase in water content of ~3% can explain the drop in wave speed, and this corresponds to an ~20–30% degree of serpentinisation. P-waves traversing through the proposed zone of serpentinisation are also observed to attenuate at a higher rate. Similar drops in crustal and mantle P-wave speeds, and increased attenuation, are seen in other subduction zones where the plate undergoes maximum bending.

THE UNESCO GLOBAL GEOPARK PROGRAMME IN NEW ZEALAND

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In some aspects of biodiversity protection, New Zealand arguably leads the world. But not so with geopreservation. While the Tongariro National Park fully justifies its UNESCO World Heritage Site status, it is recognised for its dual geological and cultural heritage designation. New Zealand's two other World Heritage Sites (Te Wāhipounamu–South Westland and the subantarctic islands), remain largely inaccessible to people. UNESCO also promotes Biosphere Reserves as part of its Man and the Biosphere Programme. New Zealand has none of these, so it is with a great deal of satisfaction that the National Commission for UNESCO launched in January this year its first ever Global Geoparks Programme, following sustained public interest and encouragement. This talk will provide an overview of what Global Geoparks are, where they are and the quite rigorous process of deciding on an expression of interest and nomination process, an external review by experts, a selection of preferred candidates, and assistance with the preparation of a full application dossier to UNESCO Paris. Submission of the successful applicant (Waitaki Whitestone) is expected by 30 November this year with desktop and site-based evaluations beginning in the first quarter of next year. The National Commission is already receiving new expressions of interest and expects there to be a growing number of applicants as the programme develops.

CHARACTERISING FOCUSED FLUID FLOW AND SHALLOW HYDRATE FORMATION USING 2-D SEISMIC DATA FROM THE SOUTHERN HIKURANGI MARGIN

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The Hikurangi Margin is New Zealand's largest gas hydrate province, with bottom simulating reflections abundant in water depths of >600 m. There is widespread evidence for active fluid flux across the region in the form of flares and cold seeps at the seafloor. The availability of extensive 2-D seismic datasets, in an area characterised by its complex structural and geological setting, makes this an ideal region in which to study these phenomena. Understanding the processes involved in sub-seafloor fluid flux and hydrate formation is significant as hydrates play a role in slope stability, climate change and are a potential alternative source of natural gas.

Here we use archive and newly acquired 2-D seismic data to characterise, in detail, features in the sub-seafloor geology that are indicative of focused fluid flux and the formation of gas hydrates. We focus on several locations south of Madden Canyon in a range of geological settings, including anticlinal ridges associated with the deformation front and channel levee complexes along the Hikurangi Channel. Furthermore, we present preliminary interpretations of recently acquired 2-D seismic data from the HYDEE TAN1808 cruise. These data reveal a diverse array of fluid flow features and extensive evidence for shallow gas hydrate occurrences, many of which are associated with underlying free gas accumulations. This underlying free gas poses a potential risk to drilling operations and may play a role in slope stability if stability conditions are altered through future climate variability or anthropogenic activity. Understanding the distribution and formation of such accumulations is, therefore, a significant area of research with implications for New Zealand and elsewhere worldwide.

REMOTELY PILOTED AERIAL SYSTEM MONITORING OF A SHALLOW MARINE LANDSLIDE AND ANALYSIS OF SEDIMENT MIGRATION AT NGATI TOA DOMAIN, WELLINGTON

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A shallow marine landslide that occurred at the southern end of the Ngāti Toa Domain in northern Wellington has been monitored using a remotely piloted aerial system (RPAS). The landslide occurred sometime during the night of 13 August 2017. It removed >1200 m^2 of beach (up to 1 m above the water level at low tide) and a large volume of shelf sediment that became redeposited into a nearby marine channel. The channel has strong tidal currents and links the Pauatahanui and Porirua inlets to the Cook Strait. The landslide likely occurred due to a combination of events that included an overnight tidal change of >1.1 m, increased channel outflow after a large storm, a high winter water table saturating the sediment, and fracturing (lateral spreading) that occurred during the 2016 M_w7.8 Kaikōura Earthquake. The landslide left a 40–50 m-wide bay with a steep drop-off into a ~15 m deep channel. Using a DJI quadcopter as the RPAS, the site has been monitored over the last year with six aerial surveys; the first was undertaken a few days after the landslide, then two weeks, one month, two months, three months and one year after the event. The RPAS captured several thousand photographs of the beach area that have been combined into detailed, sub-centimetre ground resolution digital surface models and orthophotographs using Structure from Motion. Surface model differencing techniques have determined where sediment was lost or gained between each survey and show how the shoreline has recovered and migrated with coastal sediment transport. These results are compared with historic shorelines mapped from aerial photographs of the site dating back to 1944, which indicate that the geometry of the steep-sided deep channel and small beach is quite typical, and that shallow marine landslides may be common in this area.

UNDERSTANDING OUR CAPITAL'S SEDIMENTARY BASIN: DEVELOPMENT OF A 3D MODEL FOR WELLINGTON CITY USING GEOTECHNICAL, GEOLOGICAL AND GEOPHYSICAL DATA

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To understand the seismic risk in Wellington we need to understand the geology and structures underlying the city. Utilising the wealth of geological data in the region, modern computer software, new geophysical measurements, surface and sub-surface data such as Light Detection and Ranging (LiDAR) and a new borehole database, we have developed a 3-D geological model of Wellington City that builds on previous studies. The model maps five different geological packages deposited above the basement rocks underlying Wellington that are distinguished by their sedimentary, geotechnical and geophysical properties. Our model improves on the shape and structure of the Thorndon and Te Aro basins using new borehole data (particularly from those holes that reach basement rock) and from the use of the Wellington Fault and the newly defined Aotea Fault as block boundaries within the 3-D model. We have utilised recently collected geophysical measurements to test and improve the geological model through a modelling feedback process. To understand the confidence of the geological model, an uncertainty model is created using a process that subjectively weights important properties in the 3-D workspace. These include borehole data quality, distance from surface and sub-surface observations and basin depth. By using known shear wave velocity ranges for sediments in Wellington we have derived a 3-D velocity model for the region. The model has also been used to create other datasets, such as the calculated fundamental site period, depth to basement rock and the thickness of fill. These are all important attributes that need to be considered for seismic studies, city planning and building construction.

POCKMARK FORMATION, MODIFICATION AND FLUID SEEPAGE ON THE CANTERBURY SHELF

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Escalating water supply in coastal areas and the effects on coastal environments have significantly increased scientific interest in submarine groundwater discharge (SGD) over the last decade. Submarine hydrocarbon seeps also attract much interest because of their relevance to hydrocarbon exploration and the specific micro-environment they create at the seafloor, characterised by specialised bacterial and faunal activity, mineral precipitation and their effect on overlying water column dynamics. Active seepage of both groundwater and gas through shelfal sediments can result in the formation of seafloor pockmarks and induce sediment instabilities that can lead to submarine landslides and tsunamis.

Bathymetry data acquired during Tangaroa cruise 1703 in 2017 revealed widespread pockmark formation on the Canterbury Shelf, indicating widespread fluid seepage in the area. Water column imaging techniques revealed acoustic anomalies potentially related to gas and/or groundwater vents on the seafloor. We present the results of a follow up cruise investigating the nature of the acoustic water column anomalies. Repeated water column imaging surveys will determine the temporal and spatial variation of the acoustic anomalies identified during the 2017 cruise. We use Conductivity, Temperature and Depth (CTD) casts undertaken along transects across and around the acoustic anomalies to constrain the nature of the potential fluid seepage. Measurements of dissolved methane concentrations within the water column and $\delta^{18}O$ analysis reveal formation mechanisms of the pockmarks. High-resolution bathymetry and backscatter data, boomer seismic data and high-resolution chirp data complement our investigation of sub-surface geological mechanisms for pockmark formation, modification and distribution on the Canterbury Shelf.

TESTING ADVANCED SEISMOLOGICAL METHODS TOWARDS A BETTER UNDERSTANDING OF THE BUILT ENVIRONMENT RESPONSE TO EARTHQUAKES

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Earthquakes of the last decade have shown that while most structures were able to prevent loss of lives, the costs associated with assessing building integrity were affecting the New Zealand economy excessively. Detailed, automated, near real-time building monitoring data can be used to inform decisions on re-entering or abandoning buildings after an event.

New Zealand benefits from a world class network of seismic instruments (GeoNet) and the Building Instrumentation Programme that has been recording earthquakes in numerous buildings for the past ten years. Recent research has demonstrated the value of applying system identification and damage detection methods to seismic structural monitoring data, for example, the Smart Seismic Cities project undertaken by Wellington City Council in association with the University of Auckland, GNS Science and QuakeCoRE Technology Platform 2.

We present preliminary results applying advanced seismological techniques usually applied to Earth Studies to further expand this building monitoring toolkit. This will allow for a robust assessment of the ability of each method to correlate the rich recorded information with more thorough building performance.

TOWARDS GROUND MOTION PREDICTIONS FOR A LARGE HIKURANGI SUBDUCTION EARTHQUAKE: LESSONS FROM THE KAIKŌURA EARTHQUAKE

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The 2016 M_w 7.8 Kaikōura Earthquake struck the east coast of the northern South Island, New Zealand, on November 13th 11:02 (UTM). The damaging earthquake generated extreme surface displacements, land deformation and ground motion, a regional tsunami, and triggered significant slow-slip events on the Hikurangi subduction interface. Sadly, it also caused two fatalities and many New Zealanders were affected by this earthquake.

The overall earthquake rupture process as suggested by advanced source models is complex and unexpected. The earthquake bypassed the Hope Fault, the largest source of regional seismic hazard, as it ruptured exclusively to the north (despite most of the stress from the 2010–2016 Canterbury earthquake sequence having accumulated to the south). Source models based on teleseismic and/or regional data suggest that the subduction interface did contribute to the overall rupture. However, many observations strongly support evidence of only minor (if any) contribution of the subduction interface in the overall rupture.

These unexpected source characteristics are not considered by seismic hazard models but significantly impact ground motion results. We consider a range of realistic source characteristics of a future Hikurangi earthquake to explore ground motion variability. Our findings show that strong ground motion is mostly controlled by rupture directivity, stress drop, asperity size and the presence of sediments, and exhibits a large variability despite the tight range of “realistic” parameters employed in our simulations.

A NEW UPLIFT RATE MODEL FOR SOUTHERN NORTHWEST NELSON, SOUTH ISLAND, NEW ZEALAND REVEALED BY COSMOGENIC NUCLIDE DATING OF THE SEDIMENTS OF BULMER CAVERN

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The landscape of northwest Nelson, which is in the northwestern part of the South Island of New Zealand, shows evidence of significant tectonic activity since the inception of the Austro-Pacific plate boundary in the Eocene. Evidence of tectonic subsidence followed by rapid uplift in response to the southward migration of the pole of rotation of the Pacific plate from the Eocene to the late Miocene is preserved in the sedimentary basins of northwest Nelson. However, the effects of erosion mean there is very little evidence of post-Miocene tectonic activity preserved in the northwest Nelson area. This is a period of particular interest because it coincides with the onset of rapid uplift along the Alpine Fault, which is located to the south, and the very sparse published data for this period suggest very low uplift rates compared to other areas close to the Alpine Fault.

Cosmogenic nuclide burial dating of sediments preserved in Bulmer Cavern, an extensive multi-level cave system located within the Mt Owen massif in the southern part of northwest Nelson, indicate an uplift rate of 0.13 mm/a from the mid-Pliocene to the start of the Pleistocene and 0.067 mm/a since the start of the Pleistocene.

The Pleistocene uplift rate is similar to other published uplift rates for this period from the northern parts of northwest Nelson, and to a cosmogenic nuclide derived erosion rate that covers the Holocene from the summit of Mt Owen, suggesting that the whole of northwest Nelson has experienced relative tectonic stability during this period. The mid-Pliocene uplift rate is possibly the first precisely constrained uplift rate in the area for this period and suggests that there has been a progressive decrease in uplift rates in the area since the Miocene.

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 (0.5–1.0 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 $\delta^{13}C$ 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 during which deep-sea temperatures cooled by 3 °C over four 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.

APPLYING DEEP LEARNING CONVOLUTIONAL NEURAL NETWORKS FOR IMPROVED AUTOMATED CLASSIFICATION OF POLLEN

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Pollen-based vegetation reconstructions underpin much of our understanding of late Quaternary climate change in New Zealand. Yet pollen analysis is a time-consuming and subjective process. Thus, it is no surprise that the automation of pollen counting has increasingly featured within the literature, especially with the rapid enhancements of computing and imaging technology in recent decades. While the results of existing studies can be regarded as promising, they are limited in that they typically deal with a relatively small number of taxa (max. 26, mean 8), and accuracy rates vary. While some palynological applications may require a lower level of taxonomic diversity than others, it is arguable that many real-world pollen problems, such as those faced in Quaternary vegetation reconstructions, will require higher diversity than that of most of the existing studies. Previous reviews have suggested that the minimum number of taxa for paleoecological applications would be around 40 types.

Here we have applied two types of deep learning convolutional neural networks (AlexNet and DenseNet) to classifying pollen images from 46 different taxa. Our dataset includes several pairs of morphologically similar types, which human analysts traditionally have difficulty separating (*Leptospermum scoparium* and *Kunzea ericoides*, *Fuscospora truncata* and *Fuscospora fusca*, and *Brachyglotti*s and *Olearia*). Images were captured automatically using the Classifynder™ automated palynology system.

The DenseNet and AlexNet CNNs achieved 99% accuracy in classification. On a 46-class problem, 97–99% is the highest success rate, when weighted for the number of taxa, of any attempt at automated pollen analysis currently documented in the literature. Our next steps are to modify the algorithms to provide a classification confidence measure to help with “unknown” pollen types and other objects not featured within the training library, and to test the systems on broken and deformed pollen, such as those encountered in Quaternary samples.

COMPLICATIONS IN TEPHROCHRONOLOGY: A CASE STUDY FROM HAWKES BAY

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Tephra deposits are utilised by many disciplines of Natural Science as isochronous tie points. This process relies on the accurate correlation of them to other well-dated deposits. However, the ability to uniquely identify tephra deposits, and thus correlate them with certainty, is not without its complications. Using preliminary research from Hawkes Bay we will highlight the complications in achieving robust tephra deposit correlations including; (1) large uncertainties associated with direct dating techniques for older (≥1 Ma) tephra horizons; (2) the lack of/or minimalist amount of published and accessible geochemical data in New Zealand; and (3) the lack of data pertaining to the source regions themselves (specifically Coromandel Volcanic Zone).

Six of the tephra horizons sampled from the Hawkes Bay region contained sufficient zircons for fission-track dating. Ages of the horizons range from 1.4 to 5.7 Ma, in good agreement to previously assigned age constraints based on biostratigraphic and/or palaeomagnetic markers. However, the precision of these ages (2σ uncertainties of ±0.4–1.6 Ma) is insufficient to correlate the tephra horizons to either their specific source (eruption event) or alternative tephra deposits using geochronology alone. Therefore, in addition to the new (and existing) age data, we will present the results of major and trace element analysis of glass shards from 18 tephra horizons. We will discuss the correlation of the tephra horizons to onshore and offshore counterparts, and also to source, and use our results to emphasise the importance of combining geochronological constraints with geochemical fingerprinting and additional parameters in order to provide the most accurate correlations. As a result, we encourage the use of new electronic storage files in publications to give access to full geochemical and chronological datasets. Thereby allowing complete characterisation of the tephra and rigorous statistical assessment, producing accurate correlation to other deposits in future studies.

GEOCHEMICAL RELATIONSHIPS OF COUPLED ERUPTIONS IN THE AUCKLAND VOLCANIC FIELD

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Monogenetic basaltic volcanic fields are common across the globe and are of particular interest where they occur close to or coincident with cities, such as at Auckland, New Zealand. The term "monogenetic" implies that the volcanic centres in the fields are active only once, and that the eruptions are discrete in both space and time, unlike "polygenetic" where multiple eruptions occur from the same centre. However, many global studies investigating these volcanic fields have highlighted this understanding as too simplistic. For example, mixtures of polygenetic and monogenetic centres have been observed in single fields and flare-ups in activity are identified in many fields globally. Current hazard and risk models do not account for this complexity, and thus may be underestimating the threat posed by this type of volcanism.

Here we present evidence and detail of coupled eruptions identified in the Auckland Volcanic Field, New Zealand. Coupled eruptions are here defined as two centres within a field that vented closely together in both space (<1 km) and time (<1 ka). In the Auckland Volcanic Field, approximately 20 of the 53 documented centres show this dual venting. We present a detailed characterisation of these eruption couplets, and discuss their physical characteristics, temporal constraints, and geochemical compositions. We use geochemical data to highlight the relationships between these coupled centres, their mantle source(s), and magma ascent characteristics, showing a complex interplay between (1) mixing of heterogeneous sources, (2) fractional crystallisation and assimilation processes during ascent, and (3) relationships between edifice size and geochemical signatures. These characteristics allow us to comment on the eruptive patterns of the couplets, their frequency, and relationship with their sources.

DEPOSITION, RE-WORKING AND RECYCLING OF HOLOCENE RHYOLITIC TEPHRA IN MARINE SEDIMENTS AT AN ACTIVE PLATE MARGIN

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Rhyolitic marker horizons provide critical isochronous tie points for marine sediment cores, however, at active plate margins their characterisation and correlation can be complex. On a recent voyage of the RV Tangaroa (TAN1613) along the northeastern New Zealand coast, 33 tephra horizons were identified within 17 shallow piston cores. Using deposit morphology, clast composition and glass geochemistry, we characterise these deposits as three types: (1) primary air fall, (2) reworked volcanoclastic-rich turbidites, and (3) discontinuous “blebs” of volcanoclastic material. Detailed geochemical analysis of major and trace elements not only facilitates these characterisations, but also allows cross-correlation between cores, and from horizon to source.

Tephra identified in the cores were sourced from the Kaharoa eruptive event (AD 1314) from the Tarawera complex, the Taupō eruptive event (AD 232) from the Taupō caldera, and an as yet unidentified eruption pre-dating the others. Some of the thicker tephra deposits (>10 cm) exhibit bimodal or multi-modal geochemical signatures, which record the geochemical evolution of the eruption. In addition, we present isopach maps for these eruptions drawn from our distribution of core site locations that span a large proportion of the East Coast of New Zealand. The dispersal of the tephra highlights changes in wind direction and/or explosivity throughout the eruption sequences.

TRIASSIC–JURASSIC BOUNDARY STUDIES OF MURIHIKU AND WAIPAPA TERRANES, NEW ZEALAND

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Triassic–Jurassic boundary (TJB) studies in New Zealand have been conducted since early 1990 as a joint research project involving scientists from New Zealand and Japan. This long-lived research has established the following results: (1) a remarkable facies change occurred within the TJB zone preserved within Murihiku Supergroup sequences (Akikuni et al. 2010, Stratigraphy 7: 7–24); (2) deep marine pelagic TJB sequences exist within Waipapa Composite Terrane; and (3) C-isotope curves obtained from these TJB sequences can be correlated with records from the Northern Hemisphere (Okada et al. 2015, NOM Special Volume 15: 219–232). This presentation will describe these results and discuss the TJB recorded in the basement rocks of New Zealand.

Murihiku Supergroup sediments accumulated along the Gondwana continental margin, during the Early Triassic to Late Jurassic, with a considerable potential for a record of TJB phenomena. We have examined the TJB sequences from the Kawhia coast and Awakino Gorge sections, and have discovered a distinctive, thinly-laminated, lithofacies in the TJB transition zone at both localities. Neither contains fossils, which implies low biological activity on the Gondwana margin during TJB time.

Pelagic sequences spanning Triassic to Jurassic time are widely distributed in the Waipapa Composite Terrane and are well-exposed in the Hauraki Gulf, near Auckland. We have identified two different accretionary slices: (1) the upper slice which is an accretionary complex containing the Permian–Triassic boundary (Hori et al. 2011, Palaeoworld, 20: 166–178), and (2) the lower slice contains Late Triassic–Early Jurassic chert-dominated sections including the TJB, and is topped by Late Jurassic green argillite that records a transition to more terrigenous sedimentation as the accretionary complex was drawn closer to the Gondwana margin with ongoing subduction.

At Pakihi Island, there are two TJB chert sections dated by radiolarian biostratigraphy, but they have not yet yielded any conodonts. Further studies are required to clarify the apparent absence of these fossils.

LATE OTIRAN GLACIAL ADVANCE TIMING FROM WAIMAKARIRI OUTWASH GRAVEL AGES

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Optically-stimulated luminescence (OSL) dates from trench and quarry sites on the central Canterbury Plains provide evidence for more than one major glacial advance during the Last Glacial Coldest Period (LGCP). Seven ages are from Burnham Formation sand lenses from within the Waimakariri fan gravel deposits at depths of 0.9 to 4.0 m, and one from loess in a surficial channel. The intra-gravel sand lenses returned median ages ranging from 20.2 ± 1.9 to 33.0 ± 2.0 ka, generally consistent with their stratigraphic order, while the loess yielded an age of 10.0 ± 0.7 ka. These ages are consistent with previous OSL and radiocarbon dates from Burnham Formation gravels at the coastal edge of the Rakaia and Ashburton fans (Rowan et al. 2012, Quaternary Geochronology 8: 10–22).

When plotted together with OSL and radiocarbon ages from the Rowan study, the deposits cluster in time intervals of ~20 to 24 ka and ~28 to 33 ka. Together the sites span over 50 km perpendicular to the main transport direction of the fans, and the catchments of the fans' associated valley glaciers encompass a large part of the central Southern Alps. This indicates that the valley glaciers which produced the deposits did so during two major advances either side of a period of glacial retreat and the correlation between catchments indicates the factors driving the advances were at least regional-scale. Although they are low-resolution data, these outwash deposit ages supplement other, indirect methods, such as pollen and moraine dating. Together they provide for a more detailed picture of glacial timing during the LGCP.

REES–DART DELTA AGGRADATION: THE SQUEEZE ON RIVERSIDE COMMUNITIES

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The Rees and Dart rivers coalesce just upstream of Lake Wakatipu to form the Rees–Dart Delta. Adjacent to the lake, the settlements of Kinloch and Glenorchy are situated on the west and east peripheries of the Delta, respectively. The delta is rapidly (1–2 m per year) prograding into the lake while the beds of the rivers are aggrading. This latter effect is less noticeable, even to long-lived residents of the community, and poses a risk to flood and erosion protection as flood flows of the river are forced higher with each event, and lateral bank erosion increases on previously stable stretches of riverbank. The hazardous setting of Glenorchy is complicated further by its proximity to the Buckler Burn alluvial fan and landslide dam upstream.

In response to community requests to address river bank erosion and gravel build-up around lake-front infrastructure, Otago Regional Council (ORC) have this year initiated a project to work with the community to establish a forward-looking natural hazards plan. This will aim to address the challenges of maintaining infrastructure (in a post-Catchment Board "river control" era), planning for increasing tourism pressure, and ensuring safety of all in the event of a major flood event. The hazard of such an event will increase over time as the river bed (already at the same or higher elevation as parts of Glenorchy) aggrades and the delta builds out past the town. Parallels with sea-level rise may be drawn with the slow-onset nature of these hazards. Both the immediate year-to-year plans and multi-decade timescales must be addressed, with a theoretical end-point of the current lakeside settlement location eventually becoming part of the Rees–Dart Delta.

THE NEW ZEALAND GEOTECHNICAL DATABASE: A USER PARTICIPATION MODEL

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The New Zealand Geotechnical Database (NZGD) contains one of the largest datasets for geotechnical information in the Southern Hemisphere. Active since 2016, the database has >90,000 datapoints and >5500 users from across the country. Building on the success of the Canterbury Geotechnical Database (CGD), which was developed for the Christchurch rebuild following the 2010–2011 Canterbury earthquake sequence, the NZGD is an online repository (www.nzgd.org.nz) for new and existing geotechnical information. Unlike other databases around the world, the NZGD enables geotechnical information to be shared between the private and public sectors. One of the defining characteristics of the dataset is stakeholder buy in and participation. Usage of NZGD data is predicated on the understanding that the user will upload their own data to the platform. The system then becomes a self-building structure. Originally, the database was built to store >18,000 CPTs done on behalf of the Earthquake Commission in response to the Christchurch Earthquake. With this seed dataset, consultancy buy-in to the user-based model in Christchurch was fairly rapid. However, when the database became a national platform in 2016, few other areas of New Zealand contained enough data to incentivise consultants to participate. One method for building usership in other regions has been to seed the NZGD with historical data from major public infrastructure project (i.e., roads, sewers, railways, etc.). To date, this effort has added >15,000 datapoints to the Auckland region, >3000 datapoints to the Wellington region, and >2000 datapoints to the Tauranga area. In all cases, consultancy participation has been slowly increasing in each of these areas as more historical data are added to the system. Upload of historical data is entirely based on client approval, with most of the data being directly supplied via client reports. The NZGD is, thus, a data repository for both clients and consultants.

3-D CO-SEISMIC OFFSETS DURING THE 2016 M_W 7.8 KAIKŌURA EARTHQUAKE FROM AERIAL PHOTOGRAMMETRY

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For several earthquakes during the past decade, differencing of LiDAR point clouds has been used to map 3-D co-seismic deformation. Point-cloud differencing is very effective for mapping near-fault deformation, but its use is generally restricted by an absence of pre-earthquake LiDAR data. For example, pre-earthquake LiDAR near Kaikōura only covers the region closest to the coast.

We use point clouds generated from pre- and post-earthquake aerial photographs (rather than LiDAR) to estimate co-seismic slip and off-fault deformation for the Kekerengu and Papatea faults and the Jordan Thrust. First, we validate our approach using: (1) differential LiDAR from the Papatea fault; (2) field observations of deformation from the Kekerengu Fault; (3) offsets from differential InSAR; and (4) sub-pixel correlation of aerial photographs. Second, we present measurements of near-fault deformation around the Jordan Thrust.

Our results demonstrate that point clouds generated from photogrammetry can be an effective tool for mapping surface offsets during earthquakes. Since almost all of New Zealand is covered by high-resolution aerial imagery, detailed mapping of surface deformation should be possible for future large earthquakes.

COMPARISON OF 2016 CO-SEISMIC AND HOLOCENE COASTAL UPLIFT ALONG THE KAIKŌURA COAST

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During the 2016 M_W 7.8 Kaikōura Earthquake, vertical motions of the coastline were highly variable. Observed displacements ranged from 2.5 m subsidence to 6.5 m uplift, with sharp discontinuities in the magnitude and sense of displacement associated with major faults. We map the elevations of Holocene raised shorelines (marine terraces) that were probably formed by coastal uplift during prehistoric earthquakes. By comparing the timing and spatial distribution of Holocene uplift with the pattern of 2016 uplift and subsidence, we aim to identify: (1) groups of faults that have previously ruptured together; and (2) any faults that did not rupture in 2016.

We use a surface classification model to identify smooth, flat surfaces. These surfaces are manually inspected to differentiate between marine, fluvial and human-made terraces. Where necessary, we use field observations to determine whether a terrace has a marine origin. We also use land-cover classifications to identify regions where the coastal geomorphology might not preserve uplifted terraces, such as sand dunes.

Flights of marine terraces are most prominent around the Kaikōura Peninsula and Cape Campbell but are present along much of the coastline. The coast between the Papatea and Kekerengu faults subsided co-seismically in 2016, but the presence of terraces suggests that this part of the coastline may be uplifted in the long-term. More field observations and age constraints are required to correlate terraces and identify prehistoric multi-fault ruptures like the 2016 earthquake.

DIAGENETIC PATHWAYS OF SPINICAUDATANS FROM THE YIXIAN FORMATION (LOWER CRETACEOUS) AND THE DAOHUGOU BEDS (UPPER JURASSIC) IN WESTERN LIAONING AND ADJACENT AREAS, CHINA

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The Jehol and Yanliao biotas constitute two world-famous Mesozoic lacustrine lagerstätten. In contrast to numerous comparative studies on their different fossil assemblages, their taphonomic features have rarely been compared. Here we investigate the preservational pathways of spinicaudatans from the Early Cretaceous Yixian Formation and the Jurassic Daohugou Beds, to figure out whether they are similar. The specimens were categorized into eight types based on the colours of the carapaces and the characteristics of the surrounding matrix, and subsequently studied using a scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDS). Spinicaudatan carapaces from the Yixian Formation are phosphatised and lack any traces of organic remains, whereas those from the Daohugou Beds consist of a mineralised layer and a carbonaceous layer (possibly remains of the chitinous layer). Phosphatisation was a common taphonomic pathway of spinicaudatan carapaces in the Yixian Formation, while in the Daohugou Beds preservation of carbonaceous material, probably the diagenetic products of chitin, are common. This suggests that the taphonomic environment and water chemistry to which the Jehol and Yanliao biotas were subjected were different.

AFTER THE CRISES? TALES FROM THE MIDDLE–LATE JURASSIC ZEALANDIAN MARGIN OF GONDWANA

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The low diversity of Jurassic Zealandian marine faunas is unsurprising given the near-polar position of this portion of the Gondwana margin. In contrast to the relatively diverse brachiopod-rich benthic faunas of the Early Jurassic, those of the remainder of the Jurassic are frequently dominated by one or two bivalve genera and brachiopods are rare. Belemnites are the dominant nektonic molluscs, frequently common to abundant from the earliest Temaikan (latest Toarcian). They provide the basis for a fine-scale local biostratigraphy, which compliments that based on benthic bivalves (*Retroceramus*, *Malayomaorica* and *Australobuchia*). In contrast, ammonites are rare. Consequently, the limited diversity of Ammonitina led to the development of a local New Zealand geological timescale in the 1950s. Discoveries of new ammonite taxa in the past three to four decades have enhanced the formerly sparse tie points to the international timescale. These discoveries are ongoing, and recently include *Lissoceras* in the early Temaikan (late Toarcian–latest Aalenian) and *Peltoceras* in the early Heterian (middle Callovian–middle Oxfordian).

In the Zealandian region, the earliest Temaikan (latest Toarcian) marks a change from a trickle of mainly Tethyan arrivals to a veritable flood. These immigrant genera rapidly dominate molluscan faunas; while at the species level endemism remains high. Amongst the earliest of these early Temaikan arrivals are the *Trigoniidae* (6 species), *Meleagrinella* and *Neocrassina*. The benthic molluscan fauna reaches its maximum diversity during the late Temaikan to earliest middle Heterian (late early Bajocian–early late Oxfordian) before decreasing to a much lower level for the remainder of the Jurassic.

TRACKING CO_2 DEGASSING USING STABLE ISOTOPE FRACTIONATION IN BASALTIC MAGMAS

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Magmatic CO_2 is an important part of the global carbon cycle, transferring carbon from the mantle to the atmosphere, as well as a major driver of volcanic eruptions. It is difficult to measure the initial CO_2 concentration of magmas because CO_2 has low solubility in silicate melts and is therefore largely degassed by the time magma reaches the surface. Mineral-hosted melt inclusions give us a record of degassing but are unlikely to trap melt with the initial CO_2 concentration as CO_2 begins to exsolve at greater depths.

During degassing, CO_2 undergoes stable isotope fractionation whereby the melt becomes isotopically light (^{12}C-enriched), whilst the vapour becomes heavy (^{13}C-enriched). Theoretically, a suite of melt inclusions would record this change in $\delta^{13}C$ and therefore CO_2 and $\delta^{13}C$ analyses of melt inclusions could be used to calculate the initial CO_2 concentration and isotopic ratio, and style of degassing, prior to eruption. Changes in the $\delta^{13}C$ of magmatic gases have been interpreted to be caused by this process.

To do this requires quantification of the fractionation factor of CO_2 between melt and fluid (Δ_{f-m}), but there is a lack of data in mixed CO_2–H_2O systems at crustal pressures. To measure the equilibrium Δ_{f-m}, we simulated degassing for basaltic melts of different H_2O:CO_2 ratios at 1250 °C and 1–7 kbar using an Internally Heated Pressure Vessel. Glasses were analysed for CO_2, H_2O, and $\delta^{13}C$ using Stepped-Heated Mass Spectrometry (SHMS) and Secondary Ion Mass Spectrometry (SIMS).

Our data indicate H_2O may change Δ_{f-m} substantially, which may be important when interpreting carbon isotopes signatures in hydrous basaltic magmas, such as those from arc settings. We show preliminary SIMS data on glassy melt inclusions from Etna, Italy, and Rangitoto, New Zealand, to investigate the initial CO_2 concentration, $\delta^{13}C$ of the source, and style of degassing.

VOLATILES IN BASALTIC MAGMAS FROM THE OKATAINA VOLCANIC CENTRE

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Magmatic volatiles (e.g., H_2O, CO_2, S, Cl, F) are an important driving force for eruptions. They are also a critical component of the global volatile cycle, transferring volatiles from the mantle to the atmosphere with potentially large impacts on the local and wider community. Also, changes in magmatic gas emissions at the surface are used to monitor the potential activity of volcanoes in real-time. Currently, there are no data available on the volatile concentrations of basaltic magmas from the Okataina Volcanic Centre (OVC), despite New Zealand's largest and most deadly historic eruption (Tarawera 1886 AD) occurring in this region.

We sampled scoria from four basaltic OVC eruptions: Terrace Rd, Rotokawau, Rotomakariri and Tarawera 1886 AD. Major and minor element chemistry of minerals (olivine, pyroxene and plagioclase) and melt inclusions (MIs) was analysed using electron probe microanalysis (EPMA). Melt inclusion volatile concentrations were analysed using EPMA (S, Cl, F and H_2O using Water by Difference), Raman spectroscopy (H_2O), and Secondary Ion Mass Spectrometry (SIMS; H_2O and CO_2) and Fe oxidation state using EPMA. We compare the volatile concentrations between basaltic eruptions to investigate differing eruption sizes and to OVC rhyolitic eruptions to examine the source of the volatiles. We also use H_2O–CO_2 barometry to understand the magma plumbing system.

To connect the MI volatile concentrations with current volatile emissions, a soil CO_2 survey was conducted within the Tarawera 1886 AD fissure. Most of the mountain is not releasing magmatic CO_2, but one area next to an 1886 AD dike is releasing significant CO_2 associated with warm ground. The CO_2 isotopic signature confirms its magmatic origin—a somewhat surprising finding. This data is combined with CO_2 fluxes from the Waimangu Geothermal System and Lake Rotomahana, and the Tarawera MI CO_2 concentrations, to constrain the total CO_2 flux from the 1886 AD fissure today.

THREE-DIMENSIONAL FLOW IN THE HIKURANGI MANTLE WEDGE: IMPLICATIONS FOR CENTRAL NORTH ISLAND MAGMATISM

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Flow of material within the mantle wedge of a subduction zone fundamentally influences the generation and transport of melt to feed crustal magmatism and surface volcanism. Mantle flow induces the preferential alignment of olivine crystals, the orientation of which can be inferred through seismic anisotropy. We perform shear-wave splitting analysis on over a decade of data from the GeoNet seismic network, supplemented by additional data from temporary seismic deployments across the North Island. By restricting measurements to earthquakes originating in the down-going slab, we exclusively consider ray-paths that sample the mantle wedge. We then perform 3-D shear-wave splitting tomography, allowing us to directly solve for the orientation of olivine crystals within the mantle volume. These results are used to infer 3-D flow in the Hikurangi mantle wedge to unprecedented detail. Our results enable us to test previously proposed hypotheses for mantle flow-regimes at subduction zones and to consider how local features, such as the Taranaki–Ruapehu line, relate to mantle flow in New Zealand. In addition, we discuss the inferred mantle flow patterns within the context of fluid release from the down-going slab and consider how the flow may influence crustal magmatism, as expressed at the surface in the Taupō Volcanic Zone.

PROTECTING GEOHERITAGE THROUGH THE AUCKLAND UNITARY PLAN

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The Auckland region contains a wide range of geological features recognised for their scientific, educational, aesthetic and cultural values. Perhaps the best known of these are the volcanic landforms of the Auckland volcanic field, however, the region also contains a range of other significant geological features, such as the many noteworthy geological exposures and dynamic landforms along its extensive coastline.

In the past, regulatory protection for these features has been incomplete and inconsistent. Volcanic landforms within urban Auckland were reasonably well represented in geological schedules in District Plans, while a selection of coastal geological features was recognised in the Auckland Regional Plan: Coastal (2004). Geological features and landforms in Auckland's rural hinterland were largely ignored in planning documents.

Following the establishment of Auckland Council in 2010, the development of the Auckland Unitary Plan provided an important opportunity to consolidate regulatory protection for Auckland's geological features and landforms. A comprehensive region-wide Outstanding Natural Features (ONF) overlay was adopted for the first time. Identifying more than 250 features of regional and greater significance, the overlay schedule and mapping was informed by a range of sources, notably the New Zealand Geopreservation Inventory.

An important outcome of the Unitary Plan is that a robust, independent decision-making process has now accepted that geological features of scientific interest qualify as ONFs under section 6(b) of the Resource Management Act. While Outstanding Natural Landscapes have been well-defined for many years, the Unitary Plan process advanced the characterisation and recognition of ONFs.

Although the ONF overlay achieves more comprehensive regulatory recognition for Auckland's ONFs, implementing the Unitary Plan to get positive outcomes for their protection remains challenging due to the strong development pressures in the region. An active and engaged community is necessary to maintain the profile of these issues.

PROCESSES RESPONSIBLE FOR EXCEPTIONAL PRESERVATION OF FOSSILS IN LAKES ASSOCIATED WITH VOLCANISM

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The Mesozoic Yanliao and Jehol Biota in northeast China have yielded numerous completely preserved fossils, such as feathered non-avian dinosaurs, birds, pterosaurs, mammals, insects, and plants. Most of the specimens show exceptional preservation, such as clear impressions of the body outlines to traces of soft tissues (e.g., teleost air sac, eye spots, muscles, skins) and external body coverings (e.g., scales, feathers, hairs). These fossils are mostly preserved in lakes that were closely associated with frequent volcanic eruptions. The role that volcanic eruptions played in the process of exceptional preservation in these lakes is far from well understood. By reviewing the preservation condition of these fossils, such as the degree of fragmentation, density, diversity, plan-view orientation, size frequency, type of biomineralization, and lithofacies of the fossil-bearing layers as well as their relationship with volcanic rocks, the causes of mass mortalities, transport and burial of the fossils in these lakes are revealed. The cause of frequent mass mortalities, transport and rapid burial of the remains by pyroclastic sediments and maturing of soft tissues by chaocoalification are considered to be the dominant environmental factors that influenced exceptional preservation of fossils in lakes associated with volcanism.

EVALUATING EL NIÑO–SOUTHERN OSCILLATION SIGNATURES IN OFFSHORE ADÉLIE LAND, EAST ANTARCTICA SEDIMENT CORE

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In 2010, a 180 m sediment core was collected offshore East Antarctica in the Adélie Basin during International Ocean Discovery Program Expedition (IODP) 318. Bulk organic carbon and carbonate materials date the core to ~12,000 years BP, and high sedimentation rates create a unique record capable of resolving both large- and small-scale climate variabilities on sub-decadal frequencies. Centimetre-scale laminations occur continuously throughout the length of the core and are inferred to reflect periodic phytoplankton bloom events. Using X-Ray Computed Tomography (CT) image analysis to characterise the frequency of these laminations, we present a new offshore East Antarctic Holocene record that shows a 2–3-year frequency in these phytoplankton bloom events. We suggest El Niño–Southern Oscillation (ENSO) to be the main driver of phytoplankton bloom events in this region and explore how ENSO activity and its influence on this particular site has changed during the Holocene. Our record reflects changes in both the eastern and western Pacific sectors during an El Niño event, in that it displays a similar pattern to an Australian stalagmite record reflecting monsoon variability, as well as to the El Junco sand record from the Galapagos Islands. All records show increasing ENSO frequency starting around 4.5 kyr and we identify the most plausible mechanism explaining the ENSO influence at our site. This study is unique in that most ENSO studies in Antarctica focus on the Antarctic Peninsula, and no equivalent ENSO record currently exists in East Antarctica. Consequently, it allows us to assess decadal to millennial scale climate variability at both the eastern and western edges of the Pacific Ocean margin of the Antarctic Ice Sheets.

TOWARDS TSUNAMI-SAFER COMMUNITIES IN NEW ZEALAND: EVALUATING REAL EVENTS, EXERCISES, DRILLS AND AWARENESS PROGRAMMES

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Tsunami awareness in New Zealand has evolved over the last 58 years since the 1960 Chilean tsunami, which struck New Zealand without official warning and caused significant damage, despite occurring at low tide. From 1960 to 2004 various measures were put in place, such as becoming part of the Pacific Tsunami Warning System, which led to improvements in official warning mechanisms. However, surveys in 2003 showed that public understanding of tsunami risk and correct warning-response action still had room to improve. Following the 2004 Indian Ocean tsunami the New Zealand government initiated an extensive review of national tsunami hazard, risk and preparedness. New initiatives represented significant steps forward in our preparedness for future tsunami. Recent evaluations of real events, exercises, drills and awareness programmes have shown a steady improvement. However, there is still a way to go to ensure adequate awareness and preparedness of individuals and communities. This poster outlines the results of recent tsunami social science research and highlights future opportunities for building tsunami-safer communities in the New Zealand and in other at-risk countries.

A 3-D GEOLOGICAL MODEL FOR THE HERETAUNGA PLAINS, HAWKES BAY

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As part of the GNS Science Urban Geological Mapping project, a geological dataset has been compiled for the Napier–Hastings area, which lies on the Heretaunga Plains in the Hawkes Bay region. The dataset includes a 3-D geological model that is intended to provide a framework of the sub-surface materials. Key to the 3-D model has been the development and integration of lithogenetic units that reflect the dynamic paleoenvironments that existed across the Heretaunga Plains in the late Pleistocene and Holocene. Beneath the Heretaunga Plains is a linear, fault-bounded subsiding basin filled largely with alluvial materials deposited by the Ngaruroro, Tutaekuri and Tukituki rivers. At the peak of the Last Glaciation about 20,000 years ago, the braided river systems of the region drained to a paleoshoreline at the edge of the continental shelf ~45 km off the present coast. From about then to 6500 years ago, the sea progressively rose to its present level, creating a transgressional environment in which the coastline and back-beach dunes, estuaries and swamps retreated landward, burying the river gravels with estuarine and marginal marine deposits. Ongoing deposition from the rivers and development of a barrier bar under stabilised sea-level conditions has subsequently infilled the estuary with gravel-dominated alluvial fan deltas and longshore drift beach gravels interspersed with fine grained clay, silt and sand deposits of both alluvial and marine origin. The 3-D model conveys an interpretation of the architecture and distribution of these different deposits within the broader regional geological setting of the Heretaunga Basin.

WHY REGIONAL SCALE DATA CAPTURE IS IMPORTANT FOR DYNAMIC EARTHQUAKE RESEARCH

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Following the 14 November 2016 M_w 7.8 Kaikōura Earthquake, significant landslide damage was observed across the North Canterbury and Marlborough regions of the South Island. Remote sensing data played an important role in the mapping of the fault rupture and landslide failures with the rapid collection and processing of satellite, aerial and terrestrial data acquired through radar, optical and laser technology. However, data capture is often constrained by cost resulting in patchy and incomplete coverage at both spatial and temporal scales (often pre-event coverage). Collecting data remotely, often from airborne- or space-based platforms, can ensure the capture of regional scale datasets for wider spread mapping and analysis of landscape processes. Complete spectral coverage of the inland Kaikōura Earthquake landslide damage zone has produced a world class landslide inventory. The potential to convert this from a 2-D to 3-D dataset and comparison to pre-earthquake conditions yields more multi-discipline hazard research. Having a regional scale pre- and post-event baseline survey enables further research into post-seismic landscape dynamics. Damaged and often de-vegetated slopes continue to be susceptible to failure with rainstorms and aftershocks supplying more debris over time, causing rapid riverbed aggradation and depending on the off-slope delivery relationships, potentially overwhelming the existing fluvial transport systems on a temporal scale. Analysis of on-going remote data capture allows for research to expand beyond local catchment-based sediment pathway connections to explore regional-scale sediment flux drivers and the broad-scale landscape response.

DEEP-EARTH GOLD: EXPLORING AU IN NEW ZEALAND PERIDOTITES

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Gold (Au) is a unique noble metal and a necessary mineral resource with behaviours that are not fully understood in a geological context, particularly within the deep Earth. The specific mantle residence of Au and the terrestrial replenishing mechanisms from this reservoir need to be defined. This study aims to better understand the behaviours of mantle Au by analysing its concentrations within major mineral phases and exploring enigmatic sulphide and alloy mineral sites in a suite of Zealandia mantle rocks at varying degrees of chemical enrichment and metasomatic alteration. Analyses show that major peridotite minerals can hold trace Au in their structures and we find varying quantities within silicates and oxides throughout the sample suite, with maximum values of 0.5000 ppm in olivine, 0.2440 ppm in orthopyroxene, 0.0660 ppm in clinopyroxene, 0.0730 ppm in serpentine, and as high as 1.3500 ppm in spinel. Higher Au concentrations are expected to reside within finely dispersed metallic phases. Preliminary characterization of these metallic minerals identifies the sulphides: millerite (NiS), heazlewoodite (Ni_3S_2), pentlandite ($(Fe,Ni)_9S_8$), pyrite (FeS_2), pyrrhotite ($Fe_{1-x}S$), chalcopyrite ($FeCuS_2$), chalcocite (Cu_2S); and the metal alloy awaruite (Ni_3Fe). Within this variation are an abundance of species with minor and trace Fe, Ni, Cu, Co, Hg and Zn, with patterns emerging with respect to locality and lithology.

With known economic gold deposition and a variety of exposed mantle rock localities—including an extensive ophiolite belt and myriad occurrences of mantle-derived xenoliths providing lithospheric mantle rock accessible for sampling—New Zealand provides an ideal locale for exploring this unique subject. Synthesising SEM and LA–ICP–MS analyses informs the investigation into the geochemical conditions that promote Au retention and mobility beneath Earth's surface and understanding preferential emplacement of Au from the deep to shallow Earth can establish whether geological settings become more favourably endowed in Au based on the mantle compositions beneath the surface.

GEOPHYSICAL SIGNATURES OF HYDROTHERMAL ALTERATION FOR EVALUATING VOLCANIC FLANK INSTABILITY

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Catastrophic collapses of the flanks of stratovolcanoes pose a major hazard to human life and property. Many such collapses are triggered by hydrothermal alteration processes that can mechanically weaken the volcanic edifice or favour pressure build-up within the sub-surface. How these alteration processes manifest themselves as geophysical signals in volcano monitoring systems is, however, not well understood. The complexity arises from competing alteration processes, which include dissolution and secondary mineral precipitation, often producing contrasting geophysical signatures. Here we aim to establish a link between measurable petrophysical properties of variably altered rocks and their corresponding elastic and magnetic geophysical signatures. Lava and pyroclastic rocks from two stratovolcanoes, White Island and Mt Taranaki, will be used as representative samples. We will first characterize the elemental composition and mineralogy of these samples to determine their alteration type and intensity. We will then measure the physical properties (porosity, permeability and density) and geophysical characteristics (elastic wave velocity and magnetic susceptibility) on a laboratory scale and study their relation. We will also investigate the variation in the mechanical strength of the rocks with hydrothermal alteration. Our goal is to provide a calibration and better understanding of geophysical images acquired over stratovolcanoes in New Zealand and around the world. The geomechanical study will help inform hazard evaluation and risk assessment on the stability of volcanic flanks in active hydrothermal environments based on geophysical signatures measured in the field.

EXTREMELY LONG DURATION OF GROUND MOTION ARISING FROM SEDIMENTARY STRUCTURES ABOVE SLOW-SLIP AREAS OF THE HIKURANGI SUBDUCTION ZONE

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It has been widely recognised that sedimentary basins amplify earthquake-induced ground motions and increase their duration. This is often referred to as basin effects. The resonance period of amplified and prolonged ground motion in a basin largely depends on the impedance contrast between the less consolidated material and bedrock, as well as the size and shape of a basin. In this study, we report strong basin effects in the North Island of New Zealand during seismic wave propagation from the M_w 7.8 Kaikōura Earthquake that was centred ~600 km away. Onshore and offshore Kaikōura Earthquake waveforms in the northeastern North Island show one of the longest durations of long-period (>10 s) ground motions ever recorded at an equivalent epicentral distance for similar size earthquakes. We aim to reproduce the extremely long durations of Kaikōura Earthquake ground motions using numerical simulations of seismic wave propagation incorporating 3-D velocity and attenuation models of New Zealand. We find that simulation of Kaikōura earthquake waves using the reference velocity model cannot reproduce the extremely long durations of long-period ground motions in northeastern North Island. Using a revised 3-D velocity model that includes a large (~200 km by ~150 km) wedge characterized by low seismic velocities, our model reproduces the long durations of long-period ground motions, which are caused by the reverberation of seismic waves within the low-velocity wedge. In addition, we show that the extremely long duration of long-period ground motions leads to prolonged dynamic stressing on the plate interface, likely accentuating the triggering of slow-slip. The wedge characterized by extremely low seismic velocities may be linked to the generation mechanisms of slow-slip events and tsunami earthquakes observed in northern Hikurangi.

CURVED FAULT STRIATIONS, RUPTURE DIRECTIVITY, AND DYNAMICS OF THE KEKERENGU FAULT DURING THE 2016 M_W 7.8 KAIKŌURA EARTHQUAKE

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Slip-parallel grooves (striations) on fault surfaces are considered a robust indicator of incremental fault slip direction, but their potential for recording details of earthquake rupture dynamics has received little attention. During the 2016 Kaikōura Earthquake, ten-plus meters of dextral strike-slip on the steeply dipping Kekerengu Fault exhumed >200 m^2 of fresh fault exposure (free faces) where it crossed deep gullies in bedrock. Inscribed upon these surfaces, we observed individual fault striae up to 2 m long, all of which had formed during the Kaikōura Earthquake. These were typically curved and in part overlapping of one another. Collectively, the striae recorded a temporal rotation of the co-seismic slip vector that was common between sites: recording, first, dextral–reverse motion followed by a longer interval of nearly pure dextral strike-slip. Using the simulations of spontaneous dynamic rupture on a vertical strike-slip fault employing slip-weakening friction laws, we are able to reproduce the observed, curved morphology of near-surface striae on the Kekerengu Fault with remarkable accuracy. Our dynamic models with purely horizontal pre-stress reveal that vertical stress changes induced by fault slip within the so-called cohesive zone result in vertical slip and temporal changes in fault slip direction. The degree of changes in fault slip direction is enhanced at shallow depths (<3 km) where there is low confining stress and is amplified by a free surface effect. The models show that the geometry and sense of striae curvature is sensitive to the direction of rupture propagation. To match the geometry of the striations observed on the Kekerengu Fault, our simulations require the rupture propagating from southwest to northeast, which is in agreement with the rupture propagation direction of the Kaikōura Earthquake. Our study highlights the potential for fault striations to record aspects of earthquake rupture dynamics, including the rupture direction of paleo-earthquakes.

THE ANTHROPOCENE IN NEW ZEALAND: HAZARDS OF UNINTENDED CONSEQUENCES OF A PANACEA

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Since 1950s the world has exited the Holocene and entered the Anthropocene. The fall-out from nuclear testing, proliferation of plastics in marine sediments, wide-spread use of halogenated chemicals and huge volumes of synthetic fertilisers have changed the geochemical landscape.

In New Zealand after World War II, a new trend to hire retired pilots to spread low-cost fertilisers caused a dramatic increase in the use of superphosphate. Essential nutrients like phosphate and nitrogen were spread over farms along with such contaminants as fluorine, uranium and cadmium.

Cadmium is as toxic to humans as mercury. Almost a kilogram of cadmium, 2–3 kilograms of uranium and 520 kilograms of fluorine have been added to each hectare. New Zealand's agricultural surface soils have now on average 5 times more cadmium than the natural level.

Until recently cadmium was bound to organic matter of the soil. Less than 1% of cadmium is present in porewater from where it is taken up by the plants humans and farm animals eat. In recent years to combat facial eczema, farmers that graze animals began to apply large doses of zinc to pastures unaware that zinc binds in the soil the same way cadmium does. Zinc application at rates are 1000 times higher than cadmium. This results in a cadmium release to porewater and from there to groundwater.

The panacea to cure facial eczema in farm animals with high levels of locked-up cadmium in the soil is now causing problems with zinc replacing cadmium in the soil causing this to migrate to plants via porewater and to our drinking water via groundwater. These transport mechanisms are slow but once started are unstoppable. The New Zealand agricultural sector must change its course to avoid a chemical disaster in its Anthropocene.

IMAGING FAULT ZONES AND FRACTURED GREYWACKE USING BOREHOLE AND SURFACE GEOPHYSICS

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Greywackes of the Torlesse Supergroup are the primary rock type in the Wellington region. The major faults that cut through the city and surrounds (e.g., Wellington and Ohariu faults) have a wide range of deformation features including crush zones, steep fault scarps, splay faults, and bedrock steps that complicate the development of city infrastructure. Geological studies of the greywacke basement have been supported by geophysical analysis of the rock using surface methods and borehole investigations. Drilling vertical wells behind steep man-made and natural slopes has provided a large set of data on the morphological characteristics, orientation, and distribution of fractures within the greywacke blocks based on acoustic and optical televiewers, and descriptions of the core. Geophysical logging of the holes provides rock property data, such as density, compressional wave and shear wave velocity, and natural gamma counts. These data can be used to model the behaviour of the slope during ground shaking. In many parts of the city the bedrock is covered by Pleistocene and Holocene sediment, so surface geophysical methods are required to map the bedrock geometry. The density difference between the greywacke (2.69 kg/m^3) and the unconsolidated sediment (2.2 kg/m^3) makes gravity a suitable technique for mapping lateral changes in bedrock depth. Combining the rock properties from the well logs with surface geophysics is improving our ability to characterise the sub-surface in heavily developed areas. Including local rock properties, and more accurate bedrock geometries into geotechnical models of the slopes and basins will provide more reliable estimates of ground motion during major earthquakes. On a more regional scale, understanding the geometry of these faults in three dimensions and the lateral extent of the damage zone around the faults will help predict how these faults behave during a complex earthquake at depth on any single section.

INITIATIVES FOR MAPPING FAULTS IN URBAN CENTRES

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Active faults under urban centres are often difficult to detect because the land surface has been heavily modified by urban development. It is important to understand the geometry of these faults and to determine the risks from earthquakes that cause major ground motion and damage to infrastructure. Over the last two years we have reviewed the geophysical data available to image faults under several small cities in New Zealand. The project is funded by a Royal Society Catalyst Seeding Grant with the aim of establishing connections between the New Zealand research team (GNS Science), and a German research team (Leibniz Institute of Applied Geophysics). Surprisingly large amounts of geophysical data have been collected through urban centres for resource and groundwater exploration, geotechnical engineering, and research. With careful supplement of additional geophysical data, detailed geological models of the faults can be produced. We show two examples. Whakatane was the focus of the first case study where high-resolution reflection seismic data was supplemented with ultra-high- resolution shear-wave landstreamer lines to map the trend of some of the faults that run through the city. In the second case study around Napier and Hastings, the link between regional faults and the near-surface expression of faulting was investigated using a combination of petroleum industry seismic, surface geomorphology, and shallow boreholes. While these case studies already involve a range of different data, many other methods are available for investigating the sub-surface. A workshop was held to review these methods (e.g., seismic, landstreamer, ground penetrating radar, spectral analysis of surface waves, gravity). The next phase of the project is to extend the scope of the study to look at a wider range of cities, and to develop some of the methods and approaches recommended in the workshop.

CAPTURED IN AMBER: ECOLOGICAL COMPLEXITY IN ZEALANDIA'S ANCIENT ARAUCARIAN FORESTS

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The New Zealand amber record is unique in providing successive windows into past ecosystems from the Late Cretaceous to the still extant *Agathis* (kauri) forest ecosystems in northern NZ. Amber has been found in coal deposits and reworked into a variety of fluvial and marine sandstones and mudstones. Amber samples were collected from more than 40 Late Cretaceous and Cenozoic NZ localities. Inclusions are now known from four separate sites, one of late Oligocene, and three of early Miocene age, and numerous samples remain to be screened.

The majority of NZ amber is derived from araucarians. There is a near-continuous record of Araucariaceae-like fossil wood from the Jurassic to the Present. Foliage attributed to Araucariaceae is widespread in Late Cretaceous and Paleocene sediments. Individual leaves, which can be assigned to *Agathis* are reported from several sites that also have amber and araucarian-type wood (e.g., Newvale, Bennett's Pit, Roxburgh).

Palynomorphs from associated sediments have enabled us to place most amber samples within the NZ biostratigraphic framework. The extensive *Araucariacites australis* pollen record may represent *Araucaria* and/or *Agathis* as their pollen are not readily distinguished. *Dilwynites subgranulatus* pollen is also commonly recorded and may represent *Wollemia* or another *Agathis* species. Pollen occurrences in the NZ Fossil Record File indicate a continuous record of Araucariaceae pollen from the Jurassic to the present.

Amber inclusions reported to date include a variety of sooty mould fungi, nematodes, and representatives of ten orders and 20 families of terrestrial arthropods. Ecologically, the organisms include predators such as spiders, microcarnivores such as pseudoscorpions, soil-dwelling mites, detritivores such as springtails, a variety of midges, parasitoid and other wasps, ants, beetles, bark lice, and lepidoptera. These fossils demonstrate significant ecological complexity and provide fresh insights into antecedents of the modern NZ terrestrial biota.

INTEGRATING AIRBORNE HYPERSPECTRAL AND AERO-MAGNETIC SURVEYS FOR BUILDING A 3-D GEOTECHNICAL MODEL OF MT RUAPEHU

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Mt Ruapehu has suffered several large-scale flank collapses and many smaller collapses of the crater rim that have resulted in debris avalanches, landslides, and lahars. These phenomena can affect large areas and pose a threat to both human populations and critical infrastructure. This project aims to assess future mass movement hazards by combining field, laboratory, and surface and sub-surface remote sensing measurements of the chemical, physical, and mechanical properties of the edifice. While collapses can be triggered by many mechanisms in active volcanic environments, hydrothermal alteration due to the active magmatic–hydrothermal system at Mt Ruapehu can progressively weaken volcanic rock and increase the likelihood of a collapse. To identify the geometry and volume of hydrothermally altered material, we combine hyperspectral and aero-magnetic aerial surveys to identify the surface and sub-surface details of the volcano's geological units and magmatic–hydrothermal plumbing system. Field sampling is used to support remote sensing data, as well as to determine the chemical (e.g., surface mineralogy, surface fraction of hydrothermally altered minerals) and physical properties (e.g., porosity, permeability, strength, and magnetic susceptibility) of the mapped units. Here we present first results from geological mapping using hyperspectral image data, and preliminary aero-magnetic inversion models to image the internal architecture of Mt Ruapehu. Both hyperspectral and aero-magnetic data are sensitive to clay minerals formed due to hydrothermal and weather-related processes. We mapped the distribution of alteration to highlight areas of potential flank collapse. These datasets will create a 3-D geotechnical model of the volcano to determine flank stability and input for mapping areas susceptible to mass flow hazards through numerical simulations. This will contribute to development of long-term land-use planning, volcano monitoring, and natural hazard mitigation at Mt Ruapehu.

THE CURRENT ERUPTION OF AMBAE VOLCANO: INITIAL GEOLOGICAL RESULTS

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Ambae volcano, Vanuatu, began erupting in September 2017 from a summit vent within Lake Vui. Until now, this basaltic eruption has waxed and waned over a series of eruptive phases resulting in two island-wide evacuations; villagers have been transported to neighbouring islands where they remain at the time of writing. The impacts of this eruption have mainly involved heavy ashfall, sourced from plume heights up to 10 km and acid rain associated with a high flux rate of SO_2.

A multi-disciplinary scientific response was initiated in May 2018, and our team visited in mid-July, where we focused on analysis of eruption deposits. Sampling of recently fallen pyroclasts and directly from the plume meant that the teams were able to make ash deposit density and time-averaged thickness measurements. Pristine samples are ideal for later grain size, leachate, petrological, and physical analyses. Here, we focus on understanding the magmatic conditions from both a geochemical and physical perspective to elucidate the controls of the high explosivity and the high SO_2 emissions.

We focus on the volatile content of phenocryst-hosted melt inclusions to explore the governing controls of the high SO_2 flux, which, based on OMI imagery reached ~100 kt/day. Initial results indicate a homogenous groundmass glass composition with varying microlite density. Scanning Electron Microscope imagery indicates a high quantity of anhydrite adhering to the surfaces of ash particles. Melt inclusion compositional analysis is ongoing.

Stratigraphic relations based on field mapping allow us to construct deposit isopach maps of the variable eruptive phases, including an assessment of the amount of ash compaction that occurs through time. This will help significantly in understanding how the geological record modifies the perceived impacts of explosive, basaltic eruptions at previously active centres and has relevance for comparisons to explosive volcanic deposits of the Auckland Volcanic Field.

EFFECTS OF POROSITY ON THE MECHANICAL BEHAVIOUR OF ACTIVE PLATE BOUNDARY FAULTS

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Porosity reduction in rocks from a fault core can cause fluid overpressure, and consequently influence the recurrence time of earthquakes. We have compared the porosity distribution in samples recovered during the Deep Fault Drilling Project (DFDP) along New Zealand's Alpine Fault and the Japan Trench Fast Drilling Project (JFAST), which sampled the plate boundary thrust that accommodated the 2011 M_w 9.1 Tohoku-Oki earthquake. X-ray computed tomography analyses of open pore spaces show total porosities in the range of 0.1 to 0.2% and 1.5 to 5% in DFDP and JFAST samples, respectively. Transmission electron microscopy (TEM) reveals that (1) pores are associated with grain boundaries, especially of clay minerals, (2) large clay grains are typically nanofolded, and (3) pores contain finer clay grains that we infer precipitated from pore fluids. X-ray diffraction analyses reported elsewhere are consistent with our TEM observations that clays are more abundant in the JFAST samples than those from DFDP. Our observations suggest that Alpine Fault gouge porosity was substantially reduced due to compaction and pressure solution processes, but that in the JFAST samples porosity created during dilation of the clay minerals during nanofolding overcame this effect. We conclude that the proportion of clay minerals in any fault gouge has a significant influence on total porosity, and consequently on the tendency for fluid overpressures to impact earthquake rupture propagation within them.

HIDDEN BY "SUPER-ERUPTIONS": TEMPORAL–VOLUMETRIC CHARACTERISTICS OF SMALL-VOLUME VOLCANISM OF THE TAUPŌ VOLCANIC ZONE, NEW ZEALAND

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The Taupō Volcanic Zone (TVZ) is one of the most productive silicic volcanic regions on Earth. Its mass magma output is dominated by 12 caldera-forming eruptions in the past 350 ka. Next to the calderas at least 300 other eruptions occurred with considerably smaller eruptive volumes totalling a minimum of 260 km^3 DRE volcanic material accumulated in the same period. The temporal–volumetric distribution of these small-volume eruptions indicates four distinct periods. Each period is characterised by different magma output rates indicating spatio-temporal fluctuations of overall magma production of the TVZ likely linked to changing regional tectonic stress regimes. Period one is characterised by an intense ignimbrite flare-up and a comparably insignificant apparent magma output from small-volume eruptions. Period two begins at ~275 ka at the end of the ignimbrite flare-up producing an overall increased but individually still small volume eruptions. This increased small-volume activity declined significantly at ~180ka, marking the start of Period three (from 0.8 km^3/ka to 0.2 km^3/ka). The relatively eventless Period three lasted until ~50 ka, when both caldera-forming and small-volume activity increased, marking the start of Period four (magma output 3 km^3/ka). The cumulative ~150 km^3 DRE magma from small-volume eruptions during Period four is one and half times higher than the median volume for caldera-forming eruptions calculated for the last 350 ka. The two active caldera complexes of the TVZ displayed very different temporal–volume pattern of small-volume activity in the past 50 ka, which may suggest that their magma reservoirs are either characterized by different rates of magma resupply/generation, or they have similar magma generation rates, but Okataina is more tectonically tuned for extraction and eruption of this magma. It is speculated that the latter could indicate a potentially higher probability for future caldera-forming eruptions at the Taupō area. This is currently being statistically analysed to provide further constraints.

A NEW 3-D MODEL OF PEGASUS BASIN PREDICTS GAS HYDRATE DISTRIBUTION ALONG THE HIKURANGI MARGIN

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The presence of gas hydrates along the New Zealand Hikurangi margin has been established based on observed widespread bottom simulating reflectors (BSRs) and velocity anomalies suggesting the presence of free gas beneath gas hydrate deposits. The trench basin and the rapidly uplifting thrust anticlines represent ideal environments for gas hydrate accumulation. The trench basin has been filled rapidly during the Plio-Pleistocene with sediments distributed mainly by the Hikurangi Channel system and stacked channel deposits provide potential fluid migration pathways. Due to high sedimentation rates, rates of biogenic gas generation underneath the hydrate stability zone are high. In addition, the geological setting of the Hikurangi Margin is unique, as the modern plate boundary overlies and incorporates sediments deformed during Mesozoic subduction beneath Gondwana. There is a significant potential for generation of thermogenic gas from sediments originally deposited seaward of the Mesozoic subduction margin that are now subducted at the modern margin.

To assess the impact of the architecture of the various structural and sedimentological elements of the offshore Hikurangi margin on fluid flow and gas hydrate formation, we have mapped key sedimentary horizons, BSRs, and the distribution of basin floor and channel sandstones across the basin and constructed a 3-D basin model using PetroMod™ software. The thermal regime predicted by the model has been calibrated to the depth of the BSR. The modelled temperature history of the margin has been used to predict thermogenic gas generation from potential Cretaceous and Paleogene source rocks and biogenic gas generation from Plio-Pleistocene sediments. The model predicts three major trends in fluid migration and gas hydrate formation associated with anticlines in the accretionary wedge, focused migration of thermogenic gas from buried Cretaceous–Paleogene sediments seaward of the main deformation front, and accumulation in sandstones of the buried Hikurangi Channel system.

THE MIDDLE MIOCENE IN SOUTHERN TARANAKI BASIN: A RECORD OF OCEANOGRAPHIC AND TECTONIC CHANGE

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New Zealand-wide marine transgression in the Oligocene was followed by regression and the evolution of a pronounced shelf-slope system in Taranaki Basin during the Miocene. Ahead of the evolving shelf, basin floor sandstones and mudstones of the Moki and Manganui formations were deposited. The resulting sedimentary succession is a repository of information on how climatic change may affect New Zealand and the southwest Pacific region. It also is a recorder of structural changes related to the evolution of the convergent plate boundary.

We have mapped the character and distribution of basin floor sedimentary units in southern Taranaki Basin using 3-D seismic reflection data and developed a sequence stratigraphic model. Tectonic uplift in the South Island leading to increased sediment input into the basin was the driver for the deposition of the sandstone-dominated sequence set. The stacking patterns of depositional sequences reflect an overall progradation of basin floor sedimentary facies through time, as well as a change in geometry and increase in dimension of associated elements such as fan lobes and channel systems. Five sequences are recognised in the middle Miocene deep-water succession. They consist of channel and fan deposits that formed during lowstands and are capped by regional hemipelagic mudstones interpreted to represent highstand deposits. These well-developed highstand systems tracts suggest a strong eustatic signal. In the western part of southern Taranaki Basin, sandy fan deposits became progressively reworked into deep marine plain contourite drifts. Their Lillburnian to Waiauan ages suggest deposition during a time of climatic cooling, ice sheet expansion, and ocean current intensification. The intensified currents may have been accelerated by a now-buried sill between the Challenger Plateau and the South Island, southwest of Taranaki Basin, leading to previously unrecognised, but widespread middle Miocene drift sedimentation in western Taranaki Basin.

SEDIMENTARY CHARACTERISTICS OF LATE CRETACEOUS DINOSAUR EGG BEDS AND THE POSSIBILITY OF THE K/PG BOUNDARY EXISTENCE IN WESTERN HENAN PROVINCE, CHINA

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Late Cretaceous dinosaur egg beds are widespread in the western Henan Province of China. The high density of dinosaur egg fossils has attracted world-wide attention. This paper focuses on the depositional environments, paleogeography and paleoclimate characteristics of egg fossil strata of western Henan Province, and provides a scientific basis for the study of dinosaur egg taphonomy. The Cenomanian–Maastrichtian sequences mainly consists of red clastic rocks, including conglomerate, sandstone, siltstone and mudstone, that are related to exhumation of the basin margins. The dominant lithofacies are alluvial fan debris flow facies, flood plain facies, braided river facies and shore–shallow lake facies. Detailed sedimentology (e.g., conglomerate superposition and cross-stratification), lithostratigraphy, conglomerate provenance, and trace element analyses of oxides, suggests that the paleoclimate in the western Henan Province changed from hot, semi-arid with a short-lived sub-humid excursion, to hot and dry, which was in a sub-tropical arid climatic zone. This change was coincident with a period of global warming. Due to the drastic changes in the hatching environment, a large number of eggs did not hatch and were preserved *in situ* in flood plain environments, while a smaller number were preserved in alluvial fan and braided river environments. Based on the lithostratigraphy, sedimentary characteristics, fossils and geochemical anomalies of Liguanqiao Basin, it is likely that the K/Pg boundary is preserved in the basin.

RECONCILING ON- AND OFF-FAULT PALEO-SEISMIC AND PALEO-SLIP RECORDS FOR THE NORTHERN SECTION OF THE ALPINE FAULT NEAR SPRINGS JUNCTION

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The northern section of the Alpine Fault (NS-AF) is characterised by a decreasing slip-rate to the northeast as deformation is transferred to the Marlborough Fault System (MFS). The northeast-ward evolution of the NS-AF (with respect to the MFS) establishes a hypothesis that its ruptures will be more complex with variable slip, rupture length and/or recurrence interval, compared to the central and southern sections of the Alpine Fault. Joint Earthquake Commission–Natural Hazards Research Management Platform-funded projects undertaken near Springs Junction provide an ideal opportunity to reconcile a high-precision record of off-fault paleo-earthquake timings from lacustrine seismites, with a low-precision-timing record of on-fault paleo-earthquakes from paleoseismic trenches. Two new trenches at Calf Paddock (Maruia River), which has a known slip-rate and paleo-slip observations, have revealed up to four paleo-earthquake ruptures that occurred within the last ~1800 years. The exact timing of these events is poorly constrained by charcoal and Infrared-stimulated luminescence (IRSL) ages. Similarly, up to four high intensity regional shaking events have been recognised by the presence of seismites in Lake Christabel, located ~6 km to the south in the hangingwall of the NS-AF. These four events occurred within the last ~1400 years and are precisely determined from well-dated lacustrine sediments. Results from a combination of on-fault and off-fault data show that the most recent faulting event on this part of the NS-AF occurred post-1717 AD and was associated with only ~1.5 m of fault slip. In contrast, the two paleo-ruptures prior to this must have involved at least 5 m of dextral slip to construct the famous Maruia River offset terrace sequence. The fourth paleo-earthquake event is broadly associated with the enactment of fluvial degradation at Calf Paddock. These results highlight the power of combining both on- and off-fault signals of very large paleo-earthquakes.

PALEOSEISMICITY OF 2016 MW 7.8 KAIKŌURA EARTHQUAKE FAULTS: WAS THIS EVENT THE NORM OR ONE "OUT OF THE PARK"?

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The M_w 7.8 14 November 2016 Kaikōura Earthquake was a complex earthquake that ruptured ~20 faults across two tectonic regions: from the North Canterbury Domain (NCD) northward into the Marlborough Fault System (MFS). Was this event the norm, or was it an exceptional earthquake scenario that seldom ruptures in this fashion over geologic timescales? A two-year Natural Hazards Research Management Platform (NHRP) project has been funded to investigate this question. The project targets several faults that ruptured in the 2016 earthquake: the Humps and Leader faults near the epicentre of the event, and the Hundalee and Papatea faults, SW and NE of Kaikōura, respectively. The project also seeks to understand the role of the seaward section of the Hope Fault, which did not rupture in the Kaikōura Earthquake. In addition, recent results from other Earthquake Commission (EQC)-, National Science Foundation (NSF)- and NHRP-funded projects on nearby faults will be considered. Specifically, the Conway segment of the Hope Fault, Kekerengu Fault, and results from paleo-coastal uplift and deformation studies will provide additional data on the wider system of ruptures across this portion of the plate boundary. The goals of the project are to assess the Holocene paleoseismicity of this system of faults and to investigate spatio-temporal patterns between paleoseismic records on individual faults. This poster aims to provide an overview of the NHRP project at the one-year mark. While current data is meagre or in preparation, basic geomorphic arguments from existing slip-rate, paleoearthquake and landscape data and inferences, for example, low- versus high-slip rate faults and short versus long recurrence interval faults involved in 2016, suggests that the specific configuration of the Kaikōura Earthquake was probably a rarity.

QUANTITATIVE OCEAN-COLUMN ACOUSTIC IMAGING OVER THE CALYPSO HYDROTHERMAL VENT FIELD, BAY OF PLENTY: FIRST RESULTS FROM RV TANGAROA TAN1806-QUOI VOYAGE

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The aim of the TAN1806-QUOI (Quantitative Ocean-Column Imaging using hydroacoustics) voyage on RV *Tangaroa* was to improve methods of characterising bubbles in the water column originating from seafloor targets such as cold gas seeps and hydrothermal vents. The July 2018 20-day voyage focused on the Calypso Hydrothermal Vent Field (CHVF), ~15 km SW of Whakaari/White Island volcano.

Six complex experiments were designed: (1) Calibration and cross-calibration of two multibeam and six split-beam echosounders systems (SBES) providing 38, 70, 120, and 200 kHz frequencies; (2) multibeam surveys with 75% and 95% swath footprint overlap on natural seeps and bubbles generated using a synthetic seep generator (bubble maker), allowing us to model the angular response of seafloor and water-column backscatter, and sidelobe interference; (3) a multi-angle survey over synthetic and natural bubbles using a hull-mounted pan and tilt device; (4) a horizontally looking SBES for lateral observation of bubble streams; (5) a five-day passive acoustic recording at the northern CHVF; (6) video footage, sediment and water samples for signal validation.

The different frequencies show strikingly different acoustic responses, demonstrating the potential of multi-frequency and wideband data for analysis of gas bubbles. Correlating acoustic frequency responses with physical parameters (depth, temperature, salinity) will enables us to estimate bubble-size distributions and flux rates (rising speed). When coupled with video observations and water sample analysis, these methodologies enhance our ability to model gas flux for discrete areas of seafloor. Preliminary results show potential for the development of automated methods to extract estimates from water column acoustic data in real time. The survey demonstrated that acoustic means can be used to differentiate spatially coincident gas bubbles (methane and CO_2) and could be applied elsewhere (e.g., freshwater streams).

USING BASALTS AS PROXIES FOR MAFIC MAGMA PLUMBING SYSTEM IN THE TAUPŌ VOLCANIC ZONE

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The Taupō Volcanic Zone (TVZ) is one of the most productive silicic magmatic systems in the world, erupting large volumes of rhyolites in the last 2 Ma. However, our knowledge of the driving forces behind large-scale silicic eruptions is still incomplete. Basalts are rare in the TVZ. Despite, their scarcity at the surface, they provide valuable snapshots into the sub-volcanic plumbing system and, hence, give insights into the drivers of silicic magma genesis.

Here, crystal-specific oxygen isotopic and textural analysis, reveal the nature of the mafic plumbing system. By assessing crystal–crystal and crystal–melt oxygen isotope equilibria we are able to establish the relative timing and amount of crustal assimilation in mafic magmas. We find that eruptions from the south are dominated by mafic cumulates of olivine ± orthopyroxene rims, oscillatory-zoned clinopyroxene crystals and are generally plagioclase poor. Textures from eruptions further north are overprinted by shallow crustal mineral assemblages and by interaction with rhyolite crystal mushes. However, oxygen isotopes of minerals in the north and south overlap and we infer that the crystal cargoes from the south hold clues to the early conditioning of the crust beneath the TVZ prior to the dominance of the rhyolitic volcanism that now blankets the surface of the TVZ. We propose a model whereby underplating dominates the lower crust and recharge of primary mantle melts remobilises crystal cumulates. Eruptions that are plagioclase-dominant have stalled in the middle–upper crust, before subsequent fault-controlled ascent, whereas eruptions that are plagioclase-poor are sourced directly from the area of underplating.

METALS IN SUBDUCTION-RELATED MAGMAS: INSIGHTS FROM MELT INCLUSIONS AND ASSOCIATED GLASSY GROUNDMASS FROM THE SOUTHERN KERMADEC ARC, NEW ZEALAND

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The Kermadec Arc–Havre Trough is an intra-oceanic arc–back arc system where the Pacific Plate is subducting beneath the Australian Plate. Importantly, three volcanic centres along the Kermadec arc host hydrothermal mineralization (Brothers, Rumble II West, and Clark). Hydrothermal deposits, such as volcanogenic massive sulphide (VMS) deposits present a potentially economic source of base metal elements (e.g., Cu, Mn, Au, Zn, As). However, current understanding of the sources, movements, and accumulation of metals associated with porphyry copper and exhalative base metal deposits within a subduction–arc setting remains limited.

Element cycling related to subduction settings and associated arc magmatism is notably complex due to several key components and processes: slab recycling; partial melting of the mantle; and crustal processes, which include crystal fractionation, degassing, magma mixing and crustal contamination. This research reports the chemical compositions of olivine-hosted melt inclusions and associated groundmass glass providing representative compositions of relatively primitive and evolved melt compositions, respectively. Analysis of both melt inclusions and groundmass glass aims to better constrain the impacts of magmatic processes on melt compositions, with particular focus on base metals.

Samples in this study were collected from a transect across the southern Kermadec Arc–Havre Trough. They include samples from the large stratovolcanoes Rumble II West and Rumble III as representatives of arc front compositions. Back-arc samples are also investigated to provide insights into how base metal behaviour and mobility may potentially vary perpendicular to the arc. In particular, back arc samples furthest from the arc front, may constrain a composition minimally affected by slab recycling and allow identification of base metal concentrations of the mantle wedge prior to slab input, thus providing a baseline with which to quantify the impacts of slab recycling.

DIVERSE OLIGOCENE–MIOCENE PALEOENVIRONMENTS AND COMPLEX FOREST ECOSYSTEMS IN SOUTHERN ZEALANDIA

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Mid-Cenozoic Zealandia was traditionally considered a low-lying archipelago with little ecosystem diversity. However, studies of a diverse range of lowland sites in southern Zealandia indicate significant environmental heterogeneity and complex forest ecosystems from the late Oligocene to middle Miocene. Climates were warm temperate to subtropical. Depositional environments included an extensive estuarine system (Pomahaka), coastal plains along a rocky shoreline (Cosy Dell), swamp forests (e.g., Newvale, Roxburgh, Hyde), a long-lived regional lake system (e.g., Bannockburn, Nevis), small, deep maar lakes (Foulden, Hindon) and a river delta system (Landslip Hill).

Highly fossiliferous sediments associated with these sites include mudstone, sandstone, lignite, amber, diatomite and silcrete. Palynomorph lists for all sites except Landslip Hill highlight diverse local and regional floras and vegetation types. Anatomically preserved wood, in the form of *in situ* stumps, logs and branches, is derived from forest trees, including Araucariaceae, Podocarpaceae, Casuarinaceae and Nothofagaceae. The most abundant fossils are leaves representing ~40 plant families, many preserved with cuticular detail. Ferns are well-represented as isolated spores, but fronds, including fertile examples, occur at Bannockburn, Landslip Hill, Foulden and Hindon maars. Dozens of flowers with *in situ* pollen are now recorded from Foulden and Hindon. Pollen-bearing conifer cones occur at Hindon, sedge seeds at Pomahaka, Casuarinaceae foliage and “cones” at Bannockburn, Nevis and Landslip Hill, and a wide variety of angiosperm fruits and seeds are preserved at Foulden Maar.

New research on the faunas preserved in amber, diatomite and mudstones at these southern sites has dramatically increased the number of terrestrial spiders, pseudoscorpions and insects to ~540 specimens, representing 16 orders and 55 families, and there is fossil evidence of diverse arthropod–plant interactions. Most sites reveal compositionally varied conifer–broadleaved forests, some dominated by Lauraceae, Myrtaceae and/or Nothofagaceae, with considerable ecological complexity and diverse trophic networks associated with rainfall and soil gradients.

CONVEYING GEOSCIENCE INFORMATION IN NEW ZEALAND URBAN AREAS

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GNS Science's Urban Geological Mapping project gathers, manages and provides detailed geological data on selected urban centres in New Zealand. Data packages are produced for selected urban areas with emphasis on geomorphology and/or surface geological maps with supplementary sub-surface data included were appropriate. Current urban areas of work are in Dunedin, Christchurch (Begg et al. 2015, GNS Science Geological Map 3), south Auckland and Napier–Hastings.

The urban geological data packages, distributed via web services and other physical media (e.g., DVD or datasticks), are provided in digital formats that are accessible with GIS and 3-D modelling and other freely available software. The geology and drillhole data conform to international geoscience data models (GeoSciML, vocabularies) and geotechnical (AGS4) standards respectively, to ensure consistency and accessibility. Geomorphology and/or surface geology maps are compiled to provide regional overviews of the landforms and rock types in each area, and drillhole data provides lithological and stratigraphic information for sub-surface interpretations. The interpreted drillhole data with the surface-based geology and geomorphology information are, for some areas, further interpreted in forms ranging from cross-sections, structural contours and isopachs, through to digital 3-D geological models.

The latest example of these urban geological data packages is the nearly completed Napier–Hastings project that comprises geomorphology and geology maps, and a 3-D model. The geomorphological map identified more than 30 landform types, many relating to the evolution of the Heretaunga Plain and coastline. The geological map consists of over 60 stratigraphic units and new interpretation of the extension of the Awanui Fault under the Quaternary cover. The units in the 3-D geological model comprises Holocene marine and non-marine sediments, Last Glacial alluvial gravel, a middle to late Pleistocene unit, early–middle Quaternary marginal marine to non-marine sediments of the Kidnappers Group, and undifferentiated Pliocene and older units.

TIME MATTERS: GEOLOGICAL TIME AND THE EVOLUTION OF THE NEW ZEALAND ENDEMIC FLORA

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New Zealand has an exceptional and enviable Cenozoic fossil record of terrestrial ecosystems that enables assessment of vegetation shifts in response to major environmental changes over evolutionarily relevant time periods. While much of the forest flora persists to the present day, the extinction and diversity declines of sub-tropical elements and the arrival of new groups following the Miocene climatic optimum provided the antecedents of the modern flora, especially in non-forest habitats. Pliocene and Pleistocene cooling and the emergence of the alpine zone were a critical context for plant colonisation in New Zealand, and subsequent diversification of the flora. New approaches facilitating integration of evidence from the fossil record, molecular phylogenetics and modern community composition are collectively identifying the relative role of climate, colonisation chronology, arrival frequency and local biome availability as key factors in understanding the formation of New Zealand's endemic terrestrial flora.

ASSESSING HIGH-TEMPERATURE HAZARDS ASSOCIATED WITH BLOCK-AND-ASH FLOWS AT MT TARANAKI

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Dome growth and destruction is ubiquitous at many stratovolcanoes around the world and has led to several major historical catastrophes. The main hazard is from hot and high-speed block-and-ash flows (BAFs), a type of pyroclastic density current formed from exploded or collapsed lava domes descending volcano flanks. The temperatures of BAFs vary depending on the source conditions, spanning between very hot actively growing domes, to cooled dome margins, or older dome remnants disrupted by new dome growth. Here we used paleomagnetic methods to assess the thermal hazard of BAFs at Mt Taranaki by determining the emplacement temperatures of deposits at varying distances from source. The latest AD 1780–1800 Pyramid dome collapses show emplacement temperatures ranging from ~250 °C to over 500°C in units emplaced within 5 km, indicating a wide thermal gradient existed in this dome during its collapse. Different emplacement temperatures in deposits within separate river catchments may indicate an early collapse of mostly cooler carapace material followed by a larger-scale collapse of the much hotter dome interior. At ~10–15 km a series of BAF deposits from larger eruptions during the 200–1200 yrs BP Maero Eruptive Period were mostly emplaced at >500 °C, indicating a series of large, hot domes that collapsed soon after emplacement. The presence of some cold deposits within the sequence indicates some reworking of deposits after cooling before their final emplacement. In the most extreme example, a similar pyroclastic density current from Mt Taranaki was emplaced ~11 ka BP at between 250 and 500°C out to >24 km from source. These results show that extreme thermal hazard persists for considerable distances from stratovolcanoes and should be considered out to at least 25 km from source.

BUILDING A HIGH-PRECISION MILLENIAL ERUPTION RECORD FOR MT TARANAKI USING A MULTI-METHOD APPROACH

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Establishing high-resolution stratigraphic and geological records is vital for understanding the frequency and magnitude of hazards a volcano poses to its surrounding community. In particular, the youngest part of the geological record helps to determine the current volcanic state if strong time-variability of volcanism is suspected. The last pulse of volcanism at the 2518 m stratovolcano, Mt Taranaki, New Zealand, is denoted as the Maero Eruptive Period. This 1000-year-long period is represented by a series of block-and-ash flow (BAF) and associated deposits in Taranaki's northwestern river catchments. Here we used radiocarbon dating along with paleosol and stratigraphic relationships to improve the resolution of the sequence of events. Tree-ring dating and paleosecular variation dating techniques were used to further improve the resolution and fill gaps in the record. We identified ten episodes, some consisting of multiple eruptive events, over the last millennia, with the shortest quiescence represented by near-consecutive events and the longest seen in the latest pause of ~200 yrs. This analysis helped to uncover a shift in the geochemical composition of Taranaki magma during the eruptive period, which is also distinctive from previous Taranaki episodes. Our results provide more precise constraints on the ages of the last ten eruptive episodes from Mt Taranaki's recent history and indicate that some eruptive episodes could be decadal in length. These age constraints were used to analyse probabilities related to future Taranaki repose periods and eruptions.

ANTARCTIC ICE SHEET-OCEAN CONNECTIONS ENHANCE EARTH SYSTEM SENSITIVITY TO OBLIQUITY FORCING

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Antarctic ice sheet (AIS) growth and decay is strongly influenced by astronomical variations, yet it is not known why the response to this climate driver varies through time. Here we examine AIS variability from 34 to 5 million years ago through integration of geological records from the Antarctic margin and a novel assessment of sensitivity to changes in Earth's axial tilt (obliquity sensitivity) derived from the oceanic oxygen-isotope proxy for global ice volume. Three phases of AIS development are found: (1) ~34–24 Ma—a largely terrestrial ice sheet with low obliquity sensitivity; (2) 24–14 Ma—frequent ephemeral marine ice sheets with amplified obliquity sensitivity; and (3) 14–5 Ma—episodes of extensive marine ice sheet advance, persistent sea ice, and a general decrease in obliquity sensitivity. These phases are associated with decreasing atmospheric CO_2 and progressively colder mean climate states. Our analysis suggests the AIS is most sensitive to obliquity forcing when it extends into marine environments and sea-ice extent is limited. We infer this is due to obliquity-driven changes in meridional temperature gradient that affect the position and strength of circum-Antarctic easterly flow, which enhances (or reduces) ocean heat transport across the Antarctic continental margin.

TE TAI PARI O AOTEAROA—NEW ZEALAND SEA RISE PROGRAMME

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A recent report by our Parliamentary Commissioner for the Environment stated: "It is certain that the sea is rising and will continue to do so for centuries to come. But much is uncertain—how rapidly it will rise, how different coastal areas will be affected, and how we should prepare." Clearly there is a need to know how future sea-level rise (SLR) will affect New Zealand and New Zealanders, yet detailed knowledge of likely sea-level change along our coastline and the environmental impacts of this change, is limited. The NZ Sea Rise programme will address knowledge gaps that are hampering our ability to anticipate and manage the impacts and risks of future SLR because of: (1) the uncertain contribution of the polar ice sheets to global and regional projections; and (2) a lack of understanding of the influence of vertical land movements (VLMs) and changes in sea-surface height (SSH) in local predictions.

Through partnerships with local and international researchers we will deliver three linked outputs:

(1) Improved region-specific estimates of the magnitude and rate of SLR to 2100 and beyond for a range of future climate scenarios outlined in the Intergovernmental Panel on Climate Changes 5th Assessment Report, including new knowledge of vertical land movements, latest estimates of polar ice sheet melt, global glacier inputs, ocean thermal expansion and sea-surface height changes and the regional dynamical expression of melt water on our oceans.

(2) Probabilistic relative SLR scenarios for New Zealand's coastline, with spatially-resolved estimates of costal inundation and increasing frequency of flooding and associated risk (consequences) for the main coastal cities.

(3) Co-designed impact assessment/risk programmes with local authorities, communities, iwi/hapū and stakeholders, utilizing the improved projections to better manage and adapt to the physical impacts associated with SLR, such as flooding, rising groundwater levels, coastal erosion, drainage and salinization.

INVESTIGATION OF COMPLEX INDUCED SLIP BELOW FIORDLAND

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The Fiordland region of southwest New Zealand has experienced three earthquakes larger than M_w 6.5 in the past 15 years: the 2003 M_w 7.2 Secretary Island, 2007 M_w 6.8 George Sound and 2009 M_w 7.8 Dusky Sound earthquakes. The 2009 Dusky Sound earthquake induced slip on a patch of the subduction interface that had previously ruptured during the 2007 George Sound earthquake. Here, we investigate whether a similar phenomenon occurred in the region that ruptured in the 2003 Secretary Island earthquake. We examine a ~20-year catalogue of Synthetic Aperture Radar (SAR) data to identify new regions of reactivated slip below Fiordland. As Fiordland is sparsely covered by seismological or terrestrial geodetic instruments, Interferometric SAR (InSAR) provides a means of analysing deformation across the region where other techniques have limited spatial coverage.

We have constructed a time-series of interferograms centred on Secretary Island to identify the occurrence of triggered slip following the George Sound, Dusky Sound, and distal 2016 M_w 7.8 Kaikōura earthquakes. Initial time-series analysis shows a potential new region of induced slip below Secretary Island following the Dusky Sound Earthquake. Slip of 0.5–1 m on the subduction interface is calculated to produce a surface deformation signal with a long wavelength (tens of kilometres) and small amplitude (tens of millimetres). The signals identified in our dataset are of the same scale and at the same locality as the Secretary Island rupture. Further modelling will determine whether the identified surface signal is from a slip source on the Puyseguer subduction interface.

STRUCTURAL GEOLOGY OF A MOLETRACK ACCOMMODATING 9-PLUS METERS OF TRANSPRESSIONAL STRIKE-SLIP DURING THE 2016 M_W 7.8. KAIKŌURA EARTHQUAKE, KEKERENGU FAULT, NEW ZEALAND

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During the M_w 7.8. Kaikōura earthquake, the Kekerengu Fault slipped dextrally by up to ~12 m, and vertically by ~1–3 m. Throw was primarily reverse and varied along strike. Near the coast, a back-filled paleoseismic trench, originally excavated across a structurally-controlled depression in February 2016, was displaced dextrally by 9.1 ± 0.25 m. Fault furrows, pull-aparts, and fault striae in the trench had suggested that this part of the fault was transtensional. Additionally, in the trench, sagging of peat and clay layers recorded subsidence after each of the last three paleoearthquakes (since ~1300 cal. yrs BP). During the Kaikōura earthquake, however, the ground was up-bulged into an up to 1.5 m-high moletrack encompassing *en echelon* Riedel fissures that bound clockwise-rotated strips of turf.

For this study we ask: (1) Was the style of ground deformation in 2016 different from previous events, and if so, why?; and (2) what structures accommodated ~9 m of slip? We exhumed and re-logged the walls of the offset trench and excavated a new trench spanning the moletrack. Our conclusions include: (1) At this site, the 2016 earthquake produced a deep-seated, strike-parallel bulge bounded by convex-upward thrusts that emplaced the bulge's upper margins horizontally across the ground. "Squeezing" of its clay-rich core accommodated >1 m of convergence; (2) Convergence was here unheralded, inverting a long-lived, peaty basin. Relative to the last several events, the 2016 earthquake had distinct kinematics—implying, perhaps, that the complexity of rupture sources for the 2016 earthquake was atypical; (3) ~9 m of strike-slip was accommodated almost entirely on one pre-existing fault strand near the depression axis; (4) This slip was exactly horizontal, causing only cm–dm dip-separations; (5) Root cohesion did not control bulge formation or geometry; and (6) Fissures opening in 2016 were infilled rapidly with recycled soil and colluvium.

DEGLACIAL EVOLUTION OF REGIONAL ANTARCTIC CLIMATE AND SOUTHERN OCEAN CONDITIONS IN TRANSIENT CLIMATE SIMULATIONS

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Constraining Antarctica's climate evolution since the end of the Last Glacial Maximum (~18kyr) remains a key challenge but is important for accurately projecting future changes in Antarctic ice sheet mass balance. Here we perform analysis of two transient deglacial climate simulations, one using a fully-coupled GCM and one using an intermediate complexity model to (1) better understand the regional differences observed in paleoclimate records, and (2) identify the main strengths and limitations of the models in terms of parameters that impact ice sheet mass balance. The climate simulations show the greatest continental surface warming over the continental margins and regions with the greatest decrease in ice surface elevation, suggesting that sea ice–albedo feedbacks and ice sheet dynamics likely played strong roles in driving regional surface temperature differences during the deglaciation. Accumulation–temperature scaling relationships are fairly linear and constant further inland but exhibit higher variability in the early to middle Holocene over coastal regions. This climatic shift in the Holocene coincides with a weakening of the Amundsen Sea Low and a reduction in sea ice coverage. Circum-Antarctic coastal ocean temperatures at grounding line depths are highly sensitive to the meltwater forcings prescribed in each simulation, which are applied in different ways due to limited paleo-constraints. Although modelled centennial-scale rates of temperature and accumulation change are reasonable, clear model–proxy mismatches are observed regarding the timing and duration of the Antarctic Cold Reversal (ACR) and Younger Dryas/early Holocene warming, suggesting that the Meltwater Pulse 1A and 1B events may be inadequately represented in these simulations. The incorporation of dynamic ice sheet models in future transient climate simulations could aid in improving meltwater forcing representation, and thus model–proxy agreement, through this time interval.

STACKED LATE HOLOCENE UPPER-SLOPE TURBIDITES IN THE TECTONICALLY ACTIVE TUAHENI CANYON, POVERTY BAY

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An understanding of the processes that transport and preserve gravity flows in sub-aquatic settings is essential when interpreting trigger mechanisms. This is particularly true in relation to marine paleoseismology which uses earthquake triggered turbidites to infer location, intensity and existence of past earthquakes. Fundamental to the marine paleoseismology paradigm is the idea that turbidity currents are triggered by earthquake shaking and that there is sufficient time between events for hemipelagite sediment to deposit.

We use three late Holocene aged sediment cores and detailed bathymetry data (14–8 m grids) from the Tuaheni Canyon, Hikurangi margin, to show a highly active upper slope depocentre comprised of stacked turbidites and devoid of hemipelagite. The cores were collected in 2016 during the RV Sonne SLAMZ research voyage (SO247).

Detailed facies analysis of the cores reveal a sequence of non-graded, basal reverse-graded, and normally-graded sandy silt and silty sand turbidites that fine from coarse sand to medium silt. Tephra chronology and ^{14}C radiocarbon dating are used to give bulk ages and reveal unexpectedly high sedimentation rates up to 110 cm/ka for the last ~3 ka. A novel method for determining sediment source depth using foraminifera was employed. A planktic regression formula indicates that sediment was sourced from 150 mbsl to 1300 mbsl. Depth-indicative benthic foraminifera species show between 3–18 % of the foraminiferal assemblage sampled from turbidites are shelf-restricted foraminifera. Surprisingly, silt beds, which are often inferred to be hemipelagites contain shelf and upper bathyal restricted benthic foraminifera, indicating that they too were deposited as sediment gravity flows originating from upper bathyal and shelfal sources.

Our study reveals: (1) extraordinarily high sedimentation rates in an upper-slope canyon during the last 3 ka; (2) derivation of sediment from the outer shelf and slope; and (3) an absence of hemipelagite.

JURASSIC CRISES IN ZEALANDIA

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The end-Triassic and Toarcian crises led to major changes in Zealandian marine faunas. This paper concentrates on brachiopods and bivalves from the Murihiku Terrane and its equivalent in New Caledonia. The two key sections are in the Otapiri Valley in Southland and Kawhia in the North Island.

Latest Triassic faunas of Zealandia belong to the Otapirian local stage, generally equivalent to the international Rhaetian Stage. This contains the distinctive Maorian marine fauna, with the brachiopods *Clavigera* and *Rastelligera* and the bivalves *Maoritrigonia* and *Maikomya*. In the latest Otapirian rhynchonellide *Vincentirhynchia pomeyroli* and the terebratulide *Zeilleria spiculata* appear. They coexist with the Maorian fauna, which disappears at the end of the Otapirian, and with psiloceratid ammonites in the Early Jurassic. Several species of the pterioid bivalve *Otapiria* are present in the Late Triassic and Early Jurassic.

Early Jurassic sequences have a number of gaps, and only the Otapiri Valley includes the earlier Hettangian. From the latest Hettangian, a diverse brachiopod and bivalve fauna with more cosmopolitan affinities becomes established. Brachiopods are generally of smaller size. No trigoniids are present. In the Pliensbachian (Lower Ururoan) the pterioid *Pseudaucella marshalli* forms shellbeds. This fauna is most diverse in the Upper Ururoan local stage (early Toarcian), especially the *Dactylioceras* bed on the open coast of Te Maika Peninsula (Crassum subzone, top of the early Toarcian) and is not found much higher.

Overlying beds contain a few “*Inoceramus*” *ururoaensis* and are followed by a much shallower-water Temaikan (late Toarcian and above) fauna dominated by inoceramid bivalves and belemnites, and by non-marine beds. Rhynchonellide and terebratulide brachiopods are rare in the lower part and less common thereafter. As elsewhere in the world, the spiriferides do not survive the Toarcian. Middle and Late Jurassic faunas have a Tethyan aspect.

FINITE-ELEMENT MODELLING OF HAUPAPA/TASMAN GLACIER'S BASAL SLIDING EVENTS

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The combined rate of ice loss from glaciers, ice caps, and ice sheets is a significant uncertainty in predicting sea-level rise out to 2100. Short-term and long-term variability in glacial ice discharge contributes to this uncertainty because it is driven by poorly constrained processes acting at the base of glaciers. One such process is the interplay of subglacial water and the friction between ice and bedrock. Changes in subglacial water pressure can trigger glacial acceleration and short-term sliding events. Global Positioning System (GPS) data from instruments on Tasman Glacier, South Island, New Zealand, have recorded speed-up events that demonstrate a strong correlation with high-rainfall rates. The rapid collection of surface water beneath the glacier is thought to elevate basal water pressure, reduce basal friction, and enhance glacier sliding. Here we present a numerical model simulating the internal deformation and basal sliding of Tasman Glacier before, during, and after episodes of heavy rainfall. By varying the basal boundary condition that links basal friction, water pressure, and sliding velocity (the sliding law), we seek to determine what type of sliding law is sufficient for reproducing surface velocity variation in the GPS record. Due to its pronounced speed-ups, Tasman Glacier is a useful analogue for investigating the processes that govern the sliding of all large glaciers or ice-streams prone to mass loss under changes in surface water inputs.

EXTENSIVE CONTOURITE DEVELOPMENT OFFSHORE NORTHLAND FROM THE EARLY PLIOCENE TO PRESENT DAY

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Contourite Depositional Systems (CDSs) are composed of depositional and erosional features that form by bottom-currents. Bottom-currents are considered to be any persistent water-current located near the seafloor, generally with an along-slope flow.

We use 2-D seismic reflection data to show extensive development of CDSs on the west coast of New Zealand in the Northland and Reinga basins. Based on a regional seismic stratigraphic interpretation of six horizons bounding five seismic units we highlight the evolution of CDSs from the early Pliocene to Recent.

Contourite deposition initiated suddenly in the early Pliocene revealing complex intermediate- and deep-water mass interactions with the slope and Miocene volcanoes. We have identified two large contourite drifts on the Northland slope; a plastered drift located along the middle and upper slope and a sheeted drift located along the lower slope.

In more detail, asymmetric erosive scours abutting the Whangape volcanic seamount located on the Northland slope indicates a northward current in intermediate waters that effects deposits on the mid-slope at depths of 1125–350 m. We hypothesise this newly defined northward current has been controlling plastered contourite drift deposition along the middle to upper slope. Correlation with the Waka-Nui 1 well suggest it has been active for ~5 Myrs. At the base of slope, we observe an unnamed seamount with abutting scours indicating a southward deep-water bottom-current at 1100–2200 m depths. This southward current is inferred to be the West Auckland Current (WAUC), which appears to also have been active for the last ~5 Myrs and led to the formation of a sheeted contourite drift around 500 m thick at the base of slope.

The interpretation of these CDSs further widens our understanding of the Northland slope by illuminating recent active ocean current history, uncovering potentially impactful paleoceanographic considerations, which may inform future regional models.

DOOMED BY THE EARLY TOARCIAN CRISIS: THE FINAL RECORD OF SPIRE-BEARING BRACHIOPODS

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The Early Toarcian Mass Extinction Event (ETMEE) is regarded as one of the “big five” that punctuated the development of marine biotas during Phanerozoic times. The effects of this severe biotic crisis have been blamed on a variety of causes, such as widespread oceanic anoxia, acidification of seas, generalised water temperature rise, intense volcanism, or a combination thereof. The critical environmental conditions are reflected in several sedimentological, paleontological and geochemical signals that were initially recognised in Europe but have since been found worldwide (T-OAE). Among the various groups of marine organisms affected, the phylum Brachiopoda suffered severely from ETMEE—two orders (namely, Spiriferinida and Athyridida) became extinct.

Most of the supporting evidence published comes from studies carried out in the Northern Hemisphere, hence, this overview aims at integrating recent advances on the knowledge of spire-bearers from the Southern Hemisphere. In many European (and North African) basins, recent research points to occurrence of spiriferinides up to the tenuicostatum or polymorphum ammonite zones, although in some deep-water facies may locally extend up to the lowermost serpentinum zone, but do not straddle the elegantulum–falciferum boundary. In Andean basins, detailed systematic samplings in localities with strict stratigraphic control has revealed that some species occur in the Rhynchonelloidea cuyana brachiopod assemblage zone, which approximates to the spinatum to tenuicostatum ammonite zones. In contrast, they are not known from the Rhynchonelloidea lamberti assemblage zone, which is equivalent to the falciferum to bifrons standard zones. Alleged occurrences of spiriferinoids in younger Toarcian (or even Aalenian–Bajocian) strata are questionable. In latest Pliensbachian–earliest Toarcian times, konickinoid athyridides experienced a bloom and expanded its distribution from relatively deep Intra-Tethyan basins to shallower NW European areas before dying out within the early serpentinum zone. The drastic impact of the ETMEE on spire-bearers is thus confirmed to have been global.

SAND SOURCES AND ROUTING OPTIONS ALONG THE HIKURANGI MARGIN: USING MARGINS SOURCE-TO-SINK RESULTS FROM THE WAIPAOA SEDIMENTARY SYSTEM TO INTERPRET QUATERNARY FOREARC AND TRENCH SUCCESSIONS DRILLED ON IODP EXPEDITIONS 372 AND 375

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The Waipaoa River System (WSS), located in northeastern North Island, New Zealand, is a MARGINS Source-to-Sink focus site. Several studies in the WSS have focused on understanding the generation of coarse sediment through petrologic study of the geologic units that crop out within the WSS catchment and along the coast and relating them to their ability to generate coarse sediment based on their lithology, induration and propensity for mass wasting. Each major stratigraphic interval was linked to specific derived sand compositions: Cretaceous, Paleocene, Miocene, Pliocene, and Quaternary, including remnants of Taupō tephra deposits. This was demonstrated through analysis of detrital modes of sand and gravel within the various rivers that make up the WSS, older river terrace deposits, and beach sediment across the system. Offshore sand samples collected in box, Kasten, vibra and piston cores on the mud-dominated shelf were compositionally similar to beach sand samples suggesting that they may be linked to coastal erosion. Few shelf samples could be attributed to offshore transfer of WSS sand through Poverty Bay. Gravel with Torlesse Composite Terrane provenance recovered in the southern part of the shelf suggests that the large low-stand river system in Hawke Bay likely extended north into Poverty Shelf feeding Poverty Canyon. Compositional data from piston cores taken across the shelf to slope to trench of the WSS indicate more complex sourcing of sediment downslope into the trench likely affected by forearc deformation and reworking of Taupō tephra. Quaternary sand-bearing cores recovered across the slope and trench on International Ocean Discovery Program Expeditions 372 and 375 will allow for a more regional analysis of sand dispersal within the system and contributions from outside the WSS. Samples from thicker stratigraphic successions may also define temporal changes in sand provenance reflecting tectonic, volcanic, climatic, eustatic, and/or anthropogenic influences across the WSS.

PATTERNS IN TRANSFORMED PATHFINDER ELEMENTS IN SOIL RELATED TO OROGENIC-STYLE MINERALISATION

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Nine elements (Ag, As, Au, Bi, Mo, Sb, Sn, Te, W) in soil from an 8 km-spaced, regional survey over Otago and Southland were treated to account for lithological and metamorphic variation in the underlying bedrock. Interpolated plots of the treated data were interrogated relative to known orogenic-style deposits, for example around Glenorchy (W ± Au), the actively-mined portion of the Hyde-Macraes Shear Zone (Au ± W) and Hindon (Sb ± Au). Chemistry in soil around these sites varied between commodity types, as well as between similar commodity types formed under variable pressure–temperature–time conditions. Known, larger deposits were associated with larger and more complex (multi-element) soil anomalies. Chemical soil anomalies are likely related to the progressive metamorphic breakdown of minerals, especially rutile and pyrite. Several regions in the survey area were explored at only a reconnaissance level also contain multi-element in-soil anomalies. This study demonstrates the importance of normalisation of chemical data in complex geological settings and highlights the value that can be extracted beyond only plotting raw concentration, single-element maps. Techniques employed in this study provide a significant opportunity for future multi-element studies of soil in mineral exploration for orogenic-style mineralisation.

PETROGENETIC OVERVIEW OF THE EREBUS VOLCANIC PROVINCE, ANTARCTICA: RECENT DEVELOPMENTS

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Over one hundred years of petrographic research on rocks from the Erebus volcanic province have contributed to understanding the petrogenesis of alkalic volcanic rocks in Antarctica and globally. Based upon petrogenetic and geographic discrimination, the province can be subdivided into four volcanic fields and one local suite. The mantle sources for primitive volcanic rocks of the province is complex and variable with HIMU, enriched mantle, carbonatitic and eclogitic crustal components all being involved to variable extents. Equilibration of radiogenic Sr, Nd, Pb and Hf isotopic systems is best explained in terms of a high time-integrated HIMU *sensu stricto* component in the mantle source, at least beneath the Ross Island Volcanic Field. A model Pb isotope age and major and trace element modelling of melting of a peridotitic source are consistent with an asthenospheric mantle source for the depleted mantle and HIMU components. This is in contrast to some Cenozoic volcanism localities in Zealandia, where a HIMU-like component reflects the relatively young (Mesozoic) development of highly radiogenic Pb. Spatial (west–east) variations in Sr, Nd and Pb isotopic compositions and Ba/Rb and Nb/Ta ratios can be interpreted to indicate increasing involvement of an eclogitic crustal component eastwards. If the Pb isochron ages for Ross Island are applicable across the province, then this increasing eclogitic crustal component could indicate the involvement of fluids derived from, or modified by, a subducting slab with an age >0.5 Ga (i.e., not related to subduction of the paleo-Pacific plate around 0.5 Ga). Despite the long history of detailed petrological study of volcanic rocks in the Erebus volcanic province, many new and exciting research questions remain, and these should, in the future, provide a new generation of earth scientists with fruitful areas for further research.

OVERVIEW OF THE STABILITY OF LAND IN DYNAMIC ENVIRONMENTS PROJECT, WELLINGTON REGION

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Stability of Land in Dynamic Environments (SLIDE) aims to assess the performance of Wellington slopes during earthquakes and rain storms. The project combines regional slope inventories and slope stability assessments with site-specific investigations and laboratory testing to develop landslide hazard and risk assessment best practices that can improve landslide mitigation approaches and inform the design of resilient infrastructure.

The slope inventory was based on geomorphic mapping, which identified anthropogenic (cut and fill) slopes using historical aerial photographs, legacy data, the 2013 LiDAR digital elevation model (DEM), and a surface difference model calculated by subtracting a digital surface model derived from low elevation historical aerial photographs from the 2013 DEM. The regional landslide hazard assessment comprised the development of rainfall-induced landslide (RIL) and earthquake-induced landslide (EIL) probabilistic susceptibility models. A regional-scale landslide runout model was also developed based on an empirical method, using a dataset of EIL and RIL (of varying volumes and types). The EIL, RIL, and debris runout models were combined to develop a catalogue of hazard footprints for different rain and ground shaking magnitudes representing return periods from 50 to 1,000 years. The hazard footprints were overlain on maps of lifeline infrastructure density to generate a hazard-exposure matrix to identify and rank locations where multiple lifelines occur within a hazard footprint.

Using the hazard-exposure matrix as a guide, six sites representing a range of cut, fill, and natural slopes were identified for a more detailed site investigation, laboratory testing, and numerical modelling. The site investigation included outcrop mapping and boreholes (geotechnical and geophysics). The laboratory testing comprised of both soil (conventional and back-pressure shear box) and rock (UCS and Brazilian) testing programmes. The numerical modelling integrated the results from the site investigations and laboratory testing to assess the controls on the various slopes during seismic and rainfall forcing events, which in-turn provided a validation for the regional assessments.

As well as providing new scientific insights into how the slopes in Wellington might perform in future earthquake and rain events, the models are being used to provide the landslide hazard component for regional scale landslide loss modelling. The models could also be used to inform future land use hazard zoning.

STRUCTURE AND FLUID FLOW IN ANDESITIC SYSTEMS OF THE TAUPŌ VOLCANIC ZONE: A FRAMEWORK TO UNRAVEL SUB-SEAFLOOR HYDROTHERMAL FLOWS AT BROTHERS VOLCANO, KERMADEC ARC?

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The subduction of the Hikurangi Plateau beneath the Indo-Australian plate is associated with arc volcanism and hydrothermal systems both onshore (Taupō Volcanic Zone, TVZ) and offshore (Kermadec arc). While the TVZ offers large exposures of active volcanoes and geothermal drilling data, the sub-surface of the Kermadec arc was explored for the first time at Brothers volcano this year as part of International Ocean Discovery Program (IODP) Expedition 376. Here we present the preliminary structural interpretation of the borehole image log acquired at Brothers volcano alongside structural patterns observed in andesitic systems of the TVZ. Terrestrial laser scanning of a recent (~6000 years) lava flow of the Mt Ruapehu volcano, located at the southern tip of the TVZ, reveals a highly connected fracture system of cooling joints partially connected to surrounding breccias. Borehole image log interpretation and statistical analysis of three boreholes of the Rotokawa Geothermal Field, hosted in a buried andesitic volcano in the central TVZ, highlight the interaction between cooling joints formed during emplacement of the lavas, and tectonic faults and stresses of the intra-arc TVZ rift. Numerical models of discrete fracture networks consistent with fracture orientation, linear density, and fracture thickness observed in drill cores and borehole image logs from the Rotokawa Geothermal Field indicate the presence of numerous flow pathways of variable tortuosity. These pathways support the circulation of sub-surface geothermal fluids through open fractures and may provide the loci for mineral precipitation. The variable residence time of fluids through these pathways potentially allows for fast fluid flow travel in the pathways of low tortuosity, as well as mineralisation in more geometrically complex pathways. Inferences from these generic numerical models based on onshore andesitic geothermal systems will be used for future interpretation of fluid circulation through fractures at the submarine Brothers volcano.

IMPROVING SPATIAL RESOLUTION FOR QUANTITATIVE MICROANALYSIS BY SEM-EDS

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It is challenging to measure the chemical compositions of very fine-grained minerals. A method with broad utility to measure with high spatial resolution for quantitative microanalysis has not yet been established for geological materials. We have developed such a method using energy-dispersive spectrometry (EDS) in a scanning electron microscope (SEM) by (1) reducing the accelerating voltage, and (2) developing a method for standardization. We have evaluated how these methods can improve the spatial resolution and quantitative accuracy.

The interaction volume of incident electrons within a mineral expands due to electron scattering, resulting in X-rays being generated from a wider region than the incident probe diameter. It has been demonstrated that the X-ray generation volume is smaller at lower accelerating voltage, so reducing this should result in an improvement of spatial resolution. However, this correction also results in a significant decrease in the signal intensity of the X-ray spectra which makes it more difficult to quantify elements present in low abundances.

For a range of SEM optics and EDS detector settings, the spatial resolution was evaluated theoretically by Monte Carlo simulations and also by line scan and point measurement analyses using a sharp vertical edge. The analyses were performed by EDS (Oxford X-Max^N 80 mm^2 with AZtec) in a HITACHI SU-3500 SEM at the GSJ-lab, Geological Survey of Japan, AIST. The evaluated spatial resolutions are ~500–1700 nm, ~1100–2300 nm, and ~2500–3300 nm at 7 kV, 10 kV, and 15 kV, respectively, demonstrating that the resolution improves with decreasing accelerating voltages.

We have also verified the method through measurement of anhydrous and hydrous natural mineral and glass samples. To quantify mineral compositions at lower accelerating voltages requires standardizing using standards for each element with similar elemental concentrations to the expected concentrations in the unknown minerals and their K-ratio. The best possible operating conditions are 10 kV accelerating voltage, spot intensity (condenser lens) of 65, aperture No. 3 (50 µm), and the longest processing time available within Aztec software. At this voltage, Si, Ti, Al, Mg, Ca and Na can be quantified when the oxide concentration of those elements is >3 wt% with relative differences of less than ±3.5%, and Fe can be quantified when the oxide concentration is >5 wt % with relative differences of less than ±5% compared to values obtained by wavelength dispersive spectrometry (WDS) or EDS at an accelerating voltage of 15 kV.

STRATIGRAPHIC RECORD OF PALAEOSEISMICITY ON THE HIKURANGI SUBDUCTION MARGIN: INSIGHTS FROM OUTCROP AND SUBSURFACE STUDIES

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Mass-transport complexes (MTCs) represent a significant proportion of the fill of many deep-water basins, particularly in tectonically active slope settings. Although establishing linkages remains challenging, tectonic events are known to trigger slope failures and deposit MTCs. Regardless of the trigger, debris flows may constitute substantial geo-hazards, and slope failure and emplacement of MTCs may entail significant modification of the slope. Here we document large-scale MTCs, of preserved volume hundreds to thousands of km^3, from outcropping Miocene trench-slope sub-basins and in the sub-surface.

Geological mapping and logging in the Akitio and Coastal sub-basins of Wairarapa have identified two major MTC events, whose emplacement ages can be constrained by micropalaeontology. A middle Miocene (Lillburnian) MTC, up to 100 m thick, comprises remobilised mudstones, with carbonate clasts tens of meters long. A late Miocene (Tongaporutuan) MTC up to 150 m thick contains rafts of thin-bedded turbidites, each tens of meters long. Erosion of the substrate occurred below both events, which coincided with evolution of the depositional system and architecture of subsequent turbidite systems. Deposits of a similar scale have been mapped offshore using 2-D and 3-D seismic data. Mass-transport complex seismofacies show erosion of the substrate and may comprise relatively homogenous deposits or may contain clasts hundreds of meters in size. Although often associated with local growth structures, major MTCs, such as those observed at outcrop have a widespread distribution on the margin and are mapped across multiple sub-basins. A combination of mapping and kinematic analysis indicates that large MTCs were derived from shelf and upper slope failures.

Beyond implications for resource exploration, recognition of major MTCs in the Miocene yields insights into the evolution of the Hikurangi margin, demonstrating distinct phases of structural reorganisation, alteration of sediment pathways and provides an older record of paleoseismicity on this margin than hitherto recognised.

ROSS SEA WEST ANTARCTIC ICE SHEET HISTORY IN THE LATE CENOZOIC: INITIAL SEDIMENT CORE RESULTS FROM IODP EXPEDITION 374

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International Ocean Discovery Program (IODP) Expedition 374 collected a latitudinal and depth transect of five drill sites from the outer continental shelf and rise in the eastern Ross Sea between January and March 2018. The expedition aimed to resolve the relationship between climatic/oceanic change and West Antarctic Ice Sheet (WAIS) evolution over the past 20 million years. This location was selected because numerical ice sheet models indicate that it is highly sensitive to changes in ocean heat flux and sea-level. The drilling was designed for optimal data–model integration, which will enable an improved understanding of the sensitivity of Antarctic Ice Sheet mass balance during warmer-than-present climates (e.g., the early Pliocene and middle Miocene). The objectives were to: (1) Evaluate the contribution of West Antarctica to far-field ice volume and sea-level estimates; (2) Reconstruct ice-proximal atmospheric and oceanic temperatures to identify past polar amplification and assess its forcings/feedbacks; (3) Assess the role of oceanic forcing (e.g., sea level and temperature) on Antarctic Ice Sheet (AIS) stability/instability; (4) Identify the sensitivity of the AIS to Earth's orbital configuration under a variety of climate boundary conditions; (5) Reconstruct eastern Ross Sea bathymetry to examine relationships between seafloor geometry, ice sheet stability/instability, and global climate. This talk will present the initial scientific results that resulted from this expedition, with a focus on the paleoenvironmental reconstructions that were obtained from the sedimentolgical, geochemical and paleontological datasets.

PERSPECTIVES ON THE STRUCTURE, VENT DISTRIBUTION AND COMPOSITION OF PIRONGIA, THE NORTH ISLAND'S LARGEST BASALTIC VOLCANO

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The Pirongia Volcano (2.49–1.6 Ma) of Waikato is the single largest basaltic landform in the North Island and was the site of voluminous, extremely porphyritic eruptions of ankaramite lava unique within Zealandia and the wider SW Pacific. In this study, we present the first volcanological map of Pirongia, which reveals the post-erosional distribution of lava fields, dike swarms, volcaniclastic breccias and ring plain deposits produced over a period of ~1 Myr. Field relations indicate that Pirongia is a compound volcanic system formed by dispersed, Hawaiian-type fissure eruptions and overlapping vulcanian cone-building phases. Erupted products range from coarsely porphyritic augite (±olivine)-phyric basalts (ankaramites) to basaltic-andesites to low-silica hornblende andesites. New petrographic and geochemical data for these rocks will be documented within our volcano-stratigraphic framework, highlighting the spatial and temporal variations in magmatism at Pirongia.

AUSTRALIAN JURASSIC FLORAS AND PLANT–INSECT INTERACTIONS

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Australian sedimentary basins host a relatively rich succession of Jurassic plant fossil assemblages. In contrast, only two significant insect assemblages of this age are known from the entire continent. The floras are rich in both adpression fossils and permineralized remains. Apart from elucidating the evolution of the mid-Mesozoic austral flora, these assemblages reveal examples of foliar and wood damage that help fill in the scanty record of insect activity in the Australian Jurassic. Identified plant damage falls into the categories of leaf-margin feeding, surface feeding, lamina hole feeding, galling, piercing-and-sucking, leaf-mining, boring and oviposition. These types of damage are spread across a wide range of fern and gymnosperm taxa, but are particularly well represented on advanced broad-leafed gymnosperms, such as Pentoxylales and Bennettitales. Several Australian Jurassic plants show morphological adaptations in the form of minute marginal and apical spines on leaves and bracts, and scales on rachises that likely represent physical defences against arthropod herbivory. The two entomofaunal assemblages presently known from the Australian Jurassic contain a moderate range of taxa, incorporating particularly Orthoptera, Coleoptera, Hemiptera and Odonata, all of which are candidates for causing the dominant forms of feeding damage evidenced on the fossil leaves and wood. Plant–arthropod interactions in the middle to high southern latitudes are represented by a similar diversity of feeding strategies to those evident in Jurassic communities from other floristic provinces.

DEFINING THE CARBON, OXYGEN, AND HYDROGEN ISOTOPIC ALTERATION FOOTPRINT IN EPITHERMAL SYSTEMS: NEW INSIGHTS FROM WAIHI AND KARANGAHAKE

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Better tools are needed to map the thermal structure and fluid properties of ore deposits. Historically, stable isotope measurements have been made using mass spectrometric techniques. Here, we develop and test new methodology for quantification of hydrogen isotope ratios (δD) in phyllosilicates and oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) signatures in carbonates using off-axis integrated cavity output spectroscopy (OA-ICOS) near-infrared laser analysers. Analyses were carried out at two major andesite-hosted epithermal Au–Ag deposits within the Hauraki goldfields. Both Waihi and Karangahake have been focal points for mining for over a century and have well-constrained mineralogical and elemental signatures. At Waihi, clumped isotope results are paired with conventional $\delta^{18}O$ measurements from 220 whole-rock, and vein and propylitic calcite samples to provide high-density temperature contouring across carbonate precipitating environments within the deposit. Measurements of δD in whole-rock pulps and clay separates were carried out at Waihi that encompass the three principal Au–Ag vein systems—Martha, Correnso and Favona—and also areas of less altered rock, up to 1.2 km distal to known mineralised veins. At Karangahake, 30 measurements were carried out on clay and calcite. Collectively, these results provide the groundwork to better map paleo-hydrothermal fluid flow as a vector towards metal deposition in hydrothermal ore forming environments.

VARIATIONS IN TECTONIC STRESS REVEALED BY A DECADE OF RELOCATED EARTHQUAKE CATALOGUE FROM THE CENTRAL ALPINE FAULT, NEW ZEALAND

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The Alpine Fault is a major plate boundary oblique strike-slip fault, known to fail in large M_w 7–8 earthquakes, but currently exhibits low levels of seismicity when compared to adjacent areas. We examine earthquake activity occurring along the central portion of the Alpine Fault using data from five temporary and permanent seismic networks deployed between late 2008 and early 2017. We have constructed a long-duration earthquake catalogue containing 9,111 earthquakes. To quantify the spatial distribution of the earthquakes' moment release, we have derived a new local magnitude scale, calibrated by M_w values determined by GeoNet/GNS Science. To examine variations in stress, we have calculated 840 focal mechanisms for earthquakes with magnitudes greater than 1.5, using P-wave first motion polarities and a Bayesian method. Earthquakes mainly occur southeast of the Alpine Fault (in its hangingwall) and are of low magnitudes (M_L −1.2 to 4.6). We observe a lack of seismicity beneath the Aoraki/Mount Cook and the surrounding area of highest topography, which we associate with high uplift rates and high heat flow. Seismogenic cut-off depths vary between 8 km, beneath the highest topography, to approximately 20 km in adjacent areas. We obtain an average azimuth of maximum horizontal compressive stress of 121 ± 11°. Work is underway to develop an updated thermal model of the orogen based on published uplift rates and thermal properties measured during the Deep Fault Drilling Project, and to use this to interpret the strong lateral variations in seismicity cut-off depths.

VOLCANIC TEXTURE IDENTIFICATION USING A BOREHOLE RESISTIVITY IMAGE LOG IN THE WHAKAMARU GROUP IGNIMBRITE, WAIRAKEI GEOTHERMAL FIELD, NEW ZEALAND

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High-quality, resistivity borehole image log data (Formation MicroImager; FMI) collected from the Whakamaru Group ignimbrite in well WK271, Wairakei Geothermal Field, has been used to investigate the textural characteristics of volcanic rocks in the geothermal reservoir. This is the first time the internal stratigraphy of an ignimbrite in New Zealand has been defined in such detail from sub-surface data. The interpreted interval lies between the Waiora Formation (−936.8 mrsl) and Tahorakuri Formation (−1288.4 mrsl), within which 303 geological layers were identified. Of these layers, 82 were within ignimbrite flow units and 201 were in bedding intervals between ignimbrite flow units.

The image response of lithofacies identified within the Whakamaru Group ignimbrite has been compared with core textures or outcrop analogues from ignimbrite units of the Taupō Volcanic Zone and elsewhere. The resistivity characteristics of the FMI image indicates there are five dominant lithofacies: (1) non-welded ignimbrite, (2) partially-welded ignimbrite, (3) welded ignimbrite, (4) tuff beds, and (5) breccia. Ignimbrite flow units are delineated by tuff beds with closely spaced layers. There are clear variations in grain size and abundance of both pumice and lithics within the intervals interpreted as ignimbrite flow units. Along with overall variations, there are also zones of coarse textured breccia, which may represent material segregated in the pyroclastic density currents that deposited the ignimbrite. Tuff beds show varying thickness, and in places cross-cutting relationships.

Textural analysis of the FMI log in the Whakamaru Group ignimbrite was able to provide an improved internal stratigraphy compared to that derived solely from drill-cuttings. Based on volcanic textures identified, seven individual flow units in the Whakamaru Group ignimbrite are recognised, which are separated by texturally characteristic intervals of airfall tephra. These data provide the opportunity to more closely examine the processes involved in the eruption and deposition of this complex, regionally significant ignimbrite.

INSIGHTS INTO THE LARGEST PLINIAN ERUPTION FROM TUHUA (MAYOR ISLAND) APPROXIMATELY 7,000 YEARS AGO

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The 7,000-year-old Tuhua eruption from Mayor Island was the largest eruption to have occurred during the islands eruptive history. Mayor Island is a unique volcanic system for New Zealand because it is peralkaline, meaning that the lavas contain high levels of Na, K, and trace elements such F, and are similar in composition to those of Pantelleria and Colli Albani. Because of this uniqueness, Mayor Island is a great place to better understand the complex volcanic system. The peralkaline composition is likely to influence the eruptive behaviour from the volcano as the elements make erupting magma more “fluid” or “runny”. Consequently, as the eruptions are occurring volatile exsolution and expansion can form large bubbles before fragmentation occurs. The fragmentation of the magma generates pumice that have a low density and thin bubble walls visible in 3-D and scanning electron microscope (SEM) 2-D analyses. The results from the study show different stages of the eruptions from Plinian and several column-collapse phases. Sustained Plinian phases during the Tuhua eruption saw thick ashes deposited on the mainland. The eruption appears to have had a fairly constant column, but some stages of column collapse have been identified within the deposits. Along with deposits from the eruption, the internal structure of the lapilli pumice indicates that the magmas internal structure was influenced by degassing as the magma ascended. The internal structure of the lapilli provides evidence of the conditions controlling the eruption dynamics. Understanding the scale and behaviour of past eruptions will help prepare us for the kind of hazards we can expect from Mayor Island in the future.

REACTIVATING THE NEW ZEALAND ACTIVE FAULTS DATABASE

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Active faults (i.e., those that have caused surface deformation in the last 125,000 years) are a major natural hazard in New Zealand. Their future rupture has the potential to cause fatalities and significant damage to infrastructure and the economy (e.g., the recent Canterbury and Kaikōura earthquakes). The New Zealand Active Faults Database (NZAFD) has existed in digital format since the 1990s and is a key dataset that provides a foundation for the National Seismic Hazard Model, with important applications in geological research, mapping, hazard modelling and district planning. In 2016, a publicly available, generalised 1:250,000 scale version was developed for regional scale use (called NZAFD250), and can be inspected, queried and downloaded from the GNS Science website (https://data.gns.cri.nz/af/). Underlying the NZAFD250 is a digital GIS database of detailed terrestrial active fault line and point data that is unofficially known in-house as the NZAFD-HighRes. The NZAFD-HighRes is an important resource that needs upgrading and GNS Science has initiated a new project to do this, with changes flowing through to NZAFD250. The objective of this project is to revise and add data and attributes, improve database structure and update the NZAFD Data Dictionary. Recently compiled data, especially from the 2016 Kaikōura Earthquake surface rupture mapping and detailed district-scale Fault Avoidance Zone studies, will be incorporated. Photos and published scientific literature will also be linked to the mapped faults in NZAFD250, making it easy for the end-user to find and download these from the NZAFD website. We welcome feedback from the New Zealand geoscience community about our proposed plans. These changes and updates to the NZAFD will make it a more accurate and encompassing database, fit-for-purpose for New Zealand and international users.

JURASSIC ZEALANDIA

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The igneous, metamorphic and sedimentary rocks of the Zealandia continent contain a diverse, if incomplete, record of Jurassic events and processes. All components of a Late Permian to Early Cretaceous convergent margin (magmatic arc, forearc basin and accretionary wedge) are present in New Zealand, and Jurassic rocks are prominent in each.

The Cordilleran-style Median Batholith is best exposed in Fiordland and can be tracked as a curvilinear feature across the entire continent and beyond; formerly contiguous batholithic rocks are present in Australia and West Antarctica. Strongly negative $\delta^{18}O$ in fossil hydrothermal systems are attributed to infiltration of near-polar, high-altitude water. The fossiliferous, clastic Murihiku Terrane lies Pacific-ward of the batholith. Its endemic macrofaunas attest to geographically isolated, cold water environments. Middle Jurassic paleoshorelines and detrital links suggest a forearc basin site of deposition of Murihiku Terrane strata relative to the Median Batholith.

Pacific-ward of the Murihiku Terrane, lie the deformed and metamorphosed Caples, Waipapa and Torlesse terranes of the accretionary wedge. These sandstone and mudstone-dominated terranes contain structurally imbricated ocean floor basalts, in part of Jurassic stratigraphic age. Middle and Late Jurassic mica fabrics are present in the deeper-exhumed (Haast Schist) part of the accretionary wedge.

Throughout the Jurassic, Zealandia was part of the Gondwana supercontinent and straddled the South Pole. Jurassic Zealandia thus represents an interesting case of a fossil polar continental convergent margin, of which there are no modern examples.

LOCAL SOURCE PROBABILISTIC TSUNAMI INUNDATION HAZARD ASSESSMENT WITH MACHINE LEARNING SUPPORT

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Probabilistic Tsunami Inundation Hazard Assessment (PTIHA) requires a large number of scenario simulations solving the non-linear wave equation, which are computationally expensive. PTIHA has been previously discussed and demonstrated for local tsunami sources in Japan, by using a large set (~3000–4000) of full inundation scenario simulations. However, it is desirable to find an approach that reduces the number of inundation simulations required, to save time and computational cost.

Traditional probabilistic tsunami hazard assessment (PTHA) uses a certain percentile from a set of simulated close-to-shore or at-shore wave heights as the hazard variable. However, for local tsunami sources, recent simulation studies have demonstrated that single point measures of wave heights do not correlate well with the inundation extent.

For PTIHA the inundation extent can be used as a meaningful variable to classify tsunami severity and therefore to subsample tsunami scenario sets by selecting representative cases for different severity levels. We found that for a given scenario the offshore maximum wave height field can be used to estimate resulting inundation extent well with a machine learning approach.

We will present a concept that uses Machine Learning (ML) to reduce the number of required non-linear wave equation simulations to estimate of the inundation hazard. This approach uses simulations solving predominantly the linear shallow water wave equation assisted by a smaller training set of non-linear inundation simulations.

WESTLAND GEOHERITAGE OF A RIFTED GONDWANA MARGIN—A POTENTIAL UNESCO GLOBAL GEOPARK

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New Zealand National Commission for UNESCO recently initiated a campaign to invite applications to propose sites for UNESCO Global Geopark (UGG) status. In this call, the Alpine Fault appeared as a potential geosite that may provide enough geological justification to be centred in a UGG proposal. Unquestionably, the Alpine Fault is a major geological feature, transecting a region with huge geodiversity and unique ecosystems, however, to utilize it as the backbone for a geopark development is challenging. Here we suggest a different approach where Westland is the focus of UGG status using its geoheritage links to the Gondwana margin and record of subsequent Zealandia rifting. The recent success of the UNESCO World Heritage (UWH) application of the Chaine des Puys–Limagne Fault in France is one of only a few geological UWH associated with rift systems despite rifts being important places where the Earth's crust breaks apart. Rifts are common and diverse; they are either active or passive and/or driven by pure or simple shear. Magmatically induced pure shear-dominated types are those rifts commonly pictured as rifts, while simple shear and passive rifts are more difficult for the untrained eye to envisage. Following the formation of the new UWH site in France a new initiative to promote rifts globally has emerged. Entitled "Building a World Rift Community", this project aims to raise the profile of rift systems in the UWH and UGG programs. In Westland, ready access and excellent exposure makes this an ideal location to see the simple shear processes that operated along the Gondwana margin. From metamorphic core complexes to normal faulted blocks and their associated extensive talus deposits span the Phanerozoic, which could be interlinked by a network of geosites from Golden Bay to Jackson Bay that clearly preserve the responsible geological processes.

CENTENNIAL-SCALE SEA-LEVEL RECONSTRUCTION USING SALT MARSH FORAMINFERA IN THE CONTEXT OF NEW ZEALAND SEARISE: AN EXAMPLE FROM SOUTHLAND

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As part of the Centennial Baselines component of the NZ SeaRise programme, new sea-level reconstructions for the past few centuries will be developed at selected localities to enable recent changes in sea-level observed from tide gauge and satellite monitoring to be considered in a longer time context. Of particular interest is the role played by local–regional site factors, and in particular, vertical land movement (VLM) in relative sea-level change at New Zealand's coastlines over these centennial timescales. This paper will present preliminary results of an investigation of sea-level change at a saltmarsh on the Southland coast, near Invercargill, spanning the past ~800 years. Fossil foraminifera assemblages preserved in cored saltmarsh sediments were used to reconstruct palaeomarsh surface elevations with a local transfer function using a WAPLS regression model. Ages were determined using palynology, trace metal concentrations, stable Pb isotope analysis and ^{137}Cs. Our preliminary results indicate a 20th century acceleration of sea-level rise to 4 mm/yr, higher than eustatic sea-level rise, which implies a VLM component or some other factors are at play. However, the local modern calibration training set for the site does not appear to completely cover the range of downcore assemblages observed and ongoing work is aimed at developing a more applicable model. The results to date will be presented at the meeting, affording an opportunity to discuss the methodology and findings of this study in the wider context of NZ SeaRise.

IGNEOUS CARBONATES IN THE CANTERBURY AND TARANAKI BASINS

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Examination of cuttings from offshore exploration wells in the Canterbury and Taranaki Basins has revealed an igneous carbonate consisting of microscopic, brecciated fragments of a vitrophyric rock within an amorphous groundmass. This material, dubbed "Microfacies VS", has a highly distinct and consistent appearance under a reflected light microscope and has been observed in numerous wells not only in New Zealand sedimentary basins, but also those in Australia, South East Asia, North America and the North Sea. It has been examined under reflected light in polished section, in thin section and scanning electron microscope (SEM), and analysed via X-ray fluorescence spectroscopic (XRF), X-ray diffraction (XRD), energy dispersive spectroscopic (EDS) methods.

The elemental composition of the glass component is primarily carbonate and metal oxides, with very low levels of silica. The glass hosts a variety of euhedral phenocrysts and vesicles infilled with silica. This vitrophyric material has not been observed in an intact state, but is invariably brecciated into 10–100 µm scale fragments surrounded by an amorphous groundmass consisting of a heterogeneous mix of carbonate and silica. This groundmass occasionally contains vesicles, indicating a period of fluidisation.

Despite the fine-grained nature of the rock and the presence of vesicles, its vertical distribution through several thousand metres of stratigraphic range suggests that it is an intrusive material. Based on its physical structure, elemental composition and trace element analysis, Microfacies VS is proposed to be an igneous carbonate derived from the melting of carbonates within sedimentary basins or in the basement rocks beneath.

HOW IMPORTANT ARE MULTI-FAULT RUPTURES IN NEW ZEALAND EARTHQUAKES?

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The 2016 Kaikōura Earthquake ruptured at least 17 separate faults and reminded the global seismology community of the possibility of large earthquakes that rupture multiple faults. It is clear from the Kaikōura event that such ruptures can be complex, however, questions remain about how common multi-fault ruptures are and whether we should expect similarly complex ruptures in the future. To address these questions, we have analysed eight moderate to great historical earthquakes (M_w 6.5–8.2) that ruptured the ground surface in New Zealand post-1840. Of these earthquakes, five ruptured at least three faults (Wairarapa 1855, Hawkes Bay 1931, Edgecumbe 1987, Darfield 2010 and Kaikōura 2016) and show a strong time-dependence with all but one post-dating 1930. The importance of these multi-fault events over the last ~90 years may reflect the improving quality and quantity of the available data, rather than a change in the style of surface-ruptures. Independent of these sampling biases it is clear that rupture of multiple faults during individual earthquakes has been common in New Zealand during the last ~180 years. Multi-fault ruptures occur for a range of fault types, with variable fault displacement rates and in different tectonic settings. In some cases, co-rupture of the Hikurangi subduction thrust may have facilitated (and linked) rupture of more than one fault (Wairarapa 1855, Hawkes Bay 1931 and Kaikōura 2016), whereas other events were far removed from subduction (Edgecumbe and Darfield), and the subduction-thrust cannot have directly contributed to the observed complex rupture geometries. Consistent with the subduction hypothesis, we suggest that fault intersections promote multi-fault ruptures, increasing both rupture lengths and earthquake magnitudes. Future multi-fault ruptures can be expected in parts of New Zealand where active faults are hard-linked or closely spaced (e.g., 5 km).

ASEISMIC TO SEISMIC TRANSITION AT THE BRITTLE TO DUCTILE TRANSITION: INSIGHTS FROM HYDROTHERMAL RING SHEAR EXPERIMENTS AND A MICROPHYSICAL MODEL

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Earthquakes typically nucleate at the base of the seismogenic crust at temperatures (T) where the major rock constituents such as quartz (T = 350 °C) or feldspar (T = 450 °C) are expected to deform plastically at geological strain rates. However, the seismic cycle is associated with a wide range of strain rates, and it is unclear how this affects the depth extent of earthquake propagation. In this presentation, I will show results from hydrothermal ring shear experiments on a variety of fault gouges derived from carbonates, quartz, quartzofeldspathic Alpine Fault rocks (New Zealand) and gouges derived from felsic rocks from the East African Rift. The results consistently show an apparent frictional weakening at high temperatures (up to 700 °C), which evolves over significant displacement and is most severe at the lowest velocity. At the same time, there is only minor deviation from linearity in the normal stress dependence of shear stress, indicating that, even at the highest temperatures, deformation remains predominantly frictional over the velocities imposed (0.03 to 1 µm/s). Shear stress estimates using flow laws obtained from compression experiments on low porosity intact rocks are consistently higher than those measured. Our microphysical model (CNS model) is capable of reproducing some of the experimental results of monomineralic gouges. The model, based on competition between porosity creation via granular flow and porosity reduction via time-dependent compaction, highlights the crucial role porosity plays in governing the transition to velocity-weakening, potentially earthquake-generating slip with increased strain rate, as well as in maintaining a linear dependence of shear stress on normal stress. Seismic cycle simulations based on the microphysical model show that a continued loading of creeping fault segments by nearby earthquakes can push these segments into the velocity-weakening regime. The crucial parameter controlling this transition is the rate of the time-dependent creep mechanism, which remains poorly constrained for most mineralogical compositions of interest. There exists ample scope for future experiments that focus on flow laws for polymineralic fault rocks at conditions that span the velocity range of the seismic cycle under hydrothermal conditions.

FOREARC BASIN FORMATION AND ITS RELATIONSHIP WITH MATERIAL FLUX IN SUBDUCTION ZONES

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Strata in forearc basins preserve useful information for understanding subduction. However, there is no unified theory of forearc basin formation. Here, I introduce recent work focusing on forearc basins, which include (1) classification of modern forearc basins based on material flux along the plate boundary and strain within the basins; (2) numerical simulations to examine development of basin stratigraphy with changing sediment influx/outflux in the subduction system; (3) analogue sandbox experiments to analyse interactions between sediment supply, accretionary wedge growth, and basin stratigraphy.

Modern forearc basins can be classified based on their geometry and stratigraphic patterns. For example, the compressional accretionary type (positive material flux) have reverse faults, landward tilting strata, landward onlapping strata, and a uniform basin width/depth ratio. On the other hand, the extensional non-accretionary type (negative material flux) includes normal faults, and variable basin width/depth ratios. Therefore, basin formation patterns could be associated with the material flux between the plate boundary. Numerical simulations indicate forearc basin stratigraphy depends on the degree of filling (underfill versus overfill) and volume balance between sediment supply and accommodation space. Variable sediment fluxes alter the growth pattern of the accretionary wedge and affect basin stratigraphy. Analogue sandbox experiments show that thrust motion and basin filling patterns are closely related to variations in sediment supply. Higher sediment supply rates induced larger overburden stress on the thrusts, which modified uplift and displacement patterns in the accretionary wedge. These results in combination with seismic profiles and sediment cores, can be used to understand the evolution of forearc basins developed along subduction zones like the Hikurangi margin.

SANDBOX ANALOGUE EXPERIMENTS OF FOREARC BASIN FORMATION: INFLUENCE OF VARIABLE SEDIMENT SUPPLY

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Forearc basins are an important component in subduction zones. Although the stratigraphic record of forearc basins are key to unravelling subduction zone evolution, the interaction between forearc basin formation and accretionary wedge development remains poorly understood. To examine forearc basin–accretionary wedge interaction, we designed a series of sandbox analogue experiments.

The sandbox was 100 cm wide and 30 cm deep with a sandpaper-surfaced wooden backstop at the end. The sandbox was filled to a depth of 2 cm with glass beads and dry sand on top of a plastic sheet, which was retracted at a rate of 0.5 cm/min. Maximum shortening was 30 cm for each experiment. We added dry sand to fill topographic lows (forearc and piggy-back basins) every 2 cm of shortening. We ran four types of experiments that differed in the amount and rate of sand that was added: (a1) no additional sand added, (a2) constant sand supply, and (a3/a4) variable sand supply. The total number (13) of times that sand was added and the total amount (910 g) of added sand were equal in all experiments.

Growth patterns of the accretionary wedge can be divided into two stages based on differences in amplitude, period, and displacement, all of which were lower in the first compared with the second stage. The timing of transition from the first to second stage was closely related to the amount of sand supplied to the basin. High sediment supply appeared to enhance initial wedge growth. Movement on fore- and back-thrust faults was also associated with variation in sand supply; each fore-thrust was active for longer and back-thrust activity ceased earlier with increased sand supply. Final basin stratigraphy and wedge geometry seem to be strongly affected by the volume, timing and location of sand added to the wedge. These results provide useful insights for the study of modern and ancient subduction zone evolution using forearc basin stratigraphy, seismic profiles, and sediment cores.

FEEDING THE DEEP: SUBMARINE CANYONS AS CONDUITS FOR TRANSFERRING TERRESTRIAL ORGANIC MATERIAL FROM THE COAST TO THE DEEP OCEAN

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Submarine canyons are focus points for transferring terrestrial and coastal materials off the continental shelf into the deep ocean. The continental margin of New Zealand is dissected by numerous submarine canyons on either side of the active plate boundary. The Hokitika Canyon is a low gradient, ~500 km long incised feature on the West Coast, South Island/Te Waipounamu, that lies west of the Alpine Fault and the rapidly uplifting and eroding Southern Alps/Kā Tiritiri-o-te-Moana. The Kaikōura Canyon on the eastern seaboard off north Canterbury is a relatively short, steep system that comes to within a few kilometres of the coastal mountains. Using the carbon and nitrogen stable isotopes of bulk organic matter and specific organic compounds (fatty acids), we have traced the relative contributions made by terrestrially and marine-derived material through the reaches of these two geomorphologically-contrasting canyons. The results show that in Hokitika Canyon organic matter in the canyon axis was comprised almost entirely of land-derived material, down to 2000 m depth and up to 200 km from the coast. In Kaikōura Canyon, high concentrations of land-derived organic matter were found in areas near the coast and down to 1000 m depth, but very little land-derived material was found further away from the coast (25 km) and deeper in the canyon, where marine-derived organic matter predominated. The significant differences in the local sources and quantity and quality of organic matter mirror the predominant sediment dispersal processes. The Hokitika Canyon is representative of a continually fed sediment system driven by a near-constant supply of material derived from a proximal, rapidly eroding and uplifting mountain range. In contrast, the Kaikōura Canyon is driven largely by geologically significant episodes of canyon flushing, probably related to the cycle of large plate boundary earthquakes and local ground-shaking, as evidenced spectacularly in 2016.

RADIOCARBON PRE-TREATMENT OF SMALL TERRESTRIAL MACROFOSSILS

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Leaves and other terrestrial macrofossil remains are ideal targets for building chronologies in paleoenvironment reconstruction studies using radiocarbon. Yet macrofossils in sediment cores are often of low mass. The regular Acid–Alkali–Acid (AAA) chemical pre-treatment used to remove contaminating carbon can greatly reduce the initial mass so that insufficient material remains to proceed with radiocarbon analysis. This study addresses whether milder chemical pre-treatment can be adopted to minimise sample mass loss, whilst still removing all contamination from samples.

Four different AAA pre-treatment methods were trialled on macrofossils from highly organic New Zealand lake sediments representing different time periods from middle Holocene through to Last Glacial Maximum: (1) acid wash only at room temperature; (2) mild AAA treatment at room temperature; (3) standard AAA treatment heated to 85°C; and aggressive AAA treatment heated to 85°C with multiple alkali washes. The results demonstrate that the “mild” AAA treatment (room temperature acid, base, acid washes) is effective at removing contamination and does not detrimentally affect sample mass. Acid only treatments did not remove all contamination whereas standard and aggressive AAA treatments remove contamination but reduce the sample mass available for combustion.

IMAGING THE KAIKŌURA AFTERSHOCK SEQUENCE ON A 3-D MARINE SEISMIC STREAMER

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Between the 15th of October and 2nd of December 2016 the MV PGS Apollo was conducting a multi-client 3-D seismic reflection survey in the offshore southern Taranaki region. The 2016 M_w 7.8 Kaikōura mainshock and aftershock sequence produced significant disruption and waveform contamination on the records from the 3-D survey. After an initial shut down and risk assessment by the crew, data acquisition was continued, capturing a high-fidelity record of earthquake energy. The 3-D acquisition system comprised 10 streamers each with 648 hydrophones, at 12.5 m spacing (nominal coverage of the array is 1.4 × 8.1 km), recording seismic energy continuously at a sample rate of 500 Hz. We have analysed over 20 hours of raw data files, observing numerous earthquake arrivals, some not identified by the national GeoNet array. The dense geometry of the marine receiver array has allowed intricacies in the arriving earthquake energy to be revealed, however, the array was constantly moving adding further complexity. We assess wavelengths and travel times and use beamforming techniques to remove airgun energy and determine the back-azimuth of incoming earthquake signals. In conjunction with observers' visual records and comments on the results of passive acoustic monitoring, we have further identified and imaged signals likely generated by marine mammals. Utilising the vast number of recordings (6480 hydrophones) summed into a single semi-continuous time-series we can make an assessment of changes to the generation of low-frequency energy across the region in the days following the mainshock.

ARCHITECTURE AND STRUCTURAL EVOLUTION OF THE GLADE–DARRAN FAULT, FIORDLAND, NEW ZEALAND

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The southern Glade–Darran Fault is a major dextral strike-slip fault that strikes NE–SW through ~20 km of northern Fiordland, New Zealand. The fault has an extremely straight surface trace which lies broadly sub-parallel to the Alpine Fault, ~40 km to the northwest. Previously unreported mylonites, cataclasites, pseudotachylites and fault gouge were identified within plutonic host rocks in the Hut Creek–Mistake Creek area. The exposed assemblage of fault rocks records the thermal, seismic and rheological history of the Glade–Darran Fault as it was exhumed. Here we integrate methods to characterise the fault rocks and fracture damage zone of the Glade–Darran Fault from Glade Pass to Mt Aragorn. We use (1) new structural datasets and augmented circular scanline analysis to detail geometrical relationships between structural features, and (2) energy-dispersive spectrometry (EDS), X-ray diffraction (XRD) and electron back-scatter diffraction (EBSD) analyses to describe the mineralogy, kinematics and microstructures of fault rocks. We propose that the brittle architecture of the Glade–Darran Fault was inherited from a pre-existing ductile shear zone. Greenschist facies mylonitic shear zones in the host rocks parallel the main fault trace and contain quartz crystal-preferred orientations (CPOs) typical of high strain. These are overprinted by a sub-parallel fault core containing cataclasites and pseudotachylites. Injection veins, chilled margins and euhedral microlites confirm a previous melt phase and suggest that the fault was seismic in the brittle regime. Furthermore, a narrow (<0.2 m) zeolite-bearing fault gouge layer overprints the cataclasites and pseudotachylites. The gouge composition is suggestive of low-temperature, low-pressure environments at shallow crustal levels. The Glade–Darran Fault provides important insight in to the structural evolution of faults in crystalline basement rocks and, therefore, it is important to determine its thermal, seismological and rheological properties.

ENVIRONMENTAL RECONSTRUCTION FROM EASTERN AND CENTRAL ROSS EMBAYMENT SEDIMENT CORES

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During the Last Glacial Maximum (LGM) the Ross Ice Shelf was a large, grounded, ice sheet that extended to the Antarctic continental shelf edge. Numerical simulations imply that its retreat since the LGM was initiated in the central Ross Embayment. However, the retreat is poorly or unconstrained in the central and eastern portion from empirical data, therefore, these simulations cannot be verified. Our project aimed to use existing sediment cores from the eastern and central Ross Embayment to reconstruct the retreat history of the Ross Ice Shelf. Here we present new sedimentary logs, and sedimentological, paleomagnetic and rock magnetic data. Paleomagnetic analyses of a ~6-m-long core from the central Ross embayment (NBP03-01A-20PC) reveal that the core has a basal age that may exceed 1 Ma, and that the nature and rate of sedimentation around the Ross Embayment were variable. On the contrary the 4.65-m-long core, NBP96-01-17JPC, from the eastern sector records high sedimentation rates and contains an intact record of Ross Ice Shelf retreat and the transition to modern conditions. Ramped temperature pyrolysis ^{14}C indicates that the grounding line retreated from this location between 6 and 7 kyr, which is 6–7 kyr later than predicted by current models.

STRESS AND STRENGTH CONTROL ON THE 2016 KAIKŌURA EARTHQUAKE INFERRED FROM SEISMIC OBSERVATIONS

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During the 2016 Kaikōura Earthquake, at least 17 faults ruptured, with various geometries and kinematics. Since the commencement of the 2010–2012 Canterbury earthquake sequence we have deployed a dense portable seismic array in the central and northern South Island. We have undertaken seismic tomography and stress tensor inversion using focal mechanisms in the region surrounding the focus of the Kaikōura Earthquake. Data from both the 51 temporary stations and 22 GeoNet stations collected from March 2011 to December 2017 were used. Earthquakes were located and identified by GeoNet.

We have determined hypocentre locations and the 3-D velocity structure. We located a region of low P-wave velocities (V_p), low S-wave velocities (V_s) and high V_p/V_s surrounding the mainshock and aftershocks of the Kaikōura Earthquake, and beneath other major faults in the northern South Island. These low-V_p, low-V_s and high V_p/V_s zones are coincident with low electrical resistivity areas detected by magnetotelluric (MT) soundings and can be interpreted as zones with overpressured fluids.

We also have determined stress tensors before and after the Kaikōura Earthquake. We derived focal mechanisms and used CMT solutions derived by GeoNet for stress tensor inversion. Both before and after the mainshock, the horizontal maximum compressional axis had an azimuth of ~120 that did not appear to change significantly after the earthquake.

One notable feature of the predominantly strike-slip ruptures in the 200-km-long surface rupture zone is that they are very poorly oriented for reactivation within the prevailing stress field, many lying at ~70° to σ_1 trajectories, except possibly in the zone of rupture initiation near the epicentre. This adds to the likelihood of the involvement of overpressured fluid in rupture propagation.

POSSIBLE REVERSAL OF FLUID FLOW AT THE SEAFLOOR FOLLOWING GAS PRODUCTION FROM METHANE HYDRATES: NUMERICAL SIMULATION STUDIES

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The Hikurangi margin east of New Zealand, is reported to contain significant gas hydrate deposits. Gas hydrates are predicted to be present in areas of the margin covering over 50,000 km^2. With New Zealand's conventional gas supplies being rapidly depleted, these gas hydrates have attracted attention as a possible unconventional energy source. They are also being studied because of their possible role in submarine slope stability, climate change, and ocean acidification.

The Hikurangi margin marks the boundary where oceanic lithosphere of the Pacific Plate subducts beneath Australian Plate continental lithosphere. It is characterised by anticlinal ridges that are adjacent to a Mesozoic basement composed of Torlesse Composite Terrane greywackes. The anticlinal ridges can be subdivided into three main heterogeneous groups: (1) Late Cretaceous and Paleogene rocks, (2) late Cenozoic trench-fill turbidites, and (3) a sequence of Miocene to Recent shelf and slope basin sediments, which may act as traps for gas hydrates.

In our studies, we used TOUGH+HYDRATE to construct a 2-D cylindrical axisymmetric gas production model of the Hikurangi margin using measurements from geophysical and geochemical surveys. The focus of our studies is the significance of overburden gas production, particularly simulating both permeable and impermeable overburden. The model is based on seismic images from an anticline, Uruti Ridge, at 725 m water depth and a site close to the up-dip edge of gas hydrate stability. We will present results for various basic scenarios varying in overburden permeability. The models suggest that at higher permeabilities, seawater is being sucked into the reservoirs with permeable overburden. Such a reversal of fluid flow near the seafloor would have significant implications on seafloor biologic communities, which constitute a major challenge for possible gas hydrate production.

CHARACTERISATION OF THE HOLOCENE TURBIDITE RECORD PRESERVED IN SEDIMENTARY DISTRIBUTARY CATCHMENTS ALONG THE TECTONICALLY-ACTIVE SOUTHERN HIKURANGI MARGIN

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A margin-wide study of the Holocene turbidite record preserved in sedimentary distributary catchments along the southern Hikurangi margin was initiated in 2016, as part of the Ministry of Business, Innovation and Employment (MBIE) Endeavour programme "Hikurangi subduction earthquakes and slip behaviour". The hypothesis being tested is that turbidites reflect the frequency of earthquake-ground motions, the largest of which could synchronously trigger events over distances of several hundred kilometres, leading to synchronous deposition of turbidites in multiple distributary catchments. Our immediate research aim reported here is to characterise the lithostratigraphy of the marine sediments, continental-margin sediment sources, turbidity-current transport routes, and the depositional environments within the basins. The future goal is to then correlate the timing of these deposits to dated terrestrial deposits along the adjacent coastline generated by another research team within the programme.

National Institute of Water and Atmospheric Research voyage TAN1613 collected 61 cores up to 5.5 m long between the Marlborough and Poverty Bay slopes. Core locations were selected using a terrain drainage analysis of multibeam bathymetry to capture likely turbidity current paths down the continental slope, through a mixture of canyon axis and overbank core sites at each distributary system. The recovered cores yielded a rich record of silt-dominated turbidites, which over the last two years have been lithologically logged, imaged using computed tomography scanning (CT), and chemically profiled using micro-X-ray fluorescence spectroscopy (XRF) using an ITRAX Corescanner. Broad chronological control has been attained through a selection of seven radiocarbon dates from the Cook Strait and Madden Canyon dispersal systems, complimented by the identification of tephra-rich deposits from three Holocene Taupō Volcanic Zone eruptions. These data have underpinned a number of student thesis projects, some of which are now completed and others currently progressing. This talk will provide a status report of the research effort to date and our progress towards unravelling the turbidite and paleoseismic history for the Hikurangi margin.

GEOHERITAGE VALUES AND GEOTOURISM POTENTIAL OF THE WAIRARAPA "MUDSTONE COUNTRY" AND MANAWATU "TERRACE-LAND"

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The Manawatu and Wairarapa regions, lower North Island, are not among the iconic geotourism attractions of New Zealand. Recently the geoheritage values of the region have been discussed by various groups and Horizons Regional Council with an aim to develop regional geoparks. The suggestion has been the Manawatu River form the backbone of a geopark. While Manawatu River is regionally significant, we argue it lacks the globally unique attributes needed for globally significant geoheritage values. Here we demonstrate the wider region has at least two globally unique and geologically superb features that should be evaluated using global comparative studies. The Manawatu landscape is the home of marine and fluvial terraces that provide key information to the global sea-level changes and the Quaternary evolution of the North Island, including a unique record of volcanism in the past one million years. Farther east, the Wairarapa region hosts one of the best exposed accretionary prism successions in the world. The exceptional turbidite successions are comparable to the iconic "flysch" locations of the North American Cordillera, the Alps, the Pyrenees and the Carpathians. Furthermore, a succession of thrust faults and related mélange sequences are among the best exposed and most accessible in New Zealand. These undoubtedly carry high geoheritage value and we propose that these two geological features, with community support, regional council funding and the local university (Massey) facilitating the transfer of knowledge to the community, could successfully become the UNESCO Global Geopark of the Manawatu Terrace-land and Wairarapa Mudstone country within the next 15 years.

USING THE GEOCHEMICAL SIGNATURES OF SCHEELITE AS A TOOL FOR DETERMINING THE PROVENANCE OF ITS CONSTITUENT METALS AND MINERALISING FLUIDS

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Scheelite is the major host of tungsten (W) within New Zealand and was mined at Glenorchy and Macraes in Otago in the early 1900s. It is the W endmember of the scheelite ($CaWO_4$)–powellite ($CaMoO_4$) solid solution series, but the Ca site in its crystal structure can accommodate a variety of trace elements, including the Rare Earth Elements (REE) and strontium. Knowing the geochemical signature of scheelite can aid in constraining the pathways of mineralising fluids and metals, as has been shown for Mesozoic orogenic occurrences within the Otago Schist (Glenorchy, Macraes, Barewood, Waipori etc.). However, magmatic related scheelite mineralisation is also present within New Zealand and the geochemistry of it may provide insight into higher temperature and lower fluid flux systems. Two such locations are Batemans Creek near Reefton and Canaan Downs near Takaka. Scheelite samples from different textural environments have been analysed for their trace element, and Sr and Nd isotopic compositions via *in-situ* LA–ICP–MS. At Canaan Downs, scheelite grains contain Sr between 500 and 1000 ppm, total REE+Y between 500 and 3500 ppm and normalised REE plots show middle REE (MREE) enrichment with or without a small positive Eu anomaly. At Batemans Creek, the Sr concentration and total REE+Y of scheelite grains vary considerably as a function of the host rock geochemistry and this variability is reflected in the normalised REE plots. Radiometric Sm–Nd dating of scheelite grains broadly indicates a Devonian–Carboniferous age of mineralisation at Canaan Downs, which corresponds with a new U–Pb zircon date of ~345 Ma obtained from the host granodiorite that was previously thought to be Cretaceous.

IMPROVING UNDERSTANDING OF RUATANIWHA BASIN GEOLOGY

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The Ruataniwha basin is an active forearc basin located in Central Hawkes Bay. Complex basin geology, including a wide range of recent infill, results from structural deformation associated with the adjacent subduction zone (e.g., faulting) and spatio-temporal variability in depositional environments. The basement and western margin of the basin are Jurassic and Triassic greywackes on which predominantly marine Miocene–Pliocene sediments were deposited. Quaternary fluvial sediments, some of which comprise significant proportions of volcaniclastic material, have infilled the basin over the last two million years. These sediments contain aquifers that provide important sources of groundwater for residents and farmers in the area. While providing hydrogeological assistance during well drilling projects in the Ruataniwha Basin, Lattey Group have collected and interpreted geological information to assess the local ground conditions and to gain a greater understanding of basin geology. This includes preparation of geological logs and cross-sections and drill cuttings photography. New geological units identified during these projects include the Young and Salisbury gravels and other marker beds, including the Poutaki Pumiceous Formation and Tukipo Aquitard.

LONG-TERM EVOLUTION OF LOW FREQUENCY EARTHQUAKES AT NGAURUHOE VOLCANO, NEW ZEALAND

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Ngauruhoe Volcano released a continuous swarm of low frequency volcanic earthquakes (LFs) from 2005 to 2010. To examine these earthquakes, we applied a template matching method finding eight earthquake families. Through a detailed analysis of occurrence time, spectral characteristics and correlation coefficient patterns, the families can be classified into four super-families generated from four different mechanisms, and/or source locations or geometries. The first super-family mainly occurred in 2005 with no significant evolution of frequency content. The second super-family shows high seismicity rates as well as progressive evolution to higher frequency over a two-year period from mid-2006. The third super-family started in early 2008, evolved in late 2009, and re-emerged in 2010 with an increase in peak frequency. The fourth super-family predominantly occurred from late 2008 to mid-2009 and had its highest peak frequency in 2009.

We hypothesised that the seismic unrest was caused by a modest increase in the flux of gas and heat. However, the pattern of increased Ngauruhoe seismicity coincides with the summer months when the minimum temperature rises above the melting point. Thus, a primary driver of the LF families may relate to an interaction between the flux of gas and heat from a deeper relict magmatic zone and seasonal meltwater ingress from above. We interpret the activity as a propagation crack(s) tip or the progressive sealing of crack(s) due to hydrothermal system fluctuation.

A STUDY OF SUBSIDENCE IN CHRISTCHURCH CITY

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The Christchurch City Ground Height Monitoring project involves four GNSS receivers that lie on a north–south transect extending from Sumner to New Brighton. The GNSS data from these stations as well as four other cGNSS sites located around Christchurch have been processed using the Bernese software package using 24-hour daily position solutions and the resulting position time series were analysed to estimate rates of change in the height component.

After three years of monitoring, the coastal suburbs between South New Brighton to Waimari Beach are currently undergoing rapid subsidence of nearly 1 cm/yr. In contrast, in the western suburbs, the rates of subsidence decrease. Unfortunately, we have no data to determine how far north the high rates of subsidence extend since this is outside the scope of the study. The high rates of subsidence appear to be related to the region underlain by unconsolidated estuarine sediments. Our site at Sumner, which is located on bedrock, does not show a significant vertical velocity at the 95% confidence level.

Over the last three years the vertical change in the area is complicated by the vertical displacements from two earthquakes. The Valentine's Day earthquake (14th February 2016) caused uplift while the Kaikōura Earthquake (13th November 2016) caused subsidence at all of the stations. Although the Kaikōura Earthquake (M_w 7.8) was a far larger event than the Valentine's Day Earthquake (M_w 5.7), the fact that the Valentine's Day Earthquake was located near our study area meant that the uplift associated with it exceeded the subsidence from the Kaikōura Earthquake in New Brighton and South New Brighton. As a result, the earthquakes have produced several centimetres of net uplift in these areas that has offset the subsidence associated with the vertical velocity trend. However, for the northern sites, the coseismic displacement contributes to the total subsidence.

RESPONSE OF GAS HYDRATE SYSTEMS TO TECTONICS, SEDIMENTATION, AND FLUID FLOW—HIKURANGI MARGIN, NEW ZEALAND

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A number of studies in recent years have shown that gas hydrates near the up-dip limit of the hydrate stability field are strongly susceptible to changes in pressure or temperature. However, gas hydrate systems appear to only adjust gradually to such changes. International Ocean Discovery Program (IODP) Expeditions 372 and 375 targeted the northern Hikurangi subduction margin east of New Zealand. These expeditions, combined with a number of site surveys, provided us with a vast dataset that sheds new light on the evolution of gas hydrate systems in subduction zone settings.

At several locations in the study area, double-bottom simulating reflections (BSRs) are encountered. From pore water chemistry and head space-gas analysis, there are no indications for any thermogenic gases, making it unlikely that double-BSRs form from fractionation of a thermogenic gas mix. Beneath a ridge in the northern part of our study area, double-BSRs are thought to be linked to depressurization from tectonic uplift. Further south near the IODP drilling transect, double-BSRs may be the response to a thermal signal from a sedimentation pulse. Modelling suggests gas hydrate dissociation in conjunction with such double-BSRs to take place over thousands of years. Actively dissociating gas hydrates may, therefore, be present between the double-BSRs. Furthermore, results from a heat flow transect near the up-dip limit of the hydrate stability field indicate that gas hydrates are actively dissociating. Anomalies in thermal gradients suggest that latent heat from gas hydrate dissociation may act as a buffer to transient advective heat flux.

Our findings suggest that gas hydrate systems that respond to tectonic processes, sedimentation, or fluid flow may be in a transient state leading to on-going hydrate dissociation over thousands of years. Such ongoing gas hydrate dissociation could affect a number of seafloor processes.

CREATING AN EARTH SCIENCE GARDEN FOR TEACHING

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It has long been recognised that Earth Science depends upon field data and experience, often surveyed as the leading reason for why geology students enjoy their degree. Petrologist H.H. Read (1957) sums this up in his famous quote “the best geologist is he who has seen the most rocks”. Earth science gardens are a novel and exciting way to take the field to campus and classroom. Many geoscience educators understand the reality of transferring classroom knowledge to the outdoors.

There are many examples of Earth Science gardens both nationally and internationally, however, most of these follow the format of an outdoor exhibit, typically with disconnected rocks displayed in an informative but largely static way (e.g., University of Waterloo, Ontario, Canada or Bush City at Te Papa, Wellington, New Zealand). In recent times there has been a move to a more interactive mapping area (e.g., University of Alberta North Campus, Edmonton, Canada or the award-winning garden at Monash University, Melbourne, Australia). In these types of gardens students are required to solve various geological problems as they would in the field based on the rocks being arranged in a deliberate way. Currently, there is no such type of Earth Science garden in New Zealand.

Interactive Earth Science gardens provide students with the opportunity to practice and enhance the skills of 3-D visualisation and basic field techniques, and observe geological relationships, allowing them to collect a variety of both qualitative and quantitative data that can be further analysed by laboratory methods. Additionally, they can provide outreach opportunities for schools and potential students, and in New Zealand, an innovative way to incorporate the geologically themed regional purakau of Māori to enrich the story.

ACTIVE STRUCTURES IN THE NORTHERN NORTH ISLAND INTERPRETED FROM GNSS GEODESY

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Analysis of data acquired during a three-year, >40-station geodetic campaign targeting the greater Hauraki Rift region has provided constraint on the active but slow (<1 mm/yr) crustal deformation throughout much of the northern North Island. While deformation is primarily accommodated via widening and dextral shear along the Kerepehi Fault/Hauraki Rift, parallel N–S strain discontinuities also appear to the west acting on the active Wairoa North Fault and on a speculative structure west of Auckland and parallel to the coastline. These distributed N–S striking faults appear to be situated at the weaker sutures within the N–S striking basement structure. The geodetic velocity solutions also show dextral activity on the Waikato fault, which strikes E–W perpendicular to the basement fabric between the west coast and the Hauraki Rift, in addition to another basement structure-parallel dextral fault originating near the Raglan Harbour and continuing E towards Hamilton. It is hypothesised that these E–W trending faults serve as transforms to partition the strain along the NW bending basement. In Northland, geodetic velocities maintain a significant SW velocity relative to a fixed continental Australian reference frame suggesting that even northernmost New Zealand may not be stable relative to the Australian Plate.

MIDDLE CENOZOIC UNCONFORMITIES OF WAIHAO VALLEY, SOUTH CANTERBURY BASIN

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Development of New Zealand Cretaceous and Cenozoic basins is related to the evolution of Zealandia which has been influenced by eustatic sea-level changes, local tectonics and plate boundary activity. The Waihao valley includes field sites that contain a mid-Oligocene unconformity. This unconformity is widespread globally and occurs in the North Sea Basin and Atlantic coastal plain, as well as many other localities. Study of the Waihao valley sequence will, therefore, yield additional information about the origin of the mid-Oligocene unconformity and Oligocene paleoclimate.

The Eocene–Oligocene shallow marine sedimentary sequence of the southern Canterbury Basin has been studied since the early 1900s, but additional work needs to be done to make sense of the existing unconformities, especially at the margins of the basin. These gaps in time can be either associated with local tectonics, erosion, sediment supply, non-deposition or eustatic sea-level changes. To understand the origin of these unconformities, a sequence stratigraphic and biostratigraphic framework based on field data and foraminifera samples collected at particularly localities will be developed. Petrographic, portable X-ray fluorescence spectroscopy (pXRF) and magnetic susceptibility analyses will be carried out to understand the source of the sediments, which will help in reconstructing the evolution of the Waihao basin.

The final outcome of this study will be a chronostratigraphy that will identify the age of the missing strata and broaden our knowledge of southern Canterbury Basin geology. Furthermore, it will yield new information regarding the possible relationship between unconformities in the Waihao valley and the globally-distributed mid-Oligocene unconformity.

PALEOTSUNAMI DEPOSITS WITHIN LAKE GRASSMERE, SOUTHERN HIKURANGI MARGIN, NEW ZEALAND

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The seismic potential of the southern Hikurangi margin is poorly understood due to an absence of historic subduction earthquakes and a short (<1000 years) paleoseismic record. As a consequence, the hazard of earthquakes and tsunamis to Wellington city and other regional population centres is poorly constrained. Here we describe a paleotsunami study of Lake Grassmere, a large, shallow-water embayment situated on the northeastern Marlborough coast, on the southern section of the Hikurangi subduction margin.

Two probable paleotsunami deposits have been identified, extending more than 1.5 km inland and characterised by a dense cockle shell hash in a medium sand. The lower tsunami deposit is accompanied by a probable change in paleoenvironment from finely laminated sub-tidal silts and fine sands, to homogenous lower intertidal silt, suggesting that the earlier high-energy wave event may have been accompanied by coseismic uplift. Radiocarbon dates have been obtained from shells within the paleotsunami deposits and suggest that the two events occurred within the last 2000 years, with approximately 500 years between them.

At present it is not possible to distinguish whether the tsunami and vertical deformation recorded at Lake Grassmere were caused by rupture of an upper-plate fault, or subduction interface, or a combination of both. Future work aims to better constrain the source of the tsunami deposits by: (1) improving the age constraints on the deposits to allow better comparison with known paleoseismic events along the Hikurangi margin, and (2) applying a range of techniques, including micropaleontology and sedimentology, to consider the change in environments that coincides with the paleotsunami deposits so we can better define the magnitude of vertical deformation.

AGENT-BASED MODELLING OF TSUNAMI EVACUATIONS

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New Zealanders are advised to self-evacuate if a long or strong earthquake is felt due to the threat of local tsunami. These large-scale evacuations can involve tens of thousands of people and pose many practical challenges as pedestrian infrastructure has generally not been designed with such large volumes in mind. In small communities (up to a few 100s of people) it is possible to use drills and exercises to identify bottlenecks and other problems, but this becomes impractical once there are thousands of people involved.

In our project we attempt to identify such problems, and to suggest solutions to them, by using agent-based evacuation modelling. Our “agents” are simulated evacuees, and have individual properties such as variable walking speeds, and make decisions regarding the route to take to reach safety. We have been applying the agent-based modelling technique to the communities of Petone in Lower Hutt, Sumner in Canterbury, and Tolaga Bay on the East Cape. We are in the process of running a series of community workshops at these locations to gather local knowledge and receive feedback to improve our modelling, as well as to stimulate discussion around how tsunami evacuations could be quicker and safer.

We will present simulation results from our modelling so far and summarise the outcomes of the community workshops that have taken place. We will describe the use of our models to evaluate the benefits of possible infrastructure changes to assist evacuation and summarise the remaining research to take place within this project.

A NOVEL MULTI-CENTURY ARCHIVE OF TREE MAST USING POLLEN FROM LAKE SEDIMENTS

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The potential for generating long (centuries–millennia) proxy records of tree mast seeding from pollen captured in lake sediments is demonstrated using an example from New Zealand. This proxy record uses pollen recovered from annually-banded (varved) sediments from a sediment core collected from Lake Ohau, South Island, New Zealand, to reconstruct masting events for two genera of Southern Beech, *Fuscospora* spp. and *Lophozonia* spp. We consider the three key components required for such a record of mast seeding to be reliable: (1) The site-level relationship between pollen production in spring and seed fall in autumn, (2) the timing of pollen entry into the lake system, and (3) that pollen extracted from the lake sediments faithfully records the regional inter-annual variability in seed fall. Four five-year datasets show that modern *Fuscospora* pollen rain during the spring preceding mast years was two to three times greater than that of average pollen rain. This variability is also observed in pollen entering Lake Ohau, where *Fuscospora* pollen concentrations in the trapped sediment collected during the spring preceding mast years was 2.5–4 times average pollen concentrations, while *Lophozonia* pollen concentrations were 1.8–8 times average concentrations. Variability of *Fuscospora* and *Lophozonia* pollen concentration in the lake floor sediments of Lake Ohau corresponds closely to mast events observed in a compilation of seed fall events. Our compiled seedfall record (from sites 10s to 100s of kilometres from Lake Ohau) shows evidence for four mast years of *Lophozonia*, all of which were detected in the sediment record, and four *Fuscospora* mast years, of which half were detected in the pollen record from Lake Ohau sediment.

THE 2.1 MA WAITEARIKI IGNIMBRITE: PRODUCT OF A LARGE EXPLOSIVE SILICIC ERUPTION DURING THE COROMANDEL–TAUPŌ TRANSITION

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Subduction-related volcanism within the North Island, New Zealand has migrated southeast since the late Miocene. The resulting volcanic deposits and landforms are classified as two broad volcanic zones—the currently active Taupō Volcanic Zone (TVZ) and the older Coromandel Volcanic Zone (CVZ). The transition from the CVZ to the TVZ occurred at ~2.9–1.9 Ma and is represented by the Tauranga and Kaimai volcanic centres. Outcrops of eruptives associated with this transitional interval are exposed in the eastern Tauranga Basin and adjacent Kaimai Range. Despite its significance, our understanding of volcanism during this period remains limited. The focus on this eruptive period and locality forms the basis of a PhD programme that aims to reconstruct the proximal record, ages and scale of volcanism of the Tauranga and Kaimai volcanic centres with a major focus on large-scale explosive events.

The voluminous and crystal-rich ~2.1 Ma Waiteariki Ignimbrite, forms the gently sloping upper surface of the Whakamarama Plateau that dips eastward beneath younger sediments of the Tauranga Basin. Preliminary analysis of ~170 m of continuous core through the Waiteariki Ignimbrite reveals that the ignimbrite is extensively devitrified and welded and is composed of a least two cooling units and a basal sequence of pumaceous breccias and ash. We present initial petrological descriptions detailing crystallinity, mineral phases and variations in pumice and lithic size along with whole-rock X-ray fluorescence spectroscopy (XRF) analyses of juvenile clasts. The physical characterisation of the Waiteariki Ignimbrite is the first step to unravelling the extent of explosive volcanism during the initiation of the TVZ. Future work will focus on mineral phases and mineral-hosted melt inclusions, which will provide insights into the magmatic system that fuelled volcanism of the Tauranga and Kaimai volcanic centres.

ICE DYNAMICS AND OCEAN PRODUCTIVITY DURING THE LATE MIOCENE OFFSHORE WILKES LAND, EAST ANTARCTICA

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The middle Miocene (~14 Ma) is characterised by an abrupt ~1‰ increase in $\delta^{18}O$, associated with the significant advance of the East Antarctica Ice Sheet (EAIS). Previously interpreted to mark the transition to a hyper-arid climate, and a stable polar-style ice sheet. However, evidence suggests continued instability and abundant meltwater along low-lying margins during the late Miocene (11.6–5.3 Ma). This has been identified in Ross Sea and in the Pagadroma Group (Prydz Bay). Here, we investigate International Ocean Discovery Program (IODP) U1361A, located offshore the Wilkes Land margin, to assess the variability of the EAIS in the Wilkes sub-glacial basin, one of the largest marine-based sectors.

This work aims to establish the response of the EAIS during the late Miocene, and assess the relationship to primary orbital configurations, when mass balance may be directly influenced by substantial surface-melt. Additionally, investigating offshore plankton productivity along the margin, during periods of potentially enhanced meltwater discharge. The study interval of U1361A contains twelve intervals of nannofossil ooze, interbedded with laminated mudstones and diatom-bearing mudstones. Here, we identify the orbital configurations during this carbonate deposition and how changes in the planktonic response to orbital forcing can be driven by the background climate state, and nutrient supply from enhanced glacial meltwater.

To identify, what sedimentary processes influenced the biological systems, we have developed a high-resolution record (~450 samples) of iceberg rafted debris (IBRD), grain size and bulk geochemistry. Pilot samples have been assessed for lipid biomarkers. Preliminary results show lower amounts of IBRD compared with the Plio-Pleistocene indicating iceberg rafting was reduced. Peaks of IBRD correlate to Si/Al and diatom-rich facies. Ca/Al correlate to the alternating nannofossils. Biomarker analysis indicates presence of alkane leaf waxes and hopanes, with insignificant abundances of alkenones. Preliminary spectral analysis of the IBRD shows strong eccentricity (100 kyr), with a possible switch to obliquity (41 kyr) in the upper part of the record.

STRATIGRAPHIC REVIEW OF THE NEW ZEALAND JURASSIC FLORA

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In New Zealand, Jurassic fossil plants are known from the Drumduan, Murihiku, and Torlesse Composite terranes, which bordered the Antarctica–Eastern Australia segment of Gondwana in the Jurassic. Taxonomically, the macrofloral and palynofloral assemblages are similar to those of Eastern Australia, with prominent filicalean, cycadophyte, and coniferophyte (especially cheirolepid, araucarian and podocarp) components.

The Murihiku Terrane includes a more or less continuous outcropping sequence of shallow marine to non-marine strata from the Late Permian through to the Late Jurassic, with some gaps and possible extension into the Early Cretaceous. Miospore palynofloras have been recovered from macrofaunally-dated marine as well as non-marine strata, and a zonation for the Early and Middle Jurassic has been proposed. Late Jurassic palynofloras have been less studied, although reconnaissance studies show richly diverse dinoflagellate assemblages are present. At the top of the outcrop sequence in the Kawhia Regional Syncline, the fluvio-lacustrine Huriwai Group overlies early or middle Tithonian marine strata but contains an apparently pre-Cretaceous miospore palynoflora correlated with the Australian *Retitriletes watherooensis* Zone. Distribution of significant macrofossil assemblages reflects that of non-marine strata which, except for the Huriwai Group, are mostly of Middle Jurassic age (New Zealand Temaikan Stage).

To the west of the Murihiku Terrane, the volcanic arc-related Drumduan Terrane in Nelson includes a mid-Jurassic macroflora, but the lawsonite-facies metamorphic rank is too high for palynomorph preservation. To the east, Middle to Late Jurassic macrofossil and palynomorph assemblages are known from the Torlesse Composite Terrane. This unit, which includes a diverse array of highly deformed marine delta-front to coastal plain facies, may have been tectonically translated from a more northerly location but floras are similar to those of the Murihiku Terrane.

PATHWAYS FOR ATMOSPHERIC CO_2 INTO CHEMICAL WEATHERING PROCESSES

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Surficial weathering processes (i.e., the conversion of rock to regolith to soil), in mountainous systems consume large volumes of atmospheric CO_2 through dissolution reactions with silicate minerals. In large-scale models, mechanisms of silicate weathering are commonly simplified to carbonation by passively sourced atmospheric-CO_2.

Recent work reports an absence of weatherable minerals containing biologically limiting nutrients in quickly weathering New Zealand soils. This suggests the potential presence of a biota-driven weathering mechanism. Here we present an investigation of facilitated diffusion of atmospheric CO_2 by metabolic processes (i.e., CO_2 respiration, exoenzymes etc.) into the weathering zone. We present a comparison of two simple chemical weathering models derived from empirical data where: (1) CO_2 is sourced from the atmosphere; and (2) CO_2 is sourced from biologic processes.

MID-CRETACEOUS RUDIST ASSEMBLAGE FROM THE LHASA BLOCK, TIBET, CHINA

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Rudists are sessile molluscs that belong to the order Hippuritida and lived in the margins of the Tethyan–Atlantic–tropical Pacific oceans from the Oxfordian to the end of Cretaceous. They differ from other bivalves by their bizarre shell shape. In mid-Cretaceous times, shallow marine rudist-bearing deposits were widely distributed over the Lhasa block, represented by the Langshan Formation in its northern part, and the Sangzugang Formation in scattered outcrops along its southern margin. A total of four rudist taxa had been distinguished from the Lhasa block by the author: (1) *Auroradiolites biconvexus*, (2) *Magallanesia rutogensis*, (3) *Eoradiolites* cf. *hedini* and (4) *Sellaea* sp. *Auroradiolites* was established for a group of SW Asian to Pacific endemic radiolitids, which were originally assigned to *Prearadiolites* but now are regarded as *Eoradiolites*. *Auroradiolites* differs from *Eoradiolites* mainly by their compact outer shell layer (OL), slightly or strongly convex left valve (LV), and strongly developed myocardinal apparatus and invaginated ligament. Compared with the type species *A*. *gilgitensis*, the Tibetan *A*. *biconvexus* is characterized by a more convex LV and radial undulation in the OL of right valve (RV). *M*. *rutogensis* is featured by the rather thick OL, sub-equal teeth, and the single row of pallial canals that subdivided the posteroventral cavity of the LV. *E*. cf. *hedini* is characterized by mixed compact and cellular calcitic OL, short, truncated ligamentary infolding in the RV, and a slightly convex LV. *Sellaea* sp. shows typical features of a relatively thin OL, an erect posterior myophore and adjacent broad posterior ectomyophoral cavity in the RV. This rudist assemblage is probably late Aptian to Albian in age, which is confirmed by the association with orbitolinids in the Sangzugang and Langshan formations.

NATIONALLY SIGNIFICANT AND IMPORTANT GEOSCIENCE COLLECTIONS AND DATABASES

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Most of New Zealand's geoscience information comes from our own research institutes and universities, commonly acquired and processed in collaboration with international partners. To re-use this information beyond the immediate requirements of the research project for which it is generated, that is, by the wider community in the future, this information must be findable, accessible, interoperable and re-usable.

GNS Science provides key geoscience information such as geological maps and stratigraphy, rock and mineral properties data, fossil and age data, mineral and petroleum earth resource information, groundwater and geothermal fluid chemistry data, active faults, landslides, earthquakes, tsunami hazards information and a myriad of geophysical and environmental datasets. These are managed and developed in an applied research framework for end-users. International data standards are increasingly being embedded into many of these datasets to enhance their interoperability and versatility, including in data analytics and other machine learning applications.

The accessibility of New Zealand geoscience information through web services has improved significantly for end-users. With these services and the increasing adoption of common data models and terminology, New Zealand is well-placed to participate in the application of global data mining and other artificial intelligence methods to capitalise on our enormous data wealth.

NEW GEOLOGICAL MAPS AND GEOLOGICAL DATA PRODUCTS

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New Zealand's latest geological maps and associated data products are being produced as part of the GNS Science Geological Map Series with Nationally Significant Collections and Databases funding. Five map product publications have been completed in the series. The first, the GIS-based Geological Map of New Zealand 1:250,000 dataset in 2014, seamlessly integrates all 21 QMAP print- and GIS-published geological maps. This dataset has recently been substantially upgraded as a second edition (2018). The second map publication is the second edition 1:1 Million Geological Map of New Zealand based on simplification of the QMAP series. This map was printed as North Island and South Island sheets in 2015 and an explanatory text for them was published in 2017.

The third map publication is the Geology and geomorphology of urban Christchurch and eastern Canterbury, a digital-only product that includes a geomorphological map/GIS dataset, an explanatory text and 3-D models, two geological (eastern Canterbury, Christchurch City) and one geotechnical (inner Christchurch).

The fourth map publication is the Geology of the Middlemarch area at 1:50,000 (2016), another digital-only product containing a geological map and associated GIS data with an explanatory text. This map integrates aeromagnetic and electromagnetic data interpretation and includes geophysical images as part of the GIS product. The fifth map publication is the Geology of the Tongariro National Park area (2018) comprising a printed geological map at 1:60,000 and an explanatory text. An equivalent GIS dataset is still in production.

Further map products are in progress; Victoria Range and Reefton Goldfield geological maps at 1:50,000 and urban geological and geomorphological map products for Napier–Hastings, Dunedin and South Auckland. Printing of geological maps will become increasingly rare and reserved for anticipated high-demand maps, with physical media delivery expected to be supplanted by internet-downloadable products.

ASSESSMENT OF THE EFFECT OF GEOTHERMAL UTILISATION ON RESERVOIR PROCESSES INFERRED FROM INSAR (INTERFEROMETRIC SYNTHETIC APERTURE RADAR) MONITORING OF GROUND DEFORMATION: EXAMPLE OF THE REYKJANES HIGH-TEMPERATURE GEOTHERMAL SYSTEM, SW ICELAND, 2015–2017

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InSAR is a satellite imaging technique that can be used to monitor ground motion induced by geothermal utilisation. Interferometric analyses of Sentinel-1A and 1B images offers new opportunities to create time series of deformation with a high temporal resolution, due to a satellite revisit time of 12 days since 2014 and 6 days since 2016. We generated series of interferograms in ascending and descending orbits to determine the average line-of-sight (LOS) displacement rates of the surface above the high-temperature geothermal reservoir of Reykjanes, SW Iceland, between April 2015 and October 2017. The approximate vertical and east displacement rates were estimated at coherent pixels, indicating a steady and linear subsidence within a sub-circular bowl centred on the well field together with horizontal contraction. The LOS velocities were inverted to determine the depth and the contracting rate of the deformation source by modelling the geothermal reservoir as a body of simple geometry within an elastic half space. Using pressure–temperature monitoring data from geothermal wells at the source's depth, the reservoir structure and the rocks properties, we suggested that the recent estimated volume change can be attributed to a combination of compaction under pressure decrease and/or thermal contraction due to cooling of the rocks within or near a steam cap situated in the topmost part of the reservoir. In addition, we compared the production history with long-term InSAR deformation studies and modelling results for earlier time periods to identify and characterise changes in the deformation mechanisms and processes occurring over time in the produced reservoir. The quality of the results obtained with Sentinel-1 data at Reykjanes for a period of only two years here gives promising opportunities to monitor "real-time" effects of geothermal production and to support the management of resources located in low vegetation areas in New Zealand at a very low cost.

HYDROGEOLOGY OF THE POUREWA STREAM SUB-CATCHMENT, LOWER NORTH ISLAND, NEW ZEALAND

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The Pourewa Stream, a tributary of the Rangitikei River, provides a unique cross section through rural landscapes of New Zealand. The stream dissects the Whanganui Basin, a marine basin with one of the most complete Quaternary stratigraphic records exposed on-land anywhere in the world. Preservation of alternating coarse and fine-grained sediments deposited during sea-level cycles has resulted in a curious display of perched water tables, springs and seeps in a geologically young landscape. Gravel entrained from the Rangitikei Rivers' headwaters forms an important constituent of the valley fill. Faults and corresponding basement highs run approximately NE–SW up the valley, providing a control on the underlying nature of the Plio-Pleistocene sediments and modern-day drainage network.

Agriculture constitutes 90% of land use in the region, placing pressure on fresh water resources required for ongoing agricultural development and production. Recent concerns around the availability and long-term sustainability of freshwater resources have initiated research into the local groundwater systems. Limited knowledge and information is currently available on local-scale hydrogeological settings within the region, including a present knowledge gap concerning the hydrogeochemical characteristics of its various rock types. A sound understanding of local hydrogeology is necessary for improved mapping and quantification of the regions groundwater resources. Furthermore, this is essential information for improving our understanding and ability to map and quantify water and nutrient flow pathways from farmlands to receiving waters, informing practices and policies for targeted and effective water quality management. This study investigates the hydrogeology of a single sub-catchment of the Rangitikei to aid with development of local scale knowledge. Preliminary results from analysis of the main representative catchment lithologies are discussed with respect to their potential to store and transmit water. Relationships observed involving ground water flow are explored with the aim of providing an overview of the areas hydrogeology.

SEISMIC CHARACTERISATION OF OTAGO HARBOUR SEDIMENTS TIED TO A CARBON-DATED CORE RECORD

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Otago Harbour contains a largely unexplored geological record, that only now is being investigated and understood. The harbour geology, presumed to be primarily Quaternary in age, is an important record of past climate fluctuations, sea-level change and potentially extreme events such as earthquakes and landslides. The geology of Dunedin and the surrounding Otago region has been well documented and understood using land-based observations; however, little investigation has been done into what lies beneath the surface of the harbour. The submarine geology could provide evidence of the sedimentary and structural processes that have influenced the shape and dynamic nature of the present-day Otago Harbour.

Building on previous seismic reflection lines, two sets of lines were collected: in the region between Port Chalmers and Aramoana in the outer harbour and in the vicinity of Portsmouth Drive in South Dunedin in the inner harbour. The seismic data collected across the harbour were processed to provide representative cross-sections of the geology of Otago Harbour. The seismic sections were used to propose representative sedimentary horizons, which allowed comparison with sediments cored from the Edgar Centre in South Dunedin.

To constrain changes in sedimentation within the harbour that were observed in the seismic data, a number of organic samples from the Edgar Centre core have been radiocarbon dated showing that the upper 17 m or so of the core is Holocene in age. Additionally, the core was scanned using portable X-ray fluorescence to create an elemental analysis log. These elemental counts were used to produce elemental ratios along the core's length, indicating several changes in the depositional environment as well as changes in the regional climate during times of deposition.

LARGE RECENT EARTHQUAKES LEAD TO INCREASED PROBABILITY OF LARGE EARTHQUAKES IN CENTRAL NEW ZELAND

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The EEPAS (Every Earthquake as a Precursor, According to Scale) earthquake forecasting model contributes to GNS Science's published hybrid earthquake forecasts and to the seismic hazard models developed following the Canterbury and Kaikōura earthquakes. The model is based on the observation that seismicity tends to increase in frequency and earthquake size prior to large earthquakes. It applies empirical scaling relations derived from examples of this seismicity increase to calculate the contribution of an individual precursory earthquake to the rate density of earthquake occurrence at a future time, magnitude and location. The model has two components, a background and a time-varying component, and there are different versions depending on the fitting area and the size of the magnitudes of interest. Recently we corrected the EEPAS model forecasts for the earthquakes that are expected to occur between the time of the forecast and the end of the forecast period. For this correction, we estimated the completeness of the precursory earthquake contributions at a given target magnitude when forecasting with a given time lag. We considered two end-members for compensating for incompleteness, by augmenting (1) only the background component, and (2) only the time-varying component of the EEPAS model. Using the New Zealand earthquake catalogue, we derive an optimal combination of these two end-members for different target magnitudes and time lags and illustrate the effect on forecasts of major earthquakes in central New Zealand. Here we explain this most recent update of the EEPAS model and discuss the increased probabilities between 2019 and 2030 for central New Zealand.

A NEWLY IDENTIFIED OCEANIC ANOXIC EVENT AT THE NORIAN–RHAETIAN BOUNDARY

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The upper part of the Late Triassic was an interval of prolonged and stepwise biotic extinction which culminated in the so-called End-Triassic Extinction (ETE), close to the Triassic–Jurassic boundary (TJB). More precisely, the onset of this interval in European sections occurred within Sevatian 1 (late Norian) time, with a first severe extinction "event" at the Norian/Rhaetian boundary (NRB). This time interval of ~5 million years is associated with a significant perturbation of the global carbon cycle and is interpreted to have been triggered by unusually high volcanic activity of the Angayucham Province. The volcanogenic CO_2 emitted by this magmatic province to the ocean–atmosphere system accelerated chemical weathering. This in turn increased nutrient discharge to the oceans and, consequently, increased biological productivity. Higher primary productivity and oxidation of organic matter led to subsequent anoxic conditions of the NRB oceans. The onset of this interval of declining diversity is attributed to a previously unrecognised oceanic anoxic event (OAE) of global extent at the Norian–Rhaetian boundary (NRB).

BASEMENT MORPHOLOGY UNDER THE TONGARIRO NATIONAL PARK, SOUTHERN TAUPŌ VOLCANIC ZONE

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Gravity data recorded across the Tongariro National Park during the 1950s are interpreted in terms of the morphology of the presumed greywacke basement underlying the younger surficial sediments and volcanics. The gravity data were processed to Bouguer anomalies at a height of 500 m (the average elevation of the survey region). These anomalies were then separated into regional and residual anomalies after deriving a smoothly varying regional anomaly based on observed values at stations on greywacke outcrops in the region. Density–depth relations for sediments were derived from measured values in boreholes. Simple 2-D gravity models using these density relationships were used to derive a 3-D structural model for the region. The final model shows a deep trough with a steep eastern margin running from the south end of Lake Taupō (2.5 km deep) and under Mt Tongariro (1 km deep) before fading away as a major feature near Mt Ruapahu.

THE MOROCCAN ATLAS AS A MEETING PLACE OF EARLY AND MIDDLE JURASSIC AMMONITE FAUNAS FROM DIFFERENT PALAEOBIOGEOGRAPHIC PROVINCES: MEDITERRANEAN, EURO-BOREAL, ARABIAN AND PACIFIC

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During the Jurassic, the Moroccan Atlas was located on the southwestern paleomargin of the Tethys at the junction with the proto-Atlantic ocean. For this reason, it was a true paleobiogeographic cross-roads where faunal associations resulting from interaction of Mediterranean faunas with those of Euro-boreal, Pacific and Arabia have been recorded through time as follows:

(1) During Pliensbachian times, ammonites present in the High Atlas show a clear-cut mesogean character, since they are dominated by Hildoceratids (a distinctly "Italian fauna") and which have certain elements that share a common origin with those of western America. During the late Pliensbachian, the boreal Amaltheids fauna is absent, but it is known from other regions of the Atlasic domain.

(2) During Toarcian times, the ammonoid display both a mesogean character (early Toarcian, Gradata, Bonaralli, Speciosum and Meneghinii zones) and also ubiquitous elements which are equally known in the Mediterranean domain and Western Europe (Bifrons and Aalensis Zones). On the other hand, during the early Toarcian the Arabian fauna, including *Nejdia* and *Bouleiceras*, is also missing. However, these taxa are known from other regions of the Atlasic domain.

(3) During Aalenian and early Bajocian (Discites Zone) times, ammonites show affinities with both mediterranean faunas (Tmetoceratinae. Grammoceratinae, Hammatoceratinae, Erycitinae, Zurcheriinae and Bradfordinae) and euro-boreal faunas (Graphoceratinae). *Staufenia*, a typically boreal genus, is absent, but some Pacific elements (*Asthenoceras* and *Fontannesia*) are present. Furthermore, at the base of the Laeviuscula Zone, some taxa with western American affinities (*Newmarracarroceras*, *Zemistephanus*) and certain Sonninids (*Fissilobiceras*) from British Columbia are present. During the Propinquans and Humphriesianum zones, the ammonoid fauna is represented by a cosmopolitan association dominated by Stephanoceratacea.

(4) During late Bajocian times, the presence of rare Arabian elements is noted ("*Clydoniceras*").

This brief overview of the composition of Moroccan Atlas ammonoid faunas shows that faunas from the Mediterranean Tethys area was influenced several times by faunas from diverse paleobiogeographic provinces. Homogenisation events appear to coincide with periods of sea-level fluctuations. The similarities between High-Atlas and Betic faunas are striking.

CRETACEOUS FAULT EVOLUTION IN THE GREAT SOUTH BASIN: OBSERVATIONS FROM FAULT GROWTH ANALYSIS

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The architecture of the sedimentary fill and rift faults are well preserved in the Great South Basin (GSB), providing unambiguous information on the timing, extent and distribution of faulting related to rifting. This study includes an interpretation of high-quality and regionally extensive 2-D seismic data that have recently become available and focuses on a detailed analysis of fault growth and rift architectures in the basin.

Three phases of rifting (early rift, rift climax and late rift) are identified in the GSB during the period of rifting (112–83 Ma). The early rift phase is characterised by the development of broad half-grabens and mainly occurred in the central and southern part of the GSB. Sediments deposited during this phase are restricted to fault-bounded grabens/half-grabens and fault displacements are <600 ms (two-way time, TWT). The rift climax phase is characterised by widespread and large-scale faulting in the GSB with maximum fault displacement of ~1400 ms. Two main sets of faults (NE–SW and WNW–ESE trending) are observed in association with these two initial phases of rifting. Northeast-trending faults are widespread and dominantly controlled deposition of rift sediments. West-northwest trending faults trend parallel to the basement terranes. The late rift phase is characterised by NE-trending faults with smaller throws (<250 ms), lower fault density and a continuation of graben filling. Some of the rift fault systems became reactivated during the post-rift phase in the Late Cretaceous (83–66 Ma), however, fault displacements are <30 ms. Four different architectures of rifting are observed in the GSB: (1) a single broad half graben controlled by a basin-bounding master fault, (2) a series of half-grabens with a segmented fault-complex at the footwall side, (3) a series of half-grabens with simple basin-bounding master faults, and (4) grabens bounded by master faults.

DRILLING INTO MAGMA: APPLICATION FOR NEW ZEALAND GEOTHERMAL ENERGY

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Can we get more energy from our geothermal resources? Based in Iceland, the Krafla Magma Testbed project (KMT) is an international collaboration aiming to drill into, sample, manipulate and study magma to understand its resource and hazard potentials. Past experiences of geothermal wells intercepting magma or supercritical systems (from Iceland, Kenya, USA, Japan and Mexico) show that energy extracted at the boundaries of magma chambers can allow extraction of one magnitude greater power than conventional wells. Magma intrusions can be found at less than 4 km depth and can be reached by drilling moderately deeper in existing geothermal fields, with minor impact on the environmental footprint. The potential to access unprecedentedly powerful renewable energy leads KMT to investigate the response of magma bodies to drilling, methods of drilling material under challenging conditions, and the suitability of shallow magmatic systems for long-term energy production.

As part of the project, our research investigates quenched magmatic chips from an accidental encounter with magma (IDDP-1 well, Krafla). Our results suggest a series of semi-isolated sequentially-tapped melt pockets atop the magma body. Measured OH/H_2O ratios also indicate an increasing quenching temperature during drilling across the rock–magma interface. In addition, our field studies of rock mass properties associated with shallow rhyolite intrusions in Iceland highlight a correlation between intrusion thicknesses and physio-chemical damage to country rocks. These data allow better estimations of changing rock and magma properties as a drill hole approaches and enters a magma body.

MEASURING EARTHQUAKE-INDUCED DAMAGE IN VOLCANIC ROCKS

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The characterisation of earthquake-induced damage to a volcanic edifice is complicated by the inherent heterogeneity of the volcanic system. This heterogeneity scales from large-scale fracture networks all the way down to pores and cracks in rocks, which can dictate the strength and ductility of a material. Although earthquakes are known to impart permanent strain on material, and in some cases trigger landslides, the degree of damage in rocks with varying physical properties is rarely systematically measured. Here, we aim to characterize the specific conditions for earthquake waves to impart damage to volcanic material by subjecting dacitic dome rocks from Unzen Volcano, ranging from 15–35% porosity, to repetitive seismic loading laboratory experiments in uniaxial compression and tension. Samples begin under a percentage of their expected failure load, and earthquakes are simulated by varying the piston position within 5% of the hold position. Damage is measured using real-time acoustic and strain rate data during the test. Results indicate that damage, or permanent strain, is accumulated with subsequent earthquake oscillations, although it tends to be more pronounced in the beginning of the experiment. This study has applications for measuring damage in rocks masses after stressing events, and numerical modelling of earthquake-induced landslides.

DIAPIR PIERCEMENT THROUGH THE OCEAN FLOOR: NEW EVIDENCE FROM SANTOS BASIN, OFFSHORE BRAZIL

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Diapir piercement through the ocean floor marks the final stages of a dynamic migration path. Once exhumed, a diapir extrudes from the seafloor, placing an obstacle for the flow of ocean bottom currents. While the hydrodynamic response of the flow has been previously studied, the detailed depositional and weathering modifications involved in the piercement process are less understood. To bridge this gap, we gathered already available multibeam bathymetric data and multichannel 2-D seismic reflection profiles and collected new single-channel CHIRP profiles, Acoustic Doppler Current Profiler data and sediment samples across Santos Basin, offshore Brazil. In this region, the processes connecting the uppermost sub-surface with the lowermost section of the water column are unknown. Data show three main stages of diapir exhumation: pre-, syn- and post-piercement into the seafloor. Extensional faults crown the pre-exposed diapir before its piercement through the seafloor. Ocean bottom currents rework the top of the faults to form elongated depressions. The bottom currents tightly detour the diapir during and after its exposure at the seafloor. This interaction forms a drift and moat contourite depositional pattern. Our high-resolution data allow us to relate these morphologies to seafloor processes and distinguish them from other reflector geometries related to diapir flank deformation, such as outward dipping of reflections. We further use this geometrical distinction to suggest a key for interpreting the exposure versus burial history of other diapirs worldwide.

INTEGRATED GROUND, MARINE AND AEROMAGNETIC STUDY OF THE KINNERET–KINAROT TECTONIC BASIN ALONG THE DEAD SEA TRANSFORM, NORTHERN ISRAEL

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High-resolution magnetic mapping is crucial for understanding the spatial distribution of magmatic lithologies and geological structures. Aeromagnetic and common marine surveys deliver lower resolution regional coverage with a high cost. Ground surveys are much cheaper, yet their coverage is limited to site surveys. Quantitative integration of varying datasets is one of the challenges of the magnetic method. These datasets differ in the type of acquisition equipment used, geographical coverage, measurement height, distance between measurement points and profiles and use of different datums. Here we tackle these challenges through (1) designing a new method for collecting high-resolution magnetic data using a bike as the equipment carrier; (2) applying a new multi-layer modification of the equivalent source technique to integrate all available data sources (ground, marine and air); (3) constructing magnetic anomaly maps of a 45 × 65 km area. The unprecedented 1-km grid resolution of the calculated TMI and RTP maps allows for the first time the magnetic data in conjunction with independent geological, geochronological and geomorphological data to be interpreted. Results show a high correlation between mapped volcanic centres and RTP anomaly peaks, between the spatial extent of volcanic units (outcrops and subcrops) and the coverage of magnetic RTP anomalies, and between the distribution of faults and lateral truncation of RTP anomalies.

STRUCTURAL EVOLUTION OF SOLANDER BASIN AND IMPLICATIONS FOR REGIONAL DEFORMATION IN SOUTHERN ZEALANDIA

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The Solander Basin is perched on the shelf underlain by continental crust of Southern Zealandia, which is immediately north of the 45–30 Ma southeast Tasman–Emerald Basins (SETEB) formed by mid-ocean ridge spreading. The structure and tectonic history of the Solander Basin constrains the geometry of the northern SETEB and its relation to faulting south of the New Zealand landmass. Here we analyse 147 2-D seismic reflection lines mainly tied to the Solander-1 and Parara-1 wells to determine the geometry, kinematics and timing of structures in the Solander Basin from the late Eocene to late Miocene. The seismic stratigraphy is interpreted to indicate pre-Miocene extensional faulting followed by late Miocene contraction. In many cases this shortening reactivates earlier normal faults and produces basin inversion. Extension in the Solander Basin produced fault throws of up to 0.7s two-way time (TWT), which is significantly less than the 5.2s TWT inferred for the main normal faults bounding the SETEB immediately south of the basin. We infer that much of the extension of the SETEB passes west of the Solander Basin with this deformation appearing to terminate close to the Fiordland coastline. Late Miocene reverse faults and associated folds accommodate ~15% shortening across the Solander Basin and do not appear to produce significant deformation of the SETEB. The timing of contraction is approximately synchronous with increased shortening of the Alpine Fault and Taranaki Basin, and could reflect a New Zealand-wide deformation event. Presently, there is no clear evidence in the available seismic reflection lines for significant strike-slip and we infer that if such strike-slip did occur, it was most likely west of the Solander Basin.

RECONSTRUCTION OF THE FOSSIL FISH FAUNA (TELEOSTEI) FROM NEW ZEALAND USING OTOLITHS

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Fossil bony fish faunas are reconstructed by studying articulated skeletons and otoliths. Articulated skeletons offer unique insight into character evolution but require specific taphocoenoses to be preserved. Otoliths are much more common in the geological record and are represented in a large variety of environments. A monograph of early Eocene to late Pleistocene marine fossil otoliths from New Zealand has yielded 389 otolith-based species and the assemblage ranks as one of the most complete of any worldwide.

Eocene otoliths indicate a Tethyan origin. Putative endemic groups played a major role, although many represent extinct lineages. Immigrants from the Weddellian bioprovince arrived during the late Eocene. After a Runangan/Whaingaroan hiatus, the late Oligocene/early Miocene fish fauna shows a distinct shift away from Tethyan relationships. Southern Ocean temperate faunal elements gained significance following establishment of the circum-Antarctic current. Endemics flourished in the temperate Canterbury Basin province, while northern New Zealand contained many fishes with Indo-West Pacific connections. The first immigrants appeared from the North Atlantic (*Gadiculus*) and rare NW Pacific elements (*Micropercops*). The late Miocene to Pleistocene saw a gradual shift in faunal composition with the rise of southern temperate groups, predominantly mesopelagic Myctophidae and continuation of endemic groups (Hemerocoetidae, Moridae, Tripterygiidae). Ocean circulation changes led to increased immigration and dispersal of temperate fishes of different origin: gadids and macrourids from the North Atlantic, an arid catfish from South Africa and dispersal of previously endemic morids to the NE Pacific. Cool Southern Ocean mesopelagic myctophids occur for the first time. Of particular interest are the widely distributed mesopelagic Myctophidae, which today represent the largest biomass of any vertebrate at family level. They dominate all otolith associations below 100 to 200 m in the Neogene and their rich fossil record in New Zealand could help formulate zonations for southern temperate and subtropical faunal belts.

THE STONE JUG FAULT: FACILITATING SINISTRAL DISPLACEMENT TRANSFER DURING THE M_W 7.8 KAIKŌURA EARTHQUAKE

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The M_w 7.8 Kaikōura Earthquake initiated 15 km northeast of Culverden, New Zealand, on November 14th, 2016. The earthquake propagated northeast rupturing at least 17 faults in the northeastern South Island, including the Stone Jug Fault (SJF), which connects the Hope and Hundalee faults. Prior to the Kaikōura Earthquake only the northern 5 km of the SJF was identified. Preliminary field mapping and post-earthquake LiDAR interpretations indicate that the full length of the active trace is about 18 km long and has an average strike of north to northwest. At its northern and southern tips, the SJF rotates in strike towards a westerly orientation, as it approaches the Hope and Hundalee faults. Oblique sinistral normal faulting occurred along the majority of the traces examined, with approximately equal components of strike-slip and dip-slip. Displacements range from 0.05 to 1.1 m with an average of ~0.3 m. In the hill country south of the Charwell River terraces, at the northern end of the fault, the SJF is segmented and secondary faults trending at up to 70° to the main trace accommodated oblique displacements of up to 0.4m. These traces form a fault zone up to ~2.8 km wide and are often responsible for facilitating changes in dip-slip direction at the main trace. The sense of both strike-slip and fault upthrow direction changes along the fault, with about 30% of measured segments displaying dextral or reverse movement. From north to south the fault is upthrown to the southwest (4.5 km length), east (7.5 km length), west (3 km length) and finally to the northeast (3 km length). These changes in upthrow are generally associated with changes in the fault dip direction, segmentation, and basement fabric orientation. The SJF is currently interpreted as a displacement transfer structure operating between the Conway–Charwell and Hundalee faults.

DOUBLE BOOM: SEISMIC TRIGGERING AT CORDÓN CAULLE VOLCANO, CHILE

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It is now established that earthquakes can trigger volcanic eruptions, yet, the underlying mechanisms remain elusive. Here, we investigate the hypothesis that seismically-triggered eruption deposits exhibit significant textural differences, that can lead to insights into eruption triggering mechanisms. The 1960 eruption of Cordón Caulle, Chile occurred only 38 hours after the M_w 9.5 Great Chile earthquake, indicating a possible seismic trigger. The previous eruption in 1921, was not preceded by a large earthquake. We, thus, compared the bubble texture of pumice lapilli from the 1921 and 1960 eruptions. The two eruptions are similar in style, size and composition. We show that the 1960 clasts are consistently denser and present distinctive features. We then assessed whether these textural differences result from the earthquake or arise from inherent natural variability. Finally, we performed a similar analysis on the most recent 2011 eruption, which trailed the 2010 M_w 8.8 Maule earthquake by 16 months and consider the possibility that this eruption was seismically triggered, too.

THERMAL PROPERTIES OF BASALT SCORIA

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Basaltic volcanoes usually eject individual scoria clasts within the vent area, but if the rate of these ejections is high enough, these clasts will coalesce to form a spatter-fed lava flow. Here we attempt to understand the transition from individual scoria clasts to lava flow by investigating how heat is held and transferred within the volcanic rock. We have determined the thermal properties of several basalt samples collected from a scoria quarry near Taupō. The samples range in vesicularity from ~2% up to ~72%. A portable electronic divided bar apparatus was used to determine the thermal conductivity and specific heat capacity of samples. Thermal conductivity of the samples ranges from 0.4 to 1.52 W/mK, with higher vesicularity (more pore space volume) having lower thermal conductivity. The relationship between thermal conductivity and pore space is not linear, and presents as a mean square root relationship, suggesting that the thermal conductivity increases more rapidly when pore space is already low.

TIMING OF HISPANIC CORRIDOR OPENING AND MIGRATION ORIENTATION OF PAN-TROPICAL COSMOPOLITAN JURASSIC PECTINID AND OSTREID BIVALVES

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The temporal and spatial distribution of some pan-tropical cosmopolitan Jurassic epi-byssate pectinid and epi-cemented ostreid bivalves from Middle and Late Jurassic deposits in the Tanggula Mountains, northern Tibetan Plateau, China, which were restricted to paleo-latitudes between 60 °S and 60 °N, demonstrates that: (1) the Hispanic Corridor played an important role in connecting paleo-Pacific with Tethyan and European bivalve faunal provinces since the earliest Jurassic Hetangian, even earlier (end-Triassic), and (2) some pan-tropical thermophilous bivalve species, including *Camptonectes* (*Camptonectes*) *auritus*, *Chlamys* (*Chlamys*) *textoria*, *Actinostreon gregareum*, *Nanogyra nana*, and possibly *Chlamys* (*Chlamys*) *valoniensis* migrated across the vast palaeo-Pacific from east to west.

MICROSTRUCTURES AND CRYSTAL-PREFERRED ORIENTATION EVOLUTION OF HARZBURGITE AND LHERZOLITE XENOLITHS IN SUBCONTINENTAL LITHOSPHERIC MANTLE BENEATH EAST OTAGO, NEW ZEALAND

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To infer the tectonic evolution of upper mantle beneath ancient Zealandia, we have completed a quantitative microstructural analysis of harzburgitic and lherzolitic xenoliths from Trig L in East Otago, New Zealand. Microstructural observation shows that both olivine and pyroxenes have numerous subgrain boundaries. Some olivine subgrain boundaries were cut by orthopyroxene inclusions and orthopyroxene subgrain boundaries coincide with bent lamellae. Olivine grains have either curved or straight boundaries with ~120° triple junctions. For CPOs (crystallographic preferred orientations), olivine in two rock types are all dominated by AG- ((010) [100]/[001]) and/or A-type ((010) [100]) CPO, orthopyroxene have (100) [001] CPO in all samples and (010) [001] CPO in harzburgites, clinopyroxene have similar (010) [001] CPO in harzburgites and weak (010) [100] CPO in lherzolites. Most olivine and orthopyroxene CPOs are coherent (i.e., olivine [100] axes are parallel to orthopyroxene [001] axes). Initially, under high temperature (~1100 °C) conditions the upper mantle experienced diffusion creep with partial melting, which generated orthopyroxene (010) [001] CPO in harzburgites. Subsequent carbonate metasomatism (120–98 Ma) in harzburgites resulted in orthopyroxene replacement by clinopyroxene and a clinopyroxene CPO inherited from orthopyroxene. Olivine AG-type CPO generation mechanisms are mainly formed by deformation at melting conditions, however, lithospheric extension and static recrystallisation (by mantle decompression) also were also involved. Decompression related to asthenosphere upwelling lead to mantle cooling, so that lamellae appeared in orthopyroxene grains. The dominant deformation mechanism was dislocation creep in the absence of melt, which activated clinopyroxene (010) [100] CPO in lherzolites. Simple shear on Alpine Fault (from ~45 Ma) not only transformed olivine CPO to A-type dominant, but also cohered olivine and orthopyroxene CPOs, especially in harzburgites, orthopyroxene (100) [001] CPO in all samples were generated by this process.

NON-CONTACT MEASUREMENTS OF THE ELASTIC PROPERTIES OF ROCKS UNDER IN-SITU CONDITIONS

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The elastic properties of rocks are of interest to a wide range of geoscientists. From understanding fault zones to calibrating seismic exploration data, the relationships of porosity, mineralogy, fractures, fluids, and temperature to seismic velocity form an important component of many geophysical investigations. Elastic wave speeds are commonly recorded with ultrasonic transducers in the laboratory. To reproduce the immense pressure rocks experience in the sub-surface, measurements of these velocities on rock samples are commonly carried out inside fluid-filled pressure vessels. In the Physical Acoustics Lab, we substituted the transducers for a pulsed laser as the source and a laser Doppler vibrometer as the receiver, allowing us to precisely measure absolute displacements over a small area (<1 mm) without contacting the rock surface with equipment. These small-footprint laser ultrasound measurements provide high-resolution direct and coda wave velocities. However, laser ultrasound until now has been limited to atmospheric pressure and temperature, which does not replicate the in-situ environment of rocks. We have developed a system to perform measurements at high confining pressures (up to 40 MPa) and temperatures (200 °C) without encountering the electrical or mechanical issues associated with transducers. This is achieved by measuring a rock sample inside a gas-filled pressure vessel with two optical windows, allowing the source and receiver laser beams line-of-sight to the surface of the rock. The system recreates a range of shallow sub-surface geological environments. We present high-resolution in-situ wave speed measurements of an Alpine Fault mylonite and cataclasites from the Deep Fault Drilling Project, demonstrating the dependence of the seismic velocity and anisotropy on pressure and temperature.

AN ABANDONED RIFT, A SINKING UNDERPLATE AND A SLIPPERY DÉCOLLEMENT: THE ALPINE FAULT PACEMAKER AND POSSIBLE TRIGGER MECHANISM?

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A broad magnetic anomaly, collinear bounding faults, localised surface exposure of associated magmatic rocks, and a high P-wave velocity anomaly in the lower crust together indicate the presence of an abandoned rift beneath the Greymouth–Hokitika area. The Kumara abandoned rift formed directly prior to Late Cretaceous initiation of Tasman Sea spreading centre, through continued movement on the locally dominant Pike Detachment Fault.

Fresh interpretation of a deep seismic profile indicates a sub-vertical shear zone exists in the mafic underplate of the rift. This allowed the relatively dense, isostatically unstable underplate to subside during Neogene plate boundary development, creating the Grey valley fault and a lower crustal décollement in the process.

Less deformed Pliocene–Recent strata indicate the underplate has generally reached isostatic equilibrium to the south of the rift axis. However, an isolated patch of recurring deep (80–125 km) earthquakes directly beneath the axis of the rift, as well as a remarkable absence of recorded crustal earthquakes in the eastern Grey valley, indicate the underplate has not yet gained isostatic equilibrium north of the rift axis. The underplate is currently subsiding in a hinge-like manner creating a sub-vertical shear zone extending to the base of the lithosphere beneath the axis of the rift, and a “slippery” décollement beneath the Grey valley.

It is plausible that this décollement is responsible for the regular earthquake recurrence interval observed on the Alpine Fault. If this is the case, there is a possibility that an Alpine Fault rupture may be preceded by a measurable slow-slip event on the décollement. Installation of well-placed continuous GPS stations are needed to monitor this, given the imminence of an Alpine Fault rupture.

GEOCHEMISTRY OF INTRAPLATE BASALTIC SYSTEMS IN NORTHERN NEW ZEALAND

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Small-scale intraplate basaltic systems are a significant albeit volumetrically minor component of the volcanic associations of northern New Zealand. In Northland, intraplate volcanism began at ~8 million years ago and has continued to the present. Discrete chemical compositions define a northern Kaikohe–Bay of Islands field with a lithospheric mantle source chemical signature, and to the south the Whangarei volcanic field with a subduction-modified mantle source signature. These Northland basaltic fields show a range of chemical compositions that indicate the involvement of crustal storage reservoirs. Further to the south, in the Auckland region, intraplate volcanism began with the Ngatutura volcanic field ~2 million years ago and migrated progressively northward through the South Auckland Volcanic Field (± 1 Ma) to the presently active Auckland Volcanic Field. Chemical compositions of these volcanic fields reflect a close connection to asthenospheric sources and imply rapid rise of magma from mantle depths. The compositional differences between Northland and Auckland volcanic fields indicate spatially separate but broadly contemporary sub-crustal sources that have responded differently to the late Cenozoic tectonic environment of northern New Zealand. The geochemical compositions of these young volcanic fields suggest static Northland sources and dynamic Auckland sources. In particular, the range of compositions observed in the Auckland Volcanic Field is interpreted to originate within a mantle mush zone that developed as upwardly convecting heterogeneous mantle rose above its solidus. The Northland volcanic fields have developed on thicker relatively stable continental crust. In contrast, the Auckland area volcanic fields overlie thinner crust and appear to show behaviour that is influenced by the activity of the active convergent plate boundary that underlies the central North Island.

VERTICAL GPS, TECTONICS AND EFFECTIVE SEA-LEVEL RISE IN NEW ZEALAND

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Measuring sea-level is traditionally done with tide gauges. These are referenced to the shore line. If, however, the land itself is moving up or down due to tectonics then the tide gauge is measuring the sum of tectonics and (global) sea-level change. Here we present data on vertical tectonic movements of the Earth's surface in New Zealand, computed from the processing of GPS data collected between 2000 and 2015 by 189 permanent GPS stations. We present an "Uplift Map" for New Zealand and an interpretation of the observations (Houlie and Stern 2017, EPSL 457: 292–301). Subsidence of >3 mm/yr is observed along southeastern North Island, from Napier south, and is interpreted to be due to the locked segment of the Hikurangi subduction zone. For a global sea-level change of ~3 mm/yr the effective sea-level change for this part of New Zealand is now ~6 mm/yr. On the other-hand there are parts of the western North Island coastline undergoing tectonic uplift of 1–2 mm/yr and in these areas the effective sea-level change will be less than the global rate.

The biggest signal in the GPS field is over a region of 100 × 50 km where subsidence has a maximum value of ~25 mm/y in the Taupō–Rotorua area. This vast area is fringed by areas of coeval uplift, and the overall pattern has been interpreted to be due to the action of shallow, episodic, mantle convection beneath the central North Island (Lamb et al. 2017, Nature 547: 84–88). From a hazards viewpoint, we identify the consequent southward tilting of the Bay of Plenty coastal plain as an issue for future flooding. Here the rate of tilt is 700 Radians/yr, which is an order of magnitude higher than tectonic tilting measured elsewhere in New Zealand.

CRUST AND MANTLE STRUTURE OF THE HIKURANGI PLATEAU: IMPLICATIONS OF HIGH UPPER MANTLE WAVE-SPEEDS FOR FABRIC CREATED BY FLOW IN THE HEAD OF A SUPERPLUME

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P-wave velocities of 8.7–9.0 km/s are documented in the shallow mantle of the oceanic Hikurangi Plateau (HP) just east of and beneath North Island, New Zealand. P-wave speeds this high represent a ~11% anomaly for sub-Moho depths, yet a simple azimuthal anisotropy explanation is ruled out because we observe the high speeds on mutually perpendicular lines. The rocks with this high P-wave velocity are unlikely to be eclogite because of the high P-wave/S-wave velocity ratio (Vp/Vs; 1.95 ± 0.04), the shallow minimum depth (25 km) for the rocks, and gravity data that require the HP to be less dense than the regular adjacent oceanic lithosphere. We also observe a spectacular splitting of the Sn wave indicating ~10% radial anisotropy.

The HP is part of a much larger and now fragmented oceanic plateau, comprising the Ontong–Java, Manihiki and HP remnants (OJMHP) that together made up the most voluminous Large Igneous Province (LIP) on the planet. Similar high P-wave velocities, at comparable depths to the HP, have been observed on mutually perpendicular seismic lines beneath the Manihiki Plateau and Siberian Traps. We suggest that these high wave velocities, with no significant azimuthal anisotropy, but strong radial anisotropy, are a feature of the shallow mantle beneath very large LIPs. This combination of high velocities, in horizontal orientations, is typical of the anisotropy in olivine for the so-called 'AG' crystallographic fabric, caused by radial dilation together with vertical contraction. Such a strain fabric is difficult to explain by general convective flow related to plate tectonics. We show, however, with a simple numerical model that it is a characteristic feature for the heads of very large plumes. Thus, the high mantle P-wave velocities (>10% velocity anomaly), with this type of anisotropy, could be a characteristic seismic signature of past super plumes.

SEDIMENTARY PROCESSES WITHIN THE HOLOCENE HIKURANGI CHANNEL

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Off the east coast of New Zealand lies one of Earth's longest and most enigmatic deep-sea channels, the colossal ~2000-km-long Hikurangi Channel. Unlike submarine channels of a similar size, it is located along a destructive convergent tectonic plate boundary, transports coarse-grained sediment and is thought to be geologically young.

During the Holocene, the Hikurangi Channel is thought to have been largely inactive, with relatively small volumes of sediment entering the channel via the Kaikōura Canyon. However, the Kaikōura 2016 Earthquake, revealed that significant sediment flushing of multiple canyons and generation of co-seismic turbidity currents is possible and that the Hikurangi Channel may be more active than hitherto realised.

Here we present a comprehensive overview of 20 sediment cores from the Hikurangi Channel that we use to demonstrate a staggering array of gravity flow processes that have been active during the Holocene. Our dataset comprises a series of short cores. We quantify the physical, chemical and biological properties of the strata focussing on depositional processes that occurred prior to November 2016.

In this poster presentation we highlight active processes and deposit types from four canyons that feed the Hikurangi Channel, these include Pegasus, Kaikōura, Opouawe and Cook canyons. Next, we highlight deposit characteristics longitudinally for 600 km along the channel. A comparison of channel thalweg and overbank deposits reveals insights into turbidity current flow structure and vertical and longitudinal stratification. Where possible, we have used ^{14}C radiocarbon ages to develop basic core chronologies that allow us to show bulk sedimentation rates and make correlations between cores. Preliminary results reveal a complex array of Holocene processes and surprisingly high sedimentation rates that appear to increase down-channel.

NORTHERN ZEALANDIAN CENOZOIC SEDIMENTATION AND DEFORMATION CONSTRAINTS FROM IODP VOYAGE 371

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Six new boreholes were cored in North Zealandia on International Ocean Discovery Programme (IODP) voyage 371, providing a substantial increase in knowledge of Cenozoic sedimentation and deformation across the region. The expedition, titled "Tasman Frontier subduction initiation and paleoclimate", aimed to drill boreholes at targeted sites where structures key to elucidating the tectonic history of the region were identified on multi-channel seismic data. Sediments recovered from four of the six boreholes during this voyage were predominantly calcareous oozes and chalks from Eocene to Recent age. These carbonates contained siliceous fossils in the Eocene and are variably diagenetically altered. Older sediments were sampled in two boreholes. Paleocene and Cretaceous clays were cored in the southern New Caledonia Trough and in the Tasman Sea abyssal plane. Microfossils were used to date lithological changes in all boreholes but constrain the timing of observed deformation events the boreholes need to be tied to horizons on co-incident multi-channel seismic data. Two of the six boreholes were wireline logged allowing simple borehole ties to seismic data. The remaining four required the application of methods to convert laboratory core measurements of physical properties to in-situ physical properties to produce a synthetic seismic trace that mimics co-incident multichannel seismic data. We present new lithologic data, and deformation ages from borehole ties to seismic lines for the six new IODP boreholes in North Zealandia that can be attributed to subduction initiation tectonics.

BECK INTERNATIONAL JADE RESEARCH COLLECTION

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In 2017, the late renowned pounamu/jade expert Russell Beck donated his scientific research collection of jade/pounamu to the national rock and mineral collection held by GNS Science. The Beck International Jade Research Collection is an internationally unique collection of ~1,500 specimens from all the major jade localities worldwide. Approximately half of the specimens are New Zealand nephrite and bowenite (pounamu) and related serpentine. There are many mineralogical and textural varieties, some with country-rock contact zones, as the samples were collected as much for their geological interest as for their beauty. It was Russell's wish that the collection remains intact as an active research collection that will promote further work on the unique properties and formation of pounamu/jade. It is housed in the National Petrology Reference Collection at GNS Science in Lower Hutt and is available to researchers who demonstrate an understanding of the cultural sensitivity of pounamu/jade. Any research involving New Zealand material will require close consultation with local papatipu rūnanga, who are kaitiaki of pounamu, and a clear pathway for keeping Te Rūnanga o Ngāi Tahu involved and partnered in the work. Researchers will be required to preserve the integrity of the natural uncut specimens as much as possible while carrying out any research.

In New Zealand, pounamu is deeply embedded in the essence of Te Rūnanga o Ngāi Tahu history, whakapapa, and traditions. It is treasured as both Ngāi Tahu's and New Zealand's icon mineral material, but the resource is under increased pressure, facing issues of sustainability, imported copies and trade marking. For many years GNS Science has worked to provide science that helps rūnanga understand, manage and protect the resource and has used pounamu to trace processes of erosion and gravel movement. It is expected the Beck International Jade Research Collection will become increasingly important for distinguishing genuine New Zealand pounamu from imported stone, and for understanding the source of archaeological artefacts. Since pounamu/jade has a complex internal crystal structure that makes it incredibly tough, the collection may also be of interest to those studying material property science.

LIFE ON THE WELLINGTON FAULT: MANAGING GEOLOGICAL COLLECTIONS AND EARTHQUAKE RISK

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GNS Science is home to New Zealand's national rock, mineral and fossil collections. The National Petrology Reference Collection (NPRC) is a "nationally significant" collection of rocks and minerals from on- and off-shore New Zealand, Antarctica and elsewhere. The National Paleontological Collection (NPC) is also a "nationally significant" collection, comprising fossil material from New Zealand, the Southwest Pacific region and Antarctica, with some overseas additions. Their status as nationally significant collections mean that GNS Science has a stewardship role in preserving them for the New Zealand Government. Collectively, the NPC and NPRC constitute more than 200,000 sample lots and many millions of individual specimens, dating from the earliest days of New Zealand geologic exploration in the late 1800s. The collections continue to grow by hundreds to thousands of samples per year, and samples are loaned nationally and internationally for scientific research. The NPC and NPRC are by far the largest collections of fossils, rocks and minerals housed in New Zealand, and are important earth science archives for the entire Zealandian–Southern Ocean region.

The collections are housed on-site at GNS Science in Lower Hutt, a few hundred metres from the surface trace of the Wellington Fault and within striking distance of other active faults that could generate major earthquakes, and on a floodplain adjacent to a significant river. Best estimates suggest that the Wellington region has an average return time of about 150 years for very strong or extreme ground shaking. Such proximity to this significant, active hazard means that steps must be taken to ensure the long-term security and integrity of the collections in the event of earthquake shaking, as well as other natural and man-made disasters. To that end, the collection managers have written and implemented disaster mitigation, preparedness and recovery plans for the NPRC and NPC. Here, we define the earthquake hazard posed by the Wellington Fault, assess the risk to the collections, and present steps taken to manage that risk.

HAZARDOUS MATERIALS IN GEOLOGICAL COLLECTIONS

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New Zealand's National Petrology Reference Collection at GNS Science includes samples of radioactive and asbestiform minerals and rocks. The legislative requirements for managing these potentially hazardous samples have recently changed as the Radiation Safety Act, Radiation Safety Regulations and Health and Safety at Work (Asbestos) Regulations were revised in 2016–2017. Steps have been taken at GNS Science to ensure legislative requirements are met, and procedures put in place to safely store and manage radioactive and asbestiform-bearing samples within the collection. These procedures may have application to other curated geological collections at New Zealand universities and museums involving potentially hazardous materials.

RAPID THINNING OF DAVID GLACIER AT THE LAST GLACIAL TERMINATION

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The reconstruction of the Antarctic Ice Sheet through time provides critical understanding of past, present and future global sea-level and climate change. Marine ice sheet processes, strongly influenced by ocean heat, have been monitored for less than 50 years yet large glaciers and ice sheets respond over longer time periods. Reconstructions based on geological evidence can extend this record over centuries to millennia, providing insights into the processes and rates of change that drive marine ice retreat. In this study, we document the long-term thinning of David Glacier, the largest outlet glacier in northern Victoria Land, Antarctica.

We present the initial results from our 2017 field season, where we sampled ice-transported cobbles and bedrock from nunataks adjacent to David Glacier. *In situ* cosmogenic nuclide exposure dating of glacial deposits, spanning from the modern ice surface to several hundred metres above, constrains the David Glacier thinning history. Exposure ages from glacial erratics deposited at two end-member field sites along the flanks of the glacier show, in high resolution, the rapid drawdown of the upper ice surface from 20,000–19,000 years ago. This record represents one of the first ever evidence for ice mass changes during this time interval and highlights the overall utility of terrestrial based ice surface reconstructions for the predictive modelling community. Ongoing process-based modelling studies aim to disentangle glacier sensitivity to topographic, climatic and sea-level controls.

SEVERAL FOSSIL PLANTS FROM THE MIDDLE JURASSIC OF XINJIANG, CHINA AND THEIR GEOLOGICAL SIGNIFICANCE

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Several well-preserved fossil plants were collected from the Middle Jurassic Xishanyao Formation of the Turpan–Hami Basin, Xinjiang Uygur Autonomous Region, northwestern China. One is Ginkgo hamiensis, and its immature male cones are cylindrical and catkin-like, with two longitudinal stripes on the stalk. The pollen grains are oblong or fusiform and monocolpate. By comparison with previously reported fossil records of Ginkgo plants, we determined that the this one different from all other reported species. The reproductive organs of the Ginkgo fossils described herein can provide valuable information for the study of Ginkgo plants. In addition, the pollen cones described are similar to the pollen cones of the extant Ginkgo, which strongly indicates that the morphology of Ginkgo plants may have remained highly conserved over millions of years.

The second plant fossil is a liverwort. Liverwort is considered one of the earliest divergent land plants. They are spore-producing and have small and simple thalli and show an alternation of generations between the independent gametophyte generation and the dependent sporophyte generation. However, liverworts are herbaceous and delicate in texture. They are presumably susceptible to mechanical damage and biological degradation compared to the vascular plants. Their fossil records are rare, and many of them are incomplete. The fossil liverworts from the Xishanyao Formation were classified and identified according to the general morphology and their anatomical features. They are mainly Marchantites, Pallaviciniites, Pelliaites and Ricciopsis. The stable carbon isotope compositions ($\delta^{13}C$) of Pallaviciniites sandaolingensis and Ricciopsis sandaolingensis were measured. The paleo-atmospheric CO_2 concentration of the early Middle Jurassic was reconstructed using the BRYOCARB model. According to the distribution of the related living species of the fossil liverworts, the paleoclimate of Hami Basin, Xinjiang during the early Middle Jurassic was humid and warm. It is noted that the fossil liverwort can be used as paleoclimate proxy. Fossil liverworts are important in shaping their paleo-ecosystems and are significant in understanding the origin and evolutionary history of land plants and terrestrial ecosystems more generally.

EVIDENCE FOR WARM CLIMATE FROM THE LATE MIDDLE JURASSIC DAOHUGOU FLORA, CHINA

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During the Middle Jurassic, the Daohugou fossil locality in eastern Inner Mongolia, China, was part of Eurasia in a complex paleogeographic situation with a diverse landscape. The Daohugou fossil-bearing strata are mainly lacustrine deposits, consisting of greyish-white to yellowish-white, tuff, tuffaceous sandstone, siltstone and shale, with a tuffaceous conglomerate at the base. The Daohugou Biota from these strata represents an unusual Jurassic terrestrial ecosystem. It is well-known worldwide for its abundant fossil remains, particularly the exceptional preservation of salamanders, squamata, pterosaurs, dinosaurs, mammals, insects, insect eggs, fungi and plants. A radiometric age of 165–164 Ma for the overlying volcanic rocks provides an upper limit on the age of the Daohugou fossil-bearing strata. The palynoflora and macrofossil flora suggests that the Daohugou Biota pre-dates the early Callovian and is possibly late Bathonian–early Callovian (late Middle Jurassic). The Daohugou palynoflora mainly contains bisaccate pollen of conifers, monosulcate pollen of Cycadales, Bennettitales or Ginkgoales, along with *Cyathidites*, *Deltoidospora*, *Granulatisporites*, *Osmundacidites* and *Classopollis*, indicating a warm-temperate to medium-temperate humid climate of zone with distinct seasonal changes. The occurrence of *Classopollis* implies the existence of a hotter climate with seasonal drought. Macrofossil plants are also abundant. They belong to Filicopsida, Cycadopsida, Ginkgopsida, Czekanowskiales and Coniferopsida. The floristic composition indicates that the Daohugou Flora was a forest ecosystem belonging to the North Floristic Province, suggesting a warm-temperate and humid climate with seasonal temperature and precipitation variations. The paleobotanical and paleopalynological data provides valuable evidence for understanding the local climate change and global latitudinal climatic zonality during the late Bathonian–early Callovian.

CAVE ARCHIVES OF THE MOST RECENT SUPERERUPTION ON EARTH

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New Zealand has an extensive history of large volcanic eruptions. In general, these eruptions are studied from the physical record preserved above ground, although weathering and erosion can remove evidence of small or distal volcanic deposits. New Zealand's extensive cave systems have great potential to accumulate and store volcanic deposits, in association with speleothems that may chemically record the eruptions and a means to date the volcanic deposits.

The Waitomo region is a well-developed and extensive karst region located proximal to the Taupō Volcanic Zone (TVZ). Ruakuri Cave in Waitomo contains a distinct dm-scale, grey ash layer, which has been fluvially reworked into the cave. This ash layer is ponded against and found throughout a very large rockfall in the cave. Electron microprobe and laser ablation inductively-coupled plasma mass spectrometry (LA–ICP–MS) analysis of the major and trace elements in fresh glass from this distinct grey ash layer indicate that it may be an as yet unidentified phase of the Oruanui supereruption. The large rockfall and cave breakdown, which appears to have shortly predated the transport of the ash into the cave, contains broken speleothems and is overgrown by new speleothems. Given that the tip of one broken speleothem has a U–Th-series age within error of the Oruanui supereruption we hypothesize that intense ground shaking (i.e., earthquakes) might have taken place shortly prior to or during the supereruption.

Work is ongoing to further geochemically identify the tephra deposit in the cave, determine if speleothems growing during eruption contain geochemical anomalies linked to volcanically induced perturbations of the karst hydrology, and further date speleothems broken by the rockfall and those that subsequently grew on it.

THE HUCKLEBERRY RIDGE TUFF, YELLOWSTONE: EVACUATION OF MULTIPLE MAGMATIC SYSTEMS IN A COMPLEX EPISODIC ERUPTION

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Silicic magmatic systems have the potential to generate exceedingly large explosive (super-) eruptions that have global impacts. Due to their scarcity in the historical record, understanding of these eruptions and their magmatic systems is developed through the study of deposits in the geological record. One such deposit is the 2.08 Ma, ~2,500 km^3 Huckleberry Ridge Tuff (HRT), the first and largest caldera-forming eruption from Yellowstone. The HRT comprises three ignimbrite members (A, B and C) and two fall deposits, an initial one and another prior to member C. The eruptive deposits show field evidence for a prolonged episodic eruption, with the initial fall deposits occupying some weeks, then time breaks of months between members A and B and decades between members B and C.

Single juvenile silicic (>65 % SiO_2) clast compositions, coupled with their groundmass glass and crystal characteristics, show that the HRT eruption tapped four discrete magmatic systems. These systems, in turn, were composed of multiple, laterally-adjoining melt-dominant bodies, as shown by clustered glass compositions. Systems 1 and 2 were simultaneously tapped at the eruption onset and continued to be evacuated throughout member A ignimbrite deposition. During deposition of member B, system 1 was tapped, following large-scale mixing and reorganisation, but system 2 was not. Eruption of member C saw renewed tapping of magma from system 2, coupled with evacuation of two additional magmatic systems, 3 and 4.

The four magmatic systems are related to two independent and contrasting mafic root zones and were hosted in two contrasting crustal reservoirs: pristine Archean basement (systems 3 and 4) and Archean basement that had been metasomatised in the Eocene (systems 1 and 2). Overall, the HRT is unique globally in its complexity for any silicic magmatic complex vented in a single (in the geological sense) eruption.

PREDATION AT HIGH-LATITUDE: A CASE STUDY IN EVOLUTIONARY ESCALATION FROM THE LATE TRIASSIC

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Marine predator–prey interactions from the Early Jurassic are notably different than those of the Triassic, especially with regard to pelagic systems. Discerning the internal or external forcing agents that induced these changes are poorly understood. Late Triassic ecosystem changes among predators and prey may elucidate the conditions in the Early Jurassic by illustrating how early Mesozoic benthic systems were shifting prior to the end-Triassic mass extinction.

New Zealand benthic assemblages differ in several key ways from lower latitude deposits in the Late Triassic but share a feature of pre-extinction faunal turnover during the Norian Stage. Lower latitude assemblages in Nevada, USA, and the Southern Italian Alps are characterised by Late Triassic decline in reclining surface-dwelling taxa (including brachiopods and some bivalves) followed by a surge in burrowing and cementing clams. Shallow marine deposits of the same age from the Hokonui and Taringatura hills, Southland, New Zealand, contain few burrowing or cementing taxa, but nonetheless the fossil assemblages undergo a shift from flat, thin-shelled reclining taxa to deposits abundant with more spherical and highly ornamented taxa. These shifts in both low- and high-latitude deposits may reflect a differential prey response to an increase in specialised shell-crushing predators operating on the surface of the seafloor. Ongoing work will discern whether faunal shifts in New Zealand were caused by environmental, geochemical, or ecological forcing agents.

RARE EARTH ELEMENT MINERAL SAND, WESTLAND, NEW ZEALAND

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Rare earth elements (REEs; lanthanum to lutetium, La–Lu) are an important commodity as the current mining industry broadens its focus towards green technologies. Rare earth elements are increasingly required to make batteries for hybrid and electric cars, screens of smartphones and computers and large magnets. While the beaches of the West Coast of the South Island are known to contain mineable gold and garnet, they are also potentially enriched in REE-bearing sands derived from the erosion of inland plutons and high-grade metasedimentary rocks (e.g., French Creek Granite and Westland dike swarm). The heavy mineral fraction of sand from West Coast beaches (Camerons to Karamea) was concentrated by magnetic and heavy liquid separation. The sand was analysed by scanning electron microscopy and laser ablation inductively-coupled plasma mass spectrometry (LA–ICP–MS) to identify and characterise the mineralogy and chemistry of the REE-bearing minerals. Allanite [$(Ce,Ca,Y,La)_2(Al,Fe^{3+})_3(OH)$] and monazite [$(Ce,La)PO_4$] are the two major REE-bearing minerals found in West Coast sand. The heavy mineral fraction is dominated by titanite, zircon, garnet, epidote, ilmenite and rutile. The abundance of allanite and monazite increase to the north; accompanied by the addition of xenotime (YPO_4). The variation of the proportions of the different detritus mineral phases along the coast reflect that the samples were taken from close proximity to different major river systems (including Grey, Buller and Karamea rivers). Since New Zealand's green mineral potential has not been examined in great detail, this research will aid in establishing if any potential REE-bearing placer deposits occur on the West Coast.

GOLDTRACE: TRACKING GOLD IN ARC LAVAS

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Strategic metals, such as gold, silver and copper, are in high demand in support of our modern society. Yet we still struggle to understand where chalcophile (akin to sulphur), and siderophile (akin to iron) elements originate within the crust and how they are transported to the Earth's surface. The capacity to liberate precious metals from the mantle and carry them in magmas significantly increases when volatiles (e.g., H_2O, CO_2, S) are present. Mantle that overlies down-going plates at convergent plate boundaries (i.e., subduction zones) is volatile-rich and commonly produces volatile- and metal-rich mafic magmas. While subaerial arc volcanoes release large quantities of volatiles and metals into the atmosphere during magma degassing, much of the metal-load in submarine intra-oceanic arcs is captured in arc lavas and glass owing to high hydrostatic pressures prevailing at the seafloor. Kermadec arc front volcanoes, NE of New Zealand, are ideal for studying processes involving metal enrichments in arc lavas. Here, we present volcanic glass major and trace element, and metal data from volcanoes spanning the length of the Kermadec arc to understand the role the subducting plate (including the Hikurangi Plateau) has on metal-flux beneath arc volcanoes. Preliminary results suggest that S, Cu and Ag contents are higher in lavas erupted above thick subducting Hikurangi Plateau than in lavas erupted above normal oceanic Pacific crust, suggesting that the composition, angle and thickness of the subducting plate affect the metal-fertility of arc magmas. In this project, we aim to identify first-order, large-scale parameters that lead to the formation of metal-fertile melts aiding the formation of seafloor massive sulphide deposits endowed with strategic metals.

LONG LATE QUATERNARY RECORD OF VEGETATION AND TEMPERATURE CHANGE FROM ELTHAM SWAMP, TARANAKI

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The Eltham Swamp pollen record published in 1994 has formed a key part of the palynological foundation for reconstructing the post-glacial glacial vegetation and climate history of the North Island. Re-coring of the swamp in 2008 recovered an even longer sediment archive, which has allowed us to extend the vegetation record back to 43,000 cal. yr BP, during the MIS 3 interstadial. Application of the MAT and PLS temperature transfer functions to the pollen record have produced quantitative temperature reconstructions over this timeframe, for which few other terrestrial temperature reconstructions exist.

Vegetation of MIS 3 in the Eltham area comprised a silver beech–shrubland–grassland mosaic, indicating cool yet moist conditions, but relatively free from frosts, as indicated by the low but continual presence of *Ascarina lucida*. MAT and PLS temperature reconstructions suggest mean annual temperatures were approximately 4.5–5 °C cooler than present, which is in keeping with records from elsewhere in the North Island at this time. Silver beech pollen constitutes >30% of the dryland pollen in some samples from the MIS 3 interstadial, suggesting a more widespread distribution of beech in the Taranaki region, where it is now largely absent.

Grass pollen increases substantially at 28,500 cal. yr BP at the expense of beech forest, reflecting the transition to cooler and drier conditions of the Last Glacial Coldest Period (LGCP). Sediment accumulation slows considerably, possibly ceasing altogether during the LGCP. This time period is represented by a relatively low number of samples. These limited pollen spectra indicate a dominance of grass and shrub pollen during the LGCP, with MATs approximately 5.7% cooler than present.

CHARACTERISING SEISMICITY IN A LOW-SEISMICITY REGION AROUND DUNEDIN, NEW ZEALAND

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Recent moderate and large damaging earthquakes in New Zealand have highlighted the incompleteness of the paleoseismic record as well as the large uncertainties that exist in the data used in probabilistic seismic hazard analyses (PSHA) such as the National Seismic Hazard Model (NSHM). These concerns are especially problematic in low-seismicity regions such as eastern Otago where the paleoseismic record shows aperiodic behaviour (e.g., Akatore and Dunstan faults). One way to reduce the uncertainties embedded in PSHA is to look for microseismicity, especially repeating earthquakes or tremor, that may indicate that a fault is experiencing deformation at depth despite being locked at the surface. Combining the current microseismicity record with the paleoseismicity history of a fault can improve the characterisation of identified active-fault earthquake sources that demonstrate aperiodic behaviour by providing additional constraints on whether the fault is in a period of seismic activity or quiescence. To address these issues, we present a detailed microseismicity catalogue for eastern Otago using seismic data collected during a multi-discipline Natural Hazards Research Platform project. Densely spaced seismic arrays have been shown to be effective at detecting microseismicity ($M_w < 1$) in the shallow crust. Using seismic data collected from a temporary deployment of fourteen seismometers in three dense micro-arrays, known as an array of arrays, complemented with seismic data from the New Zealand National Seismic Network (operated by GeoNet), we have improved the detection of small (M_w 1–2) earthquakes during the array deployment period in eastern Otago, in and around Dunedin city. We employ match-filter and subspace detection methods to detect repeating and near-repeating microseismicity on crustal faults within and around the array of arrays to further expand the earthquake catalogue around Dunedin and provide additional information for the eastern Otago active source region in the NSHM.

FOCAL MECHANISM CONSTRAINTS ON THE EVOLUTION OF AFTERSHOCK SEQUENCES

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Most stress-based studies of the evolution of aftershock sequences consider changes to the stress field caused by the mainshock alone, or by the mainshock and the few largest aftershocks. This approach provides some insight into the gross spatial and temporal characteristics of aftershock sequences but neglects the effects of smaller-scale interactions between low-magnitude aftershocks. Little attention has been paid to aftershocks' focal mechanisms, which, in principle, enable incremental stress changes associated with lower-magnitude events to be computed and incorporated in stress transfer models. Here I analyse the focal mechanisms of aftershocks that occurred following the 2010 Darfield (Canterbury) and 2016 Kaikōura earthquakes and investigate whether the faulting geometry of each aftershock contributes to the sequence's overall evolution.

HOW USEFUL ARE YOUR DATA? APPLYING QUANTITATIVE MEASURES FROM INFORMATION THEORY TO EVALUATE INFORMATION CONTENT AND DATA RELATIONSHIPS

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Geoscience datasets are increasingly growing in size and complexity. Together with the rapidly increasing possibilities of data storage, processing and exchange, we now have more data available for our research than ever. However, more data does not necessarily mean more information. Obviously, there is a need for methods to answer critical questions such as "Is it worthwhile to keep acquiring certain data?", "How strong are the relationships between two types of data—is it worthwhile to rely on one in lieu of the other?", and "How robust are the conclusions drawn from limited data sets?".

Information theory, firmly rooted in probability theory, offers a universal framework and quantitative measures such as Shannon Entropy, Conditional Entropy, and Kullback-Leibler divergence to address these questions. Due to its generality, information theory has become increasingly popular in recent years, with applications ranging from Earth and Computer sciences to Fundamental physics.

We will present examples of application of these measures to two geological datasets:

In fracture distributions extracted from wireline electrical logs in the DFDP-2B borehole we query:
1. Does the probability of encountering a certain type of fracture (of three types that were identified in the wireline data) vary with depth or is it uniform?
2. Does changing the resolution of depth information (i.e., changing the resolution of sampling of the dataset) change this probability?
3. How robust are both the above answers?

In particle size and shape distributions extracted by image analysis of experimentally-generated cataclasites and friction melts we examine:
1. What is the nature and strength of relationships between particle size and shape in an individual sample?
2. Which measure of particle shape is most discriminatory?
3. Do the same relationships between particle size and shape apply in different samples?

GEOPHYSICAL CHARACTERISATION OF GAS HYDRATE SYSTEMS ON NEW ZEALAND'S SOUTHERN HIKURANGI SUBDUCTION MARGIN

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The Hikurangi Margin on New Zealand's east coast contains a world-class gas hydrate province. These clathrate compounds of natural gases, trapped within a water molecule lattice, could represent a relatively low-carbon energy source for the future, and they might act as a regionally spread seal that traps large amounts of free gas below the gas hydrate stability zone (GHSZ). In addition, the study of gas hydrate systems is fundamental to the assessment of geohazards, such as seafloor stability, as well as the biology of seafloor environments and ocean acidification.

This PhD research is focused on characterising gas hydrate accumulations in the southern end of the Hikurangi subduction margin. We present initial results from one of the first aims of the project: the synthesis of recently acquired multi-channel seismic (MCS) reflection data with existing and new academic seismic surveys, which is used to better assess the mechanisms that lead to concentrated hydrate accumulations across the southern sector of the Hikurangi margin. Once individual accumulations have been identified and mapped, a quantitative characterisation will be carried to estimate the amount of gas that is accumulated in the form of hydrates within the GHSZ. To this end, an accurate and reliable velocity model will be generated through reflection/refraction tomography, pre-stack time migration and/or other seismic inversion techniques. We will also attempt to incorporate information about reservoir sediments to constrain inversions for porosity and, ultimately, gas hydrate saturation.

A MĀORI WORLD-VIEW IN THE MANAGEMENT OF AUCKLAND'S MAUNGA (VOLCANIC CONES)

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The return of 14 Auckland Tūpuna Maunga (ancestral mountains, volcanic cones) to 13 mana whenua iwi and hapū of Auckland in 2014 marked a turning point in the management of these important sites. For many decades the maunga have been managed as parks, quarries, water reservoirs and modern defence sites. In many cases modern use has disregarded the profound history of these places as ancient pa sites which were at the very centre of early Māori civilization in Tāmaki Makaurau, resulting in permanent loss of significant historic features. Despite the degradation of the maunga over decades, mana whenua have maintained an intrinsic and unbroken living connection with the maunga; they have remained taonga tuku iho—treasures handed down the generations.

The Treaty of Waitangi settlement and Collective Redress Act allowed for establishment of the Tūpuna Maunga Authority, a co-governance entity comprised of equal membership from ngā Mana Whenua o Tāmaki Makaurau and Auckland Council. The Authority has adopted a unique management structure with a Māori world-view at its heart; the health and well-being of the maunga is the decision-making paradigm and the wairua (life force) and mauri (spiritual essence) of the maunga are at the centre of everything we do.

This presentation will look at the significant geological landscape through a cultural lens and explain how current and future management will assist the maunga on the path towards UNESCO World Heritage Status. The Treaty of Waitangi settlement and co-governance structure will be briefly discussed for context, and milestone projects, such as pedestrianisation of the maunga, restoration of indigenous flora and fauna, and track and boardwalk development to preserve sensitive features, will be explained as they relate to the cultural values guiding management. The presentation will offer geoscientists a new lens through which to consider this well-known landscape.

ICE SHEET AND SOUTHERN OCEAN RESPONSE TO ORBITAL FORCING DURING EARLY PLIOCENE WARMTH FROM IODP SITE U1361A, WILKES LAND, EAST ANTARCTICA

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Ice-proximal sedimentary records provide insight into the behaviour of Antarctic Ice Sheets and surrounding oceans during periods of extreme climatic warmth. The Wilkes Subglacial Basin (WSB) is the largest subglacial basin of the East Antarctic Ice Sheet (EAIS) and is characterised by deep inland-sloping topography—making the ice sheet in this sector vulnerable to marine ice sheet instabilities. Geological studies indicate this sector experienced dramatic retreat during early Pliocene climatic warmth (5.3–3.5 Ma) under similar climatic conditions predicted for 2100. We investigate EAIS ice dynamics and oceanic response between 6.2–4.4 Ma using high-resolution sedimentological and geochemical proxies to resolve the orbital pacing of ice sheet variability.

Four-hundred-and-fifty samples from International Ocean Discovery Program (IODP) site 318 U1361A were processed for grainsize, iceberg rafted debris (IBRD) and X-Ray fluorescence spectroscopy (XRF) measurements. Spectral analysis of datasets to assess dominant orbital frequencies of IBRD mass accumulation rates were calculated using the coarse sand fraction, where peaks of IBRD correlate to increased ice flux at the ice margin. Variations in biogenic productivity in the surface oceans is indicated by changing Ba/Al and Si/Al ratios calculated from XRF data. Results show highly cyclic patterns in all datasets relating strongly to lithologic facies; interbedded silty clays contain sparse IBRD and low Ba/Al ratios, while bioturbated diatom-rich muds contain IBRD peaks followed by high Ba/Al and Si/Al values. This co-varying relationship suggests ice sheet variations controlled the relative influence of biogenic versus siliciclastic sedimentation. During glacials sedimentation is enhanced by low-density turbidity flows, whereas diatomaceous muds deposited during interglacials suggest increased influence of pelagic deposition and reduced turbidite delivery. Iceberg rafted debris peaks occur at glacial–interglacial transitions as the ice sheet destabilises. Preliminary spectral analysis shows 100 kyr eccentricity-driven ice discharge, with nodes of 40 kyr obliquity in the late Miocene. This data fits within a larger study to complete a late Miocene–Pleistocene orbital-resolution history of marine-based ice sheet retreat and advance from site U1361A.

INSIGHTS INTO PHASING AND EVOLUTION OF THE OCEAN BIPOLAR SEE-SAW FROM THE RICE ICE CORE

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The last glacial in Antarctica is punctuated by several episodes of warming, when air temperature rose between 1–3°C, which are referred to as “Antarctic Isotope Maxima” (AIM). The comparison of Antarctica and Greenland ice core records shows an out of phase relationship between AIM events and their northern counterparts, Dansgaard/Oeschger (DO) events, referred to as the “Bipolar see-saw”. Possible explanations include oceanic teleconnections via a shift in strength of the Atlantic Meridional Overturning Circulation (AMOC) and Antarctic Bottom Water formation (AABW). Although there are evidences for a weakened AMOC and stronger AABW formation, uncertainty remains on the mechanism of AABW formation during AIM events.

Roosevelt Island is a local ice rise at the northern edge of the Ross Ice Shelf. A 764-m-deep ice core was obtained as part of the Roosevelt Island Climate Evolution (RICE) project. Due to its proximity to Ross Sea, RICE records have the potential to provide new insights into the drivers and consequences during the evolution of AIM events.

Here, we present the major ion record of the RICE core spanning the period between 60,000 to 25,000 years BP, presented on the RICE17 age scale. The major ion record provides useful indicators of past environmental conditions, such as changes in sea ice extent, primary productivity and latitudinal shifts in circumpolar westerlies. From the intrinsic relationship observed between sea ice, primary productivity and temperature during AIM events, complemented with LOVECLIM model outputs, we propose open ocean convection as the driving mechanism of AIM events in the Ross Sea region. The well-constrained RICE17 age scale supports detailed analysis of the phasing between RICE δD and North Greenland Ice Core Project $\delta^{18}O$ record. During AIM events we observe at times an Antarctic lead, which has the potential to contribute to the evolution of the DO–AIM event interaction.

A SINGLE DEFORMATIONAL FRAMEWORK FOR MODELLING TECTONICS AND SURFACE PROCESSES

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The landscape serves as a nexus between the solid Earth, with its geodynamic processes, and the atmosphere. At many spatial and temporal scales, landscape morphology and topography provide a constraint on the tectonics of the deeper Earth and the processes active within it or that have been previously active. To unravel these, we need to understand the complex relationships between surface processes, their drivers and the Earth materials upon which they act.

In my talk, I will explore recent developments in modelling tectonics and surface processes within a single deformational framework. I will focus on collisional settings such as New Zealand's Southern Alps, SE Alaska and the Himalaya where rapid uplift combines with vigorous climate regimes to create dynamic landscapes. Our 3-D mechanical models, constrained by field observations, solve for the complete stress tensor, including both geodynamic and geomorphic components (tectonic, dynamic, topography, fluvial and glacial). They also predict where imposed tectonic driving forces result in deformation induced weakening of the rock mass in the form of faults and other structures. The balance between the material strength and 3-D stresses acting upon the material determines whether or not rock at the surface experiences failure, which makes it potentially available to be transported by surface processes.

THE AOTEA SEAMOUNT

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The Aotea Seamount was first described by Brodie in 1965 as an elongate ENE-trending seamount of unknown age seven miles (11 km) wide and 30 miles (48 km) long. Sampling had been attempted but only Pliocene and Pleistocene organic sediments were recovered and no bedrock. Oil exploration seismic data has imaged the seamount more comprehensively showing that the feature is considerably larger than its sea-bed expression. Stratigraphic relationships confirm the initial suspicion of a Miocene age for this volcanic complex, but its composition is unknown due to the lack of samples. Its Miocene age implies that it is related to the development of the modern subduction boundary below North Island, but its location, around 150 km west of Northland's Miocene western arc means that its relationship is not clear. While it might be expected that magmas would take a route of least resistance, perhaps along a fault in thin crust, the Aotea Seamount sits on a basement high. One suggestion is that it was erupted along a leaky Cretaceous transfer fault, but none have yet been described from seismic data and the trend of the seamount is oblique to the theoretical trend of a transfer fault. In short, this large geological feature is remarkable for its size and anonymity.

JURASSIC EXTINCTION EVENTS AND SOME NEW DATES FROM NEW ZEALAND—COMPARISON BETWEEN THE VEGETATION SIGNALS OF SOUTHERN AND NORTHERN HEMISPHERES

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The Jurassic (~201–145 million years ago) records the recovery and development of ecosystems following the end-Triassic mass extinction (ETE), one of the so-called “big five” mass extinction events of the Phanerozoic. The supercontinent Pangea, which started to fragment during the Triassic, continued to separate through the Jurassic. However, the close arrangement of the continents meant that floras and faunas included many cosmopolitan elements. Elevated atmospheric CO_2 levels, high-latitude vegetation, and a general lack of evidence for polar glaciation suggest that warm climates extended to high latitudes. Several major evolutionary advances of the terrestrial biota took place during this period, including the appearance of the birds, the rise of the dinosaurs as the dominant land-based vertebrates, and the proliferation of bennettite-, advanced seed fern- and conifer-dominated floras.

The vegetation changes across the Triassic–Jurassic (Tr–J) boundary were possibly related to major volcanic events during the break up of continents. The End-Triassic mass extinction event is typified in the Northern Hemisphere terrestrial successions by the extinction of certain seed-ferns followed by a short time of fern-dominance and subsequent conifer proliferation.

Although the floral turnover is more pronounced in the Northern Hemisphere, changes can also be traced in the southern Gondwanan successions. More specifically, palynological analyses from the Otapirian –Aratauran boundary strata from the Awakino gorge section, New Zealand reveal a change from *Falcisporites*-dominated to *Classopollis*-dominated assemblages that show a dramatic decline of corystosperm seed-ferns and the proliferation of large conifers. Here, the state of knowledge of the global terrestrial Tr–J boundary record will be presented, together with new palynological data from Australian and Swedish successions and new zircon dates from New Zealand Jurassic strata.

IMPACTS OF SURFACE FAULT RUPTURE ON RESIDENTIAL STRUCTURES DURING THE 2016 M_W 7.8 KAIKŌURA EARTHQUAKE, NEW ZEALAND

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Areas that experience permanent ground deformation in earthquakes (e.g., surface fault rupture, slope failure, liquefaction) typically sustain greater damage and loss compared to areas that experience strong ground shaking alone. The 2016 M_w 7.8 Kaikōura Earthquake generated ≥220 km of surface fault rupture. The amount and style of surface rupture deformation varied considerably, ranging from centimetre-scale distributed folding to metre-scale discrete rupture. About a dozen buildings—mainly residential (or residential-type) structures comprising single-storey timber-framed houses, barns and wool sheds with lightweight roofing material—were directly impacted by surface fault rupture with the severity of damage correlating with both total displacement and local strain. However, none of these buildings collapsed. This included a house that experienced a discrete fault rupture with ~10 m of lateral displacement. The foundation and flooring system of this structure allowed decoupling of much of the ground deformation from the superstructure, thus, preventing collapse.

Using a combination of field observations, and differential LiDAR and photogrammetry, grounds strains were estimated at these fault-impacted buildings. Combining this with building damage observations, the following are concluded:

(1) Single-storey, regular-shaped, timber-framed residential structures with light roofs and of modest dimensions (floor area of less than ~200 m^2) subjected to low–moderate surface fault rupture deformation (i.e., shear strains ≤10^{-2} and discrete displacements of decimetre-scale or less) do not appear to pose a collapse hazard.
(2) At those levels of deformation, the prospects of damage-control and reparability and, therefore, post-event functionality appear to be improved for such residential structures if the cladding contributes to the robustness to the superstructure (e.g., plywood, timber weather boards), and is not brittle.
(3) This favourable behaviour is enhanced if building systems moderate the direct transmission of ground deformation into the superstructure (either by decoupling or by other means) and allow for re-levelling of the structure post-event.

LAST GLACIAL MAXIMUM GLACIAL HISTORY IN THE UPPER SHOTOVER GORGE

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The glacial history of the Shotover Valley, Otago has not hitherto been constrained by detailed geomorphic mapping or absolute age control. This poster presents the results of Quaternary geologic mapping and optically-stimulated luminescence (OSL) geochronology in the Shotover Gorge and at lower Branches Flat, providing the first evidence of the extent and timing of an early Last Glacial Maximum (LGM) glacial advance and subsequent ice retreat. We conducted detailed mapping of the Quaternary stratigraphy in the gorge, including glacial deposits, lacustrine and deltaic sediments, and widespread alluvial terrace gravels, which demonstrate a glacial advance to approximately Sandhills Creek. Optically-stimulated luminescence ages of meltwater periglacial deposits adjacent to a probable moraine at Sandhills yield a weighted mean age of 29.4 ± 3.9 ka, which corresponds to early Marine Isotope Stage 2 (MIS2). Further up-valley, a thick sequence of lacustrine and deltaic sediments, the latter with an OSL age of 24.7 ± 4.7 ka, reflect formation of an extensive paleo-lake, interpreted as a proglacial lake formed during glacial retreat following the Sandhills advance. Global Positioning System-surveyed alluvial gravels overlie these glacial and lacustrine sediments and form extensive alluvial terraces lower down the Shotover Gorge and Moonlight Creek. These terraces are interpreted as being an aggradational surface formed during a later glacial advance. These investigations provide the first dating of any late Pleistocene sediments in the Shotover Valley, allowing for a preliminary revision of the LGM glacial chronology in the valley. This shows that the upper Shotover Gorge glacial advance to be significantly younger than previously thought, and lake formation by ~25 ka may corroborate evidence elsewhere of a mid-LGM warming and ice retreat.

SHOTOVER GORGE LANDSLIDE DAM HAZARD ASSESSMENT

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The Shotover Gorge is a narrow, deep, schist gorge with abundant evidence of landslide activity, and is, thus, susceptible to damming by a future landslide. With increasing residential development in locations adjacent to the Shotover River delta, a Shotover Gorge landslide dam could pose a threat to these areas through outburst flood resulting from catastrophic dam failure, and/or subsequent aggradation increasing flood risk. This presentation summarises a landslide dam hazard assessment for the Shotover River, including dam-break flood and aggradation impacts.

Several zones of possible landslide dam formation are identified in the gorge, with maximum landslide dam heights estimated at up to 80–125m. Empirical stability indices indicate that any modelled Shotover Gorge dam is likely to be unstable and fail suddenly. Peak dam-break flows were estimated for modelled dams using empirical regression equations, dimensionless analysis and a parametric model (OUTFLOW3), with reasonable agreement between methods. Down-valley passage of dam-break flows was simulated using a 1-D hydraulic routing model (AULOS) to assess flow attenuation of the flood wave and estimate the magnitude of peak flows at the Shotover Delta. Modelling shows peak dam-break flows at the delta may be many times greater than the largest recorded Shotover River flood events. Post-dambreak sedimentary impacts were estimated to show geomorphic responses as landslide dam material disperses. This was based on comparison with geomorphic impacts of documented dam-break events and using the example of the Shotover's historic mining-induced aggradation event. A 1-D morphodynamic model (Gary Parker, University of Illinois) was used to numerically model the impacts of increased sediment supply to the river system. Development of hazard event and impact scenarios summarises the possible cascade of hazards resulting from formation and failure of a Shotover Gorge landslide dam.

ARE THERE HIDDEN ACTIVE FAULTS UNDER DUNEDIN CITY?

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The Canterbury Earthquakes Royal Commission recommended that "Research continues into the location of active faults near Christchurch and other population centres in New Zealand, to build as complete a picture as possible for cities and major towns". To address this recommendation, we undertook a multi-disciplinary project in Dunedin, co-funded by the Natural Hazards Research Platform, GNS Science Strategic Science Investment Funding, University of Otago, Earthquake Commission and the Geological Survey of Spain. We chose Dunedin because active faults (Akatore and Titri) have been identified that could extend beneath the Dunedin urban area.

Our study focused on two northeast-trending structural/topographic lineaments near Dunedin: (1) along the Kaikorai and Waitati valleys; and (2) along Otago Harbour. Our research aimed to assess whether these may be active tectonic features and, if so, their possible deformation rates. We integrated geology, gravity, onshore and offshore seismic reflection, microseismicity, InSAR and GNSS observations to evaluate these potential earthquake sources.

We found that the Akatore Fault does not extend into Dunedin, but the Titri Fault extends closer to the city than previously mapped. A possibly active fault, the Kaikorai Fault, was mapped in the western part of the city. In contrast, our study was non-conclusive regarding the presence of potentially active faults under Otago Harbour. We also mapped other fault traces that could have been active within the current tectonic regime in the surrounding region. Several deformation rate scenarios were developed from geological markers and geodesy data, and new seismic hazard estimates produced for Dunedin city that incorporate the new fault sources into a logic tree. These are very similar to the older hazard estimates, given the long earthquake recurrence intervals implied for our new sources. New earthquake scenarios suggest that Dunedin could experience Modified Mercalli Intensity 6, and perhaps up to 8 in some parts of the city.

FROM DETAILED TEPHROSTRATIGRAPHY TO ERUPTION DYNAMICS—INSIGHTS INTO THE ERUPTIVE BEHAVIOUR OF MT RUAPEHU DURING THE LAST 2,000 YEARS

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Mt Ruapehu has been highly active both historically and pre-historically. Tephra deposits represent a wide range of eruption styles and magnitudes and are well preserved in Ruapehu's extensive ring plain. We investigate dynamic changes in the eruption behaviour of andesitic volcanoes using Ruapehu as an example. With a focus on relatively short time-scales ranging from hours to months, we seek to understand the processes underlying sudden changes in eruption dynamics within eruption episodes to aid monitoring and forecasting of future events. Another target of this research is the investigation of changes in long-term (several hundred to several thousand years) frequency–magnitude patterns to improve our understanding of the magmatic systems that feed long-lived stratovolcanoes.

Our preliminary results suggest that at least 29 eruptions took place in the last 2000 years. Three predominant eruption types can be distinguished: (1) ash-rich multi-stage eruptions, (2) ash-rich single-stage eruptions, and (3) pumaceous eruptions. Here we present the deposit sequence of a characteristic multi-stage eruption that is composed of multiple individual fall units. This sequence shows coherent trends regarding componentry, glass chemistry, ash morphologies and macroscopic deposit textures. We combine these characteristics with selected cases of historically-observed eruption sequences to define eruption style and progression. Furthermore, we show that juvenile tephra components span a broad range in microlite content and vesicularity, and that these characteristics correlate with different end-members of pyroclast glass types. Accordingly, juveniles can be grouped in the following end-members: (a) microlite-rich dark glass, with dense groundmass and (b) bright glass, generally more vesicular and microlite-poor. Textural analyses are combined with glass composition data to identify the processes controlling the genesis of the observed pyroclast types and to understand whether specific characteristics can be related to late-stage dynamics of magma ascent or whether they represent several distinct magma batches.

JURASSIC FORAMINIFER ASSOCIATIONS OF THE WESTERN CAUCASUS AFTER LATE BATHONIAN RECONSTRUCTION

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Bajocian (Middle Jurassic) transgression led to the formation of several interconnected basins in the southern part of the Scythian platform and the northern part of the Greater Caucasus. Deposition in most of the basins ceased during the early Bathonian after marine regression. Faunal associations in Bajocian time were rich and diverse, whereas abundance and diversity are lower in Bathonian associations. The *Quinqeloculina micra* assemblage of foraminifer from the Western Caucasus early Bathonian is of low abundance and diversity. This is typical for only the northern part of this area. Lower Bathonian sediments are absent in the southern part.

In the Middle–Late Jurassic, the Western Caucasus (Russia) consisted of the several tectonic zones. Callovian transgression led to deposition of sediments containing the *Haplophragmium coprolithiforme* assemblage in the northern part of this area. Similar foraminifer associations occur in carbonate–terrigenous deposits in the southern part. Late Jurassic strata in the Western Caucasus are characterised by large facies variability. Basins on the northern slope of the Caucasus contain mostly reef, shallow marine and lagoon deposits, while the flysch and a variety of carbonate rocks dominate the southern slope. The high diversity of Late Jurassic foraminiferal assemblages is related to a certain extent to different types of sedimentation. Development of the Caucasian basins affected the evolution of foraminiferal assemblages, which in the Late Jurassic was controlled by differences in deposition environments and processes (facies).

IODP BOREHOLE OBSERVATORIES TO MONITOR SLOW-SLIP AT THE OFFSHORE HIKURANGI SUBUCTION ZONE

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The offshore northern Hikurangi subduction margin, New Zealand, is the site of some of the world's best-documented shallow slow-slip events (SSEs). Seafloor geodetic studies have suggested that SSEs there occur to within at least 2 km of the seafloor, and it is possible that they propagate all the way to the trench. International Ocean Discovery Program (IODP) Expedition 375 recently completed installation of two sub-seafloor observatories at the offshore Hikurangi margin, aimed at monitoring SSE processes in the very near field. One of the observatories intersects a major active fault near the deformation front of the subduction zone. The fault zone observatory includes three levels of formation pressure monitoring (for volumetric strain), high-resolution temperature monitoring, and geochemical sampling and fluid flow monitoring within the fault zone. A second, simpler observatory was installed directly above the area of large slow-slip on the offshore Hikurangi subduction zone, which involves two levels of formation pressure monitoring and high-resolution temperature monitoring. We will describe the installation of these observatories, and the types of instrumentation that was installed. We will discuss the scientific aims of the observatories, and the ability of the observatory configuration to resolve many outstanding questions about SSE processes. We will also address placement of the observatory monitoring intervals in the context of the coring and Logging-While-Drilling data that was acquired in advance of the observatory installation on IODP Expeditions 372 and 375.

WATER AND FIRE—A COMBINED FIELD AND NUMERICAL APPROACH TO MODELLING HAZARD IMPACTS FROM PHREATOPLINIAN ERUPTIONS

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Phreatomagmatic eruptions, where magma fragmentation is largely driven by water–magma interaction, are frequent and highly dangerous volcanic events. Phreatomagmatic eruption sequences often comprise complex and highly unsteady successions of plumes, jets, ballistics and pyroclastic density currents. Stratospheric disturbances caused by phreatoplinian eruptions have been proposed to influence climate. In contrast to dry magmatic eruptions, the dynamics of phreatomagmatic plumes and our ability to simulate these in numerical models remain incomplete. Here we outline a new research project that aims at better understanding and modelling the eruption dynamics of phreatoplinian eruptions using field, laboratory, and computational techniques.

Through reconnaissance mapping of the phreatoplinian Hatepe Ash (unit Y3) of the 232 AD Taupō eruption, we will determine the detailed vertical and lateral deposit architecture of selected and well-defined sub-units of Y3. Our focus will be on correlating macroscopic sedimentary changes within sub-units with quantitative measurements of changes in grainsize distribution, pyroclast density, componentry, and pyroclast textures. Additionally, we will combine existing and new field and laboratory data to estimate a selection of eruption source conditions (i.e., mean and transient mass eruption rates; magma temperature; magma water content; vent position and, potentially, geometry; vent overpressure; and size-dependent geometric, fluid mechanic and thermodynamic properties of pyroclasts).

These estimates will form the base for numerical simulations of the Y3 eruption using the Eulerian-Lagrangian wetASHEE model. This recently developed multi-phase model will allow us to constrain the roles of surface water and water phase changes (vapour, liquid, solid) on the ascent dynamics, plume stability, and resulting deposit architecture. Validating the wetASHEE model on the Hatepe phreatoplinian eruption will open pathways to forecast the hazard impacts of future wet eruptions from Taupō.

FLUID PROPERTIES OF PYROCLASTIC ROCKS—INSIGHTS FROM SONGLIAO BASIN, CHINA

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Volcanic rocks can be characterised by a wide range of petrophysical properties. Parameters such as porosity and permeability are mainly controlled by primary variations in texture, structure and composition volcanic rocks, and by secondary mineral alteration associated with metasomatism, fracturing, weathering and burial processes. These variations produce heterogeneity in volcanic rocks, which may influence sub-surface fluid-flow dynamics, creating preferential zones of migration and accumulation of oil, methane gas, water and CO_2. In this work, we investigate the relationship between permeability and porosity of pyroclastic rocks and compare these results to observations for sedimentary rocks. We use a large dataset from multiple projects coordinated by Jilin University, China, comprising information from 902 core samples collected from depths of 1500 to 3500 m in the Songliao Basin, northeast China. We classify the samples into five types: (1) sandstone (452 samples), (2) welded and (3) non-welded tuff (263 samples), and (4) welded and (5) non-welded lapilli (187 samples) and plot the results of porosity versus permeability on a semi-logarithmic diagram. Permeability of the pyroclastic rocks varies from 0.0025 to 33.85 mD, while porosity ranges from 0.2% to 20.1%. We observe an exponential relationship between porosity and permeability for both pyroclastic and sedimentary rocks. However, different types of pyroclastic rocks show distinctive porosity versus permeability positive slopes, with values increasing from non-welded lapilli, to non-welded tuff, to welded tuff and finally to welded lapilli. Possible explanations for these progressive increases in slope are that during burial the more rigid framework of welded pyroclastic rocks prevents loss of intergranular porosity and/or that welded rocks are more brittle with their fracture porosity increasing during burial. Irrespective of the cause of the changes in porosity–permeability relationships, welded volcanic rocks have the potential to maintain higher porosities and reservoir capacity at greater depths than would be expected for sedimentary rocks.

NON-MARINE OSTRACOD FAUNA FROM THE DALAZI AND TONGFOSI FORMATIONS OF THE YANJI BASIN, NORTHEAST CHINA

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The Yanji Basin is one of several Mesozoic rift basins located in Jilin Province, Northeast China, a few kilometres east of the China–North Korea border. Non-marine Early Cretaceous sediments are well-exposed in this basin and yield abundant ostracod fossils. In this study, fourteen species, including one new species, belonging to nine genera have been recovered from the Tongfosi and Dalazi formations: *Scabriculocypris tonfosiensis*, *Scabriculocypris yanbianensis*, *Cypridea concinaformis*, *Mongolocypris yanjiensis*, *Mongolianella kyranbeki* sp nov, *Lycopterocypris infantilis*, *Lycopterocypris* sp, *Yumenella toorojensis*, *Candona* spp, *Cypois* sp, *Vlakomia ustinovskii* and *Vlakomia jilinensis*. With the recovery of well-preserved specimens, the sieve pore, ontogeny and sexual dimorphism of *Vlakomia jilinensis* and *Vlakomia ustinovskii* are recognized for the first time. These features provide new data for future discussion of the phylogeny and palaeogeography of the Family Limnocytheridae and Subfamily Limnocytherinae. The ostracod biostratigraphic correlations suggest that the age of Tongfosi Formation is Albian and may extend into the Late Cretaceous, while the Dalazi Formation is no older than Albian and probably an early Late Cretaceous in age. The ostracod fauna of the Tongfosi and Dalazi formations shows affinities to those of Eastern Mongolia and South Korea, suggesting faunal exchanges between Northeast China, Eastern Mongolia and South Korea during the Albian to late Early Cretaceous. In addition, ostracod fauna suggest that the Tongfosi and Dalazi formations represent shallow–littoral lacustrine depositional environments that may have included small ephemeral water bodies.

TECTONIC TRANSFORMATION COINCIDED WITH SIGNIFICANT CLIMATIC AND ENVIRONMENTAL CHANGES FROM THE MIDDLE JURASSIC TO EARLY CRETACEOUS IN EASTERN ASIA

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The subduction of the west Pacific Plate is crucial to reconstructing the middle–late Mesozoic tectonic evolution of the eastern Asian continent. During the Middle–Late Jurassic, tectonism (known in China as the Yanshanian Movement) occurred in an intracontinental setting and was associated with widespread deformation, magmatism, and changes in crustal structure and composition. However, there are no unconformities related to this period of tectonism. Middle–Late Jurassic sedimentation occurred either in the frontal region of a thrust system, or a sedimentary basin that formed in a compressional tectonic regime, such as a foreland basin. In contrast, Early–Middle Cretaceous sedimentation, basin formation and associated volcanism are considered to be related to extensional tectonics.

During the Jurassic–Cretaceous, the trend of the dominant structures changed from E–W to NE–SW. This transition coincided with the change from the Middle Jurassic Yanliao Biota to the Early Cretaceous Re-He Biota, as well as significant climatic and environmental changes across China, and, more broadly, eastern Asia. Many tectonic events occurred globally at a similar time. These include, subduction of the paleo-Pacific Plate, opening of the Atlantic Ocean, extensive deformation and tectonic transformation of the Laurasia supercontinent, extensive shortening in the Mexico area, and the break-up of north Gondwana.

EPISODIC STRESS TENSOR AND FLUID PRESSURE CYCLING IN SUBDUCTING OCEANIC CRUST DURING NORTHERN HIKURANGI SLOW-SLIP EVENTS

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Slow-slip event (SSE) occurrence in subduction zones has been proposed to be linked to the presence of, and fluctuations in near-lithostatic fluid pressures (P_f) within the megathrust shear zone and subducting oceanic crust. Such high fluid pressures indicate an over-pressured fluid reservoir exists, which is capped by a low-permeability barrier (e.g., the interface shear zone or hangingwall prism). Occasional breaching of this barrier, and its link to megathrust slip is commonly described by a “fault-valving” model. In this model, P_f varies temporally, peaking prior to fault slip, before co-seismic fracture activation opens permeable pathways for fluid migration. A subsequent drop in P_f occurs until the system becomes resealed (e.g., by hydrothermal precipitation) and overpressure can re-accumulate.

While the priming conditions for cyclical valving behaviour have been observed at subduction zones globally, and evidence for post-megathrust rupture drainage exists, physical observations of precursory fluid pressure increases, and subsequent decreases, particularly within the subducting slab where hydrothermal fluids are sourced, remain elusive. Here we use earthquake focal mechanisms recorded on an ocean-bottom seismic network to show that crustal stresses and fluid pressures within subducting oceanic crust evolve before and during SSEs. Specifically, we show that the stress, or shape ratio, which describes the relative magnitudes of the principal compressive stress axes, systematically decrease prior to, and subsequently increase during the evolution of SSEs in the northern Hikurangi. We propose that these changes represent the accumulation and release of fluid pressure within over-pressured subducting oceanic crust, the episodicity of which may influence the timing of SSE occurrence on subduction megathrusts.

COASTAL LAKES WITH P PROBLEMS

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New Zealand's shallow coastal lakes are important ecosystems with a range of ecological, cultural, economic and recreational values. However, these biodiversity hotspots are commonly highly degraded with high nutrient concentrations and associated algal blooms driving ecological decline. Te Roto o Wairewa/Lake Forsyth is a small, shallow, coastal lake on the south side of Banks Peninsula, Canterbury. Blooms of potentially toxic, nitrogen-fixing cyanobacteria occur regularly in summer, and the availability of the macronutrient, phosphorus (P), is a key factor in bloom development. External (catchment derived) loads of P, delivered to the lake mainly in particulate form during flood events, cannot explain the observed short-term fluctuations in dissolved P concentrations in the lake. However, the release of P sequestered in lake sediments may both explain these fluctuations and, under the right conditions, trigger and sustain rapid increases in primary productivity leading to bloom formation. An understanding of the mechanisms that release dissolved P into the water column, and the factors that favour such mechanisms, is therefore critical to the formulation of good management responses to eutrophication of this lake.

Sequential extractions of lake sediments indicate that there is a large reservoir of exchangeable and oxide-adsorbed P available for release into the water column. The analysis of sediment porewater, confirms the mobility of P in the upper sediment profile. Release experiments and geochemical modelling, combined with in-lake observations, have quantified the effect on sedimentary P release, of low dissolved oxygen concentrations, high pH associated with increasing photosynthesis, and salinity changes associated with lake openings. A combination of these factors is key to triggering and perpetuating bloom formation.

USING PALEOMAGNETISM TO TEST ROLLING HINGE BEHAVIOUR OF AN ACTIVE LOW-ANGLE NORMAL FAULT, SUCKLING–DAYMAN METAMORPHIC CORE COMPLEX, PAPUA NEW GUINEA

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Metamorphic core complexes (MCCs) have been attributed to slip on long-lived detachment faults in extensional environments. At the surface, such faults are typically shallow dipping (<30°). This is inconsistent with Andersonian faulting theory, which dictates that normal faults should nucleate and slip at steeper dips. One possible solution to this mechanical problem is a "rolling hinge" evolution for the fault during its slip history. In this model, faults initiate at steep dips (e.g., 60º) and back-tilt to shallower dips due to flexure and isostatic uplift in response to unloading of the footwall during slip. The Mai'iu fault is an active, rapidly slipping (~1 cm/yr) low angle (dip 16–22º at the surface) normal fault. Progressive thermal demagnetisation experiments were carried out on the natural remanent magnetization of the metabasaltic footwall rocks from 37 sites covering ~10 km parallel to the slip direction. Near the fault trace the samples carry a single normal-polarity component of magnetization with moderate inclination. The maximum blocking temperature at which this component is found decreases steadily with increasing distance from the fault trace. Up-dip, an underlying higher blocking temperature component of steep, reversed-polarity is preserved. We interpret the normal component to have been acquired during uplift and cooling of the footwall rocks within the past 2–3 Ma, overprinting the older reversed component. Comparison of the direction of the normal component with the expected average (geocentric axial dipole) direction at the site latitude (~9º) indicates ~22º of back-tilting of the footwall about the strike of the Mai'iu fault, consistent with a rolling hinge-style of bending. The data indicate an original fault dip of ~44º, as is consistent with microseismicity at depth. This study is the first of its kind to demonstrate, using paleomagnetism, large-scale horizontal-axis rotations consistent with a rolling hinge evolution for a continental MCC.

FROM MICRO TO MACRO: THE EVOLUTION OF FAULT ZONES—EXAMPLES FROM TARANAKI

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Fault zones comprise clay-rich fault rock and associated minor faults. The widths of the zones of minor faulting and of fault rock display significant variation both along and between faults. Here we quantify variations in fault-zone geometry and examine the factors that influence this geometry 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 poorly lithified Mount Messenger Formation (MMF) exposed in coastal cliffs of northern Taranaki, New Zealand. Fault analysis used a combination of outcrop-scale measurements, thin sections, Scanning Electron Microscope (SEM) images and laser sizer measurements of fault rock. These data indicate that fault rock and fault zone thicknesses increase with displacement. Fault rock evolution in the MMF is mainly dependent on three key factors: (1) the initial geometry of the fault surface, which strongly influences fault zone thickness and complexity, (2) fault displacement and the associated shear strains, and (3) the particle size of the faulted protolith, which influences the relative contributions of cataclasis and intergranular sliding to fault rock production. Increases in fault rock thickness with displacement are primarily achieved by the migration of the locus of deformation within fault irregularities, shear of host-rock lenses and wallrock along, and into, fault zones. Sandstones deform mainly by cataclasis, while siltstones mostly accommodate shear by intergranular sliding. Faults are inferred to accrue slip incrementally in discrete events that may represent earthquakes associated with transient high shear strain rates that promote fault rock generation.

COMPILATION AND SPATIAL DISTRIBUTION OF SEABED FLUID/GAS EXPULSION ALONG THE HIKURANGI MARGIN

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Seabed fluid expulsion reflects the recycling of fluids from within and below the accretionary prism to the oceans, resulting in complex fluid–rock interaction. Sites of active fluid expulsion provide habitats for chemosynthetic communities, have potential geohazard implications, and are associated with precipitation of authigenic carbonates, mineral deposits, and hydrothermal reservoirs. To date, 36 sites of cold-fluid expulsion along the Hikurangi margin have been identified using hydro-acoustic flare imaging and seafloor-camera footage. Most occur along emergent anticlinal ridges and are attributed to fluid permeating through thrust faults.

We have compiled a decade of published and unpublished acoustic datasets and seafloor observations to analyse the extent and distribution of fluid expulsion features along the Hikurangi margin. This study documents >5000 individual fluid expulsion indicators including: seafloor observations of chemosynthetic communities and authigenic carbonate, acoustic water column flares, and mounds/pockmarks identified in bathymetry and acoustic backscatter.

The spatial distribution of fluid expulsion indicators suggests seabed fluid expulsion varies from north to south along the Hikurangi margin. Across the northern Hikurangi margin, active sites are mostly on the uppermost continental slope at ~250 m depth. Whereas, sites of active fluid expulsion on the southern Hikurangi margin are broadly confined to margin-parallel thrust ridges between 600–1400 m depth, consistent with previously identified seep sites. Differences in spatial distribution of active seepage may be related to differences in the structural and compositional architecture of the accretionary wedge, reflecting plate boundary processes. Pockmarks with or without evidence of benthic fauna or acoustic flares are prevalent across the entire margin (~3800 individual pockmarks), including on the Chatham Rise and Pegasus Canyon, mostly within 365–779 m depth, near the upper limit of gas hydrate stability under current environmental conditions. This study constitutes the first margin-wide database of seabed fluid expulsion features in New Zealand, providing evidence for extensive active and fossil fluid expulsion, and the spatial controls on their occurrence.

SUBMARINE GLACIAL LANDFORMS AND INTERACTIONS WITH VOLCANISM AROUND SUB-ANTARCTIC HEARD AND MCDONALD ISLANDS

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Unravelling the glacial history of Subantarctic islands can provide clues to past climate and Antarctic ice sheet stability. The glacial history of many Subantarctic islands is poorly understood, including the Heard and McDonald Islands (HIMI) on the Kerguelen Plateau, southern Indian Ocean. The geomorphologic development of HIMI has involved construction via hotspot volcanism and mechanical erosion caused by waves, weather, and glaciers. Today, the ~2.5 km^2 McDonald Islands are not glacierized. In contrast, the ~368 km^2 Heard Island has 12 major glaciers, some extending from the summit of 2813 m to sea-level. Historical accounts from Heard Island suggest that the glaciers were more extensive in the 1850s to 1870s and have retreated at least 12% (33.89 km^2) since 1997. However, surrounding bathymetry suggests a more extensive previous glaciation of the HIMI region that encompassed ~9,585 km^2, likely dating back to the Last Glacial Maximum (LGM) ~26.5–19 ka.

We present analyses of multibeam bathymetry and backscatter data that support the previous existence of an extensive icecap. These data reveal widespread ice-marginal and subglacial features, including moraines, over-deepened troughs, and streamlined bedforms. Glacial landforms suggest paleo-ice flow directions and a glacial extent consistent with previously documented terminal moraines. We have identified >660 iceberg keel scours in water depths ranging from ~150–530 m. Iceberg keel scour orientation reflects the predominantly east-flowing Antarctic Circumpolar Current and westerly winds in the region.

$^{40}Ar/^{39}Ar$ dating of submarine volcanoes around McDonald Islands suggests that volcanism and glaciation coincided. The flat-topped morphology of these volcanoes may result from lava–ice interaction or erosion by glaciers post-eruption during a time of extensive ice-sheet cover and/or wave base erosion during sea level low stands.

The prevalence and range of glacial landforms around HIMI suggest extensive past glaciation, and that glaciers have exerted a major influence on submarine geomorphology.

FIRE WATER: CHANGES IN STREAM GEOCHEMISTRY FOLLOWING A WILDFIRE IN THE PORT HILLS

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In February 2017 over 2000 ha of pasture, pine and native vegetation on the Port Hills, Christchurch, was ravaged by wildfires. The loss of vegetative cover was widely expected to lead to increased erosion of the soft loess overlying the volcanic rocks of Banks Peninsula, ultimately changing the sediment load and water quality of the spring-fed streams and rivers in the Christchurch urban area. Immediately following the fire, a water monitoring programme was implemented to detect changes in the geochemistry and sediment loads of ephemeral streams draining the burnt area (Early Valley Stream and tributaries of Cashmere Stream), using the unburnt Bowenvale catchment as a control. This included routine monthly and storm event measurements of stream discharge and of suspended sediment (TSS), trace element (including Fe, Mn, Cu, Pb, Zn, Co, Ni, Cr, As, Cd, Sb, Ge, U and V), major ion, nutrient and organic carbon concentrations. Significant increases in nutrient concentrations in these ephemeral streams were observed immediately following the fire. Very high TSS concentrations (up to 1900 mg/L) were measured during storm events in two of the tributaries of Cashmere Stream, but there is little indication so far that the relationship between TSS concentration and stream discharge has been significantly changed by the fire. The trace element geochemistry of the suspended sediment is consistent with a direct derivation from local loess deposits. There is little partitioning between different trace elements, relative to their abundance in the loess, indicating a rapid transit time with little weathering. This has significant implications for the transport of sediment-bound trace elements, and the loads delivered into downstream urban stream environments, and ultimately into the Avon–Heathcote ihutai (estuary).

STUDIES OF SEISMIC VELOCITY STRUCTURE IN SUBDUCTION ZONE FROM CONTINUOUS OCEAN BOTTOM SEISMOMETER (OBS) DATA

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Recently, Ocean Bottom Seismometers (OBS) have become widely used to record seismic data, to expand the coverage of seismic networks onto the ocean, and to improve the resolution of the subseafloor velocity structure. In this study, we use continuous recordings from OBSs deployed both offshore New Zealand and Taiwan. From 2014 to 2015, 15 OBSs were deployed offshore Gisborne, New Zealand in an area of slow-slip. At various times between 2008 and 2016, 67 OBSs were deployed offshore Taiwan. Ambient noise recorded on vertical velocity and pressure sensors are utilised to retrieve cross-correlation functions (CCFs) for studying shear wave velocity structures in both regions. We also retrieve infragravity waves from the pressure components and analyse their directionality and time variation.

For New Zealand, we measure group velocity dispersion curves of the fundamental and first higher modes from CCFs retrieved from vertical records. The extracted Rayleigh waves are dominant at 0.5–10 s with speeds of 1.2–3 km/s. A 2-D tomography is then generated using 66 grid points with a spacing of 0.1°. The resulting group velocity maps at various frequencies are combined to further determine the shear wave velocity structure down to the depth of 15 km. Further work will continue investigating the shear velocity structure and the relationship to slow-slip events and earthquakes.

For the Taiwan region, we focus on a small-scale deployment of 0.2 × 0.3° on the west edge of Okinawa Trough. Phase velocity dispersion curves with a dominant period of 3–14 s and speeds of 0.43–0.58 km/s are measured from pressure-derived CCFs. As the region is small, instead of conducting tomography, we average the dispersion curves and invert a mean 1-D velocity structure. The infragravity waves at 50–180 s mainly come from the Pacific Ocean and some vary from month to month.

CASE STUDY: TAILORING NATURAL HAZARD SCIENCE ENGAGEMENT FOR LOCAL COMMUNITIES

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The Hikurangi subduction zone is potentially the largest source of earthquake and tsunami hazard in New Zealand. This megathrust fault could produce a magnitude 8+ earthquake with associated ground shaking and co-seismic hazards (e.g., tsunami, landslides and liquefaction). If it ruptured it would have severe, widespread impacts for the East Coast and elsewhere around New Zealand.

A five-year Ministry of Business, Innovation and Employment (MBIE)-funded project is underway to understand what hazard this poses for East Coast communities and reveal the relationship between the occurrence of regular slow-slip earthquakes in the northern Hikurangi subduction zone and large magnitude earthquakes. Raising awareness with local communities and educating them on the hazards posed by the Hikurangi subduction zone is a key part of the GNS Science-led, multi-organisational project. The project is utilising East Coast LAB (Life at the Boundary) and a contracted communicator/educator to reach East Coast communities through a variety of passive and active public engagement opportunities. East Coast LAB is uniquely placed on the coast to translate hazard research associated with the plate boundary to the affected communities there.

The outreach collaboration has had the flexibility of structure and personnel to be able to tailor engagement to different segments of the population, including iwi, the general public, primary and secondary schools. The outreach team have developed web content, information sheets, school field trips, collaborative webinars for teachers through LEARNZ and the Science Learning Hub, lesson plans, social media, media releases, blogs, hui at local marae, and public talks and events. Opportunities have arisen during the course of the project to further engage different audiences.

This approach is creating sustainable relationships and collaborations that will benefit future and associated hazard research on the East Coast. Lessons learnt along the way and the effectiveness of the outreach approach will be discussed.

SURTSEY'S ERUPTION EXCAVATED A DIATREME >150 METRES INTO THE SEAFLOOR

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The volcanic island of Surtsey is the best-known product of a 3.5-year-long eruption initiated in November 1963. During the course of the eruption, four edifices grew from the seafloor along a discontinuous fissure extending 4.5 km, with a combined volume totalling ~0.15 km^3. Nearly half the volume of Surtsey's pyroclastic deposits are below sea-level (~0.3 km^3). Surtsey's emergent explosive activity, first at vent Surtur, then adjacent vent Surtungur, persisted for ~5 months, though it was more than 3 years into the eruption when the last pyroclastic activity at Jolnir ceased and during most of the time that Syrtlingur and Jolnir were erupting there was no subaerial eruption at Surtsey. New drilling and cores acquired by the International Continental Scientific Drilling Program (ICDP) project SUSTAIN in 2017 confirm that Surtur's eruption produced a diatreme, as inferred by J Moore, excavated at least 160 m into seafloor volcaniclastic rock ejected as blocks in both Surtur and Surtungur deposits. Analysis by multiple investigators of the core, drilled at a plunge of 55° and terminating below the centre of Surtur, is just beginning. Except for an interval of coherent basalt in the lowermost ~10 m of the core inferred to represent dikes, all rock transected is lapilli tuff. Hydrothermal alteration has been significant, with little if any glass preserved in original inferred-sideromelane fragments. Fragments >64 mm (bombs and blocks) are not common anywhere in the core. Some zones contain fluidal clasts potentially formed during episodes of fountaining. Future work aims to link diatreme-deposit features with eruptive phenomena and surface deposits on Surtsey. The eruption that formed Surtsey was well-documented and there are now four cores from the island, but no existing model for its eruption is consistent with all evidence currently available, nor does its formation fit easily into models established for other, wholly subaerial, diatremes.

STATIC AND TIME-DEPENDENT INVERSIONS OF SLOW-SLIP AT THE HIKURANGI SUBDUCTION ZONE USING NUMERICAL GREEN'S FUNCTIONS

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Slow-slip events (SSEs) have been observed throughout the world, and the existence of these events has fundamentally altered our understanding of the possible ranges of slip behaviour at subduction plate boundaries. These events occur frequently along the Hikurangi margin, with shallower events in the north and deeper events to the south. A recent study found that static SSE inversions that consider elastic property variations provided significantly different results than those based on an elastic half-space. For deeper events, the heterogeneous models predicted smaller amounts of slip, while for shallower events the heterogeneous models predicted larger amounts of slip. More recent work uses absolute pressure gauge (APG) data to constrain offshore vertical movement during a shallow SSE, and we confirm that when elastic heterogeneity is considered, significantly more slip is required.

In this study we summarize our static SSE inversion results, and present time-dependent inversions covering several years of SSEs. For all our inversions we generate Green's functions using the PyLith finite element code to allow consideration of elastic property variations provided by the New Zealand-wide seismic velocity model as well as the effects of topography. We then use these Green's functions for either static inversions using a non-negative least-squares approach or time-dependent inversions using the Network Inversion Filter (NIF). The use of numerical Green's functions should provide a more accurate picture of the slip distribution and evolution of SSEs. This will aid in understanding the correlations between SSEs and seismicity and/or tremor, and the role of SSEs in the accommodation of plate motion in New Zealand.

APPLICATION AND COMPARISON OF NEW AND OLD GENERATION ITRAX TSUNAMI DATA: OBSERVATIONS FROM NEW ZEALAND AND SAMOA

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Previous tsunami sediment studies have used high-resolution ITRAX X-Ray fluorescence (XRF) elemental data in conjunction with sedimentary, paleontological and contextual proxies to identify potential paleotsunami deposits in the geologic record. Previously presented ITRAX XRF results in the tsunami deposit literature have not adequately accounted for organic dilution, which is associated with the closed-sum effect. This obscures the lithogenic inputs of the sediment resulting in potentially non-representative interpretations, and thus requires normalisation against a conservative element such as aluminium (Al) to minimise this effect. New generation ITRAX instruments provide reliable Al counts, allowing the use of this element for normalisation. Using data from deposits of the 2016 Kaikōura Tsunami at Little Pigeon Bay, New Zealand, it is shown that normalisation of ITRAX element data against Al provides an effective filter for organic dilution in the dataset, enabling identification of potentially older high-energy deposits in the sedimentary record. The technique is applied to older generation ITRAX datasets obtained from Samoan sediment cores in 2010, which show good comparison despite more frequent data gaps in the profiles associated with lower detection limits of older generation ITRAX instruments. The patterns and wider implications of these observations are discussed within the tsunami deposit context.

INVERSION OF SEISMIC DATA TO MAP OFFSHORE GROUNDWATER AQUIFERS, SOUTH CANTERBURY BIGHT

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High-resolution seismic data collected from the Canterbury Bight in 2017 have been processed and inverted for porosity using coloured inversion (CI) and data from International Ocean Discovery Program (IODP) Expedition 317 site U1353B to define an offshore groundwater reservoir. This work is part of MARCAN, a 5-year multi-agency research project funded by the European Research Council, that aims to define the characteristics and dynamics of topographically-driven meteoric groundwater systems at passive continental margins.

Inversion is a process of determining physical parameters of a real system from measured data using a model of the system that is a function of those parameters and which generates the same output as represented by the measured data. One approach to invert seismic data for porosity is to determine the absolute impedance of sub-surface interfaces. It is based on elastic wave theory and considers the reflectivity of the interfaces due to a change in either density, P-wave or S-wave velocity or changes in all these parameters.

We applied a band-limited inversion of seismic data known as coloured inversion that allows for impedance inversion from seismic reflection data. The algorithm requires the creation of an operator (deconvolution operator) from the well log impedance data, which we then used to convert the seismic section close to the well into a relative impedance section. This section was subsequently converted to an absolute impedance section by adding a low frequency impedance trend also derived from the well data. Porosity information available from the well data were related to impedance and consequently impedance sections were converted into porosity sections.

The resulting porosity is being used as an input for inversion of Controlled Source Electromagnetic data collected on the same profiles as seismic data used for inversion. Porosity information will also help characterise the geological model needed to model glacial–interglacial formation of groundwater reservoirs.

RESOLVING THE CENOZOIC FOSSIL RECORD OF NEW ZEALAND: UNRAVELLING MACROEVOLUTION

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Despite centuries of research and debate, biologists and palaeontologists still do not know what fundamentally controls the number of species living in any area at any given time. This is termed biodiversity. Patterns of biodiversity over geological timescales intrinsically represent macroevolution, evolution above the species level. Prior research has focused on global patterns of biodiversity through the Phanerozoic, with limited focus on smaller spatial scales and their relationship to the stratigraphic record. Is there an overarching global force that controls patterns in biodiversity, or is variation manifested as regional or local changes, or both, that cumulatively contribute to the global signal? In order to address these questions, all spatial scales must be considered. The Common Cause Hypothesis posits that the factors that controlled the quality of the fossil record also affected true diversity, thus making it difficult to disentangle the effects of bias in the fossil record from true biodiversity changes. However, recent research suggests that patterns in the fossil record are not dominated by stratigraphic biases. Instead, spatiotemporal patterns of sedimentation and macroevolution are driven by multiple Earth systems. New Zealand provides a model system to test some of these questions due to its isolation and complete fossil and stratigraphic records.

Here I focus on Cenozoic patterns of stratigraphy and biodiversity of marine molluscs in New Zealand. Data sources include the Fossil Record Electronic Database, and new Plio-Pleistocene samples collected from Hawkes Bay. Biodiversity patterns are compared to proxies for environmental heterogeneity at relevant scales. Preliminary results suggest regional marine biodiversity peaks in the Oligocene and Miocene with a notable decrease in spatial turnover of faunas during the late Oligocene, coinciding with maximum flooding. Local scale patterns show high variability of biodiversity during the Nukumuruan in Hawkes Bay, with a notable positive relationship between spatial turnover of faunas and environmental heterogeneity.

A TIME-DEPENDENT INVERSION OF GEODETIC DATA FOR SOUTHERN HIKURANGI SUBDUCTION ZONE SLIP FROM 2013 TO 2016

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Slow-slip events (SSEs) have been documented at several regions of the Hikurangi subduction margin over the last fifteen years. Short, shallow SSEs recurring every one to two years have occurred off the east coast of North Island near Gisborne and Hawkes Bay. Longer, deeper SSEs have been observed in the Manawatu and Kapiti regions with a recurrence period of approximately five years. The GeoNet continuous Global Navigation Satellite System (GNSS) and seismometer networks detected a series of SSEs and earthquakes between 2013 and 2016. The SSEs overlapped in time with the 2013 Cook Strait earthquake sequence (up to M_w 6.6), and the 2014 Eketahuna earthquake (M_w 6.2). Previous studies have suggested some intriguing inter-relationships between these earthquakes and the ongoing SSEs during this period. To explore these relationships further we use the time dependent inversion software TDefnode to simultaneously invert GeoNet GNSS time series and Interferometric Synthetic Aperture Radar (InSAR) data for the temporal and spatial distribution of interface slip over this period, as well as the coseismic and postseismic deformation related to the 2013 and 2014 earthquakes. Such modelling, in tandem with more detailed seismological analyses of the events, may help to resolve the relationship between SSEs and seismicity and the interaction between the southern Hikurangi interface and crustal faults.

AR/AR AGE CONSTRAINTS ON THE TIMING OF HAVRE TROUGH OPENING AND MAGMATISM

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The present-day Kermadec Arc and associated Havre Trough back-arc basin is the youngest in a series of volcanic arcs that have developed along the northern New Zealand margin in response to convergence of the Pacific and Australian plates. It is bounded to the north by the Tonga Arc–Lau Basin arc–back-arc system, and to the south by the Taupō Volcanic Zone (TVZ) of continental New Zealand. The predecessor to the Kermadec Arc, the Miocene–Pliocene Colville Arc, rifted apart in response to rollback of the Pacific Plate, forming the Havre Trough and resulting in the establishment of the Kermadec Arc front.

The age of opening of the Havre Trough and establishment of the Kermadec Arc is not clear owing to a paucity of age data. This is in part due to the inherent difficulty in obtaining reliable radiometric ages on young, glassy, and vesicular submarine volcanic rocks with low potassium, and in part due to tectonic complexity where, until recently, seafloor sampling generally lacked reliable contextual information of the structural setting. Here, we present 19 $^{40}Ar/^{39}Ar$ ages on seafloor volcanic samples from across the southern Kermadec Arc–Havre Trough subduction system. The data, coupled with other published radiometric ages in the literature, suggest that opening of the Havre Trough initiated at ≤~2 Ma. Although opening occurred in a broadly eastward fashion, the oldest measured ages come from the margins of the basin and significant, young magmatism occurred in the central Havre Trough. The ages indicate magmatism occurred across the entire southern Havre Trough within the last 1 Ma. This pattern is analogous to the rifting of the TVZ in both timing and style, with young rift magmatism focused in the centre of the Taupō Rift.

THE EFFECTS OF STRUCTURAL NETWORKS ON FLUID TRANSPORT WITHIN THE HIKURANGI SUBDUCTION SYSTEM

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Slow-slip events (SSEs) fundamentally transformed our traditional understanding of seismic hazard in subduction systems. However, neither the geological and geophysical mechanisms of these SSEs nor their relationship to classical earthquakes is well understood. It is proposed that conditional stability due to reduced effective normal stress at the subduction interface can stimulate SSEs. Laboratory simulations indicate that effective normal stress, reduced by increased fluid pressure, exerts an essential role in modifying the repeat intervals and duration of SSEs. To better understand how high fluid pressures contribute to the genesis and behaviour of SSEs, we need to find out how fluid transport occurs within structural networks because faults and fractures provide pathways for fluid flow and, thus, may facilitate fluid concentration within the Hikurangi subduction system.

In this project, we acquired computerised tomography (CT) scans of core from International Ocean Discovery Program (IODP) Expedition 375 at sites U1518F, U1519C and U1520C, which are located in the active frontal thrust branching from the subduction interface, the hangingwall of an extinct frontal thrust above the SSE source region, and the incoming sediments in their pre-subduction state, respectively. Here we present preliminary characterisations of the structural networks identified from these core CT scans and contextualise them with regard to structure data available from well log data, tomography, and drill core descriptions. With the 3-D data derived from CT, we aim to reorient drill cores in geographic space to extract the true orientation of observed lithological and structural features. Then, we will focus on the effect of circulating fluids in these networks by integrating the resistivity data acquired from core samples, wireline/LWD, and magnetotelluric datasets. Our final goal is to compute fluid reservoir properties, flow pathways, and flow rates within our characterised structural networks, in an effort to determine where fluid is currently being transported within the Hikurangi subduction system.

MIDDLE-LATE MESOZOIC SEDIMENTATION AND TECTONIC SETTING FROM SE CONTINENTAL MARGIN TO TAIWAN, EASTERN ASIA

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Recent studies have shown that a continuous sequence of sediments, extending from continental Eurasia to the Pacific Plate margin, were deposited during the middle–late Mesozoic. The southeastern continental margin metamorphic belt has previously been considered Paleozoic. However, new geological investigations and isotopic dating show that it is late Mesozoic. The depositional age of sedimentary protoliths have been constrained to the Late Triassic–Early Jurassic and the magmatic ages of metamorphosed granites are Middle–Late Jurassic and Early Cretaceous. Field investigations and zircon age data indicate that there is no pre-Paleozoic gneiss (crystalline basement) in Taiwan and the source rocks of the sedimentary sequences in the metamorphic belts of Taiwan are late Mesozoic. Laser ablation inductively-coupled plasma mass spectrometry (LA–ICP–MS) dating of detrital zircons from the Pingtan–Dongshan belt in Fujian Province yields a cluster of $^{206}Pb/^{238}U$ ages at ~210–190 Ma. Dating of granitic intrusions in this belt using the same method has yielded ages ranging from 160–140 Ma. The Tailuko and Yuli belts in Taiwan have similar clusters of detrital zircon ages at 200, 160, 120 and 110 Ma, which also record later overprinting caused by arc–continent collision. From the margin of the Chinese mainland to Taiwan, the metasedimentary rocks seem to represent a continuous sequence of eastward-younging deposits ranging in age from Jurassic to Cretaceous. It can be inferred that the metasedimentary rocks in the eastern Taiwan metamorphic belt were continental shelf sequences with sources in southeast China.

VOLCANIC, CO-SEISMIC, AND SEASONAL CHANGES DETECTED AT WHITE ISLAND (WHAKAARI) VOLCANO USING SEISMIC AMBIENT NOISE

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Recent advances in seismology have brought significant improvements towards detecting small crustal seismic velocity changes by cross-correlating ambient seismic noise. At volcanoes, temporal velocity perturbations carry information about stresses and fluids present within hydrothermal and magmatic systems. White Island volcano represents an excellent case study for ambient noise monitoring, with multiple well-documented eruptions within the past six years. We have monitored this volcano from 2007–2017 by cross-correlating the different components of individual seismic stations. White Island is well suited for this approach, with only one permanent station active throughout eruptive activity. We also process seismic stations located onshore to gain an understanding of background regional changes.

Velocity increases are detected at the volcano during eruptive activity in 2012–2013 and in the months preceding an explosive eruption in April 2016. These coincide with heightened levels of volcano-seismicity and, for activity in 2016, with InSAR detected surface deformation available from early-2015. We therefore interpret velocity increases to reflect cracks closing under increased pressure beneath the volcano. We also detect clear co-seismic velocity decreases associated with M_W 5.2 (~10 km away) and M_W 7.1 (~200 km away) earthquakes. This likely reflects either opening of cracks or redistribution of fluids caused by dynamic stress changes from passing seismic waves. Finally, annual variations recorded by onshore stations are also present at the volcano, suggesting an environmental influence. Velocity changes at White Island, therefore, represent a complex interaction of volcanic and non-volcanic processes, highlighting the need for improved understanding of the underlying sources of background velocity changes.

PALEOMAGNETIC AND GEOCHRONOLOGIC STUDY OF JURASSIC VOLCANIC ROCKS FROM NORTH CHINA: IMPLICATIONS FOR ENVIRONMENTAL CHANGE OF EAST ASIA AND THE JURASSIC TRUE POLAR WANDER

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Dramatic environmental change, from warm and humid to hot and dry conditions, occurred in East Asia during Jurassic time. The sedimentary sequences deposited under warm and humid to hot and dry conditions are characterised by Early to Middle Jurassic black coal-bearing sediments for the (Nandaling Formation), and Middle to Late Jurassic red evaporate-bearing sediments (Tiaojishan Formation). Existing paleomagnetic data suggest that the eastern Asia blocks were located at ~20° to 40° N and experienced minor or no displacement during Jurassic time. However, there is a lack of reliable paleomagnetic data for this interval, especially for the coal-bearing Early to Middle Jurassic unit. The relationship between plate motion and environmental change needs to be further clarified.

In this study, 600 paleomagnetic samples from 57 sites have been collected from the Nandaling and Tiaojishan formations, and new U–Pb zircon age control has been established. After systematic demagnetisation, a total of 50 ChRM directions have been isolated from the two formations. Magnetite and hematite have been revealed as the main magnetic minerals. The ChRMs have passed positive fold tests with an additional positive bake-contact test for the Nandaling Formation. Two paleomagnetic poles have been successfully obtained for Early–Middle Jurassic (180–168 Ma) and Late Jurassic (161–153Ma) time. On the basis of this new data, the dramatic environmental contrast between the warm–humid temperature belt (Nandaling) and the hot-dry subtropical belt (Tiaojishan) can be explained in terms of plate motion. Relative N–S tectonic displacement of about 30° is implied for East Asia during Middle Jurassic time. This model of plate motion for the North China Block is strongly indicative of a significant true polar wander during the Jurassic time.

FLUID PRESSURE CHANGES SUGGESTED BY SEISMIC ANISOTROPY AND V_P/V_S CHANGES MEASURED ON OCEAN BOTTOM SEISMOMETERS DURING THE SEPTEMBER 2014 SLOW SLIP EVENT OFFSHORE GISBORNE

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We analyse data from nine ocean bottom seismometers (OBSs) that were offshore Gisborne from May 2014–June 2015. Up to 20 cm of slip occurred directly below the HOBITSS array during two weeks in September 2014. We determined the orientations of the horizontal components of the OBSs using P and Rayleigh waves. We consider shear wave splitting (SWS) and P-wave/S-wave velocity ratios (V_P/V_S) calculated for single event-station pairs on ~3000 local earthquakes during the OBS deployment. Weak temporal changes in delay time and V_P/V_S and rotations in fast polarisations are observed on moving averages of measurements on some OBS stations. Averaging measurements recorded on OBSs reveals a decrease in V_P/V_S initiating ~20 days before a slow-slip event (SSE; from 1.74 ± 0.005 to 1.72 ± 0.005), with a sharp increase (up to ~1.75) during the two weeks of the SSE. This is followed by a decrease back to the initial V_P/V_S of ~1.74 over the next ~150 days. Delay time trends are inversely related to V_P/V_S, exhibiting an initial increase, from ~0.15 ± 0.01 to ~0.2 ± 0.01 s, over ~60 days before the SSE, followed by a sharp decrease, from ~0.2 to ~0.14 during the SSE, and an increase back to the initial ~0.15 seconds during the next ~60 days. Because SWS results are sensitive to variations in earthquake locations, we analysed results from individual spatial earthquake distributions and conclude that the temporal variations are not driven by spatial variations in earthquake locations.

These results suggest that liquid-filled cracks change their shape. Cracks are rounder when differential stresses are lower, leading to smaller anisotropy and, thus, lower delay times, while the rounder cracks can hold more liquid and yield higher V_P/V_S ratios. When stresses build up, the cracks become more elongated, yielding lower V_P/V_S ratios and higher delay times. The SSE temporarily decreases the differential stress and, thus, changes the shapes of the cracks.

MAGMA TRANSFER PROCESSES IN THE NE JAPAN ARC: INSIGHTS FROM VOLCANIC ERUPTION RECORDS COMBINED WITH CRUSTAL AMBIENT NOISE TOMOGRAPHY

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Ambient noise tomography data from northeast Japan reveals upper crustal low-S-wave velocity (V_s) bodies beneath most sites of active arc-front volcanoes, with the exception of Zao. Strikingly, when small eruptions (Volcanic Explosivity Index (VEI) 1 to VEI 3) from arc-front volcanoes in the last 2 kyrs are considered (as recorded in the Global Volcanism Program database), Zao volcano has erupted most frequently and has produced more than three times the estimated tephra volumes of any other volcanoes in the region. We propose that the frequent low-volume magmatism at Zao is fed by dikes that traverse the crustal section rapidly, fracturing through brittle crust. Beneath the other volcanoes, hotter and more ductile plutonic bodies and mush zones have developed through repeated intrusive activity, hindering magmatic throughput to the surface. This positive feedback mechanism ultimately results in cataclysmic caldera-forming events. We show that the number of late Cenozoic calderas is higher above the imaged low-V_s crust, consistent with this interpretation. We propose that generation of plutonic bodies is facilitated by volcaniclastic materials buried in a Miocene rift graben, which dampen fracture propagation and promote repeated sill intrusion. In contrast, transcurrent faulting has moved cold Cretaceous granitic basement of the forearc range into the arc-front beneath Zao. These brittle rocks provide fracture pathways exploited by magmas rapidly rising to the surface. The combined data imply that millions of years of crustal growth and tectonic history have a direct control on present-day volcanic eruption style.

TOWARDS ION MICROPROBE ANALYSIS OF WATER IN SPINELS: DENSITY DEPENDENCE OF THE RELATIVE SENSITIVITY FACTOR (RSF) OF DEUTERIUM IN SPINELS

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To allow the analysis of hydrogen in nominally anhydrous spinel-structured oxides by ion microprobe, Relative Sensitivity Factors (RSFs), which are matrix-dependent, need to be determined. Spinel-structured oxides are characterised by a wide range of solid solution. For this work, we have selected 13 natural spinels, spanning the Mg–Al–Fe–Ti–Cr compositional space, as well as spinels rich in Zn (franklinite, gahnite), Mn (jakobsite), and Ni (trevorite). We present an approach to estimate the density of these spinels on the basis of their chemical composition. Densities in our samples range from 3.7 to 5.1 g/cm^3. We have also included a natural ilmenite sample for comparison. Samples were implanted with a fixed dose of deuterium (1×10^{15} atoms cm^{-2}) using an ion energy of 40 keV. Subsequently, we performed depth profiling using a Cs^+ primary beam on the Cameca ims-6f ion microprobe at Hokkaido University, monitoring secondary ion counts of $^{2}H^-$ and $^{18}O^-$, until the deuterium counts dropped below background levels. From the ion microprobe data, we calculated RSF values for ^{2}H in an ^{18}O matrix for spinel-structured oxides. RSF values ranged from 6.85×10^{21} atoms/cm^3 to 2.61×10^{22} atoms/cm^3. Ilmenite yielded an RSF value of 2.29×10^{22} atoms/cm^3. Repeat analysis (n = 7) of a chromite provided a standard error of the mean of 1.43×10^{21} atoms/cm^3. We show that for the spinel-structured oxides, RSF values correlate exponentially with the density of the spinel crystal. This indicates that the analysis of hydrogen in natural spinels may be achieved if the density of the oxide sample is known.

THE MEDIAL VOLCANICLASTIC MASS FLOW DEPOSIT APRON OF MT TARANAKI (NEW ZEALAND) RECORDS STRATOVOLCANO CONSTRUCTION AND ASSOCIATED CHEMICAL CHANGES IN THE MAGMATIC SYSTEM

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Andesitic stratovolcanoes are characterised by periodic edifice growth (construction) followed by volcano collapse events (destruction phases). The cyclic behaviour results in the deposition and accumulation of syn- and post-eruptive primary and secondary volcaniclastic successions accumulating around the volcanic edifice, commonly defined as the ring-plain. The ring-plain of Mt Taranaki offers a nearly complete lithostratigraphic and chronostratigraphic record of volcanic evolution. The identification of lithostratigraphic units or packages of like lithologies (with similar genetic properties) has proved to be very useful in medial to distal facies to understand the evolution of the volcano as these volcaniclastic successions preserve volcanic deposits that are not found in proximal sites. The aim of this research is to characterise the evolution of the volcano, in particular, the construction phases by developing sedimentological frameworks and facies categorisation of medial volcaniclastic deposits in order to track magmatic changes through their geochemical fingerprint.

Field investigations in the ring-plain around Mt Taranaki have focused on mass flows between the Te Namu (29 ka), Rama (35 ka) and Otakeho (55 ka) debris avalanche deposits that represent destruction phases. Successions along the shoreline were mapped and correlated by the identification of paleochannels and unconformities in cross-section, based on sedimentological and lithofacies classification. We constructed a stratigraphic model for the investigated time period that highlights the stratigraphic positions of hyperconcentrated flows from which pumice clasts were sampled. They constitute eruptive material that was rapidly remobilised following a significant eruptive period in a construction phase. Whole-rock geochemical analysis of pumices (>55 ka) have SiO_2 contents that vary from 48.3–57.1 wt%. Our preliminary data show significant differences relating to clast compositions of the following Otakeho debris avalanche deposit suggesting distinct magmatic differentiation during edifice construction.

INSECT EVOLUTION NEAR THE TRIASSIC–JURASSIC BOUNDARY: EVIDENCE FROM NW CHINA

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The insect fossils from Middle Triassic to earliest Jurassic strata are especially important in evaluating insect radiations after the end-Permian and end-Triassic mass extinction events. However, insect fossils from this period are quite rare, especially in China. In the past decade, thousands of insect fossils have been collected from the Middle Triassic to Early Jurassic of NW China, which reveal two obvious insect evolution events. The Middle Triassic Tongchuan entomofauna (Ladinian; Shaanxi) and Late Triassic Karamay entomofauna (Carnian; Xinjiang) include the earliest definite caddisfly cases and water boatmen, diverse polyphagan beetles, and scorpionflies. These fossils confirm that the clade Holometabola, comprising the majority of modern-day insect species, experienced extraordinary diversification in the Middle–Late Triassic. After evolution and diversification of the entomofauna during the Triassic, many taxa that became dominant during the late Mesozoic appeared during the Late Triassic, and further developed during the Early Jurassic. The Early Jurassic Tuzigou entomofauna (earliest Sinemurian; Xinjiang) contains at least 11 orders of insects, dominated by Coleoptera and Mecoptera. It resembles the Early Lias Dorset entomofauna of England. The appearance of some higher taxa in this entomofauna probably reflects a spectacular insect radiation during the earliest Jurassic.

SYN-DUCTILE SHEAR MAGMATIC FLOW TRIGGERED ON THE TRANSCURRENT MOTION OF THE WEST PACIFIC PLATE

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In southeast China, Early Cretaceous granitoid plutons were emplaced within the Changle–Nanao ductile shear zone. These granitoids are distributed in a NE–SW-trending belt, parallel to the strike of the Changle–Nanao ductile shear zone. Key textural features of the granitoids include intense schlieren layering of mafic and felsic minerals, alignment of K-feldspar phenocrysts, and elongate and lenticular microgranitoid enclaves that are aligned parallel to the magmatic fabric but lack internal deformation. Dating of the plutons by the LA–ICP–MS U–Pb zircon method indicates that they were emplaced at 130–100 Ma. Magmatic flow was contemporaneous with ductile shearing within the Changle–Nanao ductile shear zone, which was associated with oblique subduction of the West Pacific Plate beneath the Eurasian continent.

QUANTIFYING THE MATAKAOA SUBMARINE SLUMP AND EVALUATING ITS TSUNAMI POTENTIAL

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Straddling across the Pacific–Australian plate boundary, New Zealand faces tsunami threats not only from the Hikurangi subduction zone, but also submarine landslides. Paleotsunami studies show that waves over 20 m high might have hit Great Barrier Island in Holocene times.

In the 1990s, during a survey of the Pacific deep western boundary current (DWBC) offshore eastern New Zealand, the National Institute of Water and Atmospheric Research (NIWA) identified a large-scale collapse of the continental margin in the Raukumara forearc basin and four >100 km^3 mass-transport deposits (MTDs) which were named the Matakaoa Debris Flow. The Raukumara Basin is a large forearc sedimentary basin in which oil and gas companies have carried out extensive seismic surveys. This includes seismic surveys by the New Zealand government in 2007 and 2011. With this data we investigated a submarine slump near the East Cape, which we named "Matakaoa Slump". Through seismic interpretation, we quantified the spatial extent and thickness of the Matakaoa Slump. The slump covers an area of ~25 × 50 km with a maximum thickness of about 850 m and presents as a liver-shaped solid slump mass. The total volume is estimated to be up to ~250 km^3. We defined the transport direction and distance of the slump by analysing its shape, position and relationship with the slide faults and paleo-bathymetry along the 2-D seismic sections and re-constructed the pre- and post-failure paleo-bathymetry. We simulated potential tsunamis caused by this slump failure, with different volumes. The preliminary results show that the slump could have caused tsunamis of more than 30 metres along the Bay of Plenty coast and over 80 metres along the East Cape coast.