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Contents

Abstracts

Sum – Product Networks for eruption forecasting

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Volcanic eruption forecasting is a crucial aspect of hazard mitigation and public safety. This study explores the application of Sum Product Networks (SPNs) as a novel approach for forecasting volcanic eruptions. SPNs are a type of probabilistic graphical model known for several successful applications in image classification, speech recognition or natural language processing. They offer a flexible and expressive framework for probabilistic modelling and inference and can capture complex dependencies and make accurate predictions.

To investigate the potential of SPNs for volcanic eruption forecasting in New Zealand, we trained and tested a model using continuous seismic amplitude measurements (RSAM), local tectonic earthquakes rate, the number of long-period and very-long-period earthquakes and SO_2, CO_2 and H_2S gas fluxes at Whakaari – White Island volcano between 2010 and 2020, during which time six eruptions occurred. We tested different forecasting periods ranging from 2 to 90 days before an eruption to investigate the SPN's performance and ability to model complex relationships within the data. Our preliminary results indicate that an SPN-based approach is capable of accurately predicting an eruption more than 70% of the time within a time window of 40 days or more prior to eruption. Finally, we conducted a thorough comparison with other machine learning models to demonstrate the competitive performance of SPNs.

From point sources to spatio-temporal ruptures: assessing beamforming potential for characterizing regional tsunamigenic sources

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Current tsunami warning systems predominantly rely on seismological point source characterisations and, as the event progresses, DART buoy observations across the ocean basin. This can lead to ultra-conservative hazard management with slow revision to the hazard assessment. The objective of this study is to characterise the spatio-temporal behaviour of ruptures, which would better inform tsunami forecasting in real time. As a key initial step in this research, a seismological array processing technique called beamforming was tested using data from the Loyalty Island Earthquake that occurred on May 19, 2023, with a moment magnitude of 7.7. Waveforms were recorded on a dense large-aperture seismic array in Northland, New Zealand, consisting of 14 broadband seismic stations that was deployed as part of the Rapid Characterisation of Earthquakes and Tsunami programme as well as 5 proximal GeoNet stations. After accounting for the array response function and frequency content of the recorded waveforms, our analysis concentrated on the frequency range of 0.04 Hz to 0.1 Hz to track rupture propagation during this event. Preliminary results show a similarity between the beamforming picture and array response function validating the accuracy of the approach. Our findings suggest the Mw7.7 Loyalty Island Earthquake rupture length was between 100-150 km, aligning with the Finite Fault solution reported by USGS for this event. The rupture demonstrated clear unilateral directivity, extending from North to North-West relative to the centre of our array. This initial study underscores the potential of beamforming in providing a refined understanding of earthquake ruptures, making a significant contribution to the future of tsunami warning systems.

Using statistical models to reveal anomalous spatio-temporal patterns in seismicity on the San Andreas Fault and Hikurangi Subduction Zone.

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Seismic activity that does not follow the typical mainshock aftershock earthquake cycle can provide a valuable source of information regarding fault processes such as slow slip events (SSEs) that are difficult to detect. Episodic tremor and slip (ETS), where tremor sequences comprised of overlapping low frequency earthquakes (LFEs) accompany slow slip, has been documented along the San Andreas Fault. We apply hidden Markov models to the recurrence patterns of LFE events in this region. These models classify LFEs as arising from distinct hidden states. Each state is a proxy for changes in the generating mechanisms that give rise to LFE events, as these mechanisms are hypothesised but presently unmeasurable. This classification highlights the diverse behaviour of LFE generation along the San Andreas, including variations in LFE generation around the 2004 Parkfield earthquake. The evolution of LFE activity over space and time gives additional insights into how slow slip may propagate. We use clustering methods to reveal patterns in the migration of activity between spatially distinct generating locations and identify locations with similar characteristics that are likely influenced by the same generating circumstances.

Hidden Markov models present a viable choice for classifying seismic swarms, clusters of events where several have similar magnitudes and the typical aftershock decay is not displayed. Swarms are frequently associated in both time and space with SSEs but the relationship between SSEs and swarms is not fully understood. Swarm activity has diverse possible generating mechanisms along with slow slip, these include fluid movement, melt migration, and geothermal processes. We apply hidden Markov and Epidemic-Type Aftershock Sequence models to a comprehensive catalogue of Hikurangi seismicity developed using matched-filter detection, to isolate potential seismic swarms. We then use renewal processes to examine the occurrence patterns of swarms. This will help us further investigate the relationship between SSEs and swarms.

Mapping crustal discontinuities using teleseismic P-wave coda autocorrelation: application to Central Italy

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Beneath the central Apennines (Italy), a sizable shear zone likely exists, characterised by regions of diffuse seismic activity that bound shallow normal faults. Surface deformation seems to be correlated to seismicity changes within the seismogenic layer of the Appennic chain. In this study, we utilise short seismograms that follow the P-wave arrivals, using an autocorrelation approach to image the shallow interface of Central Italy. Analysis of the seismogram data reveals an onset P-wave at 10s within the 50s record. However, profound reflectivity data discontinuities necessitate the use of longer seismograms.

We built synthetic experiments to investigate the viability of using the autocorrelation technique to recover both shallow and deep discontinuities as well as multiple interfaces. Leveraging 6 years of raw seismic data recorded by 13 stations within Central Italy from the IRIS Data Management Center (IRIS DMC), this study successfully demonstrates crustal mapping using teleseismic P-wave coda autocorrelation for Central Italy.

The primary focus of this study is on determining the depth of discontinuity beneath each station, achieved through the autocorrelation of the vertical seismogram component. Notably, both vertical and radial stacked autocorrelograms provide the same information. the depth of the discontinuity was deduced by employing a 1-D velocity model and the corresponding time delays of $t2p$ and $t2s$. Our study reveals that the discontinuities beneath Central Italian stations are between 15 - 23 km. Moreover, identified interfaces that might be a representation of the depth of the seismogenic zone beneath Central Italy.

Unravelling surface UV-B variations across the Maunder Minimum and Satellite Era using sporomorph chemistry

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Chemical analysis of sporomorphs offers a novel proxy for reconstructing surface UV-B radiation levels over geological timescales. Plants increase levels of UV-B absorbing compounds (UACs) (e.g., ferulic acid and para-coumaric acids) in their sporomorphs in response to increases in UV-B radiation. Sporopollenin, the primary component of sporomorph exine is chemically inert, allowing for the preservation of UAC levels over millennia after deposition under anaerobic conditions. This allows pre-instrumental UV-B variations to be inferred from measurements of UACs in sporomorphs. While the sporomorph proxy has proven effective for UV-B variations occurring on multi-decadal to orbital timescales, its sensitivity to short-term variations such as across the 11-year solar cycles remain unclear. Our study aims to assess detectability of the 11-year solar cycles within UAC records and to address questions surrounding solar activity influence on surface UV-B receipts.

We have utilised Micro Fourier Transform Infrared Spectroscopy to measure UAC content of pollen grains from lake sediments of Nar Gölü (Turkiye), expanding on similar previous work at that site. We have produced a high-resolution UAC record for the Maunder Minimum (1645 – 1710 CE) and satellite era (1977– 2010 CE). We have identified a robust positive correlation between proxy reconstructed surface UV-B and satellite acquired solar UV-B data across solar activity cycles 22 and 23. Additionally, our study provides evidence, based on surface UV-B cycles throughout the Maunder Minimum, of the persistence of the 11-year solar activity cyclicity, challenging its cessation as reflected in sunspot records. By demonstrating the sporomorph UAC proxy's ability to detect surface UV-B variations on short timescales, we have opened new avenues for investigating historic ozone perturbations, with far-reaching implications for climate modelling.

Implementing real-time GNSS and G-FAST for rapid earthquake rupture characterisation in New Zealand

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The RCET (Rapid Characterisation of Earthquakes and Tsunami) programme is a large GNS-led multi-year public initiative to better prepare for and respond to natural disasters. With the goal of improving the speed and accuracy of scientific information to underpin emergency response decision-making, RCET aims to implement, test, and operationalise a suite of rapid characterisation tools.

Real-time GNSS is increasingly becoming a fundamental tool for rapid assessment of M7+ earthquakes that measurably deform the Earth surface within 100-200 km of the nearest GNSS stations. The GeoNet programme at GNS operates a real-time continuous GNSS network of ~50 stations in partnership with LINZ. The network is currently used for surveying applications but can be leveraged to monitor geohazards.

As part of RCET we are building a prototype system to process these real time GNSS data to generate ground displacement waveforms. Several software solutions are available, and we are testing some of these to select the best option for New Zealand. We are also implementing the Geodetic First Approximate of Size and Timing (G-FAST) algorithm, a GNSS-based module developed for earthquake and tsunami early warning in the US. The G-FAST algorithm can provide rapid, non-saturating magnitude estimates based on an empirical scaling relation for peak ground displacement, as well as invert for a centroid moment tensor and finite-fault slip estimates.

Source characterisation from real-time GNSS and G-FAST has the potential to improve shaking estimates, and in the case of large, near-shore tsunamigenic earthquakes, to better constrain tsunami forecasts and deliver tsunami early warning. The GNSS component will be particularly useful for scenarios that are challenging for more traditional seismic analyses, such as large magnitude and offshore sources. GNSS and G-FAST therefore have the potential to greatly improve our ability to rapidly respond to the earthquake and tsunami hazards in Aotearoa.

Rapid rupture characterisation for New Zealand using the FinDer algorithm and its potential for earthquake early warning

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The Finite-fault Rupture Detector (FinDer) has been implemented under the RCET (Rapid Characterisation of Earthquake and Tsunami) programme in New Zealand for rapid rupture characterisation in the seconds to minutes following an earthquake. It is designed (and used elsewhere) as an earthquake early warning (EEW) algorithm to rapidly estimate the location, extent and orientation of the earthquake fault rupture by matching spatial distributions of high-frequency seismic amplitudes with pre-computed templates, and it creates a time series of solutions as the earthquake evolves. During systematic and historic offline testing, we have found that FinDer performs reliably in the New Zealand setting for onshore crustal earthquakes, providing reasonable magnitude and location estimates for M6+ earthquakes, and also strike estimates for M7+ events. Furthermore, the FinDer solutions can be used to aid response decision making by improving early shaking estimates and indicating additional directivity and tsunami hazard. Neither the national GeoNet seismic network nor the New Zealand FinDer configuration are designed for EEW, but the current work allows us to begin exploring its potential. Real-time testing shows reliable detection for M4.5+ earthquakes, with first solution times ranging from 7 seconds for highly favourable station and event settings to greater than 60 seconds for more challenging scenarios. Further insights are gained from the calculation of EEW performance metrics for different alert thresholds for historic events, allowing us to begin to investigate opportunities and challenges for FinDer’s current setup.

A Zealandia provenance for explosive felsic and mafic volcanism during much of the Permian within the southeastern Sydney Basin and its impact on the biodiversity

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Mafic and felsic tuffs found within all formations from the Early- Late Permian of the southern Sydney Basin, in addition to dropstones and intraclasts of similar volcanic origin throughout, suggests volcanism was pervasive along the southeastern margin of Gondwana throughout the Permian.

The tuffs range in thickness from over 2 m to a few millimetres and in outcrop appear to vary from felsic to more mafic. They are commonly reworked, although a lack of abrasion on the phenocrysts and shards within the more mafic tuffs, suggests a proximal source. Dropstones and clasts of similar tuffaceous material occur throughout the lower sequence, along with dacite, rhyolite and a few large granitic dropstones. The volcanic material often dominates in the east and is rare or absent in the west. Mafic clasts become predominant upwards in the sequence with the proximal mid-Permian Gerringong Volcanics (GV) latites. Felsic eruptions return following the GV, during the Illawarra Coal Measures and above them.

Many tuffs are associated with bioturbation, including escape burrows, and death assemblages of different marine fossils. *Cruziana* ichnogenera and glendonites, often associated with the tuffs and fossils, in addition to wave-generated ripples and clast concentrations, suggest deposition was dominated by episodic storm activity with seasonal coastal ice sheets and a predominantly northerly palaeocurrent direction under cold climate marine conditions.

The felsic tuffs likely represent distal components of much larger volcanic massifs to the south or southeast, within the NW Zealandia craton, such as the Median Batholith. The mafic material was mainly sourced from more proximal island volcanoes also to the south and east of the exposed Sydney Basin. Detritus from both these mafic and felsic volcanoes periodically inundated the cratonic sediments derived mainly from the west, and its persistence throughout the Permian likely had a major detrimental impact on the biota and ecosystems.

What can Antarctic ice cores tell us about New Zealand eruptions?

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Ice cores hold vital information about Earth's past that can be used to assess changes in climate at high temporal resolution. Ice cores are also increasingly being used to assess the frequency and impacts of past volcanic eruptions as volcanic sulfate is deposited over the poles, months to years after large eruptions. Sulfate anomalies can be used as a time marker for linking ice records, particularly in deep ice extending back thousands of years. The strength of the sulfate anomaly is usually assumed to vary with the size of the eruption and the location of the volcano with respect to the poles. In addition to sulfate anomalies, insoluble particle analysis can hold clues about the unique source of the eruptions where glass shards can be extracted from ice and analysed to assess source magma chemistry.

With New Zealand being in a prime location for atmospheric ash transport to the south, Antarctic ice cores can be used to provide new information on past explosive eruptions. Here we present case studies of two of the largest events, the 1.8 ka Taupō eruption and the 25.5 ka Ōruanui supereruption. Glass shards from both events have now been uniquely located using a range of techniques, meaning that high resolution and well dated ice core records can be used to assess the timing and impacts of these events. The Ōruanui supereruption is recorded as one of the largest sulfate anomalies in ice core records and considerations of magma chemistry highlight that the event ejected >390 Tg of sulfate. In contrast, the 230 AD Taupō event produced only a minor anomaly, despite its size and energetic plume. We highlight the many challenges with pinpointing these events in ice records and outline the different tools that will be used to interpret short-term climatic and environmental responses.

New insights into Hikurangi subduction inputs, accretionary wedge, and plate interface host rocks spanning along-strike changes in fault slip behavior, New Zealand

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The Hikurangi subduction margin exhibits well documented spatial variations in convergence rate, trench sediment, accretionary wedge structure and geomorphology, and fault slip behavior ranging from stick-slip megathrust earthquakes to slow slip events (SSEs) and creep. Precisely what controls the fault slip behavior is not well understood, but variations in lithology, physical properties, subducting plate relief, and pore pressure regime have been implicated. Previous studies have interpreted (i) a northern margin impacted by subducting seamounts, and a weakly coupled plate interface comprising volcaniclastic and calcareous rocks that host fault creep phenomena including SSEs, and (ii) a wider, low tapered central - southern margin inboard of thick subduction inputs and a strongly coupled plate interface that, for up to 75 km landward, appears to be hosted in the plateau's sedimentary cover sequence. Given that megathrust slip behavior and upper plate thrust faulting have implications for earthquake and tsunami hazard, it is vital to improve understanding of the sequences that host the plate interface, accrete, and subduct.

Prior to International Ocean Discovery Program (IODP) Expeditions 372 and 375, the incoming plate and cover sequence at the deformation front had never been drilled and directly dated. Regional seismic reflection profiles tied to drilling data and core from IODP Site U1520 in the northern Hikurangi Trough provide new insights into the composition and structure of the subduction inputs, accretionary wedge, and plate interface spanning along-strike changes in fault slip behavior. We observe: (i) widespread extensional faulting and late-stage volcanism in the subducting Hikurangi Plateau, (ii) current-influenced sedimentation, erosional surfaces, and polygonal faulting in the Paleogene-Neogene calcareous pelagic cover, (iii) thick (0.5-6 km) Plio-Pleistocene clastic trench turbidites that are younger than previously inferred, implying higher rates of sedimentation and tectonic shortening, (iv) clay mineral assemblages that vary strongly with time, (v) a plate interface that smoothens southwards across the region of transitional slip behavior, and (vi) a southern interface widely hosted at the base of smectite-rich calcareous mudstones immediately overlying chalk.

An updated geological map of the Dunedin urban area

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The GNS Science Urban Geological Mapping Project provides updated geological information in selected urban areas, both established and developing, of New Zealand. An updated geological map of the wider Dunedin urban area is nearing completion. The map is compiled largely from existing geological maps, building on previously published maps of Ongley 1939 (1:63,360-scale – Geology of the Kaitangata-Green Island Subdivision), Benson 1968 (1:50,000-scale – Geology of the Dunedin area) and McKellar 1990 (1:25,000-scale – Geology of the SW Dunedin urban area). A feature of the updated Dunedin geological map is that it is drawn on a lidar basemap which enables the very precise positioning of geological unit boundaries. The essence of the widely used Benson (1968) Dunedin volcanic stratigraphy is retained, with the map units now properly aligned on contacts between volcanic rock layers visible in the lidar.

A new group/formation framework is presented for the Quaternary deposits. The new Ōtepoti Group stratigraphy emphasises geology as well as geomorphology of the Quaternary units. Eight formations are proposed: Outram Formation (distant-source river deposits); Mosgiel Formation (local-source river or stream deposits); Tirohanga Formation (alluvial fan deposits); Allanton Formation (loess and colluvial deposits); Burns Formation (landslide debris); Momona Formation (floodplain swamp and estuarine to shallow-marine deposits associated with sheltered inlet environments); Moturata Formation (beach to shallow-marine deposits within open coastline environments); and Pipikaretu Formation (wind-blown sand deposits). All are new names and have been selected because they have not been used before in New Zealand stratigraphic nomenclature. These units will be defined, with type/reference localities, in the map text.

A revised interpretation of faulting and folding is depicted on the map and illustrated on cross sections. A map text will formalize the new stratigraphic components, explain structural interpretations, summarize geological history, and describe the geological units in both lithological and geotechnical terms.

The Alpine Fault in the lidar age: refined interpretations, new discoveries, and the next earthquake

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High-resolution lidar topographic data presently cover ~60% of the onshore Alpine Fault (AF) surface trace and complete coverage is expected within 1-2 years. These data reveal complexities which are otherwise vegetation-obscured and will advance our understanding of active tectonics ahead of an anticipated large magnitude AF earthquake. Here we present select results from recent lidar-enabled studies, which better constrain surface rupture characteristics, slip rates, kinematics, and shallow structure. This includes: (1) evidence that the last three surface-rupturing AF earthquakes each generated ≥10 m dextral and ≥1 m of reverse separation on the central AF near Haast, (2) new offset measurements near Hokuri Creek that corroborate a late Pleistocene slip rate of ~30 mm/yr on the southern AF, and (3) topographic analysis and dating of Pleistocene marine terraces that indicates 1.5° NW-tilting and 2.0-4.5 mm/yr uplift of the Australian Plate near Big Bay. We also present new, detailed mapping and morphometric analysis of the AF and secondary fault surface traces. This reveals prominent along-strike changes in the style of active faulting that is collocated with a >2 km-wide, ~20° releasing double-bend in the AF main trace, in addition to a shift in kinematics and strain partitioning, each located near the central-southern section boundary. These findings are consistent with recent geophysical investigations that suggest fault plane geometry and/or segmentation control bimodal (single vs. multi-section) earthquake rupture behaviour observed in AF paleoseismic records. We identify ~65 km² of overlapping lidar datasets along the AF and present DEMs of difference (DoD) from a couple sites to help assess the best post- earthquake lidar survey parameters, likely artifacts, and expected limit of detection for surface change. Collectively, our work highlights the importance of high-resolution topographic data in fault zone characterisation and may prove valuable in future seismic hazard analysis and disaster recovery efforts.

Investigating the location of the active southern Hikurangi subduction using seismicity catalogues

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The Hikurangi subduction zone, which runs along the east coast of Aotearoa New Zealand's North Island, has the potential to host great earthquakes (Mw>8). In the southern Hikurangi margin, the plate boundary transitions from subduction to transpressional motion on the Alpine fault across the Marlborough Fault System. This transition is distributed, and the southern extent of active subduction remains an open question. While some studies suggest that subduction terminates in Cook Strait, more recent seismicity and InSAR data raise the possibility of an active interface beneath Marlborough and possibly northern Canterbury. To study the structure and slip of the southern Hikurangi interface, we review the seismicity in the northern South Island, with a specific focus on the interpretation of earthquake hypocentre locations and focal mechanisms. We use NonLinLoc, a non-linear 3D grid-search location algorithm and the Aotearoa New Zealand 3D velocity model to determine homogeneous and precise hypocentre locations. Seismicity from different catalogues is compared to existing models of the subduction interface, to identify earthquakes that could be associated with active subduction and intra-slab faulting. The data could indicate that active subduction extends beneath the northern South Island which, if correct, would inform local seismic hazard and increase local tsunami hazard. This work is preliminary, and we welcome your comments at the poster.

Controls on repeated fountaining, crater excavation and vent shifting during early phases of the maar-forming Ubehebe eruption, Death Valley, California.

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The Ubehebe crater cluster comprises 13 vents created during a monogenetic eruption at ~2.1 ka in Death Valley, USA. We have used deposit distributions and particle characteristics to determine the driver(s) of changing eruption dynamics through the first 5 events of the Ubehebe Craters eruption, which produced a high violent strombolian plume, weak cratering, and low fountaining. The initial fissure eruption localised primarily to a vent where a scoria cone formed, followed by violent strombolian activity. Concurrently, however, low-volume phreatomagmatic explosions started south of the cone, subsequently progressing northwards, to form the Amphitheatre crater series. A new fountain formed and stabilised briefly at the north end of this crater series to produce a spatter cone.

The primary cause for the differing styles and shallow sites of fragmentation in this series of eruptive phases was changing rates of magma delivery to the surface. We infer that a dike opened an initial fissure along which a primary vent produced the violent strombolian eruption in the north, while slow moving, outgassed magma at the southern end of the fissure interacted with groundwater to produce small phreatomagmatic explosions. Magma supply rates then decreased and the northern violent strombolian activity ceased. Progressive magma withdrawal starting at the south end of the system caused northward migration of explosion loci towards the violent strombolian site, forming the remainder of the N-S aligned Amphitheatre craters, the most northern of which truncated part of the violent strombolian cone. Rapid ascent of a subsequent small batch of extremely fluid magma fed the Little Hebe spatter cone.

The changes in behaviour over these 5 events of Ubehebe Craters' development reveal how deeper-seated changes in magma delivery, not surficial hydrology, drive shifts in shallow eruptive style even when immediate control of local eruptive style is magma-water interaction leading to phreatomagmatic cratering.

Particle morphologies and damage fractures created by high-energy eruptions: Comparing particles from Tonga's 2022 Hunga eruption with Krakatoa 1883, and Havre 2012 eruptions.

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The explosive eruption from Tonga's Hunga Volcano on 15th January 2022, produced a > 40 km plume, global tsunamis, PDCs, and submarine density currents. We analyse particles from five subaerial and seven submarine deposits and describe different damage crack types and their abundance on 4 phi ash. Particles were mounted on carbon tape and imaged with the Backscattered Electron Detector of a Zeiss FEG-SEM. High resolution, high magnification images were used for analysing particle fracture patterns; some were further investigated with an In-Lens detector.

Over 90% of particles analysed from the Hunga eruption present shock wave traces in the form of damage cracks: 2D hackle lines, branching fractures, 3D stepped fractures, or some combination thereof. Stepped fractures indicate maximum fracture rates. For the SE subaerial samples, there is an up-section decrease in blocky particles, damage cracks, and reduction of stepped fractures from ~58% to ~35%, while fluidal textures increase from ~5% to ~20%. Later subaerial fall deposits return to higher proportions of blocky particles, damage cracks and stepped features. For the submarine gravity core, stratigraphically higher samples show increased step-fracture abundance, from ~50% to ~75%. The lowest sample has the smallest proportion of blocky particles. Submarine box-core samples at increasing distances westward show a decrease in step fracture abundance from ~70% to ~35%.

With MatLab tools PARTIcle Shape ANalyzer (PARTISAN) and DendroScan we analysed morphological similarities of Hunga particles to those from the 2012 submarine Havre eruption, and the 1883 Krakataoa eruption. Hunga ash morphologies closely match those of Havre’s rhyolite ash, indicating that a thermohydraulic mechanism drove fragmentation in both eruptions. The greater abundance of damage cracks bounding Hunga particles indicates higher energy density than at Havre and Krakatoa 1883. These particles record the fragmentation process at work during one of the most powerful explosive eruptions ever recorded.

Seismo-Acoustic Monitoring (SAM) Toolbox

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Detecting unusual patterns in seismo-acoustic data is a common task in geohazard monitoring. While the types of patterns can be very different between, for example, volcanic unrest and submarine landslides, the methodologies to detect these patterns are often very similar.
A typical workflow can be broken down as follows:

1. Access waveform and sensor meta data.
2. Divide continuous data into fixed-size windows.
3. Compute features for each window such as statistical properties or spectrograms.
4. Detect patterns in the feature time-series. This can be either done in a supervised (e.g. patterns preceding an eruption) or unsupervised fashion (e.g. cluster analysis).
5. Visualise features and patterns on an interactive dashboard that updates as new data becomes available.

We implemented this workflow in a python package using modern, open-source Data Science tools. Several common features (e.g., spectrograms) and pattern recognition algorithms (e.g., deep autoencoders) are already part of the package. More importantly, the package was written with extensibility in mind. Our long-term objective is to make the SAM Toolbox a platform for evaluating new algorithms for seismo-acoustic monitoring.

We will describe how to deploy the toolbox as an operational monitoring system and demonstrate its application for seismic monitoring of Mt Ruapehu and Whakaari/White Island.

Bayesian Networks for eruption forecasting

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Volcano monitoring observations range from high-frequency measurements, collected a hundred times per second, to manually collected data with a few data points per year. Searching for common patterns that may precede eruptions in such disparate data streams is challenging. This is especially so when eruptions are relatively rare events from which to learn about precursors from, no matter how well monitored. About nine unrest episodes at New Zealand volcanoes since 2000 did not result in an eruption (compared to 10 eruptive episodes over the same time period). This gives particular importance to volcanologists' conceptual understanding of the physical and chemical processes inside the volcano that drive the unrest and whether it will tip into an eruption.

We propose the application of Bayesian Networks (BNs) to integrate monitoring data and expert knowledge to create probabilistic eruption forecasts. BNs are well suited to produce forecasts that reflect the, sometimes large, uncertainties in both data and conceptual models. The graphical presentation of variables and the option to model causal processes make BNs easy to understand and interpret, a key requirement for decision support tools.

We show preliminary results for eruption likelihood over a 30-day forecast window at Whakaari/White Island using seismic and gas-flux data since 2010. For five out of the six eruptions during that time, we observe an increase in eruption likelihood several weeks prior to eruption. However, increases are also observed at other times, sometimes for several months, possibly indicating heightened unrest that did not result in eruption.

What our data looks like in the cloud: the GeoNet perspective

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The country-wide network of stations operated by Geonet monitors geological hazards in Aotearoa New Zealand. With data streaming from more than 1,000 instruments currently deployed, cloud-hosted services introduce a more scalable facility for data management.

Taking it to the next level, GeoNet uses Amazon Web Services (AWS) to securely host over 100TB of data, paving the way for instant access to the data archive.
In the cloud, the GeoNet archive looks like a typical file storage system such as those in computer drives, only with an enhanced security cover, data architecture and bucket storage system. It is a centralized repository designed to handle the data's life cycle from the reception point towards its raw and derived forms. In a nutshell, an array of data 'buckets' are stored in GeoNet's cloud with contents ranging from time series data from various sensor types to processed data products and camera images. Through the AWS Open Data Sponsorship Program, GeoNet provides free and open access to end-users.

An ongoing part of network maintenance is ensuring that the waveform data and metadata are in alignment. Misalignments can be due to equipment misconfigurations, mismatch in stream naming conventions, temporary deployments, and/or overlapping data streams. Often tracked during sensor deployment, these misalignments are also captured in downstream assessments, network monitoring, data quality checks and from end-user feedback. Here, we describe the workflow in maintaining the data-in-the-cloud for use cases including data re-labelling to match the station metadata, purging of data with overlaps and data upload for manually collected and offline sensor recordings.

New Zealand's offshore sedimentary basins

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We present the distribution, extent, and sediment thickness of the 25 primarily offshore sedimentary basins within New Zealand's 5.8 million km² Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS). Sedimentary basins within New Zealand's land area and EEZ/ECS cover ~1.79 million km², of which 1.64 million km² (92%) lies offshore, representing 28% of the marine area under New Zealand's jurisdiction.

The basins primarily represent four tectonic settings with most forming during the initial stages of mid- to Late Cretaceous rifting and the breakup of Gondwana. In northeast Zealandia, a broadly linear series of basins formed atop the Gondwana accretionary wedge, whereas those in southwest Zealandia formed through rifting and seafloor spreading during the Late Eocene–Oligocene. Basins along western North Island formed due to southward-migrating long-wavelength subsidence associated with evolving Neogene–Quaternary Pacific-Australia plate subduction.
Individual basins range in size from ~225 000 km² (Aotea) to ~8500 km² (Outer Campbell Basin). The thickest sedimentary infill is up to 11 km (proximal Taranaki Basin), and all areas with the thickest basin fill (>10 km) occur within or adjacent to the Neogene–Quaternary Pacific-Australian plate boundary zone (Raukumara and East Coast basins). Up to ~7 km of sedimentary fill occurs in the Canterbury-Great South and Western Southland basins. Many of those same basins have experienced slight to intense deformation associated during the Neogene–Quaternary (e.g., East Coast, proximal Taranaki basins), whereas basins distal to the modern plate boundary have remained relatively undeformed since the Late Cretaceous (e.g., Campbell Plateau basins).

Many of the basin boundaries remain poorly constrained due to a paucity of data. Despite this, the rocks within them contain invaluable records of past climates, the evolution and spread of past lifeforms, and tectonic and volcanic histories, all of which help us understand New Zealand's unique geological and biological heritage.

Generalized inversion of New Zealand ground-motion data: implications for attenuation and site-effects

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One of the major challenges in assessing seismic hazard at a given site is to better capture the local effects that cause significant modification to incoming seismic waves. In the domain of engineering seismology such effects are called site effects essentially originating from the effects of local geology, topography, and material properties. Recently, we decomposed over two-decades of ground-motion data from 2000 to 2021 (compiled within national seismic hazard model revision 2022) into source, path, and site components to better understand the ground-motion phenomena in New Zealand. We apply a non-parametric generalized inversion technique (GIT) on Fourier spectra of the recorded acceleration traces to isolate the systematic source, path, and site effects from 20, 813 seismograms of 1200 shallow crustal events (Mw>3) recorded by 693 sensors at 439 unique localities.

In this presentation, we mainly focus on modelling of path attenuation and site-effects. Using the high-quality observational dataset of site response from GIT, we find that the soil classification scheme specified in seismic code (i.e., NZS1170.5) has a rather limited capability in discerning the site-specific frequency-dependent amplification curves. From the inverted attenuation curves, we find a multi-segment apparent geometric-spreading function and a distance-dependent quality-factor Q(f) model provide the best fit, though a single Q model is also obtained for the whole distance range. Furthermore, we observe clear regional variations in inverted attenuation curves which exhibit significant differences in Q estimates within the North Island. Also, statistically significant differences in attenuation are observed between the upper/central portion of the South Island and its south-western portion.

Frictional properties of greywacke sandstone and siltstone: implications for earthquake nucleation

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Across New Zealand, multiple historical earthquakes have ruptured faults within the Torlesse Supergroup. Yet the frictional strength and stability of greywacke fault rocks have never been investigated systematically. In this research, hydrothermal friction experiments were performed on Pahau Terrane greywacke sandstone and siltstone gouges across a wide range of conditions (v=0.01 µm/s to 100 µm/s, T=20°C to 500°C, and σn'=75 MPa). The gouges were created by gently disaggregating and sieving sandstone and siltstone samples from the fault core and footwall of the sinistral-reverse Leader Fault.

Results reveal that at T=250°C to 500°C, all sandstone and siltstone gouges have Byerlee (µ=0.6-0.8) values of sliding friction. At temperatures ≤200°C, the fault core and footwall siltstone gouges have lower friction coefficients (µ=0.32-0.53), are weaker than the sandstone gouges (µ=0.55-0.65) and are velocity strengthening. We hypothesise that the low-temperature frictional properties of siltstone promote distributed slip at shallow depths where faults are oriented parallel to bedding and/or where bedding is optimally oriented.

Experimental results also show that the velocity-weakening to velocity-strengthening transition temperature, interpreted to represent the seismic-aseismic transition, is both lithology- and velocity-dependent. At the lowest velocities imposed, the transition temperature is ~450°C in sandstone gouge and ~350°C in siltstone gouge. At the highest velocities imposed, the transition temperature increases to over 500°C in the sandstone gouge and 500°C in the siltstone gouge. Both lithologies are frictionally strong and unstable in a narrow temperature range between T=200°C and T=300°C (10 to 15 km depth for a 20 °C/km geothermal gradient). The hypocentres of the recent 2010 Mw 7.1 Darfield (~10 km depth) and 2016 Mw 7.8 Kaikōura (~13 km depth) earthquakes were located at depths where the frictional properties of greywacke sandstone and siltstone promote large elastic strain accumulation and earthquake nucleation.

Preliminary tomographic image of Fiordland, New Zealand, from temporary seismic array data

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Beneath Fiordland, the obliquely subducting Australian slab is colliding with the thick and strong Pacific lithosphere. Seismicity shows that this collision has bent the Australian slab to vertical. In the crust, faulting has reactivated long-lived shear zones, such as the George Sound, Grebe and Indecision Creek shear zones.

We use data from a recent temporary seismograph deployment and from neighbouring deployments SALSA and SOSA to image seismic properties in Fiordland. Earthquakes were captured throughout the region and in the subducted Australian plate to 150 km depth, enabling inversion for the 3D velocity structure. Preliminary images show contrasted structure across Fiordland and major shear zones.

South of the George Sound Shear Zone and West of the Spey-Mica Burn Fault Zone, where lower crustal material is exhumed at the surface, Vp is ~7km/s at just 15 km depth. North from there and between the George Sound and Indecision Creek shear zones is a low-velocity zone with Vp ~ 6 km/s to about 35 km depth, suggesting thickening of the crust directly above the vertical Australian slab. The Grebe Shear Zone, which marks the eastern margin of Fiordland, is associated with a velocity contrast to 80 km depth with lithosphere from the East Isotopic Domain abutting the vertical Australian slab and the uplifted Fiordland block above the slab.

The seismicity illustrates the vertically bent Australian slab and the character of the plate boundary deformation. Seismicity in the crust is distributed from the offshore Alpine Fault to eastern Fiordland, showing that the plate motion in Fiordland is partitioned across a range of crustal faults. This contrasts with north of Fiordland where the Alpine Fault accommodates the greater part of the relative plate motion.

The form and history of submarine canyons offshore Taranaki, New Zealand

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Submarine canyons are important in the assessment of coastal and marine hazards as many dynamic geological processes, including submarine sediment flows and large landslides frequently occur within them. A new bathymetric dataset acquired in 2021 offshore Taranaki has enabled the detailed mapping of submarine canyons in this area for the first time. Merging multibeam data acquired on four different surveys (including both dedicated surveys and transit lines) enabled the creation of a comprehensive bathymetric and backscatter grid at 25 m resolution. These data reveal 18 new canyons that extend from the continental shelf break at ~200 m to abyssal depths of ~1300 m. The maximum canyon length (streamwise distance) is at least 99 km, with channels likely extending beyond the surveyed region. Using these data, we conducted a geomorphological analysis, including computation of different morphometric parameters for each canyon (including slope, sinuosity and aspect ratio etc.). The canyons show variable sinuosity, with higher sinuosity segments being generally across the lower slope and deeper across the continental shelf. Seafloor morphology was then analysed in conjunction with extensive subsurface marine geophysical data, including newly acquired high-resolution seismic and sub-bottom profiler (TOPAS) data and industry acquired seismic reflection data.

These data provide the first glimpse into the form and structure of the modern Taranaki canyon system, and insights into their evolution, including interactions with mass slope failure processes. This study allows us to further our understanding of paleo- and modern shelf processes in the region, and investigate the interplay between submarine canyon incision, submarine landslides and sea-level fluctuations.

Alan Beu's comprehensive catalogue of New Zealand Cenozoic Marine Mollusca

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In the 33 years since the publication of Beu and Maxwell's (1990) landmark monograph on the Cenozoic Mollusca of New Zealand, Alan Beu built and maintained a comprehensive catalogue of Cenozoic Mollusca, incorporating data from a legacy card index, originally compiled by Marwick, Fleming, Boreham, Keyes and others; the list compiled by Philip Maxwell in the NZ inventory of biodiversity (2009); and another Synoptic Database compiled by Beu, Maxwell, Marshall, Crampton and Jones. Alan studiously kept abreast of the literature and applied up to date taxonomic opinion.

Beu's catalogue also incorporates data from Phillip Maxwell's lifetime of largely unpublished research. Most records of new genera in the list have arisen from this source. Additionally, data were added from unpublished theses and subsequently named taxa, including newly discovered species from Haughs' Quarry, Cosy Dell and Pomahaka River localities. Many new occurrence records were derived from Andrew Grebneff's extensive collection, now housed in the National Paleontology Collection at GNS.

At the time of his death, Alan's catalogue included 1282 genera and 5997 species, including the new taxa. The scope of the catalogue includes mainland New Zealand and the Chatham Islands; the few fossils known from the Kermadec Islands are not included. Most are marine taxa, except for Hyriidae (fresh-water Bivalvia) and the few species of Tateidae, Potamididae, Batillariidae, Thiaridae, Zemelanopsidae, Ellobiidae, Amphibolidae, Latiidae, Lymnaeidae and Planorbidae (Gastropoda). A few estuarine taxa are also included.

Following Alan's death, the catalogue is being completed and prepared for publication by Henry Gard, with funding from GNS Science and MBIE via the Nationally Significant Collections and Databases programme.

The Titirangi Sand: a marker of uplift and sea level change at the eastern end of the Chatham Rise

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The Chatham Islands occupy the eastern-most reaches of the Chatham Rise, a significant portion of the Zealandia continent. However, tectonism in this region has followed a very different path to that of the New Zealand mainland. There is ample conclusive evidence for geologically recent (Late Pliocene) emergence of the Chatham Islands from the sea. Furthermore, juxtaposition of Late Pliocene deep-water marine sediments of the Motarata Limestone beneath the early Pleistocene fossiliferous shallow-water marine Titirangi Sand indicate that this uplift was potentially rapid.

The Titirangi Sand was of great interest to the late Alan Beu. It is the subject of a near-complete manuscript which he prepared prior to his illness, alongside a partner manuscript on the uplift and emergence of the islands. Since Alan's illness and passing, we have made further investigations into the distribution and significance of the Titirangi Sand on Chatham Island. A substantial deposit previously only known from a borehole has been exposed by quarrying activities. Plus, a potential new locality has been identified to the east of Te Whanga Lagoon, in an area that was always assumed to be of Holocene age.

While the Titirangi sand has provided robust evidence for the timing of emergence of Chatham Island, its current distribution can be used to make inferences about vertical movement and sea level variations and coastal erosion in the region since emergence. All known outcrops occur within ~20m of modern sea level, and several within 10m. This positioning has several potential implications, including that uplift of the region since the deposition of the Sand at ~2.5Ma has been minimal, and/or the highest sea level stands of the Quaternary (e.g., MIS 11) were not substantial enough in the Chathams region to strip away pre-existing deposits in low-lying areas.

New Zealand Geological Timescale 2024

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It has been almost twenty years since the landmark New Zealand Geological Timescale (NZGT) monograph edited by the late Roger Cooper was published in 2004. The monograph brought together almost all relevant information available at the time to create a comprehensive reference that described all intervals of geological time represented in New Zealand, in a consistent way. Since then, the international community has produced several updated versions of the international timescale. Consequently, two updates of the NZGT were published: the first by Hollis in 2010 and the second by Raine in 2015. Both presented a summarised list of key features and any updates for each time unit; typically, the criterion used to define the base of the interval, the basis for regional or global correlation, and the current age calibration.

The NZ Earth science community has continued to elucidate NZ fossil biodiversity, and to garner new radiometric dates. New calibrations resulting from the most recent international sources (Gradstein et al. 2020, ICS 2023) have not yet been applied to the NZGT. Here we outline the latest initiative to update the NZGT. Whereas previous timescales (both NZ and international) have primarily targeted sedimentary rocks, and this update will also, effort is being made to include data from non-sedimentary units.

In late June 2023, the core writing team, together with a wider group of external stakeholders, held a workshop to review progress and discuss common issues. One of the key concerns to emerge is the parlous state of most NZ chronostratigraphic type and reference sections. Many are completely unusable today, and even those which lie within scientific reserves are not actively conserved. One outcome of this project will be to lead discussion and identify a path forward for protecting key sections.

The story behind our maps

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Maps are one of the key tools in the geoscience toolbox that we can use to communicate our science. Through careful cartographic organisation, maps distil ideas and information into a visual medium. Each component of any map is part of a longer story, often one that is detailed in reports that are inaccessible and impenetrable to people outside of the scientific community.

When GNS Science published the Tectonic and Bathymetric maps of Te Riu-a-Māui / Zealandia (Mortimer et al., 2020), we also created a companion website hosting webmaps of these posters - E Tuhura – Explore Zealandia (www.data.gns.cri.nz/tez/). Our aim was to make the maps and their component parts more accessible, interrogatable, and provide some background information.

Three years since the initial release, our focus has turned towards telling the full story of our maps. Our goal is to explain the thoughts, concepts, and data behind each webmap and bring them to a wider audience. To achieve this, we are pairing them with ESRI storymaps. Storymaps can contain a range of media that are typically omitted from traditional reports, such as animations, videos and embedded webmaps. Storymaps are an engaging way to present our webmaps as well as add depth and extra information. This will be an ideal way to introduce our users to our webmaps and provide valuable context on the data they contain.

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Multiproxy investigation of the source processes behind Mt Ruapehu's 2022 unrest period.

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Mt Ruapehu's Volcanic Alert Level was raised to Level 2 on March 21st, 2022, following strong volcanic tremor, increases in gas plume emissions, and the initiation of a new heating phase at Te Wai ā-moe (Crater Lake). We use seismic, gas flux, and lake temperature data to examine trends in drumbeat seismicity and surface expressions of magmatic processes during this unrest. Drumbeat earthquakes are repetitive, similar, and highly periodic forms of volcanic seismicity that have been observed globally to, in many instances, herald the ascent of degassing magma and precede an eruption. Ruapehu exhibited an incredibly diverse set of drumbeat sequences from March 14th to April 12th during the 2022 unrest. After the initial sonification of seismic data, approximately 50,000 events were manually window picked over this period. This dataset revealed that drumbeat sequences varied, both inter- and intra-sequence, in waveform similarity, periodicity, and onset/terminus characteristics over the entirety of this period. The March-April drumbeat sequence also correlates with the onset of increased heat flow into Te Wai ā-moe crater lake, as well as increases in volcanic gas emissions. Such diversity in drumbeats indicates a dynamic, rechargeable source mechanism from one or more locations within the conduit. With this work, we aim to add to the current understanding of Ruapehu's magmatic system and help improve seismic and volcanic activity forecasting in New Zealand.

Engaging preschool children with geoscience: challenges and opportunities.

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Early childhood is a critical time for building knowledge, skills, and attitudes. Preschool children are naturally curious and eager to learn about the world around them. Geoscience outreach can provide preschool children with opportunities to learn about the Earth and its processes while exploring their natural surroundings.

However, most geoscience outreach is aimed towards primary or high school students and there are few programmes specifically designed for preschool children. While there are challenges that come with engaging this age group, there are also many potential benefits. Preschool children are uniquely poised to learn about geoscience, and whānau are often more involved with their learning at this age, presenting opportunities to extend the scope of outreach to adults as well.

Our project, Rocks for Tots, is a participatory geoscience outreach programme that engages young learners with geoscience. We use a variety of hands-on activities that allow children to explore geoscience-related concepts such as magnetism, density, earthquakes, and the rock cycle. These scaffolded experiences lead to learners collecting data and participating in scientific inquiry in their local environment.

Our work has shown that participatory geoscience outreach can have a positive impact on learners, educators, and whānau. It can help refine children's 'working theories' about the world around them, develop a foundation for Earth literacy, and build connections between geoscientists and the community. It can also provide geoscientists with a view into the continuum between early childhood and tertiary education, as well as exposing them to educational settings that are farther along in their bicultural journey.

In this talk, we will discuss the benefits and challenges of engaging preschool children in geoscience outreach. We hope that our work will inspire others to develop and implement geoscience outreach programmes for young learners.

Temporal and spatial variations in trace element – organic carbon ligand complexes in cave water: implications for speleothem paleoclimate research

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Speleothems such as stalagmites, stalactites, and flowstones, contain paleoclimate information encoded in their geochemical properties. One of these properties, trace metal abundance in speleothem calcite, is tightly controlled by complexation reactions with organic compounds found in cave water and speleothem deposits. The structure of these organic compounds varies between cave systems and over time, but whether these variations in structure have a significant effect on the reactions between organics and trace metals is yet unknown. This has hindered development of speleothem trace metal content as a paleoclimate proxy, particularly over large spatial and temporal scales where organic structure variations are more likely. In this study I aim to identify any potential variations in the binding properties of the organic compounds affecting speleothem trace element kinetics.

This will be achieved by extracting organic compounds of known age and origin from speleothems from New Zealand, Pacific, and Australian cave systems, and comparing their kinetic properties using diffusive gradients in thin films. Principle component analysis will be used to analyse how binding strength varies with a range of spatial, temporal and climate factors, with results ready to be presented by the time of the conference. This information could decrease the potential for spatial-temporal variations in organic compound properties to act as confounding variables during paleoclimate studies.

Mt Charles, an oddity in the Waiareka-Deborah Volcanic Field

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The Waiareka-Deborah Volcanic field is a monogenetic volcanic field in northern Otago, New Zealand. It formed in the mid Eocene to early Oligocene with eruptions into shallow marine environments. The submarine setting led to mainly phreatomagmatic eruptions, producing pyroclastic rocks as the dominant product. Also present, however, and spread throughout the field are large sills, commonly intruded into marine mudrocks. One of these is the Mt Charles sill, north of the Waianakarua River. The main outcrop in this body reveals a sill intruded into a mudstone near the highway; there is a second surface exposure little further east on the other side of Bowalley Creek.

Whole-rock geochemistry reveals a distinct difference in REE pattern between rocks exposed at the two sites, with the western part of the sill matching other samples taken elsewhere throughout the field. The outcrop near Bowalley Creek on the other hand, has a different REE pattern, more similar to that of rocks from Kakanui, a group of volcanic edifices constructed by eruptions that produced the Kakanui Mineral Breccia (which is mostly lapilli tuff).

Analysis by SEM-EDS to determine the composition of the main minerals shows a distinct difference in the compositions of pyroxene and olivine in the samples from Bowalley Creek compared to the rest of the volcanic field.

The total alkali and silica content of Bowalley Creek classes it as a basanite, while the Mt Charles sill is classed as a basaltic andesite. This indicates Bowalley Creek is slightly more evolved, however the cores of the olivine have a significantly higher Mg# compared to olivine found in other locations and there are some orthopyroxene xenocrysts present. Both indicate a component of more primitive origin. This indicates mixing took place followed by a relatively rapid ascent of the magma.

Receiver function imaging of magma chambers and other lithospheric discontinuities beneath the North Island of Aotearoa

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Volcanism, slow slip and rifting are exhibited at the Hikurangi Subduction zone. Investigating Earth properties here will contribute to understanding subduction zone processes and hazards locally and globally. We perform S-to-P imaging using data from the IRIS-DMC and GeoNet, and use P-to-S receiver functions from the ECLIPSE network to further inform our analysis of the Taupō region. We use the extended-time multitaper deconvolution method and migrate data through the New Zealand Wide Velocity Model 2.3 (NZWM).

We identify several discontinuities in volcanic zones. At Taranaki, we observe a double positive discontinuity at 8-25 km. We find a double discontinuity beneath Taupō, positive at 10 km and negative at 20 km, possibly corresponding to the caldera. Additionally, a double discontinuity, positive then negative, emerges slightly northeast of Mt Tongariro at 5-10 km, indicative of a potential magma chamber.

We identify the Moho of the subducting Pacific Plate at 30-40 km depths. In contrast, the Australian Plate Moho varies from 20-40 km, shallower towards the northwest of Taupō and deeper around Mt Taranaki (~30 km depth). Moho depths agree with previous work interpolating local tomography, P-to-S receiver functions, and Crust 2.0 (Salmon et al. 2013). Southerly regions particularly agree, while the Moho off the north coast agrees with velocity increases in the NZWM.

We image negative discontinuities associated with the LAB of the Australian Plate at 60-70 km depth, likely shallow due to upthrusting against the downgoing plate. Pacific Plate LAB is imaged between 80-130 km, shallower southeast of Hawke's Bay, deeper northwest of Wellington. It likely corresponds to the base of the subducting plate and is also coincident with a melt channel, previously imaged near Wellington by active source imaging (Stern et al., 2015). Inferred LAB phases largely coincide with previously inferred melt, e.g., near Wellington, or exist beneath volcanic regions.

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The cascading impacts from an earthquake on the Hikurangi Subduction Zone: two case studies for Napier

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Earthquakes and associated cascading hazards are a threat for societies. Subduction zones, in particular, are capable of generating extremely large earthquakes which can trigger a large number of primary and secondary earthquake hazards which can cause major disruption to the built environment and loss of life.

In this study we present a cascading hazard probabilistic framework for calculating the combined risk from a range of earthquake induced perils combined. Currently the framework can calculate the combined losses from the following earthquake induced perils: ground shaking, tsunami, landslides, liquefaction, lateral spreading and land subsidence. Uncertainties of each hazard are currently modelled within a Monte Carlo based framework that can estimate the network disruption or losses from all of these earthquakes induced perils put together. Both scenario and probabilistic risk analysis can be performed within the framework.

Here we demonstrate the framework using two examples, both of which are for Napier City. In the first example we show the combined effect of hazards including ground shaking, liquefaction, lateral spreading, and earthquake induced landslides from a Mw8.4 Hikurangi Subduction Zone (HSZ) interface earthquake on the road accessibility in the Napier area. The example study also includes the effect on road access due to debris extension from landslides or collapsed materials from buildings adjacent to the road. In the second example we use the framework to do a cascading earthquake probabilistic risk assessment for Napier for earthquakes located on the HSZ interface. We do this by first creating a stochastic earthquake catalogue of events on the HSZ and then we calculate the cascading hazards and losses for each event in the catalogue. We then combine the losses across the catalogue to then produce a set of loss curves for the combined effect of all of the earthquake induced perils included in the framework combined.

Is Anybody Even Listening? The hazardous road getting science into local government policy

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Local and regional government have a significant role in translating natural hazard science into policies which affect the way people live and communities develop. The current impetus to intensify urban areas has brought into relief ongoing issues of development in areas which are at risk from natural hazards. Events such as Cyclone Gabrielle have demonstrated that in the last decade residential developments have been consented and built across the country in areas which are known to be at risk from flooding and landslides. Poor planning for natural hazards in the past has left many towns and cities with legacy issues, and the impacts of climate change on sea level rise, increased rainfall and associated natural hazards is increasing the risk to people living in these areas. Continuing our current trend of developing in areas at risk from natural hazards will create more legacy issues for the future.

Scientists and local government don't run on the same timeframes, have different priorities, and can find it difficult to understand each other. Bridging the gap requires effort from both sides to understand this and overcome it. This talk explores some of the key causes of disconnect between scientific output and local government and ways to advocate for science in policy.

Toka Tū Ake EQC is a Crown Entity responsible for providing insurance to residential property owners against the impact of natural hazards. We have a strong interest in reducing risk from, and building resilience to, natural hazards in New Zealand, and we are invested in helping to forge stronger and more transparent relationships between the scientific community and policy makers.

GeoNet Aotearoa New Zealand station metadata: managing multidisciplinary instrument and deployment meta-data using a source code versioning system

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GNS Science Te Pū Ao, through its GeoNet programme, operates a multidisciplinary sensor network to monitor geological hazards in Aotearoa New Zealand. Data from more than 1000 monitoring instruments are continuously collected, transformed and made available to a range of end users.

Managing multidisciplinary instrument metadata is a key task of the GeoNet data management centre. In 2017 GeoNet moved away from using a corporate relational database to using a modern and novel approach to manage metadata. All of this metadata is freely available and treated as a dataset (DOI: 10.21420/0VY2-C144) to give users access to whatever metadata they need and to improve visibility and usability.

This system is at the core of the GeoNet data pipeline and allows the data transformation process, from the field to end users, to be automated. This also allow GeoNet to continuously improve its metadata and keep up to date its downstream products. The system uses a software development approach: a code versioning system based on git and hosted at https://github.com/GeoNet/delta which allows instrument metadata and their changes in time to be peer reviewed, version controlled and checked for consistency. Equipment and installation details are stored as a set of CSV files and short XML seismic response file segments. This allows for easy access and maintenance, with no proprietary external software needed to decode or examine the information.

Tsunami backwash deposits as evidence of historical and prehistorical events in the south Pacific

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Although the number of studies on the geological evidence of tsunamis has increased considerably in the last two decades, reports of tsunami backwash deposits are still underrepresented in the literature. Here we present the findings of the first investigation of backwash deposits all around an island (Tutuila, American Samoa). The 2015 SAMOA-SPT oceanic campaign aboard the R/V *Alis* included bathymetric, seafloor reflectivity and very high-resolution seismic surveys as well as sediment core sampling. One core from each of three bays, Pago-Pago Bay on the southern shore, as well as Masefau Bay and offshore Fagafue Bay on the northern shore, was selected for further analysis (sedimentology, geochemistry using an Avaatech XRF core scanner, and geochronology (^{14}C, ^{210}Pb and ^{137}Cs)).

This study revealed that anomalous layers identified as backwash deposits showed large sedimentological variations, reflecting differences in hydrodynamic conditions in each bay. The event layers were coarser in one of the sheltered bays, similar to the background sediment in the other sheltered bay (but with basal soft sediment micro-deformations) and finer offshore the open bay. However, they were generally characterised by a terrestrial geochemical signature (Ti/Ca and K). The 2009 South Pacific and the 1960 Valdivia tsunamis were recorded on both the northern and southern shores of Tutuila, providing the first correlation of tsunami backwash deposits around an island. Evidence for backwash deposits associated with the 1917 Tonga Trench tsunami, the 15th-16th Century Tonga Trench tsunami as well as an older tsunami (between the 11th-14th Century) was also found. This shows that studies of tsunami backwash deposits provide means to extend the geological record of these high energy events, due to the generally good preservation potential of the deposits, which are less likely to be affected by natural or anthropogenic post-depositional changes.

Earthquake rate variability on the Hikurangi subduction zone using a dense 11-year long earthquake catalogue

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Earthquake swarms are commonly observed on and around the Hikurangi subduction margin surrounding slow-slip regions. Understanding the relationship between slow-slip episodes (SSEs) and seismic swarms is complicated by variable completeness of the catalogues of both SSEs and earthquakes. In this work we focus on developing a comprehensive catalogue of seismicity surrounding the Hikurangi subduction margin using matched-filters. Matched-filters are well-suited to detecting earthquakes within earthquake swarms due to the inherent similarity of events within swarms. Matched-filters also do not suffer from the same detection-rate limitations as other classical earthquake detection algorithms making them well-suited to high-rate sequences. Matched-filters are fundamentally the most sensitive detector available, exceeding all current classic and AI-enhanced detectors for specific cases when detecting similar events. Nevertheless, matched-filter catalogues are inherently limited by the templates used.

To ensure a representative distribution of templates we use the 80,618 earthquakes catalogued by GeoNet between 2011 and 2023 within 20km depth of the Hikurangi subduction interface. To accelerate detection, we cluster all selected earthquakes using hypocentral distance and waveform cross-correlation and select the most useful template earthquake from each group resulting in 11,008 templates. Using EQcorrscan we ran all 11,008 templates through continuous seismic data from 30 stations between 2012 and 2023. This results in 172,413 detected events. We then compute cross-correlation derived pick-corrections for all events and make picks when individual channel correlations exceed 0.15. We then remove low-quality detections likely associated with out-of-region earthquakes and finally compute absolute locations for all remaining 155,197 events. This new catalogue provides an unprecedented view of Hikurangi seismicity in time and space that will enable new inferences on the structure of the subduction zone, and the relationship between slow-slip and seismicity around the interface.

Radiated energy estimations for New Zealand earthquakes

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In seismology, the radiated energy of a seismic event can be interpreted as its rupture propagation potential. This is also a way to assess the stress field at the source, get an estimation of the rupture duration for slow events, and detect tsunami earthquakes (Newman & Okal 2998).

Following the methods of Convers & Newman (2011) to estimate radiated energy at teleseismic distances, we are developing a tool, both for Aotearoa New Zealand catalogue energy studies and near-real-time estimations of source parameters that can be used to improve our response to big earthquakes.
Currently, the estimations performed for 37 New Zealand events since 2010 present satisfactory results, using the same conditions [$M_w \geq 5.8$, stations between 25° and 80° distance, running up for 300s after P-waves arrival] as the tool implemented by IRIS (IRIS DMC 2013).

The next steps are to produce a historical energy catalogue for New Zealand in order to gain more information about local rupture process, to push the energy estimation to smaller earthquakes, and to refine the parameters implemented to better suit the New Zealand tectonic regime. We will present the current state of these efforts.

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A social science review into Tsunami evacuation mapping for Aotearoa New Zealand

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Tsunami evacuation maps are important communication products used widely in Aotearoa New Zealand; they are one of the most available evacuation maps for the public. However, there has been limited research on key decisions related to map design, in particular the number of evacuation zones to be included on the map, which colours should be chosen to represent zones, inclusion of evacuation safe zones and how these maps are used in practice.

We present an evidence-base for decision making on tsunami evacuation zones and map design in Aotearoa from academic research, global tsunami map examples and regional experiences and insights. The key findings from this review are that tsunami evacuation maps appear to have multiple purposes, audiences, and are used in different ways. Communities and the public interact with these maps at differing levels and at different times.

There is a clear preference towards public facing maps with fewer evacuation zones. However, there was no consensus on which zones should be removed or combined. There are at least four different zone options each with their own advantages and disadvantages. Choosing the colour of evacuation zones is complex, there was no particular colour that suits all preferences. Finally, safe areas, points and/or routes are important to people. This project provides recommendations to aid in decision making for future evacuation map design.

This work could not have been possible without the support from National Emergency Management Agency, Emergency Management Bay of Plenty, Auckland Emergency Management, Hawke's Bay CDEM, Wellington Regional Emergency Management Office, Canterbury CDEM group, Christchurch City Council, Environment Canterbury, Waikato CDEM group and Thames Coromandel District Council.

Stress state and earthquake triggering on the outer rise of the Southern Vanuatu Subduction Zone, Southern New Caledonia

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An analysis of earthquakes recorded in southern New Caledonia (SNC) over 14 months during 2018–2019 reveals focal mechanisms consistent with a normal faulting stress state. The minimum principal stress is perpendicular to the Vanuatu subduction zone (VSZ), which is 200 km away, and is highly oblique to the local topographic ridge of New Caledonia, which may induce additional tension. A M_w 7.5 earthquake occurred in VSZ on 5 December 2018 and focal mechanisms appear to be different to those before the big earthquake. Significant increases in seismicity rates in both VSZ and SNC are observed following this large earthquake. A strong correlation between local and subduction zone seismicity rates is confirmed by analyses of seismic records before and after large subduction zone earthquakes 200–350 km away during the period of 2000–2018. The local seismicity rate and seismic hazard in southern New Caledonia is about four times higher immediately after a large subduction earthquake and Omori decay returns it to background levels after about 30 days. The triggering mechanisms remain unclear, but our study provides the first observations and a framework for future work.

Copper in onshore New Zealand: mineral deposit types, occurrences and potential for this critical metal

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Copper was mined at several locations in New Zealand soon after European settlement, e.g. Kawau Island (from 1846), Dun Mountain (1855) and Great Barrier Island (1857), with later production at D'Urville Island (1879), Maharahara (1881), Tui (1884; 1969), Pupuke (1892), Waitahuna (1890s), Moke Creek (1917), Pakotai (1947) and Parakao (1961). These operations were short-lived because of their small size and the poor economics of shipping ore overseas for processing. The requirement for substantial quantities of copper in electricity generation and transmission has made copper a critical element for the low carbon future and therefore a review of New Zealand's deposits and their resource potential is timely.

Most of New Zealand's known onshore deposits can be classified into four main types:

(1) Porphyry Cu deposits that consist of stockwork quartz veins deposited from hydrothermal fluids generated by stocks and dikes of diorite to granodiorite composition, e.g., Coppermine Island, Miners Head, Great Barrier Island, Paritu and Ohio Creek deposits.

(2) Volcanogenic massive sulphide deposits that formed on the sea floor by hydrothermal systems generated by submarine volcanic activity, e.g., Pupuke, Pakotai, Parakao and Lottin Point deposits. A variety of this deposit type associated with chert and pillow lava in Mesozoic greywacke includes Kawau Island, Te Kumi, Maharahara, Moke Creek and Waitahuna.

(3) Serpentine-hosted Fe-Cu deposits that are shear-controlled lenses of mineralisation in serpentinised ultramafic rocks of the Dun Mountain Ophiolite Belt, e.g., deposits on D'Urville Island, Dun Mountain and Red Mountain in Otago.

(4) Gabbroid-associated Cu-Ni deposits formed by magmatic crystallisation of Cu and Ni minerals in magma chambers or conduits, e.g., igneous complexes at Riwaka, Blue Mountain and Otama.

Porphyry Cu deposits represent the best exploration target in terms of size potential, but higher Cu grades of the other deposit types may enable production from smaller deposits or as a by-product.

Earthquake forecasting in New Zealand: What have we learned from the past to implement in the future

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Public earthquake forecasting started in New Zealand following the 2010 M7.1 Darfield earthquake that initiated the Canterbury earthquake sequence. The forecasts were based on years of experience in developing and testing earthquake forecasting models. The earthquake forecasting models fall into three categories: (1) short-term or aftershock models that describe the decay of the earthquake occurrence rate following a large event, (2) medium-term models that are variations of the Every Earthquake a Precursor According to Scale (EEPAS) model, which is based on the observation that the size and frequency of earthquake occurrence tends to increase in the vicinity of an upcoming large earthquake and aims to forecast upcoming large events in the coming months to decades, and (3) long-term models, including the National Seismic Hazard Model.

The introduction of the automated seismic processing software SeisComP in 2012 caused inconsistencies in the earthquake catalogue, especially with magnitudes. It has been a slow process to resolve these issues. In the meantime, we have been limited to forecast earthquakes of magnitude 5 and larger.

In the future, we envisage to have an automated system provide regular earthquake forecasts to the public, and to engage more with users to provide the information that they need for decision-making in a seismic crisis and for planning for earthquake resilience.

Geological mapping of Princess Bay, Wellington: using aerial surveying and structure from motion to determine earthquake habitats in greywacke bedrock

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Seismic hazard in the Wellington region is enhanced by the presence of numerous local faults. To gain insights into the mechanisms that accommodate slip on faults in Wellington's greywacke bedrock, exhumed shear zone structures can be studied and interpreted.

At Princess Bay on Wellington's south coast, we used a Remotely Piloted Aerial System (RPAS, also known as a drone) to survey and capture high-resolution aerial photographs of the outcrop. These photographs and Structure from Motion (SfM) techniques have allowed us to create extremely high-resolution orthophotographs and surface models, providing a detailed digital twin of the site that supports mapping and geological interpretation.

In total, 9,208 photographs were collected over the course of 29 drone flights using the DJI Mavic 2 Pro aircraft, constrained by 19 RTK GPS-surveyed ground control points. A variety of flight heights, paths, and camera angles were used to determine the optimum settings for the survey and provide a framework for survey planning at similar sites in the future. Further flights are also planned to test the differences between electronic and rolling camera shutters; terrain following (varying the flight height as the terrain changes during a flight); and camera resolution, in order to refine these optimum settings.

Combining the interpretations from the digital twin of the site with direct observations and measurements has allowed us to create a highly detailed geological map of a section of the site that includes complex, deformed structures in heterogenous greywacke sandstone and siltstone. Further work will include more detailed geological mapping of the entire site, using geothermometers and performing thin section analysis of veins and microstructures to determine deformation temperature and style. Combined with a new 2D thermal model of the Wellington region, these results will inform our understanding of the habitat of earthquakes in bedrock fault zones at depth.

Ground truthing fault activity along the Wairarapa Coast using K/Ar thermochronology and biomarker thermal maturity

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Paleoseismic techniques provide information on the earthquake history of a fault including the timing of, and displacement during, past events. However, most of these techniques require the presence of dateable sediments and the preservation of evidence of past offset. Because of this, most conventional paleoseismic methods are restricted to faults that cut across relatively young sediment. However, numerous faults in New Zealand extend through bedrock and little is known about their past earthquake activity and future seismic hazard potential. Often these faults are considered to not be inactive (i.e., have had no earthquakes on them in the last 125,000 years) but this is based upon a lack of geologic data and alternative techniques are required to support these designations.

Here we present preliminary data from a pilot study investigating three bedrock faults along the Wairarapa Coast, the Ewe, Whakataki, and Hungaroa faults. These extend through early Cretaceous to Miocene in age mudstones, sandstones, and limestones within the Hikurangi forearc. They have been classified by QMap as inactive, but little work has been done on these faults, with past studies instead focused on regional-scale evolution of the Hikurangi subduction zone. In this work we use the relatively novel combination of K/Ar thermochronology coupled with biomarker thermal maturity to assess when these faults last experienced earthquakes and the maximum displacement these faults have accommodated during those past earthquakes. We couple this with structural observations developed from field measurements and high-resolution orthomosaics. From this work we aim to confirm whether these faults are active and if so, gain an understanding of how they contribute to seismic hazard in the lower North Island of New Zealand.

Monitoring data: what can it tell us about eruption explosivity?

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Knowing whether the next eruption at a volcano will be large and explosive, or small and/or effusive is key for emergency management as the accompanying hazards (lava, tephra, pyroclastic flows) are related to eruption explosivity. Monitoring of a volcanic system may provide insights into when, where, and how explosive a future eruption might be. Monitoring data are collected with a variety of equipment (from seismometers to thermometers) and at a variety of locations (from vent to satellite). These data provide valuable insights into the complex processes occurring beneath a volcano, helping to assess the likelihood of eruption occurrence. However, the direct links between monitoring signals and future eruptive activity remain ambiguous, especially when looking at volcanoes without recent eruptions, or that had no previous monitoring equipment installed prior to unrest. This problem is amplified when considering future eruption explosivity.

This work aims to quantitatively link monitoring signals to eruption explosivity on a multi-volcano basis Here, we present an overview of the integrated monitoring data from eruptions with volcanic explosivity indices (VEIs) from 0 (effusive) to 5 (explosive) from 23 volcanoes from around the globe.

These monitoring data come from both the Global Volcanism Program (GVP) database, and local volcano observatory reports where available. This includes GVP bulletin reports (since 1965) summarising significant volcanic activity recorded by volcano observatories and/or research institutions. Crucially for this work, these reports also include descriptions and/or raw data collected from various monitoring equipment prior to, during, and after volcanic activity. This information may give a more thorough understanding of the precursor activities and behaviours prior to an eruption and their potential to forecast the magnitude and style of the eruption, especially in cases where monitoring equipment are only installed after the onset of unrest, where deviations from background signals are impossible to determine.

Hydrous veins in the New Zealand mantle lithosphere and their implications for intraplate magmatism

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Peridotite xenoliths in an ultramafic lamprophyre in the intraplate Alpine Dike Swarm (ADS), New Zealand, are ultra-refractory, typically with olivine Mg# ~92 and spinel Cr# ~70, but many contain MARID-like veins of mica (phlogopite), amphibole (pargasite), rutile, ilmenite and diopside. Using quantitative scanning electron beam methods, mineral trace element and $^{87}Sr/^{86}Sr$ analysis, we attempt to establish the origin and significance of these veins. The benefit of inspecting formerly highly depleted peridotites is that the chemistry of the precipitated metasomatic agent is less diluted than in the cases where melts react with fertile lithosphere. The bulk compositions of the precipitated veins vary between sub-alkaline basalt and alkaline basanite, with the peridotite wallrock hosting the basanite veins commonly enriched in Fe + K, Ti and Al. Amphibole in all veins has high Nb, which suggests a non-arc-related source, and the 24 Ma age-corrected $^{87}Sr/^{86}Sr$ values for diopside and amphibole (0.7027 to 0.7031) are indicative of derivation from depleted mantle with no crustal contribution. These Sr isotope ratios also overlap with the composition of intraplate alkaline magmas across Zealandia, and melt modelling indicates that partial melting of the veins would generate magmas that show geochemical aspects of the known intraplate rocks. Vein occurrence demonstrates that this mantle lithosphere contains fusible zones that, if melted, would likely generate an alkaline intraplate melt with Sr isotope compositions matching those of Zealandia alkaline magmas.

Plutonic nature of a transcrustal magmatic system: evidence from ultra-high resolution Sr-disequilibria in plagioclase microantecrysts from the southern Taupo Volcanic Zone, New Zealand

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The residence timescales of antecrystic minerals contribute a key piece of information regarding the petrologic evolution of transcrustal magmatic systems and may be inferred using a combination of observations derived from microanalytical chemistry and diffusion modelling. Here, we present state-of-the-art stacked CMOS-type active pixel sensor (SCAPS) isotopographic images of tephra-hosted plagioclase microantecrysts from Tongariro Volcanic Centre in the southern Taupo Volcanic Zone, New Zealand. These crystals exhibit high-frequency Sr and anorthite zonation at sub-micron spatial resolution. We also find that all crystals display high-frequency intracrystalline Sr chemical potential variations, indicating that they have not resided at magmatic temperature for diffusive relaxation to advance significantly. To quantify crystal residence times at the well-constrained magmatic temperatures of these tephras, we first forward-modelled intracrystalline Sr diffusion over time using numerical methods. Results were then analysed using novel spatial Fourier-transform techniques developed to understand the systematics the diffusive decay of Sr disequilibria in the spatial frequency domain. This ultimately permitted the estimation of Sr concentration profiles at crystal formation, prior to uptake into the carrier melt at the onset of eruption. Our data imply residence times of days to weeks for the studied microantecrysts. This is inconsistent with long antecryst residence times in magmatic mushes at elevated temperatures, pointing instead to a cool plutonic nature of the magmatic plumbing system beneath the southern Taupo Volcanic Zone.

Forecasting the future state of groundwater in Dunedin under sea level rise

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Dunedin has a large number of assets, houses and critical infrastructure situated at, or close to, sea level. Presently protected from coastal inundation by a slightly elevated margin of reclaimed land and fragile sand-dunes, the city's flat-lying coastal land is crucial to its present functional operation. With concern over flooding and the potential for rising groundwater as sea levels rise, a monitoring network (15 minute records @ 27 sites) was installed in 2019 that now rewards a significant level of new information on the state and variability of shallow groundwater.

Groundwater levels (GWL) have been interpolated (8 m cells) from piezometer observations, constrained using boundary 'control points' at the harbour and coast. Depth to water (DTW) grids, were derived for GWL median, high tide and storm surge conditions relative to a 2021 LiDAR survey of topography. These highlight the lowest lying suburbs do not necessarily coincide with shallowest groundwater and, importantly, that topographic elevation does not necessarily reflect groundwater-related hazard. Instead, the water table has elevation and gradient that are variable at kilometre-scales, causing differences from suburb to suburb. DTW grids show locations of shallow and emergent groundwater or combined with rainfall event observations to map the available subsurface storage for rainfall infiltration.

Forecasts of future groundwater conditions under sea level rise (SLR) were developed by adjusting grid surfaces with a coastal forcing, using present day observations of tidal amplitude adjusted for distance from the harbour or coast. There appears to be a critical tipping point to widespread groundwater emergence at c.50cm SLR, that precedes an equivalent step in potential inundation from the harbour at c.60cm SLR. However, the incremental loss of subsurface rainfall storage, as the water table initially rises, may have already increased pluvial flooding frequency and be driving the first community decisions around adaptation, mitigation and/or retreat.

Acceleration of landscape change in the Southern Alps during the past decade

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The elevation and position of features in the landscape, and changes over time, can be defined by photogrammetry and repeated high-resolution digital elevation models. A new change detection system (MAP²3D) developed by Otago University School of Surveying uses a semi-automated pipeline to build high-resolution digital surface models (DSM) from satellite or aerial imagery. Automated surface processing enables precision and accuracy sufficient to define sub-metre scale changes in elevation models of difference (DoD). Displacement of features over time is quantified through a feature-tracking algorithm using DSM-derived hillshade models. Operational rapid response to natural events is possible whenever cloud-free stereo-imagery can be obtained.

Topographic changes in Aoraki-Mt Cook region have been quantified with MAP²3D products spanning epochs between 2008 and 2022. Dramatic snowfield retreat and glacier down wasting is revealed by these data, along with smaller scale rockfall and landslides. A GIS inventory of 920 landslides has been constructed, including previously unnoticed collapses >10^5m^3, and numerous deep-seated slope failures (reaching 2.1Gm^3 in Murchison valley). There are 119 slow-moving slope failures and 536 rapid rock avalanches, toppling or debris flow events. Attributes pertaining to source volume, slope susceptibility, runout and deposit thickness of each feature provide information on the magnitude, frequency, and spatial reach of landslide-related hazards. The region's productivity of hazardous collapses shows a near fourfold increase from 57 during 2009-2012 (n=57) to 2013-2017 (n=295) and 2018-2023 (n=208). Although potentially enhanced by dynamic stress and increased moment from large South Island earthquakes, many small-moderate (10^2-10^4m^3) collapses appear directly linked to areas of slope creep or de-buttressing induced by glacial recession. Intense precipitation events, snowfield melting, and glacier down wasting are now prevalent due to our changing climate. Regardless of direct cause or effect, the central Southern Alps is clearly destabilised, and rates of landscape change accelerated, locally elevating the level of hazard.

Why Pounamu? Using U-Pb dating of detrital zircons to better understand the tectonostratigraphy of the Otago schist

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Zealandia was built by accretion of tectonostratigraphic terranes to the margin of Gondwana from mid-Palaeozoic to Mesozoic. Previous studies have considered the Otago Schist to be the result of crustal thickening from collision of two terranes. Recent detrital zircon results indicate that this view is grossly oversimplified as the schist has protoliths that vary widely in depositional age which suggests that more than two terranes may exist. The research that we have conducted analysed detrital zircons in rock samples collected from a crustal section of the Otago Schist.

Six samples were selected for zircon separation from sites across the Dunstan Mountains. The zircons exhibit cathodoluminescence zoning and trace element compositions typical of an igneous origin. The youngest zircon population U-Pb ages that have been collected moving southwest to northeast are as follows (displayed as: age, error (Ma), young/total data); 104 Ma (±7, 3/74), 116 Ma (±5, 2/17), 110 Ma (±1, 20/82), 108 Ma (±1, 19/112), 112 Ma (±1, 48/74), 163 Ma (±7, 5/73). The samples also contain populations that have Carboniferous, Permian, Triassic, and Jurassic maximum depositional ages.

These results support the conclusions by Cooper & Palin (2018) and Mortimer et al. (2023) in terms of the existence of the Pounamu Terrane and its extension into Central Otago. Rocks of the Pounamu Terrane exhibit a persistent lithologic association of quartzofeldspathic sand with mafic volcanics and manganiferous chert suggesting trench sediments were accreted and metamorphosed no earlier than ca. 110 Ma. In previous geologic models it was thought that the Otago Schist involved tectonic juxtaposition of only two terranes with crustal thickening, however, this research suggests that this is incorrect. The ages that have been found will fill in some gaps in knowledge and advance the understanding of the tectonostratigraphic sequence of the Otago Schist.

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Biostratigraphically constrained Quaternary chronologies from the Hikurangi subduction margin of north-eastern Zealandia

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Highly resolved biostratigraphically constrained chronologies have been developed to help elucidate the complex stratigraphy of tectonically deformed Quaternary sediments from the Hikurangi subduction margin of north-eastern Zealandia. The biostratigraphic framework that underpins the dating is derived from the tops and bases of short-lived climatically tempered influxes of distinctive planktic foraminiferal species, calibrated to the well documented and dated planktic foraminiferal record of ODP Site 181-1123 on Chatham Rise. Most of these biostratigraphic markers are not unique, but sequences of markers that are unique to each marine isotope stage provide an unprecedented level of biostratigraphic detail and chronological dating when they are used within the contextual chronological framework of keystone biostratigraphic markers.

The new biochronological framework has been used to date three sites on the mid to lower slope of the accretionary prism, west of the deformation front (IODP Site 372-U1517, 375-U1519, 375-U1518) and two sites east of the deformation front (Hikurangi Trough Site 375-U1520 and Tūranganui Seamount Site 375-U1526). The dating indicates sedimentation rates are very high and variable on the accretionary prism (0.2–9.6 m/kyr), especially during the Last Glacial Maximum (LGM) when downslope redeposition from the continental shelf and upper slope is very common. Sedimentation rates at Hikurangi Trough Site 375-U1520 are also variable (0.01–3.0 m/kyr) and they increase markedly as the site approached the deformation front, especially during the LGM, in tandem with increased downslope redeposition. Sedimentation rates at Tūranganui Seamount Site 375-U1526 are low by comparison (0.04–0.4 m/kyr) and the sequence is punctuated by hiatuses that shorten in duration as the site approached the deformation front. The shorter hiatuses are attributed to the site moving away from the core flow of the Deep Western Boundary Current and closer to the supply of clastic sediment from the hinterland.

New Zealand Cenozoic stages and the macro/micro dichotomy

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During the early days of geological exploration, when the New Zealand stage classification was being developed, the focus was almost entirely on macrofossils, so much so that thick monotonous sequences of Cenozoic mudstone with no visible fossils where often described by field geologists as unfossiliferous. This changed however, in 1932, when Jablonski from the Vacuum Oil Company (the predecessor of ExxonMobil) visited Jack Marwick at the NZ Geological Survey (NZGS) looking for someone to take up the forams, to support their Gisborne and East Coast Oil activities. After the meeting, Jack Marwick wrote to Harold Finlay, who was already well known for his work on Molluscs, and this led to Finlay being employed by the Vacuum Oil Company. After completing his East Coast work, Finlay was unable to find full employment as a paleontologist, but he worked on material supplied by NZGS, on a contract basis until 1937, when he obtained a position as a micropaleontologist with NZGS. While employed at NZGS, Finlay used his newly defined local foraminiferal biostratigraphy to subdivide the enormous thickness of monotonous Cenozoic mudstone that had not been divisible previously. This was important for the revision of New Zealand's Cenozoic stages (Finlay and Marwick 1940, 1947). Since then, the stage classification has been used by most New Zealand geologists with only minor modification. This is due largely to the conservative approach of New Zealand biostratigraphers in the post-Finlay era, which has been to accept the stages as the standard, and to redefine them progressively so as to retain the original set of stages with as little change as possible.

In conclusion – If Finlay and Marwick, the fathers of our present-day Cenozoic stage classification had all of the modern biostratigraphic and chronostratigraphic tools that we have today, would our Cenozoic stage classification still look the same?

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A regional empirical approach for evaluating transport infrastructure exposure to fault displacement hazard

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Surface fault displacements can impact critical infrastructure like roads, and road network performance is crucial to post-event response and societal function in seismically active countries like New Zealand. Displacements in historical earthquakes can be used to identify parts of the transportation system exposed to different levels of fault displacement hazard.

This project uses displacement data from the 1987 Edgecumbe, 2010 Darfield, and 2016 Kaikoura earthquakes as well as rupture scenarios from the National Seismic Hazard Model for New Zealand, to conduct a national-scale, empirical fault displacement hazard exposure analysis. This analysis includes: (i) the creation of distributed displacement curves that show how off-fault displacement varies across different faulting regimes, styles of displacement, and surface geology; (ii) the creation of displacement contour maps around faults in the NZ community fault model; and (iii) a site-specific exposure analysis for areas of high importance where the road network intersects with major active faults. The rupture of an intersecting fault would likely lead to extensive damage to the road and could further induce detrimental social and economic impacts on isolated communities that heavily rely on the accessibility the road provides.

Enhancing interdisciplinary access to GeoNet's data: Tilde, an in-house developed solution

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GeoNet monitors earthquakes, volcanoes, landslides, and tsunami using diverse instrumentation and methodologies. Data from seismic, geodetic, tsunami gauges, and multi-parameter environmental sensors are continuously recorded, collected, processed, and made available to researchers and the public. GeoNet data are traditionally archived and disseminated in domain-specific formats as this allows a full representation of the data and metadata, and users can leverage existing tools and resources in their data processing and analysis. While this works well for specialised users who focus and use data from a specific domain, users and applications that need data from several domains would benefit from an analysis ready, easy to use and common data format, at least where that is possible.

To address this challenge, GeoNet has developed a data harmonization, storage and dissemination platform (Tilde). Time series data are stored and disseminated in JSON and CSV formats, and users can access these through an Application Programming Interface (API) and an intuitive Graphical User Interface (GUI).

Tildes GUI was created to allow technical and non-technical users easy access to the available data. Users can visualise the data as well as interrogate all parameters available for any data stream, download data and connect directly to the API endpoints and use the data for further data analysis.

Tilde has been fully developed on a cloud-based infrastructure. Due to the lack of a suitable and domain-agnostic standard for exchanging time series data from geophysical networks, we have developed a data vocabulary, a domain model, and an in-house developed web service. Tilde currently includes low to medium rate volcano, landslide and tsunami monitoring datasets.

In this presentation, we will focus on how we designed this product, how we have developed the GUI, the API and data tutorials to support usability, and how this links with open and FAIR data policies.

Characterising CCS opportunities: investigating how seismic resolution impacts interpretation of 3D seismic data using a synthetic depositional model

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Carbon capture and sequestration in deep geologic formations is expected to play an important role in reducing worldwide net emissions. Critical geologic factors such as storage capacity, seal competence, and barriers to lateral movement are often only able to be assessed through 3D seismic interpretation.

Sequence stratigraphic analysis of seismic data is typically used to predict reservoir and seal distribution within a CO_2 storage complex. Seismic interpretation, however, is limited by the resolution of the data, which depends on its acquisition and processing as well as properties of the subsurface. Understanding the impact of seismic resolution is important for quantifying uncertainties in storage complex characterisation.

Large-scale sand-box experiments have been used to simulate real-world depositional systems. These experiments can express the effects of sea-level change, subsidence, and sediment supply on sedimentary architectures, and have shown to be consistent with sequence stratigraphy principles. We have chosen the eXperimental EarthScape (XES02) model from the National Center for Earth-Surface Dynamics at the University of Minnesota for analysis. The XES02 model had been sliced into 118 dip-direction cross-sections and high-resolution photos had been taken of the slices. The images have been converted into elastic properties, upscaled to real-world dimensions, combined into 3D, and used to generate synthetic 3D seismic datasets at various resolution scales.

Recent advances in 3D seismic interpretation workflows have leveraged ever-improving seismic data quality; new techniques such as spectral decomposition and AI-guided waveform classification and increases in compute power and graphical visualisation. These workflows are now capable of revealing sequence stratigraphic features in unprecedented detail.

Using industry-leading seismic interpretation workflows we have investigated the impact of seismic resolution on the sequence stratigraphic interpretation of the XES02 model. This paper describes and discusses the generation of the input datasets, the analysis workflows, and the application to CO_2 storage complex assessment.

Viscoelastic deformation of natural ice from Priestley Glacier: implications for tidal deformation of ice shelves

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This poster presents the preliminary results of a laboratory-based data collection program to measure, for the first time, the viscoelastic properties of natural ice at frequencies appropriate to tidal flexure in the ice shelf. Antarctica's ice shelves are linked to several significant Earth processes as they stabilise the mass balance of the East Antarctic Ice Sheet and drive thermohaline circulation. Buttressing refers to how ice shelves restrain the flow rate of grounded glaciers, protecting the ice sheet from increased melting and sea level rise. However, the microscale mechanisms of these shelves are poorly understood, especially viscoelastic mechanisms and properties.

Ice collected from the lateral shear margin from Priestley Glacier in 2019/2020 was experimented on at Lamont-Doherty Earth Observatory throughout the second half of 2023. Attenuation was measured using a cutting-edge piezoelectric device that applied stress at low frequencies to mimic the large strain amplitude of tidal cycles on the ice shelf. Deformation history has been inferred through these results, specifically the dislocation density of the ice. Furthermore, formvar imaging presents insightful information into these dislocations and the microstructural properties of ice. The high stress amplitude and low frequency required to model tidal energy are difficult to conduct on ice. We hope to present data that reflects the viscoelastic deformation associated with tidal flexure.

Benthic Terrain Modelling across the Hauraki Gulf: habitat identification and human impacts

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Benthic Terrain Models (BTM) are an essential tool for seafloor classification studies worldwide. Derived from automated geospatial analysis of processed multibeam swath bathymetry grids, a BTM generates a comparable and repeatable seafloor morphometric classification. In addition to a BTM classification, specialist-driven interpretations of spatial derivatives and integration of seafloor backscatter further enhance modelled outputs. The outputs from a BTM may be used to identify areas of geological significance, regions which have been modified by human activity, and regions of potentially high ecological value without the requirement for towed cameras or other methods of direct sampling.

Nearly 70% of the area managed by Te Kaunihera o Tāmaki Makaurau / Auckland Council is marine. NIWA was commissioned by Te Kaunihera o Tāmaki Makaurau / Auckland Council to produce a series of BTM's using data collected for both hydrographic charting (surveys HS52, HS53, and HS54) and scientific research (voyage TAN1211). Results from the BTM analyses provide a comprehensive overview of seabed morphology and activity within the Hauraki Gulf, covering a broad range of shallow marine environments. Features of interest identified across survey areas include rocky platforms, reefs, channels, sediment waves, and pockmarks. In addition to natural features, various impacts of human activity were also noted such as marine farm foundations, buried pipelines/cables, and anchor scour. Results from this study provide further insights into Hauraki Gulf benthic habitats and will assist in prioritising areas for management and future research.

In addition to a technical report, an ESRI StoryMap was developed to present the findings from this study to a wider audience in a distilled format. The StoryMap format has been a particularly useful output for council for communicating more easily the key findings of a very complex data set. The incorporation of online media-compatible outputs provides further outreach opportunities for similar research programs.

A new perspective: emerging opportunities in legacy DTIS imagery processing through photogrammetry

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Developments in seafloor imagery technology have exponentially increased through time, enabling the production of highly accurate (cm scale) 3D photogrammetry models, providing greater analytical potential of modern seafloor environments. Although these techniques are being applied and tested with new, high-resolution imagery datasets collected using customised diver-operated camera rigs, decades of legacy towed camera video and photo imagery with associated metadata still exist in many institutions' data archives. When combined with statistical modelling of metadata and ever-improving high-resolution bathymetric elevation datasets, legacy imagery can be as valuable as modern datasets, limited only by preserved survey metadata and imagery quality. Additionally, the ability to automate photogrammetry model development of towed deep-ocean instrument platforms provides an unprecedented view of the deep ocean, previously only possible with expensive submersibles or ROV platforms. For more than 30 years, NIWA has been collecting still photography and video footage from the DTIS (Deep Towed Imaging System) platform, with many of these datasets exceedingly difficult to re-examine due to limited timeframes for examining hours of footage in current research programs.

Here, we present the first 3D modelled photogrammetry models derived from legacy NIWA DTIS datasets, collected during voyages TAN1701 and TAN2206. These voyages collected DTIS footage in very different oceanographic settings (submarine canyon and volcanic complex, respectively), with both DTIS tows occurring in water depths ranging from 100 m to >1000 m. Models were derived from the automated extraction of still images from the DTIS video camera feed, with these images stitched together using open-source photogrammetry modelling software. In addition to discussing the test methodology, we explore future opportunities and how these data may be integrated into geospatial workflows within the Esri ArcGIS Pro and Enterprise environments.

Seismogenic structures and stress state of the Puysegur Subduction Zone (Fiordland)

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How new subduction zones are formed has a large influence on global tectonics. This process, termed Subduction Zone Initiation (SZI), still holds some unresolved questions, including how the internal and external stresses surrounding the plate boundary evolve throughout the process of subduction initiation. The Puysegur Subduction Zone in Fiordland (New Zealand) is a young, steeply subduction zone and a key site for studying incipient subduction. However, due to its remote nature, it has received relatively little attention. Passive seismic data, such as from the nationwide GeoNet network, could potentially help to constrain the Puysegur Subduction Zone's structure and stress state. However, the GeoNet network has an average station spacing of +-85 km in Fiordland, which precludes detailed seismic studies regarding the region's structure and stress state. Our work aims to constrain these aspects by constructing extensive, multi-year, high-quality earthquake catalogues for Fiordland. These are constructed using data from a newly installed temporary seismic and geodetic network called PTANGO (Puysegur Tremor and Nucleation Geophysical Observatory) deployed for three years from 2022 onwards, and data from the 2018--2019 SISIE (South Island Subduction Initiation Experiment) broadband network, and the permanent national GeoNet network.

A first step in determining the region's stress regime is obtaining accurate earthquake locations. We achieve this by combining the different seismic networks, resulting in a higher station density (average spacing of +-30 km). As a result, more earthquakes can be detected and are subsequently registered by more stations. We use the Earthquake Transformer (EQT) automated earthquake and phase detector to identify earthquakes and NonLinLoc to determine earthquake locations using the NZ-wide 3D velocity model. The extensive earthquake catalogue we construct enables us to better constrain the location and geometry of the region's seismogenic structures, such as the subduction interface and its major active faults.

Landslide planning guidance: reducing landslide risk through land-use planning

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Much of Aotearoa is hilly or mountainous and experiences high rainfall and frequent earthquakes. Consequently, landslides are an existing or potential hazard in many parts of the country, with landslides resulting in average per annum costs of $300 M and have killed more people than any other geological hazard in New Zealand.

For land-use planners, guidance is critical to the management of natural hazards and reduction of risk via land-use planning frameworks. The recently updated Landslide Planning Guidance document aims to provide planners and building compliance staff with guidance on how to adequately account for, assess and manage landslide hazards and risks within a policy, planning and consenting framework. The guidance advocates greater emphasis on a risk-based approach to planning and consenting. It specifies five levels of analysis (similar to other natural hazard guidance) that may be required to be undertaken by a territorial authority, developer, or individual. These five levels of analysis range from Level A: Landslide susceptibility analysis through to Level E: Quantitative landslide risk analysis. The guidance outlines the information required to undertake each level of analysis, the types of outputs, the residual uncertainty and when and where to apply each level of analysis. It also provides planners and building compliance staff with background information on landslide hazards and risk assessment/analysis (a ‘Landslides 101’) so they will have some awareness of what geotechnical specialists need to consider; advice on plan development, plan changes and consenting. While the guidance is primarily for planners and building compliance staff it will also be of use to consultants, developers and professionals who provide landslide susceptibility, hazard and risk analysis.

How will earthquakes move Wellington's coastlines? A probabilistic coast-seismic hazard model

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As an island nation situated along a major tectonic plate boundary, Aotearoa New Zealand is exposed to many earthquake-related and coastal hazards. These hazards can also interact; if an earthquake moves the coastline up or down, coastal hazard due to other processes—such as flooding and tsunami—changes as well. Thus, understanding the location, magnitude, and probability of coseismic vertical motions is a critical part of resilience planning for our coastal communities, particularly through the lens of ongoing global sea-level rise. We develop the first probabilistic coseismic displacement hazard model with a focus on the coastlines of the Wellington region. This project integrates earthquake and fault data from the 2022 New Zealand National Seismic Hazard Model to calculate vertical deformation probabilities from both crustal and subduction zone earthquake sources over 100 years. Our preliminary estimates suggest that both fault sources pose significant displacement hazards to the Wellington region. Near Wellington city, upper plate faults contribute more to coseismic uplift while subduction earthquakes contribute more to coseismic subsidence. Along the east coast, both fault sources produce higher probabilities of coseismic uplift. We show how a simplified fault network and other data that were designed to model ground motions may not be adequate for estimating displacements. We consider this a first prototype for using large seismic hazard and fault datasets to estimate coseismic displacement probabilities. Future versions should consider other earthquake simulation data, up-to-date realistic and detailed fault geometry, uncertainties in the distribution of locking on the subduction interface, and the potential of dual subduction-upper plate fault ruptures.

Metal isotope tracing of heavy metal pollutants

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The environmental accumulation of heavy metals within New Zealand waterways has increased in the environment due to numerous reasons including population rise, primary industries, construction sector and tourism growth. The sources of anthropogenic heavy metals are diverse and ubiquitous in the environment through their use in transport, construction, agriculture and horticulture and this rising levels of accumulation of heavy metals in soils, streams, and estuaries exert toxic effects on the ecosystem and raise concerns over the potential effects on human health and environment, tarnishing New Zealand's clean and green reputation. This is conventionally monitored using metal concentrations and metal isotope tracing at specific locations. In this study, different sample materials acquired from several industrial manufacturers and Auckland council/NIWA are analysed to determine the concentration of approximately forty trace elements and the targeted heavy metals for isotopic analysis are Lead, Uranium, zinc, cadmium and copper. The isotopic analysis helps in determining the transport pathways of different contaminants in Auckland. The metal isotopic analysis is then applied as a tool to trace the sources, transport pathways and sinks of heavy metal contaminants across mixed use catchments in the Auckland region, taking advantage of the unique isotope 'fingerprints' of each heavy metal source.

A 20-year study of hydrothermal mineralization and ^{226}Ra and ^{228}Ra isotopes at Brothers volcano, Kermadec arc

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A 20-year study encompassing ~110 samples of volcanogenic massive sulphide (VMS) and IODP drill core from the submarine Brothers volcano (Kermadec arc) has found that the formation of Cu-Au-barite-rich black smoker chimneys is related to regular collapsing of the caldera floor. The barite, dated using co-precipitated Ra isotopes, ranged from < 1 year when Ba, ^{226}Ra and ^{228}Ra were newly extracted from rock via hydrothermal interaction, to > 18,000 years when ^{226}Ra had decayed below the detection limit for gamma spectrometry. Brothers has a large volume of subseafloor hydrothermally altered rock where ^{228}Ra and ^{226}Ra regrow from their parent isotopes ^{232}Th and ^{230}Th, which were not extracted during water/rock interaction. Regrown Ra isotopes have ascended through the volcano via hydrothermal circulation cells utilizing a succession of normal faults so that barite contained in mineralization at each location started with an excess of ^{228}Ra and ^{226}Ra, i.e., $^{228}Ra/Ba$ and $^{226}Ra/Ba$ values exceeded theoretical ratios derived from the Ba, Th and U content of local volcanic rocks. Since ^{228}Ra regrows much faster than ^{226}Ra, its input is continuous whereas the ^{226}Ra is effectively a single input that then decays with a half-life of 1600 years. The older Ba with excess ^{226}Ra, now remobilized into new chimneys, was datable using the decrease in $^{226}Ra/Ba$ value with time. However, the VMS mineralization is complex and variable, and all the isotope ratios used for dating were commonly disturbed by mixing of old and new mineralization. A model has thus been developed to distinguish the remobilized older barite from new mineralization which, in the case of Brothers volcano, highlights four stages of caldera collapse spanning 3840 years that is linked to seafloor mineralization. These ages consistently decrease from 4560 years at the Upper Caldera site to 720 years at the deepest NW Caldera wall site.

Cosmogenic ^{3}He constraints of postglacial edifice construction at Mt. Ruapehu

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Effusive volcanism drives edifice growth on stratovolcanoes and poses a hazard to infrastructure, the natural environment, and local communities. Accurate assessments of the hazards posed by lava flows rely on precise knowledge of eruption frequency -especially of recent volcanic activity-, which requires detailed studies of the timing and magnitude of past eruptive activity.

Most chronological studies of lava flows on stratovolcanoes are based on radiometric dating methods, such as $^{40}Ar/^{39}Ar$ and K/Ar. In many cases, however, associated errors on ages of young (<20 ka) products are still too large (16-1000% relative error) to construct detailed chronologies of recent eruptions. Cosmogenic nuclei dating can provide accurate exposure ages of geological surfaces, but the technique has not been widely used to date lava flows on stratovolcanoes.

Here, we present eruption ages of 24 lava flows on Mt. Ruapehu based on pyroxene-hosted cosmogenic ^{3}He. Our analyses were focused primarily on postglacial lavas and yielded exposure ages with relative errors of 10%. These new dates show that lava was emplaced on different areas of Ruapehu during the same relatively short time intervals, suggesting that at least two vents were active at ca 13.5 and 8 ka. The results include the first absolute ages for the Rangataua flows, Ruapehu's longest and most voluminous lava flow sequence.

These results constitute a major step towards a comprehensive understanding of Ruapehu's effusive activity during the last 20 ka and showcase the potential of using cosmogenic nuclide dating to date lava flows.

Forecasting landslide hazard and risk in Aotearoa New Zealand under a changing climate

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In Aotearoa New Zealand, rainfall triggered landslides are a significant risk to human lives and infrastructure. Present climate change projections suggest Aotearoa New Zealand is likely to experience more frequent high-intensity precipitation events in the coming decades. Our hypothesis is that an increase in extreme weather events will likely trigger an increase in the rates of landsliding. In February 2023 ex-cyclone Gabrielle brought extreme precipitation over the northern and eastern North Island. As a result, >100,000 landslides were triggered leading to widespread impacts to the built environment and local communities.

Leveraging a newly created landslide inventory for the event (Leith et al., 2023) this project aims to improve the understanding of landslide triggering conditions during extreme weather. Using recorded landslide attributes/locations and high-resolution rainfall data from a combination of models and observations, we will investigate the influence of variables controlling landslide predisposing and triggering factors. We aim to identify i) which environmental variables influenced landslide susceptibility, ii) rainfall thresholds and intensity-duration conditions that triggered landslides and iii) the influence of antecedent soil moisture conditions.

Landslide susceptibility models developed in this project aim to improve on existing methods by integrating high resolution precipitation data and the most extensive and detailed landslide inventory currently available in Aotearoa New Zealand. This will allow us to better predict the type of landslides occurring within the landscape and consecutively optimize runout predictions to better capture the probability of inundation downslope of landslide source areas. In order to anticipate the impacts of landslides triggered by future extreme storm events, trends and intensity of extreme weather events from future climate projection simulations will be evaluated to forecast landslide hazard and risks.

Reference:

Leith, K., McColl, S., Robinson, T., Massey, C.I., et al. (2023). Cyclone Gabrielle (12–16 February 2023): Landslide inventory for North Island New Zealand, version 1.0.

Investigation of the 2011-2019 temporal ground deformation changes of the Hellisheiði geothermal field, SW Iceland, using poroelastic models

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Understanding inherent physical and crustal properties is essential for assessing the sustainable production potential of a geothermal reservoir. We investigate this problem by replicating observed ground deformation from geothermal data sets using poroelastic modelling.

The Hellisheiði high-temperature geothermal field, SSW of Hengill volcanic system, started production in 2006 with estimated capacities of producing 303 MWe and 133 MWth in 2011 for the greater Reykjavík capital region, and has since increased to 200 MWth in 2020. Recent geodetic studies have quantified the average production field's subsidence to around 2.5 cm/yr, and a transient ~2 cm uplift at the onset of injection of geothermal brine in the adjacent Húsmúli field, in 2011. Increased seismicity was recorded associated with this 4-month uplift, with two earthquakes reaching M_L>3.5, leading to decreased injection rates in the Húsmúli field.

Since 2011, the deformation of the Hellisheiði-Húsmúli geothermal field has been complex, with two more transient uplift episodes in 2014 and 2016 amongst the predominant subsidence of the area. Using a finite element poroelastic model (COMSOL Multiphysics), we investigate the relation between the 2011-2019 extraction and injection rates of the Hellisheiði-Húsmúli geothermal field and the ground deformation within the same time span. We assume that the boreholes can be represented by three-point sources: one of decreasing mass flow rate in Hellisheiði, and one of increasing mass flow rates in Húsmúli and the newest injection field, Innstidalur.

Our investigation using a poroelastic model presents insights into the physical crustal parameters of the Hellisheiði geothermal field and temporal response of geothermal systems from extraction and injection changes, which can increase stress on the tectonic structures of the region. This study offers new knowledge on the Hellisheiði geothermal field and the importance of geodetic data sets to study geothermal fields around the world.

A novel model of geoscience education: empowering primary teachers through bilingual interactive science resource kits

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When a professor passionate about fun, interactive science meets a non-profit dedicated to hands-on education in Aotearoa schools, the results can be explosive.

House of Science is a national charity that resources primary and intermediate schools with bilingual science resource kits. In 2023 two new kits were developed to teach year 1 – 8 students about earthquakes and volcanoes.

This presentation will describe the kit development journey, that resulted in everything from mega slinkies to 3D spherical puzzles of the tectonic plates. These awesome resources empower teachers to deliver hands-on lessons about the science beneath our feet that gives rise to the powerful and spectacular forces that cause constant movement and changes in the Earth's landscape.

The House of Science model is unique and powerful as it removes time, cost and resource barriers for teachers. The shared kit library means thousands of children each week are receiving quality science lessons.

The response of Antarctic vegetation to major glaciation during the Oligocene/Miocene Transition

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The Mi-1 glaciation during the Oligocene/Miocene Transition (OMT) is one of the largest transient glaciations of the Cenozoic and marks a key step in Antarctic ice sheet history from the relative warmth of the Oligocene to large temperature and ice volume fluctuations in the early Miocene. Antarctic vegetation subsisted through this glacial period, before eventually disappearing from the continent as climate conditions became increasingly polar in the late Neogene. We use plant wax compound specific isotope trends ($\delta^{13}C$ and $\delta^{2}H$) in an Antarctic proximal sediment core (Deep Sea Drilling Project 270) to investigate the response and survival mechanisms of Antarctic vegetation to this extreme climate event. A marked negative n-alkane $\delta^{13}C$ excursion, coupled with a shift to more positive n-alkane $\delta^{2}H$ is interpreted to be the result of Antarctic plants sacrificing water use efficiency to maintain photosynthesis and carbon uptake during glacial conditions. This is driven by an orbital configuration which would have resulted in short, cold growing seasons with low light intensity. Further drivers of these isotopic trends are inferred to be more arid conditions, and a shift to a restricted low altitude, coastal vegetation with more stunted growth forms.

Recent developments in NZP&M's geoscience collections

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As the regulator of New Zealand's Crown-owned minerals estate, New Zealand Petroleum & Minerals (NZP&M) are responsible for the stewardship, quality assurance and provision of geoscience data and exploration reports collected by permit holders and the government. Our geoscience data repositories contain the cumulative efforts of generations of inquiry and represent strategic national assets.

The data comprises digital files available for download from the Geodata Catalogue and NZ Mine Plans, seismic field data held on magnetic tape and physical rock and fluid samples held at our National Core Store in Featherston, South Wairarapa.

There have been several recent developments that we are keen to make the geosciences community of New Zealand aware of. Come along to hear about the new Geodata Catalogue and Map, an update to the NZ Mine Plans system, the transcription to cloud storage of about 2 PB of seismic field data, and a glimpse into a possible future for the National Core Store.

Shaping landscapes: landslip analysis from Cyclone Gabrielle in Hawke's Bay

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Cyclone Gabrielle has severely impacted the Hawke's Bay region's natural capital to the extent that it will take many years to recover. Alongside its impacts on built capital, such as bridges, roads, homes and businesses, are the impacts on natural capital, including geology, soil, biodiversity, air and water. The focus here is on the impacts to soil and regolith in the form of landslides (landslips), which embed the surface process dynamics of soil/regolith erosion to runout and deposition. Research has been undertaken by Hawke's Bay Regional Council to investigate the direct impacts of the cyclone on rural land stability in the region through geospatial and regression analysis of landslips. Determinants of failure were assessed such as slope, aspect, antecedent weather, land use, land cover and the influence of any mitigation measures that promote resiliency. It is well documented that vegetation reduces erosion; with management plans stretching back beyond Cyclone Giselle and Bola. The question is, how have these historic land use changes measured up against the force of Cyclone Gabrielle? An initial farm-scale analysis found that the presence of trees at Awapapa Station in the Wairoa catchment likely influenced a reduction in slips by 71% when adjusting for farm size and slope. This research also applied the regression analysis at the regional scale to empirically tease out the influence of key drivers of landslips.

Studying the gentle dance – environmental response of remote alpine lakes to natural climate variability

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Overfertilisation, land use and climate change are putting many lake ecosystems in New Zealand under pressure. Whilst the anthropogenic drivers of deteriorating environmental health are subject to investigations, there remain uncertainties on how changing climate conditions will affect the planet's pristine ecosystems. Nestled within the centre of the Southern Alps, New Zealand's remote alpine lakes provide a distinctive arena for studying the intricate interplay between climate variability and ecological response. In this study, we reconstruct the climatic and environmental story of Lake Bright during the late Holocene as interpreted from a multi-proxy approach.

The presented stratigraphy was recovered from the centre of Lake Bright as part of the MBIE-funded Lakes380 programme in September 2019. We applied a subset of non-destructive scanning methods, such as XRF-core scanning and hyperspectral imaging, as well as analysis of lipid biomarker content, C/N bulk isotopes and biogenic silica to the cores to reconstruct changes in the provenance and composition of clastic and organic matter inputs.

The results of this study indicate that New Zealand's alpine lakes were able to preserve the imprints of natural climate variability and the local ecosystem response over a relatively stable period of the Holocene. Within a sequence spanning the last 3000 years, we were able to identify two global and one local event of changing environmental conditions affecting Lake Bright's catchment. Here, we present these major events of natural climate variability and discuss the implications that accelerated environmental change might have on New Zealand's pristine ecosystems in the future.

Classification and features of the 2004 Auckland meteorite

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On the morning of June 12, 2004, a meteorite crashed through the roof of a house, bounced off the sofa, hit the ceiling, and came to rest under a television in the Auckland suburb of Ellerslie, New Zealand. We report analytical results to classify the meteorite, almost 20 years since the meteorite crashed through the roof in Ellerslie.

Auckland has relict chondrules dominated by pyroxene–olivine–maskelynite, and a mineral assemblage surrounding the chondrules of olivine, maskelynite, low-Ca pyroxene, apatite, merrillite, kamacite, high Ca-pyroxene, chromite, taenite, and troilite. This and the bulk rock triple oxygen isotope values are consistent with Auckland being a low iron (L) ordinary chondrite.

The occurrence of low modal abundance of recognizable chondrules, abundant plagioclase (now maskelynite) grains >50 µm, indicate that Auckland belongs to petrologic type 6. Superimposed on Auckland's metamorphic history is one or more shock events. Mineralogic textures indicate a shock metamorphic (S) 5 stage. Auckland was collected immediately after the fall event, so is assigned a W0 weathering grade.

In general, fusion crusts (thin, dark glassy coating and underlying altered substrate that was formed when the meteorite passes through Earth's atmosphere) are relatively thin, usually < a millimeter. In contrast, we show that the fusion crust on Auckland can be divided into three zones that are indicated by their different sulphide occurrence and textures of sulphides and metals. Oxygen isotope values of the bulk rock and/or maskelynite of melted rim and modified substrate (within 2-5mm of rim) are 2–3 ‰ greater than the meteorite interior and indicate that up to 19% of terrestrial atmospheric O_2 was incorporated into the fusion crust during its formation.

The Auckland meteorite is interpreted to be an L6-S5-W0 ordinary chondrite that developed a mineralogically and chemically distinct multi-domain fusion crust upon interaction with Earth's atmosphere.

Seasonal dynamics of slow landslides in exhumed subduction mélange reveal quantitative and qualitative similarities to shallow slow slip in subduction zones

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In this contribution, we show that direct measurements of landslide displacement and pore water pressure at two slow landslides hosted in exhumed subduction mélange of the Franciscan complex in California, USA imply frictional velocity strengthening that is in excellent agreement with values measured in lab experiments on Franciscan matrix, clays and mudstones, and shallow subduction zone fault materials - and broadly with the velocity strengthening behaviour inferred from observed creeping behaviour and slow slip events in many shallow subduction systems. Detailed measurements of hundreds of stick slip events at one of the two landslides suggests that elastic loading due to slip on isolated velocity weakening asperities is relaxed slowly (over minutes) and aseismically by the surrounding velocity strengthening matrix. This observation also provides a view of slow landslides that is similar to creeping sections of subduction zones where isolated strong, velocity weakening asperities are embedded in weak, velocity strengthening matrix. Our work supports the view that slow landslides are intermediate scale field experiments that can link the lab and subduction zone scales and points to two important take home messages. First, idealized laboratory friction experiments can accurately predict macroscopic field-scale friction. Second, rate-and-state friction provides a useful path for predicting the dynamics of landslides, as others have suggested. Hence, it may be possible to predict which landslides are prone to catastrophic acceleration on the basis of geologic mapping and measurable material properties.

Subterranean burst and jet experiments using compressed nitrogen and glass beads to simulate particle transport and eruptive processes of diatreme-forming volcanoes

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Maar-diatreme volcanoes are the second most common type on land and are a significant hazard to nearby communities. Maar-diatreme volcanism is usually governed by subsurface thermal interaction of magma and groundwater, which fractures the surrounding country rock and causes explosive eruptions that eject volcanic clasts and fragmented country rock (lithics). Some maar-diatreme volcanoes have brought large, deep-sourced lithics to the surface, raising the question of how this occurs. There are two contrasting interpretations of subsurface processes in maar-diatreme volcanoes: (1) Massive gas flux produces a sustained eruption, excavates the diatreme, and transports lithics; and (2) Repeated explosions dig the diatreme and gradually escalate deep lithics to the surface. Neither explanation is wholly satisfying; thus, we experimentally reproduce explosions and jets variably inferred to take place in diatremes in order to observe how large particles are transported upwards in a diatreme-like granular system. The experiments build on previous works and differ in that, rather than investigating debris jets and cross-cutting structures within diatremes, we focus solely on upward transport of large lithic fragments in the system. To simulate subsurface explosions, we inject compressed nitrogen gas into glass beads containing larger "lithic" particles at various depths in order to simulate aspects of conceptual model scenarios that might explain the upward transport of deeply sourced lithics in these systems. By varying the eruption "source" from discrete explosions to brief then more-sustained jets, we observe where large-block-equivalent particles travel during an eruption or an explosion. We aim to establish a more thorough understanding of the nature of particle transport within diatremes, including the ascent of deep-sourced large lithic fragments within these systems, and to determine the extent to which current conceptual models explain these processes. These analogue experiments illuminate important subsurface processes of diatreme-forming volcanic systems.

Urban Earthquake Early Warning for Aotearoa-New Zealand

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Earthquake Early Warning Systems (EEWS) should be part of any Earthquake Resilience toolkit due to their potential to save lives and reduce injuries. Despite this New Zealand currently does not yet operate a national EEWS. EEWS currently do not take into account local modifiers including the way shallow geology or tall buildings amplify earthquake shaking. These systems therefore fail to consider complexities generated by the urban environment, which is a critical omission given:

- In New Zealand (NZ), over 85% of people live in urban areas, and
- Shaking intensity at the top of a multi-storey building can be ten times stronger than at ground level.

Regions are characterized by their own geology and geography, culture, history and Tūrangawaewae, as well as their own regional seismic hazard and monitoring networks. There are therefore obvious economical and strategical incentives to develop and tailor an EEWS for a particular region/city of interest rather than generalising outputs for the country as a whole. This has been the choice made by USA with the California and Oregon EEWS, Mexico with Mexico City, and now Canada with the West and East Coast regions.

The Wellington region is a highly seismic region hosting key national and regional infrastructures. It is also home to a population familiar with seismic hazards, resilient Māori communities, dense seismic monitoring networks, and collaborative groups in the fields of earthquake, social science, earthquake engineering, and communication engineering. We are therefore proposing to develop a collaborative next-generation EEWS for the Wellington region that is adaptable to regional, local, and building-level applications. The aim is to significantly reduce the cost to society of earthquake-related deaths and injuries and increase earthquake resilience for urban populations through increased education and awareness.

Inferred source models for Alpine Fault Earthquake Scenarios and influence on seismic hazard

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As part of the Southern Alps Long Skinny Array (SALSA) project, ~35+ seismometers have been deployed with 10–12 km spacing along a 450 km-long section of the Alpine Fault. SALSA is focused on determining the ground motions likely to be produced by a future Alpine Fault earthquake. This project is addressing three principal objectives: (1) Determine the Alpine Fault's subsurface geometry, present-day slip rates, and spatial variations in how tectonic stresses are currently accumulating on the fault, (2) Estimate the ground shaking that would be recorded at seismometers throughout central and southern New Zealand by localised slip at different points on the Alpine Fault, focusing on the synthesis of long-period Green's functions representing accurate path effects between sources distributed along the fault and population centres throughout the South Island, and (3) Calculate the ground shaking hazard from geologically informed earthquake rupture scenarios. In this presentation we will address the influence of inferred Alpine Fault source models derived from empirical data as well as current knowledge of the fault geological and geophysical parameters on regional seismic hazard.

Use of Felt Rapid Reports as a reliable data source in the production of earthquake intensity maps

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Crowdsourcing has the potential for use in a wide range of hazard applications by timely collection of large quantities of data. One example is GeoNet's Felt Rapid Report (FRR) data which has received up to 61,000 reports within 15 minutes of an earthquake. Members of the public indicate the intensity of shaking they experienced during an earthquake by selecting from a series of cartoons. This is related to a value on the Modified Mercalli Intensity scale which can then be used in statistical analyses, modelling and geospatial visualisations of the distribution of shaking. Currently, the data is shared with the public on the GeoNet website in a table of report intensities and a map of the maximum values. For the purposes of analysis, data is aggregated into Community Intensities (CI) based on the New Zealand Fire Service Suburb Database (used by local and national agencies as reference in the event of a disaster). My statistical analysis of CI's has shown that the distributions are skewed with a shift from negative through to positive skewness with increasing intensity values. This would suggest that the median value would be the appropriate representation. The Standard Error of distributions for different numbers of reports shows that a minimum of 5 reports balanced the reduction in error with maintaining the number of communities reaching this level. My aim is to develop FRR data into a robust data source by quantifying uncertainties and exploring a range of spatial aggregation units. It can then be used in macroseismic intensity maps, such as ShakeMapNZ, which indicate the distribution of shaking intensity and damage. These are made available to emergency response managers, decision-makers, and members of the public in the immediate aftermath of a major event.

A shallow crypto-dome intrudes a vent-filling volcaniclastic deposit at Seacliff, Dunedin area; implications for the Dunedin Volcano and other intraplate volcanic centres

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At a site located in an apparent transition zone between the Miocene Dunedin Volcano and its enclosing volcanic field exposures, north of Dunedin near the township of Seacliff, a small crypto-dome that intruded into deposits is inferred to represent penecontemporaneous vent-filling breccias. Peperites provide the strongest evidence for penecontemporaneity. Several stages of eruptive activity can be inferred, beginning with subaqueous explosive eruptions and continuing with intrusion of fluid magmas that formed peperites with the host volcaniclastic rocks before they had lithified. Later activity produced a domical intrusion, and its progressive cooling led to pervasive thermal columnar jointing in a radial/rosette geometry. A new rock texture, called here 'micro-columnar jointing', characterizes large lapilli in the host pyroclastic deposits, and is inferred to result from water cooling of hot and fluid bomblets in a subaqueous pyroclastic deposit. The apparent effects of water suggest submarine eruption and intrusion soon thereafter at this site near the Dunedin Volcano. Sea-level curves suggest that submarine conditions existed in this area only in the earliest periods of Dunedin Volcano magmatism.

The crypto-dome intruded into a series of unbedded volcaniclastic deposits that resemble vent-filling breccias. Large clasts of previously erupted material that have fallen or slumped back into the crater reach widths up to 1.5 m. Subsequent intrusion into these breccias, while they were still wet, produced peperites. We infer that this outcrop represents originally subaqueous deposits. The dome is exposed for nearly 120 m along the shore, and 30 m upwards from the shoreline. The columns range from 25–35 cm in maximum width across the whole outcrop. The columns are arranged radially around a point projected to be 30 m off the coast. The coherence of the radial jointing pattern is similar to that seen in other submarine crypto-domes described from Japan, Spain, and elsewhere.

Geochemical seafloor mapping of offshore Bay of Plenty using a machine learning approach

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Geospatial visualisation of data has long provided analytical insights that are vital for data interpretation, for example exploration of mineral resources, visualising soil parameters, or identifying anthropogenic heavy metal pollution. Traditionally, single variables are geospatially visualised after the generation of a surface using simple interpolation methods such as kriging or inverse distance weighting.

Here we present a case study for the incorporation of machine learning methods on surficial seafloor sediment geochemical mapping from the Bay of Plenty area, Aotearoa New Zealand. Preliminary traditional inverse distance weighting interpolation identifies key geospatial patterns that reveal terrigenous (Al, Si), and volcanic (Ni, Cr, Nb, Zr) signatures; however, additional covariates, such as mud content, show moderate positive correlation with Rb (R^2 = 0.74), and K (R^2=0.61), indicating potential improvements with a multivariate approach for some elements.

Results from traditional inverse distance weighting interpolation will be compared to methodologies that incorporate flexible machine learning methods (e.g., ensemble methods such as Random Forests) that allow covariate data types to be included, such as bathymetry, grain size, and inorganic carbon contents. Including additional covariates accounts for processes that may affect the geospatial distribution of different minerals, and hence elements, such as slope, distance from major terrestrial river terminations, and currents within the Bay of Plenty area.

Improved seafloor geochemical maps will enhance a variety of marine science studies, from habitat mapping, to identifying areas of high trace metal contents, to tracing the provenance of deposited sediments.

Inversion of NZ DART tsunami data for tsunami early warning

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Since the 1960s, tsunami early warning in New Zealand has been predicated on using earthquake characterisation as proxy information for tsunami generation. Obvious shortcomings exist with that approach. Fortunately, that paradigm has shifted. Following the recent deployment of the 12-station NZ DART array, New Zealand's Tsunami Expert Panel (TEP) can now use direct observations of tsunamis to underpin tsunami early warning forecasts. Under the RCET (Rapid Characterisation of Earthquakes and Tsunamis) programme, we have implemented a best-endeavours operational inversion of DART data for tsunami source. Results from this inversion can either be used directly within NZ's current pre-calculated tsunami threat database scheme or they can be used in our new ensemble modelling framework in which we calculate coastal tsunami threat in near real-time. In an aligned effort within the UNESCO Intergovernmental Oceanographic Commission, we have developed a risk-based scheme to assess the efficacy of tsunami early warning potential of DART networks. This scheme quantifies the relative number of tsunami sources for which data support at least 20 minutes of pre-impact warning time to vulnerable coastal populations. We apply this scheme to the NZ DART network to quantify domestic and SW Pacific resilience gains delivered by NZ DART and further highlight existing gaps, largely around local source tsunamis.

Understanding ice dynamics through natural ice air bubbles and their deformation

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The shape of air bubbles and air bubble behaviours in natural ice may provide a greater understanding of ice dynamics.

Micro-computed tomography (Micro-CT) and optically imaged data collected from samples from the lateral shear margin of the Priestley Glacier show the variation of bubble shape. These bubbles are less stretched than we would expect for the amount of shear. This poses the question of what controls the kinetics of bubble shapes. How do deformation conditions (e.g., temperature, strain rate) affect the balance between bubble deformation (stretching the bubbles) and restoration to a sphere, driven by surface energy?

We are investigating this using a deformation experiment that allows for the removal of the ice sample to take photos of the bubbles and the return of the sample for more deformation after this. The photos taken at regular time intervals during deformation allow us to better understand the processes and changes occurring during deformation.

In preliminary experiments the sample was cut at 45° to the c-axis maximum, to mimic the deformation in the field, and removed for imaging every 23-26 hours. The sample was put under ~0.55 MPa of stress at ~-11°C. The experiment run time was 172 hours, achieving a total axial strain of 0.18 at strain rates of $3x10^{-7}s^{-1}$ ($10a^{-1}$). The bulk strain and the strain calculated from bubble shape change are very similar, suggesting that at these fast rates bubble deformation is much faster than restoration. Experiments at slower rates are needed to scale back to natural conditions.

Pleistocene stratigraphy of continental margin sedimentation adjacent to the Patagonian Andes

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Continental margins are sensitive recorders of land-to-sea sediment transport in glaciated settings. Here, we present pilot data from International Ocean Discovery Program (IODP) Site U1542, a high-resolution (>30 cm/kyr) marine sediment core with a likely basal age of ~700 ka, collected from the upper continental slope of the southernmost Chilean margin by IODP Exp. 383 in 2019. The near-continuous 249m-long composite stratigraphy spliced from four holes exhibits a complex distribution of siliciclastic sediments with decimeter-scale beds of calcareous and siliceous biogenic sediments. This core is well-positioned to record glacial-interglacial climate changes north of the Drake Passage and provide new insight into regional climate drivers. Our research aims to build a reconstruction of past Patagonian ice extent and sedimentation, at higher temporal resolution than previously reported to assess the interactions between the ACC and significant Patagonian glacial-interglacial cycles.

Our shipboard scanning XRF data capture glacial-interglacial changes in sedimentation, including millennial-scale changes in the late Pleistocene. We pair these XRF measurements with physical properties data and an orbitally tuned age model to evaluate Pleistocene climate and environmental change.

High-resolution imaging of post-glacial sedimentation in New Zealand's fjords reveals regional history of deglaciation

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Each of Fiordland's 15 distinct fjords have seaward entrance sills that separate glacially eroded and overdeepened basins from the open marine conditions of the Tasman Sea. The fjord basins contain sediments that preserve a record of post-glacial sedimentation that can be used to evaluate changes in environment, including regional sea level, climate, and vegetation. For example, at the end of the last glaciation, when the entrance sills were higher than the glacial eustatic sea level, the present-day fjord basins would have been isolated glacial lakes prior to the subsequent marine ingression that occurred because of post-glacial sea level rise; this lacustrine-marine transition can be identified in seismic records and in the fjord sediments, e.g., as flooded deltas and beaches.

Over the last 11 years, we have collected high-resolution boomer-sourced seismic reflection data in most of the fjords of Fiordland using a 75-m-long 24-channel Geometrics MicroEel array recording signals from an acoustic boomer source. Processing has been undertaken using GLOBE Claritas seismic processing software. We present a summary of this work, showing profiles along most of the fjords including, from north to south, Milford, Bligh, George, Caswell, Charles, Nancy, Thompson/Bradshaw, Doubtful, Dagg, Dusky and Long sounds. Seismic sections show a wide variety of sediment accumulations in the fjords depending on, e.g., periglacial conditions, sill depth, catchment size, catchment rock types and vegetation history. Sediment thicknesses are observed to exceed several hundred metres in some of the basins – which supports an interpretation of interbedded strata of muds, silts, and fine sands. The depositional history of the sedimentary units imaged by these data, in conjunction with additional seafloor mapping, direct seafloor sampling and shallow cores, will be confirmed by future deep drilling efforts in the fjords.

Thermal properties of Rakaia Terrane, New Zealand

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New Zealand geological literature is yet to include a study on the thermal properties of its most common rock type. Rakaia Terrane outcrops over much of the South Island and lower North Island and comprises an assortment of mudstones and sandstones and their metamorphosed equivalent, Haast Schist. A smaller fraction (<1%) of the lithology comprises chert, conglomerate and limestone. Samples have been collected from geographically, compositionally, metamorphically, and texturally diverse origins within Rakaia terrane in order to capture as much variation as possible. These include samples that are highly homogenous in nature and grade into more heterogenous samples that are foliated or schistose. Metamorphic grade ranges from zeolite to greenschist facies. Hand specimens were cut into 4cm cubes and measured using a Portable Electronic Divided Bar, and all samples had at least two axes measured so that a measurement was taken both perpendicular and parallel to the direction of foliation where possible. Bulk thermal conductivity and diffusivity values are reported, and preliminary results detail several major controls on thermal properties, including mineralogy, porosity, fluid content, and alignment of minerals. Trends relating chemistry to thermal properties are also shown and correlate specific elements with high or low thermal conductivities. Importantly, a positive relationship is found between increasing anisotropy and greater metamorphic grade. This study contributes significant data to thermal geophysics studies in New Zealand and lays the foundation for future research in this area.

Eruptive histories of New Zealand's nearshore volcanoes: insights from marine cores around Tūhua and Whakaari volcanoes

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Volcanic islands can generate multiple syn-eruptive hazards including pyroclastic flows, ashfall and tsunamis. New Zealand hosts two active near-shore volcanoes in the Bay of Plenty (BoP): Tūhua (Mayor Island) and Whakaari (White Island). Both islands show evidence for explosive activity as well as caldera and/or flank collapses. Whakaari's eruptive history is only partially known due to limited exposure and preservation. Conversely, Tūhua's geology has been studied extensively but the full extent of its explosive activity remains uncertain. Understanding the magnitude and frequency of past eruptions is crucial for hazard and risk assessment, particularly for BoP communities that are vulnerable to tsunami and ashfall. Our study addresses this knowledge gap by investigating the pyroclastic eruptive histories and the frequency-magnitude relationships of Tūhua and Whakaari using marine records in the BoP. This will be achieved via the chemical analysis of tephra horizons (e.g., EPMA, LA-ICPMS) and radiocarbon dating of sediments (e.g., from planktic foraminifera) in marine cores that will be collected during the TAN2315 cruise in October 2023. Representative subaerial tephra samples from Tūhua have also been used to benchmark the expected compositional variability in the marine cores, with subaerial units displaying a range of peralkaline glass compositions that vary within and between eruptive units. Additionally, we subsampled tephra horizons and sediment layers from an existing core that was collected near Tūhua during the 2015 TAN1513 cruise. Preliminary observations and analyses from October's coring expedition are presented and compared to onshore observations, existing tephra records and previous coring work in the BoP. These data will build onto existing work (e.g., Tūhua's detailed, largely unpublished eruptive catalogue by Wilson et al.) to improve the eruptive record of New Zealand's offshore volcanoes. Probabilistic ashfall models can then be calibrated and used to assess risk to BoP and North Island communities.

A spike in the road?

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With the recent extreme weather events occurring across the motu and around the world, climate change has become one of the major concerns for most people, affecting their lives and livelihoods. Reducing our carbon emissions is one way to help lessen the effect a changing climate will have around the world, although it won't happen overnight.
Last year, GNS Science reported on its journey to be carbon neutral by 2025. We joined the Toitū Envirocare carbonreduce programme in 2020 and have been accurately measuring the carbon emissions related to our science and to our organisation, and putting strategies in place to manage and reduce impacts.

As part of the programme requirements, we established a baseline year, from which our emissions reduction targets will be measured against. For GNS Science, our baseline is the 2018-2019 financial year. In hindsight, this baseline period was pre-Covid, so provides an opportunity to see what our "normal" carbon emissions were, what difference the Covid restrictions had on some of our activities (e.g., travel), and how we are tracking in a post-Covid world, whilst still maintaining our business.

We completed the latest audit of our carbon emissions in December 2022, and are now in our fourth year of being a certified Toitū carbonreduce organisation. By reporting on Category 1, 2, 3 and 4 emissions, GNS Science's carbon emission total has reduced by ~30% since 2018-2019 (4407.69 tonnes CO_2e to 3086.05 tCO_2e in 2021/2022), largely thanks to the travel restrictions imposed by Covid.

While the data from our 2019-2020 to 2021-2022 financial years provides an indication of what can be achieved when forced to reduce carbon-emitting activities, data from 2022-2023 suggests we are returning to pre-Covid carbon emission levels, undoing some of the lessons learned. Is this a spike, or can we learn from the past?

From source to surface: insights into the timescales and processes driving young eruptions at Red Crater, Tongariro

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Stratovolcanoes are characteristic features of subduction zones and their eruptive behaviour and associated hazards can be challenging to understand and predict as they erupt both explosively and effusively, often without much warning. The magmatic systems of these volcanoes are complex, as reflected in the intermediate composition of erupted magmas, typically comprising highly variable crystal cargoes that are rarely in equilibrium with their carrier melt. Knowledge of how these systems manifest and evolve through time in response to magma recharge is vital for understanding and predicting volcanic behaviour. This study uses detailed geochemical analysis of mafic minerals (olivine, pyroxene) of recent (<1.8 ka) eruptions from Red Crater, Tongariro. We used mineral chemistry, compositional zoning and melt inclusions to identify and characterize components in the magmatic system and to reconstruct pre-eruptive magma storage conditions and magmatic timescales. Our investigation reveals four olivine populations with core compositions from Fo70 to Fo91 and thin Fe-rich rims (~Fo78). Pyroxene crystals are complexly zoned and record up to three distinct magmatic environments within one crystal. Olivine-hosted melt inclusions represent some of the most primitive melts reported in the southern Taupō Volcanic Zone (TVZ), while melt compositions found in pyroxenes are more evolved. Overall, we find abundant chemical and textural evidence for open-system processes and our interpretation supports the influx of primitive Mg-rich magma from a deep mantle source, variable interaction with at least one mid-lower crustal, more evolved magma reservoir, followed by rapid ascent and eruption. This information improves our knowledge of magmatic processes leading to eruptions in the southern TVZ and contributes to the general understanding of andesite petrogenesis at continental subduction zones.

Airwave-tsunami source inversion using barometric pressure data for the 2022 Hunga Tonga – Hunga Ha'apai volcanic tsunami

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The 2022 Hunga Tonga – Hunga Ha'apai eruption generated atmospheric pressure waves, or airwaves, that were recorded at meteorological stations around the world. This type of wave can effectively trigger tsunamis when propagating over the deep ocean. Airwaves propagate at a speed almost equivalent to the speed of sound (~320 m/s), which is faster than the typical speed of a tsunami (about 200 m/s in water depths of 4 km). By analysing the airwave data, we might obtain a sufficient lead time for an effective tsunami warning. We used airwave data recorded in New Zealand, Niue, the Cook Islands, and Japan for airwave source inversion. The unit source was constructed using a B-spline function characterised by a diameter of 50 km. We simulated synthetic airwaves by solving the long-wave equations, assuming a constant wave speed of 310 m/s. For the source inversion, the time window spanned 3 hours with a total of 30 time windows and a 90-second shift between each window. We performed the inversion for each station to determine the source time function and then analysed the differences and similarities among the estimates. Overall, all stations suggested that the total source duration is about 30 minutes, while the peak is around 15-20 minutes after the initiation. The estimated source time functions in Niue and Cook Islands are slightly more energetic than those at New Zealand and Japanese stations. We analysed the inversion outcomes to understand the explosion's magnitude and sequence. The source time functions reveal at least four distinct peaks, each corresponding to observed explosions. Furthermore, we investigated whether the inversion result can be used to forecast the tsunami.

Future opportunities for New Zealand and Australia in international scientific drilling

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After 55 and 27 years respectively, both the International Ocean Discovery Program (IODP) and the International Continental Drilling Program (ICDP) continue to facilitate significant discoveries in our understanding of the Earth's lithosphere, biosphere, cryosphere and atmosphere through scientific drilling.

The current phase of IODP ends in 2024 and the future of scientific drilling is positive. Whilst the revered JOIDES Resolution will be retired in 2024, scientific ocean drilling is a priority consideration under the US National Academies 2025-2035 Decadal Survey of Ocean Science. Europe and Japan are working to implement an expanded Mission Specific Platform approach to scientific drilling that allows coring in regions unreachable by larger vessels (e.g. ice-covered oceans and through the land-to-sea transition zone). A new Chinese ocean drilling vessel is due to come online in 2025 and the case to replace the JOIDES Resolution is gathering momentum in the US. These offshore drilling capabilities complement the infrastructure supported by ICDP to drill in a range of terrestrial and near-shore environments, including lakes.

To ensure that Australian and New Zealand researchers retain the opportunity to continue their historically significant contributions to scientific drilling around the world and to training the next generation, the Australian and New Zealand IODP Consortium (ANZIC) is actively working to secure longer-term access to IODP and ICDP research infrastructure capabilities. In Australia, ANZIC has partnered with AuScope to seek increased funds under the Australian Government's National Collaborative Research Infrastructure Strategy. Efforts in New Zealand are focused on extending current funding from the Ministry of Business, Industry and Employment Endeavour Fund beyond 2024.

These efforts are not only focused on maintaining involvement in global scientific drilling initiatives, but to expand opportunities to access subsurface samples across continents, the coastal transition zone, our extensive continental shelves and out into the deep abyssal plains.

Towards an updated national VLM estimate for Aotearoa derived from Sentinel-1 PS-InSAR data

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In 2022, the NZ SeaRise program released new probabilistic relative sea level (RSL) projections using the Framework for Assessing Changes to Sea-level (FACTS) from IPCC Assessment Report 6 that included a novel component to ingest local vertical land movement (VLM) data. This approach produced RSL projections at 2 km intervals around New Zealand's coast and included estimated VLM derived using historic Envisat Synthetic Aperture Radar (SAR) data between 2003 and 2011. Here we present an update of a new national scale vertical dataset built using Sentinel-1 SAR data from late 2014-present. With full national coverage from both ascending and descending datasets, we will highlight the improved temporal and spatial resolutions now available. In addition to better integration between the GNSS and InSAR datasets, we will show the effects of the increased spatial and temporal resolutions has on measuring building scale deformation across Aotearoa's urban centres. Notable displacement rates are identified across a number of areas in Christchurch, Dunedin and Wellington often correlated to building infrastructure on reclaimed coastal land. We also investigate the effects of the co- and post-seismic deformation due to the 2010-2011 Canterbury earthquakes, the 2016 Valentine's Day earthquake and 2016 Kaikoura earthquake on the estimated VLM across the Christchurch region and how it influences the estimates of future VLM.

SAR observations the 2021-2023 eruptive sequence at Ambae volcano, Vanuatu

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Ambae is a large, elliptical basaltic shield volcano sitting within the Vanuatu volcanic archipelago. The main crater complex consists of two concentric calderas, usually occupied by Lake Voui and a smaller lake, Manaro. Historical eruptive activity at Ambae had been limited until late-2005 to early-2006 when small-scale Surtseyan explosions through Lake Voui produced dense water-laden plumes and base surges. Because of this activity, a small scoria cone was constructed near the centre of the lake that was eroded over subsequent months. Between 2006 and late-2017, eruptive activity was restricted to small phreatic explosions in July 2011. This quiescent period ended in September 2017 when steam eruptions transitioned into scoria cone growth, lava flow emplacement and mild explosions. This style of eruptive activity continued until November of that year when the volcano began a short quiescent period. Activity significantly increased in intensity in February to April 2018 when an explosive phase generated buoyant ash plumes and very high SO2 flux. Following the 2018 eruption and gradual removal of the exposed vent, Synthetic Aperture Radar (SAR) data shows the splitting of Lake Voui in two. The newly formed lakes remained largely stable until late 2021 when a new eruptive period began. Here we use hi-resolution SAR data to track the evolution of the vent system from December 2021 to September 2023. Available satellite data reveals rapid growth of a new cone in Lake Voui in early 2022 that produced intermittent gas, steam, and ash emissions. Activity increased in April 2023 when a new lava flow filled the northern lake basin within the caldera. Using interferograms to track the post emplacement deformation, we track the ongoing subsidence of lava flow as it cools and contracts. This case study highlights the utility and resolution available for remote monitoring of a small volcanic island.

Morphological trends of pockmarks on the Chatham Rise: the interplay of fluid escape and ocean currents

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Seafloor depressions, recognized as pockmarks, have been widely observed on the seafloor around Aotearoa/New Zealand, to the east of South Island on the Chatham Rise, Bounty Trough, and Canterbury Shelf. The pockmark morphologies over this area are highly variable in diameter, relief and shape. Based on pockmarks occurrence reported in previous studies, clustering between small- (~100 - 200 m diameter), intermediate- (~200 - 700 m diameter), and large-sized (> 1 km diameter) pockmarks in circular and elongated shapes are investigated. Although the pockmarks are generally thought to be indications of fluid seepage through unconsolidated sediments and subseafloor fault systems, the processes attributed to pockmarks formation remain enigmatic.

Using new high-resolution, densely spaced muti-beam bathymetry and backscatter data, this study aims to map the geospatial distribution of various types of pockmarks to classify their morphological variation. The application of ArcGIS-based tools is used to identify, spatially delineate, and morphometrically characterize numerous pockmarks (>100 pockmarks) over the Chatham Rise, Bounty Trough, and Canterbury Shelf areas. The geomorphometric outputs allow statistical analysis of their morphological variation and provide a quantitative baseline to assess linkages to their geological and oceanographic setting. This integrated information provides further insights into the interaction between fluid escape and oceanographic processes on the morphological trends of the widespread pockmark occurrence on the Chatham Rise.

How FAIR is GeoNet data? How to assess FAIRness, and how to improve it

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The GeoNet programme at GNS Science, Aotearoa New Zealand is producer and custodian for datasets used for multi-hazard monitoring, assessment, and research. These datasets are of high national value and significance and range from highly sampled/highly automated to manual and ad-hoc datasets. FAIR is a cornerstone of GeoNet's and GNS Sciences' data principles and an area where we are always seeking to improve.

To understand and demonstrate improvements FAIRness of its datasets, all GeoNet datasets were assessed in 2019. Here we will discuss that scoring effort and the outcomes across our datasets, and show how subsequent targeted work has delivered improvements, using a few key examples:

- Our eruption history database was converted from unstructured document format (GNS report) to a csv format and made fully public; this significantly enhanced its FAIR score across the board.

- Our acoustic/infrasound dataset was made more discoverable by minting a DOI, creating a dataset description record that is based on international web standards and utilising community webservices, leading to significant increases in Findability and Interoperability.

FAIRness scoring is a powerful tool to guide dataset management improvements. It also revealed that some datasets have natural ceilings, particularly when there is a lack of clear international or community standards. More established and cross-peril datasets can achieve high compliance with FAIR data principles with relatively simple steps, while some key improvements generate nary a ripple in the score. FAIRness and open data are key policies for GeoNet, and will remain so for the foreseeable future.

Investigating the marine-terrestrial interface of Te Whakaraupō Lyttelton Harbour

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Low lying coastal areas are susceptible to future environmental changes from global climate, sea level, natural hazards and changed land use. It is crucial to have a fundamental understanding of environmental change over time to discern how environments may react to future climate variability and increased land use. To do this, we utilise a multiproxy palaeoenvironmental approach to reconstruct past environmental change over the last ~5,000 cal yr BP at Te Whakaraupō Lyttelton Harbour, Banks Peninsula. Te Whakaraupō is an historically, culturally and geologically significant location which is host to a variety of at risk or threatened native flora and wetland fauna. This area is host to the most extensive mud flats and salt marsh within Banks Peninsula. It is both a highly modified and understudied landscape. To identify both marine and terrestrial processes, we collected a transect of three sediment cores encompassing the marine-terrestrial interface. These underwent a combination of micro-fossil, geochemical, geochronological and sedimentological analyses to reconstruct past environmental variability over the last ~5,000 cal yr BP. Here we present results from all three sediment cores which record previous storm activity within Te Whakaraupō, changes in sediment provenance and rates and also variations in local sea level. This research can be utilised for future management and/or restoration of the area, as well as providing knowledge of hazards which have and may further impact Te Whakaraupō in the future.

Understanding boaties' needs for tsunami warnings in Aotearoa New Zealand: A post-event case study of the 15 January 2022 volcanic eruption-induced tsunami

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On 15 January 2022, the Hunga Tonga Hunga Ha'apai volcano erupted and generated a tsunami that spread across the Pacific Ocean. Around the time of the eruption and tsunami activity, ex-Tropical Cyclone Cody was also expected to pass east of New Zealand, producing heightened swells along the east coast of the North Island. In New Zealand, a severe weather warning and a tsunami advisory were issued on 15-16 January 2022. The most damaging impacts appear to have occurred in Tūtūkākā, Northland, where numerous boats were significantly damaged or sunk. The boating community raised concerns over the perceived lack of tsunami warnings for this event. This suggests a possible misalignment in expectations of the purpose and design of tsunami warning systems between key groups such as boat owners, and the designers and issuers of the warnings.

In this post-event case study, we interviewed boat owners and operators in Tūtūkākā and emergency management personnel in Northland to understand the various needs and expectations of the tsunami warning system. We used the Protective Action Decision Model framework to structure the qualitative data analysis.

Our findings show that the complexity of the event and its co-occurrence with an ex-tropical cyclone made it difficult to assess and convey the severity of the tsunami that was expected to affect parts of the New Zealand coastline. This event shows the importance of multi-hazard risk assessments to produce appropriate warnings and action advice. This presentation will provide an overview of these findings.

Hochstetter's long lost Auckland diary

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The "Father of New Zealand geology", Ferdinand von Hochstetter, was in New Zealand from December 1858 to October 1859. He spent time in both Auckland and Nelson provinces studying the rocks and landforms, preparing maps of the geology, and collecting natural history and ethnological specimens for museums in Vienna. Apart from the first two weeks in Auckland, Hochstetter recorded his travels and observations in a series of five diaries, hand-written in German. These diaries provided the base material for his later publications on New Zealand and its geology. Of the five diaries, the last two, on Nelson, have been translated and published by GSNZ. For more than a century Hochstetter's Auckland diary was believed to be lost until it was found in 2010 by Sascha Nolden, together with a number of unpublished sketches, photographs and documents in the keeping of his descendants in Basel, Switzerland, and digitally repatriated. This Auckland diary has now been transcribed and translated by Sascha Nolden and published by GSNZ. Although extracts from his Auckland diary were published by Hochstetter, the translation clearly spells out, for the first time, much more detail of where, when, how and with whom he travelled around, mapping Auckland's volcanoes and making multi-day forays to the west (Henderson, Te Henga, Huia, Whatipu), south (Waiuku, Port Waikato), east (Maraetai, Ardmore) and north (Whangaparaoa). The diary also provides more clarity on the validity of the competing claims by Heaphy and Hochstetter that the other plagiarised their work on Auckland's volcanoes.

New 3-D resistivity models from the Hikurangi subduction margin

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At the Hikurangi subduction margin along the east coast of New Zealand's North Island, plate coupling changes from weakly coupled in the northern part of the margin to locked in the south. In the last decade, over 470 magnetotelluric measurements have been acquired along the Hikurangi margin. 3-D inversion modelling of the data show a correlation between the resistivity at the depth of the plate interface and the areal strain rate derived from GPS measurements. In the weakly coupled region in the northern part of the margin, the plate interface is heterogenous caused by fluid and/or clay-rich sediments, whereas a more resistive homogenous and fluid poor interface is present in the south where the plates are locked.

Forty-one new MT measurements have been acquired in 2021-22 in south Wairarapa where the plates are locked. Here we present preliminary results of 3-D inversion modelling of the data using a finite element code that incorporates topography and bathymetry. These results show a shallow conductor at interface depth close to the coast and an otherwise resistive crust below the near surface conductive sediments.

Uranium isotopes record in the Southern Ocean since the last glaciation (~ 32 ka to present): Interrogating a paleo-redox proxy

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The rise and fall of oxygen in the oceans and atmosphere have been powerfully interconnected with the evolution of life, carbon-cycle perturbations, and major climate re-organisations throughout Earth's 4.6-billion-year history. The uranium (U) isotope system is widely used as a tracer for reconstructing oxygen variations in the past oceans. Today, the global ocean is largely oxygenated, and U is highly soluble. However, during periods of ocean anoxia, U, under the reduced form, becomes insoluble and is removed to sediments, inducing U-isotope fractionation in seawater. Evidence suggests that carbonates directly record past seawater U-isotope signatures without isotopic fractionation, and numerous studies have used carbonate U-isotope stratigraphies to quantify the evolution of past ocean oxygenation.

We have acquired a continuous U-isotope record spanning the last 32,000 years from a Southern Ocean sediment core. We acquired measurements on surface-ocean carbonates (coccolithophore) using a Neoma multiple-collector ICP-MS (MC-ICP-MS). Over this period, the oceans were oxygenated and therefore contained stably dissolved U with a homogenous U-isotope signature. Our new results demonstrate, for the first time, that sizeable U-isotope fractionation can occur in open-ocean carbonate without changes in ocean oxygenation, challenging current assumptions and paving the way for more accurate reconstructions of Earth's ocean-atmosphere-climate system.

The abundance and size distribution of tuaki/cockles within modern and historical near-shore habitats of upper Whakaraupō Lyttelton Harbour, and relationships to sediment characteristics.

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Throughout New Zealand tuaki/cockle populations are declining due to anthropogenic influence, primarily by overharvesting and pollution of habitats. This research aims to identify if sediment characteristics are influencing tuaki populations in upper Whakaraupō Lyttleton Harbour, and whether these changes are due to anthropogenic influence or were occurring prior to human arrival in New Zealand. Whakaraupō has undergone many changes since European arrival, including major deforestation and urban development. Additionally, mahinga kai resources in Whakaraupō have been found to have declined since European arrival. Recent studies have found that tuaki densities in Whakaraupō are typically lower than those in proximal estuaries around Banks Peninsula and Christchurch. While the characteristics of modern tuaki populations in Whakaraupō are known, the changes in these populations over time has not been investigated. Distributions of tuaki abundance and size as well as sediment characteristics are established in this research for both the current environment and recent history. Modern distributions of tuaki populations were determined by sampling at various tidal levels throughout upper Whakaraupō, while historical distributions within the last 3,000-4,000 years were established using sediment cores. Sediments collected during both coring and surface sampling were tested to determine modern and historical sediment characteristic variations. The current distribution of tuaki populations is variable, displaying a relationship with tidal level. There appears to be a significant change in tuaki populations within the sediment cores. This indicates that there have been changes in tuaki populations over time. Determining what is affecting tuaki populations in Whakaraupō will result in a clearer understanding of what needs to be done to restore the populations.

Temporal variations in seismic scattering structure during Deep Slow Slip beneath the Hikurangi Subduction Zone

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The Hikurangi margin in New Zealand exhibits both shallow (≈5-10 km depths) and deep (≈35-50 km depths) slow slip on the subduction thrust. The deep slow-slip events (SSEs) occur every ≈5 years and the rupture lasts for ≈1-2 years releasing seismic energy equivalent to an M7 earthquake. We computed receiver functions (RFs) at seismic stations above the deep slow-slip patch in the Manawatu region between 2003 and 2022 and extracted the power spectral densities (PSDs) of the RFs using multitaper method for 5-second long windows in the time lags around the P- to S-conversion at the subduction thrust. The PSDs were resampled at full-octave period averages at 1/8 octave intervals and were binned in 1.5-year-long windows with 95% overlap. The PSDs of both radial and transverse RFs and their total spectral power between 0.3 and 0.8 second periods show systematic temporal variations that correlate with the GPS displacements at collocated GNSS instruments. The total power increases during SSE periods and decreases during inter-SSE periods suggesting that the seismic velocity structure at the slow-slip patch undergoes periodic changes over time. The periodic changes may be attributed to the fluid-pressure valving model proposed for SSEs worldwide, where an impermeable seal at the plate interface breaches due to an overpressured subducting oceanic crust.

Spatial modelling to support carbon capture through enhanced rock weathering

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Large-scale carbon dioxide removal from the atmosphere is required to avoid devastating environmental impacts and accelerating natural processes with new engineering techniques can support this goal. The Earth's system naturally sequesters atmospheric carbon through silicate weathering, this process can be accelerated using the method of enhanced rock weathering (ERW) where finely ground silicate rock is dispersed onto pastural surfaces to speed up the chemical reactions between the rock material, water, and the atmosphere. To support this advancing research and technology in New Zealand, we have been using spatial modelling to locate the most suitable locations of silicate sources such as mafic igneous deposits that are required for developing the rock-derived products as well as determining the most ideal deployment sites for the processed material. Quarrying of these rock resources is not suitable at all mapped rock locations due to environmental restrictions, competing land use, or remote locations; therefore, not only are geological maps of rock type used in the model but also, for example, maps of conservation value, transport routes, visibility and population density are considered as factors that may limit or enhance site suitability. We have used a geographic information system (GIS) with geological, geochemical, soil, topographic, environmental, conservation, land use, and cultural data to map favourable and unfavourable locations based on expert knowledge and spatial statistics. The data are weighted and combined to map sites where there is the best opportunity to develop a quarry and produce an ERW rock-derived product. The model also illustrates those places around New Zealand where deployment of the material for ERW research trials and future large-scale deployment would be best suited based on climate, soil, and terrain conditions.

Over a decade of hydrate research in Aotearoa, New Zealand – what have we learned?

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Since 2010, GNS has led extensive gas hydrate research programs in Aotearoa, most recently 'HYDEE: Gas Hydrates - Opportunities and Implications'. This programme focused on the Hikurangi Margin, New Zealand's largest gas hydrate province, with abundant bottom simulating reflections (BSRs) at depths >600 m. HYDEE aimed to establish New Zealand-specific frameworks for gas hydrate energy extraction, forecast seafloor and wellbore geo-mechanical responses from production, and explore effects of seafloor stability and methane flux changes on marine ecosystems. Furthermore, the programme sought to incorporate indigeneous knowledge and deliberative community engagement into gas hydrate science to explore the broad socioeconomic implications of resource extraction.

Extensive geophysical data, seafloor sediments, and biological samples revealed numerous active gas seeps associated with gas hydrate. Dense 2D seismic data in this complex geological area facilitated analyses of gas hydrate distribution and concentration. Geological models explored gas generation, migration, and hydrate formation. Diverse data sources including multibeam bathymetry, water column imaging, and seismic data formed databases for slope failures and seafloor seepage, exploring systematic links between gas hydrate systems and natural erosional features. Biological data including seafloor imagery, sediment cores and water sampling were acquired across several voyages, targeting sites of active methane seepage and natural slope failure. These data were analysed to assess how seafloor communities and biogeochemical processes in the water column might respond to anthropogenic impacts on methane flux and seafloor stability. Economic models evaluated hydrate production viability, while research considered involving mana whenua (indigenous peoples) in meaningful ways, exploring Māori economic growth prospects and broader socioeconomic impacts of gas hydrate utilization.

This research's combined outputs offer unique insights into this geologically active region, forming a robust baseline understanding of the Hikurangi Margin gas hydrate system.

The diverse morphology of pockmarks offshore Aotearoa New Zealand – relict seeps or geomorphological anomalies?

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Seafloor pockmarks are abundant around Aotearoa New Zealand, occurring across a diverse range of tectonic, sedimentological and geomorphological settings. Globally, the formation and source of pockmarks is widely researched because they: 1) have potential links to subsurface hydrocarbon systems, 2) can provide important habitats for benthic organisms and 3) may be indications of fluid escape pathways or areas of sediment disturbance, which influence seafloor stability and could pose a risk to infrastructure. Pockmarks are widely associated with fluid release (such as gas or water) from subsurface reservoirs. However, the formation of pockmarks, the processes that shape and modify their morphology over time, and the relative timing of these events, remains enigmatic.

Here, we compile the first national database of over 30,000 pockmarks around Aotearoa New Zealand, allowing us to begin to comprehend the dynamic processes that shape and affect pockmarks by exploring regional and inter-regional patterns in pockmark geometry and seabed characteristics. This compilation reveals several significant trends, including a distinct lack of correlation between active seafloor seeps and pockmarks, and a strong association of pockmarks with mud-rich seafloor substrate. Furthermore, we highlight key knowledge gaps that require further investigation moving forward, including a lack of constraint on the timing of pockmark formation, and limited modelling of the processes involved in their formation.

Strontium isotope ($^{87/86}Sr$) dating of the base Nukumaruan Stage Boundary, New Zealand

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The late Pliocene Nukumaruan local stage boundary has long been used to mark the Pliocene-Pleistocene boundary in New Zealand; this boundary, however, has previously never been dated directly. The age for the base Nukumaruan Stage is inferred to be at 2.40 Ma, interpolated between the lowest occurrence of the planktonic foraminifera *Truncorotalia crassula* in offshore marine drill cores, and the first occurrence of the pecten *Psychrochlamys delicatula* in the Hautawa Shellbed, Whanganui Basin. However, correlation of this stage outside of the Whanganui Basin is difficult, and complicated by the commonly shallow marine setting of this interval through onshore sections, containing coarse lithologies, multiple unconformities, and a broad temporal range of preserved macrofaunal taxa. Here we apply $^{87/86}Sr$ isotope stratigraphy to selected molluscan taxa to reliably date the Hautawa Shellbed and approximately correlative units spanning the Nukumaruan and Pliocene-Pleistocene transition in the neighbouring East Coast Basin.

Jointly, these data identify the timing of the first occurrence of *Ps. delicatula* in the Wairarapa and determine a numerical age for the base Nukumaruan Stage in the Hautawa Shellbed, the proposed Nukumaruan standard section and point (SSP) in the Whanganui Basin. Notably, widespread occurrences of *Ps. delicatula* in the Whanganui and East Coast basins were assumed to be coeval; however, $^{87/86}Sr$ isotope stratigraphy, detailed age models, and comparison with the Old West Road Nukumaruan section in the Whanganui Basin confirm that these are discrete events, with marine water temperatures, rather than time, being the primary control on the occurrence and timing of *Ps. delicatula* assemblages. The strontium isotope date derived from the basal Hautawa Shellbed indicate a slightly older age for the base Nukumaruan local stage at 2.6 ± 0.15 Ma, which is more consistent with the Pliocene-Pleistocene stage boundary in the European sequence than the currently accepted age of 2.40 Ma.

Strontium isotope ($^{87/86}Sr$) stratigraphy: applications in the New Zealand geological record

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Globally, strontium isotope stratigraphy is a well-established method. However, previous applications of this method in New Zealand are very limited, despite abundant marine successions bearing carbonate material, and well-documented difficulties in dating these stratigraphic intervals. Here, we present case studies for the application of this method in various settings, demonstrating the utility of this method. Our primary example is the application of strontium isotope stratigraphy to resolving the age of sequence-stratigraphic and tectonostratigraphic events in the late Pliocene Pukenui Limestone in southeast Wairarapa. This has previously proven notoriously difficult to date due to its shallow marine setting, coarse lithology, and multiple unconformities. 87/86Sr isotope stratigraphy was applied to selected molluscan taxa to reliably date the Pukenui Limestone and adjacent units. Additionally, these data also identify the timing of the first occurrence of the cold-water scallop *Psychrochlamys delicatula* in the Wairarapa. Notably, the first occurrence of this scallop and the basal Nukumaruan Stage boundary were assumed to be coeval, however 87/86Sr isotope stratigraphy, detailed age models, and comparison with the Old West Road Nukumaruan (2.40–1.63 Ma) type section in the Whanganui Basin confirm that these are discrete events, with marine water temperatures, rather than time, being the primary control on the occurrence and timing of *Ps. delicatula* assemblages.

Strontium isotope stratigraphy has also been applied during this study to provide a date for the base Nukumaruan type section of the Hautawa Shellbed, Whanganui Basin. Additionally, this method has been applied to other studies, including providing age control for tectonic uplift histories in the Canterbury Basin, as well as refining age control in detailed annual paleoclimate records derived from individual laminae of Cenozoic molluscs. Jointly, these studies demonstrate the broad versatility of the method, and the abundance of opportunities that are available in the New Zealand geological record.

New Zealand evidence for CO_2-forcing of climatic warming following the end-Cretaceous asteroid impact

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The mass extinction that marks the end of the Cretaceous period was most likely caused by the impact of a giant meteorite in the shallow sea off the coast of Mexico. The primary killing mechanism is thought to have been a prolonged period of global darkness, caused by a global blanket of impact debris shutting out sunlight for several months to years. This shut down photosynthesis, which led to plant extinctions, herbivore extinctions and subsequent carnivore extinctions. Loss of sunlight would have also caused short-lived cooling, for which there is evidence in the geological record and from modelling experiments. Once the dust settled, high levels of atmospheric CO_2, due to the vaporisation of carbonate-rich target rock and the reduced levels of photosynthetic CO_2-drawdown resulting from plant extinctions, are inferred to have caused a period of global warmth, which may have lasted for thousands of years. There is some evidence for a period of warmer climatic conditions in the earliest Paleocene, but the climate proxy records have not been directly linked to CO_2 proxies. We present organic biomarker evidence for a linked increase of sea temperature and atmospheric CO_2 in the earliest Paleocene. Our study is based on the marine Cretaceous/Paleogene (K/Pg) boundary section at Waipara River, north Canterbury, New Zealand. Sampling resolution is too low to record the initial effects of the impact, including the putative initial cooling. Instead, the TEX86 temperature proxy indicates sea surface temperature rose by 3–4°C across the K/Pg boundary. At the same time, we observe a negative shift in both high and low molecular weight n-alkanoic acid $\delta^{13}C$ that we interpret to represent a significant increase in pCO_2. Biostratigraphic constraints indicate that this interval of elevated CO_2 and warm temperatures may have lasted 40,000 years.

Compounding coastal inundation hazards and losses in a changing climate

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Aotearoa New Zealand's insular nature exposes a large part of the population to coastal inundation hazards. While these hazards are often investigated as singular phenomena, they are in fact increasingly coupled as climate change progresses. As such, they present increasing complexity when considering their compounding nature and inter-dependency in a shifting climate. Using Samoa as an analogy, we demonstrate the influence of extreme inundation hazards on coastal assets and how these change under a warming climate, to interpret how such processes relate to the Aotearoa New Zealand context. We draw on models of relative sea-level rise (SLR) coupled with extreme 100-year water levels developed through the Pacific Risk Tool for Resilience Phase-2 (PARTneR-2) project, to quantify the impacts/losses to buildings and how these change over time based on future climate change projections. Coupled models of relative SLR and a Tohoku-oki type tsunami developed by Welsh et al. (2023) are also used to show how tsunami hazard exposure changes over time. We show that the increase in hazard exposure and expected losses to buildings from extreme storm and tsunami inundation over time are largely driven by rising sea-level. We discuss the implications of these observations and highlight gaps and challenges in interpreting/applying the findings in other contexts such as Aotearoa New Zealand in informing decision-making on coastal resilience and adaptation.

Reference:

Welsh, R., Williams, S., Bosserelle, C., Paulik, R., Chan Ting, J., Wild, A., Talia, L. (2023). Sea-Level Rise Effects on Changing Hazard Exposure to Far-Field Tsunamis in a Volcanic Pacific Island. Journal of Marine Science and Engineering 11(5): 945, doi: 10.3390/jmse11050945.

Conduit structure revealed by lithic clast variation at Taranaki Mounga

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The physical properties of volcanic conduits are an important control on eruption dynamics, modulating outgassing of ascending magma, jet velocity and plume buoyancy. Outgassing through permeable conduit walls reduces jet exit velocity. Highlighting variation in the physical properties of the conduit wall allows potential regions of low conduit permeability to be identified, which could refine future eruption scenarios. Lithic clasts, conduit wall pieces ejected during explosive activity, allow a conduit's structure, physical properties and processes to be investigated.

Here we distinguish different end-member lithic clast types ejected during the 1655 AD Burrell eruption, the most recent explosive eruption of Taranaki Mounga, Aotearoa New Zealand. We measure the porosity and permeability of cores extracted from bombs or blocks and analyse textures and composition under optical and scanning electron microscopes (SEM).

We show different types of lithic clast can be identified with differing physical properties (porosity, permeability, texture) and composition. Clasts can be grouped into: (i) edifice-building lavas that are either clean or show histories of brecciation, re-welding and alteration; (ii) dome/shallow plug material lacking intense alteration or evidence of brecciation/welding; (iii) re-sintered conduit lining from above the fragmentation depth that contains distinct glassy lenses, fragmented phenocrysts and a varying clast load.

Classifying lithic clast types allows us to piece together the shallow conduit structure. Pre-eruption, fresh and re-worked edifice lavas sit below and around dome/plug material, all widely varying in permeability. Syn-eruption, the development and removal of a low-permeability juvenile conduit lining above the fragmentation depth may drive changes in eruption style. These results, combined with ongoing research into the timing of incorporation of different lithic clasts, may help forecast changes in eruption style for Taranaki Mounga. The conduit processes identified are also inferred to be representative of andesitic stratovolcanoes globally, giving relevance beyond Aotearoa New Zealand.

A synthetic earthquake catalogue based on the Aotearoa-NZ Community Fault Model

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A synthetic earthquake catalogue is a population of thousands or millions of hypothetical (but realistic) earthquake slip distributions, created using a physics-based earthquake simulator. These catalogues have similar statistical characteristics to real-world earthquake populations, and consequently have many potential uses in earthquake science, especially seismic and tsunami hazard and risk analyses. Scenarios generated based on synthetic earthquakes can also be used for emergency response stress testing and in future it may be possible to use synthetic catalogues to develop cascading and multi-hazard probabilistic risk models.

Here, we present a synthetic earthquake catalogue created using the earthquake simulator RSQSim and realistic input fault geometries from the Aotearoa-NZ Community Fault Model within the RNC national science challenges. We illustrate how the implementation of more realistic fault geometries improves our synthetic catalogue relative to previous catalogues. We also identify areas for further improvement, including the introduction of fault roughness and potentially better approximations to real-world earthquake cycle physics. Finally, we discuss remaining barriers to the use of synthetic earthquake catalogues in seismic, tsunami and other hazard models.

Taupō Volcano 2022-23 inflation and unrest

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Taupō Volcano, located in the North Island of New Zealand, is one of the most productive rhyolitic centres in the world. It lies within the Taupō Volcanic Zone (TVZ), an active continental rift resulting from the oblique subduction of the Pacific Plate beneath the Australian plate along the Hikurangi Trench. Taupō volcano last erupted around 232 AD ejecting 35 km^3 DRE in a caldera forming event.

GNSS and InSAR measurements around Taupō volcano are limited by the presence of Lake Taupō. Since 1990 GNSS (GPS) campaign measurements have been conducted every few years around the lake. The first continuous GNSS station was installed by GeoNet in 2002, with 10 stations currently in operation for volcano monitoring.

In May 2022 seismic activity started increasing below Lake Taupō. The seismicity was caused by inflation detected at GNSS stations around the lake, with rapid uplift of > 50 mm/yr observed at a GNSS station at Horomatangi Reef (TGHO). The largest earthquake associated with the unrest took place beneath Lake Taupō on 30 November, resulting in a large coseismic uplift (18 cm) at TGHO as well as 25 cm horizontal movement away from the centre of the caldera. The inflation continued until April 2023, with seismicity gradually decreasing to background levels. Modelling of the GNSS data suggests that the source of the inflation was located at 4-8 km depth in the centre of the caldera, similar location to the 2019 unrest inflation source but at double the volume rate increase.

Insights into ascent conditions preserved in quenched pyroclasts from the 2021-2022 eruption of Hunga volcano, Tonga

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The 2021-2022 volcanic eruption of Hunga volcano (Tonga) consisted of submarine breaching explosions, ranging from typical Surtseyan activity to a climactic explosive phase associated with caldera collapse on 15 January 2022. The latter produced extreme explosions, destructive tsunamis, and the highest plume (58 km) ever recorded by satellites. Pyroclasts collected from subaerial deposits on Tongatapu and dredged from the caldera rim provide textural evidence of magma-water interaction throughout all eruption phases, which amplified during the eruption climax to fuel the high explosivity. This study focuses on syn-eruptive history preserved by samples spanning stratigraphic units: (i) lapilli and bombs from pre-climactic float pumice rafts; (ii) the first lapilli fall from the climactic event; and (iii) subsequent waning activity. We quantified vesicle size distributions and crystallinity using 2D textural analysis of back-scattered electron images. We also performed differential scanning calorimetry to determine cooling rates, and evolved gas analysis to quantify the magmatic volatile content of H_2O, CO_2, HCl and SO_2. Lapilli form three main classes: (i) massive glass, (ii) dark pumice and (iii) light pumice. Textural and thermal analysis reveal that the change from massive glass to light pumice is associated with an increase in vesicularity, a decrease in water content and a decrease in cooling rate. We interpret massive glass textures to reflect rapid quenching – precluding post-eruptive vesiculation and crystallization, therefore better representing pre- and syn-eruptive conditions. Preliminary results also show an increase in microlite content and the number density of micron-scale vesicles associated with the climactic event onset. This suggests that an increasing decompression rate was experienced by the ascending magma as caldera ring faults were activated within the overlying edifice. We integrate pyroclast textures and physico-chemical properties into assessment of rheological properties and magma ascent conditions, as important context for the ongoing multidisciplinary study of this enigmatic eruption.

VolFe: a thermodynamic framework to calculate equilibrium vapor-melt composition

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VolFe is a thermodynamic framework to calculate the equilibrium concentration, speciation, and isotope ratio of volatile elements (carbon, hydrogen, sulfur, noble gases) between vapor and melt. The framework considers O_2, H_2, CO, S_2, H_2O, CO_2, SO_2, CH_4, OCS, H_2S, and X (where X is a noble gas) in the vapor; H_2OT (OH^- + H_2O mol), CO_2,T (CO_3^{2-} + CO_2 mol), H_2, CO, CH_4, S^{2-}, SO_4^{2-}, H_2S, and X in the melt; and states when sulfide, anhydrite, and/or graphite saturation have been reached. This range in melt and vapor species means that both oxidised and reduced systems, as well as melt compositions ranging from basalts through rhyolites, can be modelled. The aim is for the framework to be flexible and adaptable such that new calculation types can be introduced as wanted and parameterisations for variables such as solubility constants, fugacity coefficients, and equilibrium constants can be added as new experimental data becomes available. Examples of the calculations that VolFe can do currently are: pressure of vapor-saturation given a melt composition and temperature; closed- or open-system degassing given an initial bulk composition of the melt and temperature; bounds of oxygen fugacity given a melt composition (specifically sulfur content) and temperature. VolFe is written in python and run through a Jupyter notebook.

Lake tsunami hazards and lacustrine mass wasting in high seismicity regions of New Zealand's South Island

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Lake tsunamis generated from terrestrial and subaqueous landslides pose a significant hazard to lakeshores globally. Despite the suggested susceptibility of South Island lakes to co-seismic landslide-generated tsunami, past records of their occurrence and future susceptibility to this hazard remain unquantified. As new research indicates there is a 75% probability of an Alpine Fault earthquake within the next 50 years, it is critical to develop a data-driven understanding of lake tsunami hazard in New Zealand.

Here, we present the findings from high-resolution bathymetric and seismic reflection surveys conducted in 2022 on four lakes in high seismicity regions of the South Island of New Zealand. These data provide a novel process-based understanding of lacustrine mass-wasting and tsunami hazard from evidence preserved on the lake floor. An inventory of mass-wasting deposits and their characteristics was compiled using the 1 m resolution multibeam bathymetry and CHIRP-derived stratigraphic sequences. Results indicate subaqueous mass-wasting is ubiquitous across this region, with deposits covering 35 km^2 of the surveyed lakebeds. 16 mass-wasting deposits over 100,000 m^3 were identified from a diverse range of subaerial and subaqueous sources. Six of the previously unmapped landslide deposits were determined to have been potentially tsunamigenic. Our ongoing work utilizes physics-based modelling to robustly reconstruct tsunami generation, propagation, and inundation for the events identified. Extensive sediment coring conducted in 2022/2023 will enable high-resolution event chronology to be produced, allowing direct links between the tsunamigenic mass-wasting and seismic triggering to be established. This research marks a novel development in the quantitative analysis of lacustrine tsunami hazard in New Zealand.

From coast to inundation: a new method of analysing tsunami hazard using physics-based synthetic earthquake catalogues

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Large earthquakes and tsunamis pose a significant risk to New Zealand, yet we do not know what the next big event is going to look like. Physics-based synthetic earthquake catalogues are a new tool allowing us to better investigate what New Zealand's next big natural disaster may be. Earthquake simulators, like RSQSim (Rate and State Earthquake Simulator), generate a vast range of earthquake scenarios over hundred-thousand-year time scales, while preserving the stress and strain relationships of both the whole fault system, and the interactions between faults. From these earthquake sources, we model the resulting tsunamis, allowing us to investigate both crustal faults and subduction zones. This allows us to investigate which regions are likely to be impacted by the largest tsunami waves, and which earthquake sources pose the greatest risk to different regions. Uncertainties in the earthquake properties specified in the simulator may also significantly affect the calculated tsunami hazard. Using a set of earthquake catalogues, that have different subduction zone configurations/properties and differing fault systems, we have generated a series of databases which contain tsunami simulations to New Zealand's coast. For each of these databases, we conducted a Probabilistic Tsunami Hazard Assessment at the coast for all New Zealand. From these results, we selected Te Matau-a-Māui/Hawke's Bay and Te Whanganui-a-Tara/Wellington and undertook tsunami inundation modelling for the 100 events that generated the largest wave heights to the coast, in each of the earthquake catalogues. Preliminary results show that the different earthquake catalogues produce similar tsunami hazard results at the coast. However, significant differences between the tsunami inundations are observed. Investigations into the differences show that, where the earthquake surface deformation is concentrated, the style of deformation (uplift/subsidence) at the coast, and the area of earthquake rupture, all significantly impact both the area of inundation and the onshore flow depth.

Understanding multi-fault ruptures and earthquake clustering in central New Zealand using paleoearthquake records and earthquake simulators

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Forecasting the probability and magnitude of future large magnitude earthquakes is typically dependent on paleoearthquake information. These paleo-records are often incomplete and the timing of earthquakes are imprecisely dated, which impacts our ability to estimate their slip and recurrence intervals.

Historical records since 1840 AD demonstrate that many large earthquakes (e.g., >Mw 7.0) rupture multiple faults with complex rupture patterns and/or trigger additional events. To improve understanding of the importance of temporally clustered events, we compare the timing of earthquakes between active faults in central New Zealand using natural and synthetic earthquakes. To support this comparison, we have revised paleoseismic records for key faults to determine the frequency of spatial-temporal clustered earthquakes. These short geological records (e.g., < 15 kyr) are compared to synthetic earthquake catalogues produced by physics-based RSQSim simulations for timescales of ~300 kyr.

The paleo-record suggests paleoearthquakes on different faults often have approximately the same age, suggesting spatio-temporal interactions between faults. Due to uncertainties in the radiocarbon dating, the observed clustering could arise due to multi-fault ruptures and/or triggered slip associated with earthquake clusters. Both scenarios are represented in the RSQSim catalogues, with co-rupture of the subduction thrust and upper plate faults being common. Multi-fault and triggered earthquakes both suggest stress interactions between faults on timescales of seconds to hundreds of years and temporally variable seismic hazards. These fault interactions have important implications for seismic hazard in central New Zealand and will be explored further using RSQSim models.

Stress relaxation around the fault edges before the mainshock of intraplate earthquakes

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After a large earthquake, many small earthquakes, called aftershocks, occur. However, additional large earthquakes typically do not occur, despite the fact that the large stress concentration near the edges of the fault is expected to trigger further large earthquakes. Here we analysed ~10,000 highly accurate focal mechanisms of aftershocks of the 2016 M_w 6.2 Central Tottori earthquake in Japan, which is a vertical strike-slip event. We determined the location of the horizontal edges of the mainshock fault relative to the aftershock hypocentres, with an accuracy of approximately 200 m. We found that aftershocks rarely occurred near the horizontal edges and extensions of the fault. Furthermore, we estimated the stress field before the mainshock from the focal mechanisms and found that the differential stress before the earthquake was very small near both horizontal edges. It is inferred from these results that the stress relaxation occurred around the fault edges before the mainshock. It is thought that the mainshock rupture was arrested within areas of the stress relaxation and that these stress relaxations explain why mainshocks are rarely followed by further large earthquakes.

Future DEEP: Future Drilling to Explore Earth's Past Workshop report

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The importance of the Southern Ocean in the narratives of the nature and history of ocean dynamics, climate variability, geohazards and sub-seafloor microbiology, is well established, but regional questions are understudied. To address this deficiency, the international scientific drilling communities (IODP: International Ocean Discovery Program and ICDP: International Continental Scientific Drilling Program) need a deeper understanding of the environmental and geological processes that affect our planet, which requires access to samples of sediments, rocks, fluids, and microbes from deep below the subsurface.

The Future DEEP Workshop was held on 3 and 4 April 2023 in Hobart, Australia, and was hosted by the Australian and New Zealand IODP Consortium (ANZIC). It provided an important channel for the development of the next generation of innovative drilling ideas and proposals covering diverse scientific topics for submission to scientific ocean drilling programs (for post-IODP drilling) and ICDP. The focus was heavily on the Southern Ocean, but also touched on key aspects of offshore drilling around Australia and New Zealand.

This presentation will delve into the key scientific ocean drilling discussions surrounding the ideas that came out of this workshop. Our goal is to share this information to create new opportunities and increase international collaborations for scientific drilling in this critical region.

New insights into the Cretaceous belemnites of New Zealand: the best 2023 stories, revealed from the study of GNS collections

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GNS Science is the custodian of New Zealand's National Paleontological Collection (NPC), which comprises about 130,000 registered collection lots from New Zealand and adjacent areas, with specimen numbers across these in the millions. All the finds are registered within the NPC online catalogue and the Fossil Record Electronic Database, which are valuable sources for quantitative paleontological research. However, many belemnite specimens were initially identified by non-specialists, and thus the nature of some atypical finds has been poorly understood or misinterpreted.

It is generally considered that during mid-Late Cretaceous time, belemnites in New Zealand were represented by a single lineage of the family Dimitobelidae, which first appeared in the region in the ?Urutawan (more confidently, Motuan) and, like other belemnites, did not cross the K/Pg boundary. Most species, besides the oldest finds, are clear NZ endemics, restricted in distribution by the shelf environments of Zealandia. The examination of GNS collections revealed a more complex history of the Cretaceous belemnite biota of New Zealand than was previously assumed.

Here we report three new determinations – a single find of *Peratobelus* from Red Island in southern Hawkes Bay (?Korangan); a pair of phragmocones from the Haumurian of the Auckland area belonging to non-belemnite coleoids; and rostra of the Haumurian age of atypical morphology, not compatible with the only nominal dimitobelid species in these strata, *Dimitobelus (Dimitocamax) hectori*. Some of these finds add data for age determination and correlation of problematic rock formations, while others extend the knowledge of the NZ fossil biodiversity and indicate possible immigration events. In particular, some Haumurian rostra are likely to represent the post-Cenomanian relicts of the family Belemnopseidae, while similar fossils were recorded from the Santonian?-Maastrichtian strata of the Magellan Rise in the central Pacific.

Geological controls on the mass balance of the 2016 Kaikōura earthquake

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In landscape evolution studies, there is the question of how large earthquakes drive topographic growth. How much does erosion from co-seismic landsliding counterbalance uplift by reducing relief? Does the interaction between fault rupture and landslide denudation drive topographically focused erosion? The mass balance of an individual earthquake event can be calculated from the difference in volume between the change in elevation above a reference plane (e.g., sea level) due to co-seismic surface deformation (uplift) and the volume of material eroded by co-seismic landsliding. The sum of these two opposing effects is often quantified as the net volumetric change. Several recent estimates from global earthquakes have found the net uplifted volume to be significantly greater than the co-seismic landslide volume. However, these studies rarely have accurate estimates of the volume of co-seismic landsliding and the timescale to remove this sediment from the landscape.

The ability to remove co-seismically generated sediment from the landscape within a seismic cycle is likely to be a function of: (i) the efficiency of sediment transport and export across the landscape and (ii) the recurrence interval of large mass wasting earthquakes. Following the 2016 M_W 7.8 Kaikōura earthquake, steep sided, highly connected greywacke catchments in the Seaward Kaikōura Range (within the Marlborough Fault System) exhibited rapid rates of sediment remobilisation and fluvial transport. Whereas in catchments dominated by large bedrock landslides within Neogene materials to the south of Kaikōura (within the North Canterbury Tectonic Domain), the evacuation of sediment within large bedrock landslides was considerably lower. From these observations, a conceptual model of how earthquake induced landscape dynamics vary throughout the evolution of a mountain belt is presented.

Towards understanding ambient seismic noise on the Alpine Fault region to estimate ground shaking for a future Alpine Fault earthquake

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The Alpine Fault is the primary source of seismic hazard in Southern New Zealand. It regularly experiences M7-8 earthquakes with a ~249-year recurrence interval and last ruptured in 1717 AD. Because the Alpine Fault has not ruptured in recorded history, no empirical information constraining Alpine Fault induced ground shaking exists. An imminent challenge is to compute realistic ground motions generated by the many plausible rupture scenarios from the still-unseen major Alpine Fault earthquake.

Analysis of ambient seismic noise recorded at multiple stations concurrently allows us to study wave propagation between those stations without the need of an earthquake or explosion. It has been demonstrated experimentally and theoretically that Ambient seismic noise provides a way to constrain realistic Green's functions. These Green's functions can then be used to accurately estimate ground shaking using the "virtual earthquake" method. In contrast to full 3D wavefield simulations, these ground shaking estimates are empirically determined and are computationally inexpensive to run. However, they are only possible for locations with a recording seismometer. Using these computationally inexpensive methods, we will simulate shaking for many Alpine Fault rupture scenarios at key locations of interest.

A necessary prerequisite for robustly simulating forthcoming Alpine Fault earthquakes using the "virtual earthquake" method is a good understanding of the ambient seismic noise field. We perform a noise analysis across the South Island of New Zealand using multiple techniques to characterise the ambient noise field. This analysis utilises records from permanent and temporary networks, including SALSA (Southern Alps Long Skinny Array), a new temporary network of broadband seismometers deployed every ~10 km between Milford Sound and Maruia along the Alpine Fault trace.

Testing pathways for rapid generation of earthquake source - shaking - landslide forecast maps for post-event response to large earthquakes (M7+) in New Zealand

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The R-CET Endeavour programme has been developing a new suite of tools to characterize the earthquake source and its shaking in near real-time. A key goal is to provide pathways to improve rapid earthquake impact forecasts.

Small-to-moderate earthquakes can be reasonably represented by a ‘point source’, i.e., the hypocentre, or point within the earth where the earthquake began. This allows first shaking maps (i.e., GNS Shaking Layers generated with ShakeMapNZ, Horspool et al. (2023)) to be generated automatically and robustly based on earthquake solutions from GeoNet.

For very large earthquakes (M7+), a ‘point-source’ is a poor representation of the earthquake, which can rupture tens to hundreds of kilometres of the earth. First shaking models based on ‘point sources’ could severely underestimate shaking in areas further from the epicentre, but close to the fault rupture. Rapid 3D characterization of the rupture area, even if approximate, has the potential to significantly improve shaking estimates, and allow meaningful first impact forecasts to be generated.

Rapid source characterization tools for New Zealand being developed and tested under the R-CET programme include FinDer (Andrews et al. 2022, 2023), w-phase (Fry et al. 2022), aftershock-based fault plane estimates based on EQCorrScan (Warren-Smith & Chamberlain 2022), G-FAST (D’Anastasio et al. 2023), energy backprojection (Aden et al.) and others. Here, we present an overview of these (and other) tool outputs for large historical earthquake scenarios in New Zealand, as well as early examination of their potential to improve ShakeMapNZ shaking models (Horspool et al. 2023) and PGA-based landslide forecasts (developed under the EILD programme, Massey et al. (2021)).

Episodic coastal uplift at Matatā: constraints from geology, geomorphology, and geodesy.

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Characterising the interplay between tectonic, magmatic, and volcanic processes in continental arc settings is a difficult, yet important issue in geoscience. Magmatic and tectonic processes can operate on long time scales (10^3-10^5 years), and extrapolating observations made on human timescales (10^1-10^2 years) across geological time is not always straightforward. In this work, we present a synthesis of vertical land motion (VLM) across a range of timescales at the western margin of the Whakatāne Graben, including new Sentinel-1 InSAR and GNSS data between 2015-2021. Other previously published sources of VLM data include Envisat InSAR and GNSS data between 2004-2011, levelling surveys between 1950-1978, uplifted Holocene beach ridges (age of 1.72 ka), and the deformed Matahina Ignimbrite (age of 0.28 Ma). Together, these data provide a unique insigt into VLM through time and space, and show changes in VLM rate from 1 mm/y to 10 mm/y. To explain the observed VLM over the last 2000 years requires brief (~5 years) pulses of rapid uplift (~10 mm/y), separated by decades of low – moderate rates of VLM (1-2 mm/y). This could suggest episodic emplacement of magma beneath the Matatā. The large displacement gradient across the western shoulder of the graben appears to be responsible for the high slip rate on the Matatā Fault (4 mm/y), short recurrence time for surface rupturing earthquakes (~500 years) and large vertical separation (~7 m) across the fault trace in the last 1700 years. If such a relationship exists, the timing of moderate-large earthquakes on the shoulder of the Whakatāne graben could be expected to coincide with an episode of rapid uplift associated with magmatic inflation in the crust beneath Matatā.

Updating our marine biodiversity inventory

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Twenty-three years have passed since the inception of the three volumes of the New Zealand Inventory of Biodiversity (Gordon 2009, 2010, 2012). This monumental project defined all of Aotearoa New Zealand's marine, freshwater and terrestrial biodiversity. In a world of changing climate and threats to ecosystems, these snapshots of our biota are vital markers of our biodiversity, identifying our ancestral biota, and tracking the health of our current natives and the progression of invasive species.

The Marine Biota of Aotearoa New Zealand is a national and international collaborative project updating the inventories done two decades ago, focusing on extant and fossil marine organisms. The project began in 2020 with the collation of taxonomic data from collection repositories and databases, as well as extensive literature reviews, and will be published at the end of 2023 as a NIWA Biodiversity Memoir. Here, we present an overview of this work, with special emphasis on updates and key challenges for paleobiota groups.

Fossils provide important baselines for past biodiversity, evolution, and extinctions. They can be used to ground-truth climate change models by adding real-life data points of how species behaved under differing climatic and environmental conditions. Additionally, from a national identity perspective, fossils are an integral part of our bioheritage. Having a clear understanding of our fossil record thus has important implications for research into our past, present, and future.

A key challenge identified for most groups covered in the Marine Biota of Aotearoa New Zealand memoir is the lack of national taxonomic expertise. For many fossil (and extant) groups, what little current research is being undertaken, is led by retired emeritus scientists, staff working on taxonomy part-time, or overseas researchers incorporating New Zealand flora or fauna as part of global studies. This is a risk our country urgently needs to address.

Volcanofest and events that bring schools, teachers, and the public into scientific conferences.

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In January 2023, international volcanology researchers descended on Rotorua (Aotearoa New Zealand) for the scientific assembly of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI). A unique aspect of this conference was Volcanofest. The idea for the Volcanofest space was to create an alternative to the academic information overload that usually dominates science conferences. The social, artistic, and science communication spaces were also ideal to involve the local teacher schools and the community.

The first day of Volcanofest was centred on the scientists exploring and sharing science communication and outreach best practices with one another. The second day focused on North Island teachers, and the third day was open to the public and media. A team of volunteers set up three indoor basketball courts full of volcano art, photography, music, demonstrations, games, rocks, films, citizen science opportunities, virtual reality experiences, storytelling, scheduled meet-a-scientist panels, and erupting volcano displays from all around the world.

The content of Volcanofest was created by scientists volunteering their favourite ideas and outreach contributions via an online form. We provided space, tables and chairs, electricity, screens, and internet for delegates to set up their activity. In addition, presenters were asked to contribute to an activities handbook containing the demonstration's title, summary, learning goals, target audience(s), materials list, and instructions) that was shared electronically via QR code during the event. The meet-a-volcanologist sessions brought together local and international volcanologists with an emphasis on diversity. They began with panel introductions and discussions, then the experts dispersed for one-on-one chats with the attendees, providing a relaxed environment and removing barriers between scientists and the public. Volcano documentaries were shown with opportunities for questions and debate with the scientists involved. There were even scheduled opportunities for indoor soccer and basketball games amongst the scientists.

Determining volcanic rock porosity through reflectance spectroscopy

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Volcanoes are dynamic and complex natural systems, constantly changing through eruptions, alteration, and erosion. They exist as three phase systems, with solids (rock), liquids (circulating fluids), and gases (steam) interact to produce variable physical and chemical interactions. This causes the physical and mechanical properties to be highly heterogenous. Porosity is one of the most commonly measured physical properties as it provides details on the rocks history and is a first order control on rock strength. Porosity is affected by the original formation conditions (volatile content, crystallinity, cooling rate) and the post-depositional environmental conditions (weathering and hydrothermal alteration). Currently, porosity measurements are completed using a pycnometer and is often destructive, either through crushing to calculate sample volume or drilling a specific sample size. A non-destructive approach would expand the porosity measurement resolution, as each sample could be measured in multiple locations, and provide the ability to measure samples in the field, especially important at sites where collecting samples is prohibited. Reflectance spectroscopy is sensitive to both physical (surface roughness and crystal/particle size) and chemical (mineral species and abundance) properties of volcanic rocks, and therefore could be used to predict the rocks porosity. This study uses visible-near infrared (VNIR; 350-1000 nm) to shortwave infrared (SWIR; 1000-2500 nm) reflectance data as the input for a Partial Least Squares Regression (PLSR) model to predict porosity. Using training data from a range of volcanoes with varying compositions (basaltic to rhyolitic), porosity (0.02-0.61) and alterations (argillic to fresh). New unseen samples from Ruapehu and Tongariro are tested to assess model accuracy via independent validation (porosity%) and cross-validation. VNIR-SWIR reflectance spectroscopy can elaborate on both porosity and uniaxial compressive strength due to the underlying mineralogy of the training data (e.g., sulfates and phyllosilicates), which can provide a new alternative for non-destructive methods in volcanic systems.

Accelerating tsunami simulation for real time probabilistic impact forecasting

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This work presents Widewave and wComcot. Widewave is an open-source shallow water simulation library and wComcot is the COMCOT algorithm implemented using Widewave and designed for response. wComcot achieves up to 1000x performance improvements over the standard implementation while maintaining excellent agreement. This performance increase enables real-time probabilistic tsunami impact forecasting.

The key to such performance improvements is scaling the computation to modern hardware accelerators. Widewave allows easy composition of custom simulation loops and distributes the computation to any XLA compatible platform (single CPU, accelerator cluster, custom ASIC, etc).

Despite wComcot's agreement with the standard implementation, we further benchmark wComcot's accuracy against a selection of standard tsunami benchmarks including analytic runup on a simple beach, a conical island wave tank experiment, and a Monai Valley wave tank experiment. We also evaluate wComcot's performance on scenarios representative of future response forecasting.

How machine learning enhances our understanding of past Antarctic climate variations through GDGT proxies.

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Investigating Antarctic climate during past warm periods with higher atmospheric CO_2 is critical to understanding how the Antarctic Ice Sheets may respond to future climate change.
Traditional climate proxies, like the TEX86 index, have played a crucial role in reconstructing past temperatures from sedimentary records based on glycerol diaklyl glycerol tetraethers (GDGTs). However, these methods are inherently limited by their reliance on fixed calibration functions and assumptions about the relationship between GDGT composition and temperature. In this study, we use Bayesian Inference, particularly Markov Chain Monte Carlo (MCMC), as a novel approach for modelling the data generating process of GDGT compounds.

Challenges associated with traditional methods stem from their inability to adapt to the complex and non-linear nature of GDGT-temperature relationships. Such relationships can vary over time and across different environmental conditions, rendering fixed transfer functions less accurate. Bayesian Inference, on the other hand, offers a flexible framework that can incorporate uncertainty in parameter estimation, accounting for the inherent variability in GDGT proxies and their response to temperature changes.

In this study, we highlight the potential of Bayesian Inference, through MCMC, to not only enhance the accuracy of GDGT-based paleoclimate reconstructions but also provide a robust framework for quantifying uncertainty and accounting for the dynamic nature of GDGT-temperature relationships. With this approach, we aim to unlock new insights into past climates, especially in challenging regions such as Antarctica and the Southern Ocean.

Sedimentary dynamics in the Hokianga Harbour tidal estuary

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New Zealand's estuarine ecosystems are important fish and shellfish habitats and hence are of significant economic, cultural and recreational value. However, estuarine habitats are under multifaceted pressure from anthropogenic and climatic change. Whilst community groups are rapidly moving ahead with restoration programmes, the sedimentary processes that drive habitat changes are often poorly documented. Hokianga Harbour, like many Northland estuaries, has been significantly impacted by land use and environmental changes leading to accelerated sedimentation and siltation. However, resulting morphodynamic responses are poorly documented. As part of on-going research with Te Rarawa iwi, we combine analysis of sediment composition and bedforms with modelled hydrodynamics and sediment transport to better understand existing sedimentation patterns and how they may respond to change. The lower estuary is dominated by a sandy substratum and sub-tidal dune fields with dominant dune heights of up to 1–2 m. From 10 km inland of the harbour entrance, dune fields become more isolated, are characterised by smaller heights, and intersect with longitudinal bedforms, whilst overall sediment composition changes to being silt and mud dominated. Predicted flow velocities are highest near the entrance with higher velocities during ebb than flood flows. Flow velocities decrease inland, reaching a minimum 12–13 km from the entrance. This point of minimum velocity is unusual as it occurs a significant distance seaward of the tidal maximum. Interestingly, seaward of this minimum, flood-current velocities during neap tides are predicted to be slightly higher than ebb-current velocities, whereas they are relatively balanced during spring tides. This hydrodynamic pattern may explain why fine-grained sediments that are transported as suspended load are largely retained in the middle and upper part of the harbour, leading to siltation of shallow water environments, whilst sand is predominantly transported in the lower reaches of the harbour and exported at the estuary entrance.

A review of occurrence, fate, and environmental pathways of erionite in soil

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Erionite is a zeolite mineral that can occur as fibrous particles in soil and inhalation exposure to erionite fibers may result in an increased risk of diseases such as mesothelioma. Numerous studies have reported erionite, but research on the occurrence of erionite in soils is sparse. In particular little is known about the processes of how erionite is transported and retained in soils, and how it may lead to human exposure when soil is disturbed during activities such as mining, recreation or transportation. A global literature search only identified nine papers related to erionite in soils. The analytical techniques used to detect and quantify erionite in nine published articles on soils were generally inconsistent, with 12% of the authors using XRPD, 15% using SEM, 17% using TEM, 15% using PCM, 12% using PLM, 7% using XRF, 10% using EDX while only 12% used Fluidised Bed Asbestos Segregator (FBAS) to separate mineral fibers from soils. This review suggests that more research is needed to develop and validate a robust approach to analyse erionite mineral fibres within soils.

Using deep learning algorithms to create a microseismicity catalogue of the Pōrangahau region to understand SSE episodicity

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Slow slip events (SSEs) occur every ~5 years in the Pōrangahau region on the Central Hikurangi Margin. However, the permanent seismic instrumentation in the region is insufficient to accurately locate earthquakes, especially to resolve depths of events on the shallow interface. The PULSE (Physical processes UnderLying Slow Earthquakes) Network was a dense amphibious temporary network active during the shallow 2021 Pōrangahau and deeper 2022-2023 Manawatu SSEs. Using PULSE data, we employ the deep learning detector EQTransformer (Mousavi et al., 2020) to pick phase arrivals and the phase associator GaMMA (Gaussian Mixture Model Associator) (Zhu et al., 2022) to link these picks into discrete events. The density of our network facilitates a microseismicity catalogue complete to a lower magnitude than previously available, as well as allowing for greater location and depth accuracies of seismicity. This work has allowed us to quantify how seismicity evolves spatially and temporally in relation to both shallow and deep Hikurangi SSEs. This work is important in understanding the physical driving mechanisms behind SSEs and their relationship with seismicity. Here we present the preliminary catalogue and results from our PULSE network alongside some of our findings from the testing of EQTransformer and GaMMA. We also discuss our work in the context of proposed physical processes underlying slow earthquake episodicity and variations in slip behaviour along the Hikurangi Margin.

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Improving earthquake magnitude and location estimations for Tsunami Early Warning in New Zealand

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As a part of the Rapid Characterization of Earthquakes and Tsunami (RCET) project, we aim to improve rapid analysis of large local and regional earthquakes by refining automated moment tensor inversions. From a tsunami early warning perspective, it is paramount to have a simple but rapid estimation of location and magnitude of earthquakes. A method to estimate these parameters is the W-phase inversion. Unlike simpler automated magnitude determinations routinely used to analyze earthquakes in NZ, the W phase does not saturate with magnitude, making it better at quantifying M_w for the largest earthquakes. It also provides the centroid, rather than the hypocentre of an earthquake, allowing better estimation of the spatial distribution of shaking impacts. For these reasons we are developing synthetic earthquake waveforms to refine W-phase inversions for ~M_w5+ earthquakes in New Zealand and M_w6.5+ earthquakes in the southwest Pacific, including the Hikurangi-Kermadec subduction zone. The current tsunami early warning procedure is calculating W-phase solutions within 20 minutes of earthquake origins and we are aiming to reduce it down to 5-10 minutes.

To improve W-phase solutions for NZ, we are simulating earthquake waveforms using a catalog of synthetic ruptures on the Hikurangi-Kermadec subduction zone, produced by RSQSim (Rate and State Earthquake Simulator) under the RNC2 project. To generate the waveforms, we use SPECFEM3D Globe, a finite element method-based software that simulates wave propagation through a global velocity model of the Earth. The simulated waveforms are then postprocessed and inverted to obtain a W-phase solution.

With a large set of events adapted to New Zealand and Hikurangi-Kermadec context, we will refine our understanding of the limits regional W-phase inversion. We are focusing on the minimum magnitude we can accurately estimate, the minimal station coverage required and the complexity of the source that can be apprehended by the W-phase.

Organic carbon stocks and vulnerability in marine sediments in New Zealand

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Marine sediments play a vital role in regulating climate change by burying organic carbon (OC) on timescales of thousands to millions of years. Following seafloor disturbance, this vast, largely unquantified amount of OC is at risk of being remineralised into CO_2, thereby offsetting the absorption efficiency of the oceans for taking up atmospheric CO_2. Knowledge of the amount of OC stored in marine sediments provides the basis for evaluating the risk to the marine environment and climate and the need for possible mitigation action.

We have derived the first inventory of marine OC in sediments in the Aotearoa New Zealand Exclusive Economic Zone (EEZ) based on methods developed for the United Kingdom. We focus on the top 10 cm of sediment, where the organic matter is likely to be the most vulnerable to natural or anthropogenic disturbances. From these first-order estimates, marine sedimentary OC stocks in the Aotearoa New Zealand's EEZ are ~2240±290 Mt OC, i.e., ca. 1% of the estimated global stocks. These stocks are distributed unevenly across shallow coastal and continental shelf environments (~7%), continental slope (~26%) and areas deeper than 1500 m (~66%), with fjords alone accounting for 8% of the national stocks.

From this, we have generated the first vulnerability index for OC to bottom trawling at water depths less than 1500 m by combining our results with sediment type lability, particle sinking speeds and OC degradation rates. This emphasizes the potential impact of trawling on vulnerable OC stocks in continental shelf and slope environments, particularly off south Westland, central northern Chatham Rise and along the east coast from Kaikōura to Hawkes Bay.

There is also a need to measure and monitor environments that have not as yet been impacted by human activities, particularly deep-water habitats that remain the greatest repository of OC on Earth.

An assessment of seismic activity during the 2022-2023 unrest episode at Taupō volcano

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Taupō is a large caldera volcano located beneath a lake in the centre of the North Island of New Zealand and most recently erupted ~1800 years ago. The volcano has experienced at least 16 periods of unrest since 1872, many of which were characterised by increased seismic activity. In May 2022 the volcano entered a new period of unrest with increased earthquake activity and ground deformation within the caldera. The unrest was notable for two reasons: (1) the Volcanic Alert Level for Taupō was raised from VAL 0 to VAL 1 for the first time, and (2) a M 5.7 in November 2022 was one of the largest magnitude earthquakes detected beneath the lake for at least 50 years, triggering a small yet complex tsunami within the lake. The unrest episode ended in May 2023 when seismic activity was considered to have returned to background levels.

Over 1780 earthquakes were detected beneath the lake over a period of 13 months, which represents the highest number of earthquakes detected during instrumented unrest episodes at the volcano. Four distinct phases in activity were identified based on weekly earthquake detection rates. Relocated earthquakes indicate seismic activity was focused on the Horomatangi Reefs and around overlapping caldera structures and the Taupō hydrothermal system. Regional moment tensor solutions for the largest earthquakes indicate mostly double-couple normal faulting solutions, except for the main M 5.7 event which included a significant explosive/inflation isotropic component. Based on the locations of the earthquakes, the recorded ground deformation, and comparisons with previous unrest episodes, we suggest the latest seismic unrest was caused by the reactivation of faults due to an intrusion of magma at depth.

Precisely dated very large landslides along the northern alpine fault zone, west coast

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Very large (>106 m3) to giant co-seismically generated landslides pose a serious hazard and risk to people and infrastructure. In the South Island the Alpine Fault forms the plate boundary and is the dominant source of seismic hazard, capable of triggering such landslides. Airborne LiDAR has significantly improved our ability to identify and map these landslides and to inform field data collection. Here we discuss the timing and potential trigger mechanism of four very large, Late Holocene landslides on the West Coast: Timpson's, mid-Blue Grey valley (midBGL) and Christabel (XTL) landslides in the Springs Junction area, and Round Top (RTL) landslide near Hokitika. Timpson's Landslide (3 x 106 m3) emanated from the Alpine Fault rangefront. Radiocarbon dating and OxCal modelling of exhumed trees yields a landslide timing of c. 1400-1450 CE which is coincident with the penultimate rupture of the northern section of the Alpine Fault locally. Logs extracted near the toe of the 45 x 106 m3 RTL were sectioned for precise redating and OxCal analysis yield a landslide timing of c. 890-994-CE which is coincident with the 4th major paleoearthquake rupture on the central section of the Alpine Fault. The 45 x 106 m3 XTL formed in the Blue Grey valley in the hangingwall of the Alpine Fault. Radiocarbon dates from an alluvial exposure upstream of Lake Christabel, and from a core, indicate a Late Holocene age for the XTL. Logs dated from within the midBGL deposit yield a timing of 980-1186 CE. In all cases, due to their timing and proximity to the Alpine Fault we consider that strong ground motions were the trigger for their occurrence. These highlight the significant hazard and risk associated with the next Alpine Fault earthquake which could result in serious impacts to life safety, infrastructure and lifelines on the West Coast.

Insights gained from geomorphological mapping of the Napier-Hastings area

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The GNS Science Urban Geological Mapping Project provides updated geological information in selected urban areas, established and developing, of NZ. Recently published updated geoinformation datasets for the Napier-Hastings area comprise a geological map and 3D geological model. A geomorphological map is currently being compiled that captures the landform features in the area.

The Napier-Hastings landscape is dominated by fluvial and coastal landforms that form the Heretaunga Plains and is flanked by hill country. The geomorphological map was created using lidar data that was captured between 2003 and 2006, and shows the distribution of these river, coastal and hill landforms.

Landforms over most of the Heretaunga Plains are Holocene in age with older, higher Late Pleistocene river terraces bordering the plains in places. The distribution of preserved river channels on the Heretaunga Plains records complex interfingering between the fluvial landforms of the Tukituki, Tutaekuri and Ngaruroro rivers. Ngaruroro River landforms dominate the central part of the Heretaunga Plains and comprise river terraces, channels, overbank levees, delta distributary lobes and interchannel troughs. Cross-cutting relationships between former Ngaruroro River channels combined with information on soil development provides a relative age sequence for formation of the channels. Historical maps and written accounts illustrate the most recent changes to the Ngaruroro and Tutaekuri river courses.

Marine transgression during the early to middle Holocene created embayments, trapping fluvial sediments that have since built up to form the modern surface of the Heretaunga Plains. Major tectonic (e.g., the 1931 Napier earthquake) and sedimentation (e.g., c.1800 yr BP Taupō eruption) events have also influenced the landform character of the area. The mapped distributions of the river, coastal, and hill landforms aid in understanding the broader evolution of the landscape system. Geomorphological information and knowledge of the underlying geology offers insights into the future behaviour of these land-forming systems.

Quantifying geomorphically effective floods with cloud computing and "big" data

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Geomorphologists have debated the relative importance of disturbance magnitude, duration and frequency in shaping landscapes; for channel change during individual floods, it is often thought that the cumulative hydrograph, rather than magnitude or duration, matters most. However, studies of flood-induced channel change often draw upon small datasets. By using satellite data to track channel adjustment, one can query these hypotheses with large datasets, and we do so here by combining 7 years of Sentinel-2 imagery with daily flow data. We apply automated algorithms in Google Earth Engine to map river planforms and detect their lateral shifting, generating a large dataset to quantify channel change after 200 flood events in laterally active rivers. We draw upon this dataset to evaluate how flood hydrograph shape correlates with the geomorphic change observed. We examine the potential of predictive models for geomorphic change during floods and explore some variables that moderate the effect of flood hydrograph shape on geomorphic change.

Reflections on the challenges of mapping >100,000 landslides triggered by Cyclone Gabrielle

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Between 12-16 February 2023, an extreme rainfall event, referred to as Cyclone Gabrielle affected much of the northern North Island of New Zealand, causing widespread damage. It was a severe event that required a national level response. States of emergency were declared for seven regions of New Zealand. Along with surface, coastal, and river flooding, the event triggered more than 100,000 landslides, destroying infrastructure and lives across the North Island. From discussions with stakeholders, it became apparent early on that they wanted to know – with a good level of spatial and positional accuracy – where landslides triggered by Cyclone Gabrielle had occurred, and where future landslides could occur in other rain events, which may pose a risk to life and/or lifeline infrastructure.

With guidance from central and local government agencies, scientists and engineers at GNS Science, Manaaki Whenua, University of Canterbury, and the University of Auckland developed a systematic workflow and methodology to map the landslides using available pre- and post-event aerial photography and satellite imagery covering the affected regions. The approach aimed to achieve rapid systematic collection of landslide data along with regular dissemination to end-users, prioritising the mapping in urban or highly impacted areas first.

This presentation provides a description and explanation of the workflow and methodology, the data used and the outputs. Landslides were mapped using orientated poly lines, where the first point of the line represents the centroid of the source area, and the polyline represents the centreline of the debris trail. A series of landslide attributes were collected that provided additional information on landslide movement types, size, mapping certainty, and quality control metadata. This rich dataset is now being used to develop landslide susceptibility, runout and risk models, which underpin the post-event recovery decision making.

Evolution of the tsunami risk management and warning end-end system over 18 years: a myriad of research, guidelines, standards, tools and remaining gaps

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Tsunami risk management in Aotearoa is built on a foundation of PTWC partnership following the 1960 Chilean tsunami, and earlier events over a wide range of scales. The current framework has been prompted by four major tsunami wake-up calls at 5-7 year fortuitous intervals since 2004. Roughly 14 key evidence and tool domains have been developed covering an end-end chain across modelling, mapping, design, awareness, communication, detection, forecasting, public alerting, signage, ports, engineering loading, etc. However, they have been developed out of sequence in response to opportunities often linked to those wake-up calls.

The tsunami research and mitigation community is now focused on revisions, integration and addressing substantial remaining gaps in key performance indicators, both in scientific creation of next-generation advice and public action on current advice. Key gaps include persistently low surveyed public evacuation rates and speed, and evacuation by car. There is also a lack of vertical evacuation buildings, with only one structure built for this purpose to date. Our ports and maritime infrastructure also remain underprepared for a major tsunami event. Each of evacuation rate and vertical evacuation improvements can save tens of thousands of lives, while tsunami response plans and hazard mitigation for ports could save millions of dollars in damage.

Important advances continue, especially faster detection and evaluation, wave size time-series forecasting, and potential techniques including satellite-based sea-level analysis capable of providing faster, more accurate, and some source-agnostic warnings. There is a strong need for widespread regular evacuation drills with social science-led support, education and evaluation; along with exploring other cognitive-decision focused interventions. Engineering of new evacuation buildings and retrospective analysis of existing buildings and port structures is critical. Closer dialogue is needed between emergency managers and tsunami forecasters ensuring the richness of novel tsunami early warning information can be effectively used in future responses.

Using radiocarbon in Southern Hemisphere tree-rings to understand the Southern Ocean carbon sink

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The Southern Ocean circulation plays a key role in regulating global climate and acting as a carbon sink, removing ~10% of all anthropogenic CO_2 over the industrial period. The impacts of climate change on the Southern Ocean are not fully understood and may alter this region's efficiency as a carbon sink. Previous observations and modelling suggest that the Southern Ocean carbon sink weakened in the 1990's and was reinvigorated in the 2000's. Radiocarbon measurements in Southern Hemisphere tree rings aim to provide unique insights into the mechanisms that drive Southern Ocean carbon uptake. In short, periods where rings present low $\Delta^{14}C$ relative to ambient background signal stronger ocean upwelling and outgassing of dissolved inorganic carbon. We present a time-series of >300 tree ring $\Delta^{14}C$ measurements from 13 sites in Chile and New Zealand from the 1980s to the present. By comparing these $\Delta^{14}C$ data to a Southern Hemisphere reference record (comprised of data from ~40°S at Baring Head, NZ, and Cape Grim, Tasmania), we show relative changes ($\Delta^{14}CO_2$) in tree-ring 14C over latitudinal gradients. We find latitudinal gradients in both Chile and New Zealand tree rings, with sites at 52-54°S 3.9± 0.1‰ lower than the reference record. From such gradients, we can diagnose changes in the magnitude of CO_2 outgassing, and changes in the strength of ocean circulation. We discuss upwelling of deep waters with reduced ^{14}C as drivers of this gradient, as well as differences in our results from New Zealand and Chile driven by variations in upwelling by ocean sector, and atmospheric transport.

Constraining volatile abundances in Vanuatu volcanoes

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The quantification of volatile budgets for volcanoes has garnered interest due to environmental impact, associated hazards, determination of inputs for climate modelling, and relation to eruptive behaviour. Whilst satellites have made it possible to quantify degassing of volcanic systems over time, observations need to be corroborated with in-situ ground-based measurements. Additionally, a comprehensive budget requires petrological assessment of dissolved magmatic volatiles. We aim to quantify dissolved volatiles of the Vanuatu archipelago through melt inclusions (MIs) and matrix glass of volcanoes across the differing tectonic regions of the arc.

We will present H_2O and CO_2 concentrations in matrix glass and glassy MIs from the 1913 eruption of Ambrym measured by micro-Fourier-transform infrared spectroscopy (FTIR). The eruption commenced with explosions in the central caldera that shifted to fissuring with lava flows along a propagating rift. Transition to an explosive event occurred when the eruptive centre reached the coast.

Matrix glass contains low volatile contents (<0.65% H_2O and CO_2 below detection), suggesting that fragmentation was driven by interaction with meteoric water in saturated coastal sediments. H_2O speciation provides no evidence of that water being incorporated into the glass at low temperature. Naturally quenched glassy MIs in olivine, plagioclase and clinopyroxene from the phreatomagmatic tephra have also been analysed to estimate volatile abundances deeper in the magmatic system and to assess eruption dynamics. Their major and trace elements will also constrain source compositions, and conditions of melt extraction and storage.

Determination of a budget for the arc will require the volatile budget of Ambrym (rift zone - this study, and central caldera - literature) to be compared to volcanoes across Vanuatu's diverse tectonic regimes. Our budgets will provide insights into the mechanisms driving shifting eruption activity, explore tectonic controls on volatile contents and eruptive style, provide inputs for climate modelling, and aid hazard mitigation.

The effect of frictional heterogeneity of earthquake cycle in subduction zones

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Seismic and tsunami hazard (and risk) modelling and preparedness are challenged by uncertainties in the earthquake source process. Important parameters such as the recurrence interval of earthquakes of a given magnitude at a particular location, the probability of multi-fault rupture, and rupture directivity, are often poorly constrained. Physics-based earthquake simulators offer a means of probing uncertainties in these parameters by generating long-term catalogues of earthquake ruptures on a system of known faults. The initial frictional stress in these simulations is typically prescribed as a single uniform value, which can promote characteristic earthquake behaviours and reduce variability in modelled ruptures. Here, we investigate the role of heterogeneity in the distribution of frictional stresses and the reasonable rate-and-state coefficients (b-a) on earthquake cycle simulations. We first focus on the Hikurangi-Kermadec subduction zone, which is considered as a single segment and may produce M9+ earthquakes and poses major hazard and risk to Aotearoa New Zealand. The results are compared with the magnitude-frequency distribution (MFD) of the instrumental earthquake catalogue and with empirical slip scaling laws from global earthquakes. Our results suggest stress heterogeneity, especially the variation of initial effective normal stress, produces more realistic and less characteristic synthetic catalogues. Heterogeneous stresses and state coefficients (b) of 0.003 and 0.004, respectively, with fixed rate coefficient (a) of 0.001 produce the best fit to MFDs and empirical scaling laws for earthquake modelling of the Hikurangi-Kermadec subduction interface. Heterogeneity of other parameters within RSQSim could further improve the applicability of the synthetic earthquake catalogues to seismic hazard problems. To explore more characteristics of the earthquake cycle in subduction zones, the approach of earthquake cycle modelling that we set up for the Hikurangi-Kermadec subduction interface will be applied to a comprehensive SW Pacific model including the Tonga trench and New Hebrides subduction zones.

The structural geology of curved slickenline patterns and modelling their geometrical evolution as a function of asperity inception timing, longevity, and rupture propagation

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Global data indicate that slickenlines inscribed during surface rupturing earthquakes are typically curved. Dynamic rupture modelling can relate slip curvature to time-varying stresses in rupture process zones. Such models have been used to interpret patterns of striation curvature in terms of the type of slip and the local direction of rupture propagation. Here, we explore the structural geology of curved slickenline patterns through 2-D kinematic models, comparing them to observations of slip striae on free faces of the Kekerengu Fault in 2016. The kinematic models simulate an early, curved slip striation trajectory—developed during arrival of the rupture front—followed by a longer, straighter path along which most of the slip is accrued. They highlight the following: (1) for strike-slip earthquakes, the early, curved increment of the slip is best preserved on free faces that form adjacent to steep canyon walls; whereas for dip-slip earthquakes, preservation is best along the upper edge of scarps; and (2) the longer, straighter part of slickenline tracks will commonly intersect older, curved parts of other tracks, giving a false impression of multiple earthquakes, and/or of a kink in slip direction (if overprinting is not recognized). Initially, the modelled fault surface is populated with a random spatial distribution of inscribers. The lifetime of individual inscribers, and the rate at which new ones are introduced, are governed by independently imposed “birth” and “death” laws. Employing a curved slip history, the models yield a diversity of slickenline patterns and track length distributions. Striae patterns on the Kekerengu Fault in 2016 most resemble model runs in which most of the inscribers were “born” at the beginning of the earthquake but soon “died”; that is, the fault smoothed during the earthquake, leaving behind a slickenline record that is usefully biased towards the early, curved part of the slip.

Impact of molecular diffusion and mechanical dispersion on gas distribution during underground hydrogen storage

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Underground hydrogen storage stores energy by converting excess electricity from renewable sources into hydrogen, thus helping to balance out the mismatch between intermittent renewables generation and consumer energy demand. Due to its safety and larger available capacity compared to surface storage, the feasibility of large-scale underground hydrogen storage in porous media is being investigated.

In underground hydrogen storage, to keep reservoir pressure high enough when hydrogen is withdrawn and to reduce cost, natural gas or nitrogen may be selected as a cushion gas and injected into the formation in the initial stage. However, because of the inevitable mixing between hydrogen and cushion gas due to molecular diffusion and mechanical dispersion, some volume of the cushion gas may be produced with the hydrogen, hence reducing storage efficiency. Thus, it is important to study the impact of mixing processes on the underground gas distribution.

To explore this problem, we use a numerical reservoir simulator that can describe a water phase alongside a mixture of two gases. Our simulation results show that molecular diffusion is slow and is not impacted by injection or withdrawal rate. This means it operates at all times, including during the storage period after injection has ceased but before production begins. In addition to rock property effects, the degree of mechanical dispersion is mainly controlled by flow rates. The larger the injection flow rate the more significant the degree of mixing in the back-produced gas. This research will eventually help us to predict future gas purity issues with underground hydrogen storage and design reservoir management strategies that mitigate them.

A high-resolution site amplification map for Wellington city

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While site-effects play a crucial role in the evaluation of local seismic hazard and risk, their quantification over the broad frequency range of engineering interest still remains challenging. Mapping local amplification at high-resolution is difficult even in high seismic hazard areas such as Wellington, which has experienced recent significant earthquakes (e.g., 2016 M_w7.8 Kaikōura). Employing traditional methods to map amplification, such as the standard spectral ratio (SSR), is realistic only with sufficient density of strong motion stations (SMS) across the city and the presence of a suitable rock-reference station. Recently, hybrid SSR methodologies (SSRh) that combine ambient vibration measurements with earthquake data are proposed to fill in the gaps and provide estimates of amplification at much finer spatial resolution. SSRh combines traditional SSR, calculated on earthquake data between a soil-reference and a rock-station, with SSR computed from simultaneous ambient vibration recordings (SSRn) at a temporary location and the soil-reference site within the sedimentary basin.

In Wellington, over 450 single-station noise measurements were undertaken, and no common co-located soil-reference station is consistently available, making the SSRh method as it stands impossible to apply. To overcome this limitation, we propose an adaptation of the SSRh to capture the same basin response between a soil site and soil-reference station as in the case of the synchronous ambient vibration data. We employ an additional interim step that uses the SSRn between each of the soil-sites and a rock reference broadband station recording synchronous long-term ambient vibration.

By employing the adjusted SSRh methodology, we were able to develop a first level high-resolution empirical linear site amplification model and the results are in good agreement with the available SSR at SMS in Wellington. Amplification factors up to ten are present in the Aotea region, where the deepest and softest soils are present, and damage was experienced during the M_w7.8 Kaikōura earthquake.

Investigation into the March 2023 Kawerau seismic swarm

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The Taupō Volcanic Zone (TVZ) is an active continental rift resulting from the oblique subduction of the Pacific Plate beneath the Australian Plate along the Hikurangi Trench. Seismicity in the region includes both large, surface-rupturing events and earthquake swarms. In March this year, the town of Kawerau experienced an earthquake swarm that caused considerable ground shaking and anxiety amongst the population. We utilize geodetic data, including GNSS measurements and InSAR tracks, along with earthquake analysis, to better understand the underlying cause of this swarm. We find excellent agreement between earthquake locations and the modelled deformation source. This reveals that this earthquake swarm was caused by slip along at least one south-east dipping fault, and that there is no evidence for the involvement of geothermal or magmatic fluids. Finally, the extension across the rift is estimated, the long-term subsidence due to magma cooling removed, and the contribution of this swarm on the extension quantified. This shows that the 2023 Kawerau swarm accommodated a significant proportion of the extension in this area, but that aseismic magmatic rifting must still play an important long-term role.

Release of the geological dataset of the Hyde-Macraes Shear Zone and Waihemo Fault Zone area, northeastern Otago 1:50 000

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The 1:50 000 scale geological map of northeastern Otago and associated data are now available for direct online download at https://doi.org/10.21420/59NX-QR39. The >3000 km² map area includes the trans-crustal Waihemo Fault Zone, the economically significant Hyde-Macraes Shear Zone in the Otago Schist and the western edge of the Canterbury Basin. The map area is two-thirds onshore and one-third offshore, amalgamated into a seamless geological map with legend and cross-sections. With knowledge of the geology of these important structures and areas at an all-time high, and still a strong focus amongst researchers and explorers, it is an opportune time to publish the available information online, both for future workers, and to aid the search for comparable structures elsewhere in Otago. The dataset illustrates the complexity of a small chunk of our local ‘frozen’ Mesozoic accretionary wedge and is a useful analogue for those researching the active Hikurangi subduction margin.

Major findings are as follows. The Waihemo Fault Zone can be traced offshore in the interpreted seismic data for at least 10 km. The Hyde-Macraes Shear Zone cannot be traced offshore and structural data suggests it may pinch out close to where the Zealandia Megasequence overlies the Rakaia Terrane near the east coast. Magnetically distinct greenschist units can be traced onshore as continuous layers in the Otago Schist rocks for up to 10 km.

The digital dataset features include the following: unpublished structural data and mapping; re-processed offshore seismic data; a complete GIS using GeoSciML and Litho2014 vocabularies; geological interpretation of geophysical data onshore and offshore; up-to-date structural and historical resources data; up-to-date mining data and; structure contour data. The downloadable product comprises .pdf files of the 2 map sheets, a downloadable GIS data package and downloadable individual GIS layer files.

Geochemical Atlas of Aotearoa New Zealand

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A geochemical atlas for Aotearoa New Zealand has been constructed using near-surface soil samples covering the North, South and Stewart islands. Soil samples have been analysed by aqua regia inductively coupled plasma mass spectrometry on the sub-2mm portion for 65 major, minor and trace elements. The results are > 75,000 element analyses from > 800 sites showing the distribution of analytes across Aotearoa New Zealand. Around 20% of samples were multiply analysed for quality assurance and quality control which quantitatively demonstrate the survey design and analysis methodology chosen were appropriate to understand regional-scale variations.

Initial results indicate a geogenic control on element distribution based on Austral Superprovince geology, Zealandia Megasequence sedimentary geology, the distribution of Rūaumoko Volcanic Region rocks and loess. In select areas, additional natural controls include Australian dust, redistribution along flood plains and mass wasting processes. Superimposed on the background signal are anthropogenic impacts from sources that may include urban development, fertilizer application and lead polluting activities such as vehicle exhausts and paint application. The completion of this survey brings New Zealand in line with global efforts to complete national-scale geochemical baseline surveys.

This is part of a multi-year project undertaken by GNS Science, in partnership with Manaaki Whenua—Landcare Research, universities and MBIE to better understand the distribution of elements, isotopes and minerals in New Zealand's active environments. It is supplemented by regional studies of strontium, carbon, nitrogen and sulfur isotopes, magnetic mineralogy and urban studies, with application to human health, mass wasting, ground water quality, environmental health, mineral exploration, carbon sequestration, anthropology, statistics and societal impacts to name a few.

Characterization of post-Pliocene dynamics of the Mangatangi Fault, South Auckland

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Normal fault systems in regions of low extension in New Zealand are comparatively understudied in favour of regions exhibiting high extension rates, such as the Taupo Volcanic Zone. A series of normal faults are present in the South Auckland Region as a part of the regional block faulting reactivated in the Late Miocene. These faults represent significant seismic hazard for New Zealand's most populated city, yet currently have poor constraints on slip rates and earthquake recurrence intervals. This study contributes towards this issue through an investigation of the Mangatangi Fault.

The Mangatangi Fault is a poorly assessed seismic risk for the Auckland region, striking NE-SW along the southeastern flanks of the Hunua Ranges. This normal fault is classed as potentially active and likely to be seismogenic in the New Zealand Community Fault Model. We used LiDAR-based geomorphic analysis along with Ground Penetrating Radar, hand auguring, and vibracoring to investigate the architecture of the Mangatangi Fault. Geomorphic analysis reveals a fault length of ~ 18 km, with a maximum measured throw of ~ 390 m. The morphology is not consistent with a typical slow moving normal fault (e.g., Basin and Range, USA). Though some triangular facets are observed on the range front, suggesting ongoing slow tectonic uplift, it does not show characteristic uplifted footwall profile and appears highly degraded. A piedmont scarp, manifesting ~ 60 m south of the main range front, is the focal field site of this study. Field investigations of the scarp reveal ~ 3.8 m of vertical displacement, elevated to the northeast. Shallow subsurface imaging shows predominantly clay which is inconsistent with the original alluvial fan interpretation made remotely. We continue to work towards understanding why a distinct escarpment is preserved at this location and what the implications are for paleoseismicity on the Mangatangi Fault.

Lipid biomarkers in sediment traps in a eutrophic reservoir

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Inland waters play a dual role in the global carbon cycle, contributing with emission of greenhouse gases, in addition to carbon sequestration to the sediments. Organic carbon sequestration highly depends on the autochthonous or allochthonous origin of the sedimentation material. One important source of autochthonous carbon is phytoplanktonic lipids, which are considered a substrate for methanogens. Otherwise, certain lipids from bacteria and archaea are methanogenic indicators and biomarkers. For instance, isoprenoidal glycerol dialkyl glycerol tetraethers (isoGDGTs), which involves carbon mineralization.In this study, we analysed material from sediment traps deployed in a Mediterranean eutrophic reservoir. We took weekly samples for chlorophyll-a and cyanobacterial abundance from the water column, and particulate organic carbon (POC), isoGDGTs and algal lipids from sediment traps over a year. We found a seasonal distribution of the total lipids (TLE), normalized with particulate organic matter sedimentation flux. Values ranged from 0.14 to 5.59 mg TLE/g POM m-2 d-1, peaks occurring between August and October, just after phytoplanktonic blooms. We also found relationship for chlorophyll-a concentration with total lipids, indicating a considerable influence of phytoplankton on lipid settling toward the sediments. For the five existing isoGDGTs and its isomers, we encountered similar seasonal trends throughout the sampling period. The most dominant isoGDGTs were GDGT-0 and crenarchaeol, with separated periods of dominance. Higher sedimentation fluxes of crenarchaeol indicate presence of the non-methanogenic crenarchaeota, unlike the presence of GDGT-0, which indicates the presence of methanogenic thaumarchaeota. Total lipids were also related with particulate organic carbon sedimentation flux, indicating influence of the lipid content in carbon sedimentation. This study provides direct quantification of algal lipids, which have effect on carbon storage at multiple timescales.

Detecting the Ōruanui supereruption in Antarctic ice cores

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Polar ice cores are invaluable archives, in this context providing exceptional preservation of chemical and physical signals from past volcanic eruptions. Glass shards from Earth's youngest supereruption, the 25.5 ka Ōruanui (New Zealand), were identified in the West Antarctic Ice Sheet Divide core, providing an incentive for new investigations of the timing and environmental impacts of this eruption in other Antarctic ice cores. Combining multiproxy published records including sulfate concentration, conductivity, and insoluble particle concentration along with new data, we have assessed eight deep Antarctic ice core records around the interval of the eruption. We have confidently located the supereruption signal in three cores at levels dated between 25,313 and 25,318 ± 250 years BP 1950, and tentatively identified it in another five cores. The magnitude of signal varies spatially, with overall stronger sulfate anomalies occurring in West Antarctica, directly downwind from New Zealand. In East Antarctica, sulfate anomalies are more complex, often including numerous significant peaks during the period of interest. The largest sources of uncertainty in detecting the Ōruanui event horizon are differences in snow accumulation rate and therefore regional signal strength across Antarctica, and larger age uncertainties associated with dating deeper ice layers. We have also analysed sulfur isotopes for the first time in the Skytrain ice core over the Ōruanui interval to investigate the stratospheric signature of the supereruption. We will explore whether the isotopic signature of Ōruanui is common across Antarctic ice core records and thus can be used to fingerprint the eruption horizon in ice cores lacking glass shards. Our identification of Ōruanui material in multiple cores will provide a unique tie-point to improve ice core chronologies and facilitate accurate dating. Future work will also analyse post-eruption ice to search for evidence of any climatic and biogeochemical impacts arising from the eruption.

A universal size classification system for landslides for improved communication

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Size is a fundamental property of landslides, but it is described inconsistently within the scientific literature. There is currently no widely adopted size classification system applicable to all landslide types. A Scopus database search shows the most used landslide size descriptor is the term large, used to refer to landslides with volumes spanning ten orders of magnitude. Some size descriptors are unintuitive or potentially misleading (e.g., the term massive which also describes a material property). We argue that a formal size classification scheme would encourage more consistent and logical usage of size descriptors and improve landslide science communication.

To that end, we propose a size classification scheme suitable for all landslide types. The scheme provides a log-scale of size classes for volume and area, with base units of m^3 and m^2, respectively. In theory, there is no limit to the number of size classes possible. Six size descriptors are suggested, each spanning three orders of magnitude: very small (10^{-3} – 100 m^3), small (10° – 10^3 m^3), medium (10^3 – 10^6 m^3), large (10^6 – 10^9 m^3), giant (10^9 – 10^{12} m^3), and monster (10^{12} – 10^{15} m^3). Our system does not replace existing (or preclude future) classifications systems for specific landslide types (e.g., snow avalanche) that use numerical size classes, and it maintains consistency with some commonly used descriptors.

Whatever system is used, we encourage people to define the terms they use, and to quantify size where possible, so that clearer meaning is given to the words used to describe landslide sizes. Ultimately, this will lead to improved communication of landslide information and hazard.

Orbital pacing of Wilkes Land East Antarctic Ice Sheet over the past 6 million years

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During past warm intervals of the Pliocene to Pleistocene, global sea levels are proposed to have been up to 20-30 m higher than present, inferring loss of Greenland, the West Antarctic Ice Sheet, as well as large sectors of the marine-based sectors of the East Antarctic Ice Sheet. Here, we present a new compilation of geological proxies for shifting ice sheet dynamic from the offshore of the Wilkes subglacial drainage basin of East Antarctic (3-4 m sle), with a continuous orbital-scale record of ice rafted debris and geochemical provenance over the past 6 million years. Eccentricity (100 kyr) pacing is pervasive in ice rafted debris throughout most of this time period. Obliquity frequencies (40 kyr) are a subordinate signature, despite obliquity usually being implicated in marine-based AIS collapse but do show strong power for short intervals of ~500 kyr duration. These peaks in obliquity-paced dynamic ice discharge show no clear relationship to the strength of obliquity orbital forcing, but instead show a near linear relationship to phases of enhanced eccentricity. Our results, and comparisons to ice sheet modelling experiments, suggests that marine-based ice sheet retreat into the interior of Wilkes subglacial required significant atmospheric warming, regulated by the eccentricity driven shifts in seasonality and summer insolation. This acted to lower surface elevations of the EAIS, thereby removing an “ice-plug” that buffers against oceanic induced collapse of this marine-based sector of the EAIS. Our results indicate that there is an atmospheric warming threshold required to trigger major retreat of the Wilkes Land subglacial basin.

Convergent shore platform evolution – demonstrating tectonics, eustatic sea level and inheritance controls on NZ shore platform formation using cosmogenic nuclides.

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The effect of accelerating sea level rise on our coasts is a major concern as we grapple with coastal hazards and managed retreat in the era of climate change mitigation. Rock shore platforms are often seen as static, but recent evidence tells us that these landforms can also change rapidly as sea level rise accelerates. In New Zealand, eustatic sea level change isn't our only concern. Tectonics can act as an important modulator of relative sea level, as was recently demonstrated during the 2016 M_W 7.8 Kaikōura earthquake and may impact shore platform evolution. Assessing perturbations in shore platform development processes over different time scales is important for understanding how shore platforms and the vulnerable land behind them will change in future. Immediate scale changes like earthquakes and slower changes like eustatic sea level rise could result in vastly different effects on processes. In addition, shore platform morphologies could be inherited from earlier highstands in sea level, which could skew our understanding of the landforms. The observational record provides little information about how these factors may play into shore platform evolution due to the typically slow rates of change at rock coasts. However, recent advances in cosmogenic nuclide techniques enable us to look deeper into the evolutionary histories of shore platforms. Here, we present the results of cosmogenic nuclide investigations at four shore platforms across three sites in New Zealand, at Auckland, Kaikōura (x2), and Dunedin. Each of the four shore platforms exhibits similar morphology and platform geometry. But in-situ Beryllium-10 and Carbon-14 concentrations show distinctly different evolution histories at each site. In Auckland, Holocene eustatic sea level change has controlled platform development, while at Kaikōura, regular earthquakes have modulated the Holocene evolution of shore platforms. However, potential evidence for platform morphological inheritance from MIS5e is discussed south of Dunedin.

A new geological map of Karioi Volcano

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Karioi Maunga (756 m) is an extinct basaltic stratovolcano within the Alexandra Volcanic Group of western North Island. Here we present a new, 1:25,000-scale map of Karioi from the forthcoming publication 'Geology of Karioi Volcano, Aotearoa New Zealand'. This map is the first example of a crowdfunded geoscience project in Aotearoa and intended for both general and specialist users. A core value of the project was collaboration with mana whenua from the Whāingaroa-Aotea area, with the map serving the dual purpose of recording volcanic whakapapa and mātauranga-a-hapū, including reclamation of early Tainui place names.

Geologic mapping involved a two-year field survey of the main Karioi edifice and its surrounding piedmont, including ring plain and monogenetic vents. Rock samples were collected for unit correlation using petrography, whole-rock geochemistry, and geochronology. This data was integrated with older, unpublished geologic datasets collected over the last 30 years at University of Waikato and compiled onto base maps (LiDAR + orthophotos) in ArcMap software. Buried volcanic features (e.g., intrusions, vents and lava fields) were identified using aeromagnetic data.

The proposed stratigraphy divides Karioi Volcanic Formation into five cone-building stratigraphic members (Te Toto, Whaanga, Central Cone, West Cone and Tamahine-o-Karewa) comprising a total of 21 stratigraphic units. The surrounding Okete Volcanic Formation contains 20 stratigraphic units erupted from at least 30 vents. Six new $^{40}Ar/^{39}Ar$ ages constrain the eruption period of Karioi to 2.6–2.4 Ma, with volcanism continuing from nearby Okete vents until 2.25 Ma.

The Karioi map provides useful insights into the early growth stages of a stratovolcano, from scattered vent activity to major cone-building. The map also contains intricate details about the scale and vent distribution (i.e., magma-fault interactions) present in monogenetic volcanic fields. Such details are valuable for interpreting the architecture of their active counterparts, e.g., Auckland Volcanic Field 100 km further north.

Simulation of snow slurry lahar hazard at Ruapehu volcano

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Snow-slurry lahars, containing a mixture of water, snow, ice and debris are highly mobile for their typical volumes and occur at a rate much higher than the geologic record indicates. This hazard may cause significant proximal impacts at snow-clad volcanoes even at small volumes. However, the occurrence, footprint and intensity of snow slurry lahar hazards are generally ill-quantified due to the lack of a reliable geologic record, as most evidence disappears after melting. A potential avenue to hazard quantification is through numerical modelling. Here, we quantify snow slurry lahar hazard at Mt. Ruapehu, New Zealand through simulations to obtain lahar intensities and footprints.

The most recently active vent at Ruapehu is located underneath the crater lake, which has resulted in a predisposition towards generating snow slurry lahars (e.g., in 2007, 1995, 1975, 1969). The volcano is located within a popular national park and has several ski fields on its slopes, with many assets and visitors potentially impacted by lahars. We applied a multi-phase numerical model to simulate the snow slurry lahars with a high-resolution DEM to estimate the impact of lahars on Ruapehu. Calibration and benchmarking of the model and parameters against 2007 and 1995 snow slurry lahars was used to measure simulation performance, as well as providing insights into lahar initiation and dynamics. Simulations of lahar scenarios using the calibrated parameters were then used to analyse potential impacts at Ruapehu though aggregated lahar pathways, impact footprints and measures of lahar pressure and velocity.

Anisotropy changes before and after the eruption of Whakaari/White Island volcano

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Whakaari/White Island has been the most active New Zealand volcano in the 21st Century, producing small phreatic and phreatomagmatic eruptions, which are hard to predict. The most recent eruption occurred in 2019, tragically claiming the lives of 22 individuals and causing numerous injuries.

We calculated shear-wave splitting to investigate variations in anisotropy during quiescent, inter-eruptive, and eruptive periods between 2018 and 2020. We found spatial and temporal variations in 7972 shear-wave splitting measurements and in Vp/Vs ratios, using automatic processing techniques to determine the best parameters for measuring shear-wave splitting.

We determined that the observed temporal changes are unlikely to result from earthquake path variations through media with spatial variability. Rather, these changes may stem from anisotropy variations over time, likely caused by a change in crack alignment due to stress or to varying fluid content in cracks over time.

Characterising the current magma reservoir beneath Taupō volcano with ambient noise and earthquake analysis

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Taupō volcano is a frequently active rhyolitic caldera volcano that was the site of Earth's most recent supereruption (Ōruanui ∼25.5 ka), as well as one of the most violent eruptions globally of the last 5000 years (Taupō, 232±10 CE). Taupō has erupted 28 times since the Ōruanui event and displays unrest activity (seismicity and surface deformation) on roughly decadal timescales, most recently in 2019 and 2022–23. This elevated activity resulted in the Volcanic Alert Level for Taupō being raised to Level 1 for the first time in 2022. Improving our understanding of the location and structure of the modern magma reservoir is crucial to interpret signals that indicate future unrest and possible eruption at Taupō. To analyse the sub-surface velocity structure, we used ambient seismic noise to calculate mean surface wave dispersion curves between different groups of seismometer station-pairs for both Love and Rayleigh waves. Our initial results indicate a 20% to 30% decrease in surface wave velocity beneath the northeastern part of the lake for 5.5–10 s periods (∼2–10 km depth). This anomaly does not extend into Western Bay or reach the Taupō Fault Belt. We interpret this low-velocity anomaly as the active magma system. On average, Love waves are slower than Rayleigh waves beneath the northern part of the lake, indicating negative radial anisotropy and vertical internal structure within the magma system. We combine these results with detailed characterisation of recent seismicity that revealed ongoing activity related to the magma system between 2019 and 2022 to identify the current magma reservoir and its recent activity.

Partnering with communities in co-produced field-based research around Taupō volcano

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From October 2019 to May 2022, we deployed a temporary seismometer network in the areas around Lake Taupō to learn about the volcano that lies beneath the lake. This deployment formed a key component of the multi-disciplinary, multi-institution ECLIPSE research programme funded by the Ministry of Business, Innovation and Employment. A core part of this work involved partnering and building relationships with members of the community, local Iwi and Hapū, as well as others involved in emergency management. We reflect upon this uncommon co-production approach to geophysical network deployment, which has improved outcomes both for communities and researchers through identifying a central theme of creating and holding space for researchers and communities to engage. We built the co-production approach into the project from the start by involving a broad team including representatives of local Iwi Ngāti Tūwharetoa and Te Arawa as supported key researchers. We worked to respect communities' time, protocols, and decisions; and to exchange knowledge about the research and results with landowners, community leaders, schools, and young people. Time spent kanohi ki te kanohi (face-to-face) built relationships and trust within and outside the research team with the potential to last beyond the scope of the original research project. We hope that other field-based researchers can benefit from a similar approach.

Microbial function characterisation of Maungaroa and Glendhu, two modern methane seeps from the Hikurangi convergent margin, New Zealand-Aotearoa

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Hydrocarbon cold seeps are extensive features along continental margins worldwide, exuding fluids rich in methane (CH_4) and hydrogen sulfide (H_2S) and hosting abundant marine life based on chemosynthesis (Campbell 2006; Campbell et al. 2010). Substantial amounts of methane and other hydrocarbons are emitted from cold seeps, thus the mineralisation by microorganisms of methane-derived authigenic carbonates is a major sink of carbon and a significant component of the oceanic carbon cycle. Modern seeps are widespread offshore east of New Zealand's North Island, in the active Hikurangi convergent margin Judd and Hovland 2009). A NZ scientific voyage part of a multidisciplinary project sampled in 2018 the Hikurangi margin sediments. We performed the characterisation of the microbial function and lipid biomarkers at two key modern methane seep sites: Maungaroa and Glendhu, thereby elucidating their adaptive responses and functional roles in these methane seeps. Our comprehensive analysis reveals that the structure of microbial communities is intricately tied to methane flux conditions. The Maungaroa site exhibited intense and localized methane flux, which significantly influenced the structure of its microbial community. High levels of microbial methane consumption were observed around the seep area, contrasting sharply with adjacent periphery zones with only a few cm of difference. Sulfate reduction did not follow this trend, indicating an uncoupled biogeochemical process. In contrast, the Glendhu site which presents a weaker and more diffuse methane profile flux showcases greater microbial diversity, including functionalities like nitrate reduction, nitrate oxidation, and nitrogen fixation. The microbial methane consumption was also more dispersed, resulting in less distinct differences between the seep and its periphery. Our comparative analysis underscores the vital influence of methane flux conditions on microbial community structure and function. We also observed a sediment redox gradient which drives changes in the sediment methane filter and microbial diversity and function. These results indicate the fragility of such ecosystems to the changes in oxygen levels in the sediment, which could be even more disturbed by near-future oxygen and temperature changes in the oceans.

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Kapuni field CO_2 sequestration opportunity: borehole seismic monitoring feasibility and design

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Todd Energy is investigating the potential for subsurface CO_2 sequestration in New Zealand. One possible storage site is the Kapuni gas field in south Taranaki. We have assessed the feasibility of using time-lapse borehole seismic surveys to help monitor the growth, movement, and geological containment of a plume CO_2 injected into the depleted reservoir interval.

Time-lapse borehole seismic surveys have become a key tool for CO_2 monitoring in Carbon Capture, Utilisation, and Storage (CCUS) projects around the world (as reviewed in White et al. (2021) because: (a) they provide a high-quality seismic image in the vicinity of the wellbore in which the survey is acquired; (b) they are accurately repeatable, such that differences in data from one survey to the next can be attributed to changes in fluid (and rock) properties; (c) the replacement of brine with CO_2 in the rock pore space usually produces a large change in seismic response; and (d) they have minimal impact on land use and the general public. The main drawback of borehole seismic surveys is the limited areal coverage of the image around the wellbore compared to surface-seismic surveys.

The Kapuni field has a rich history of borehole seismic acquisition, from an analogue checkshot survey acquired in discovery well Kapuni-1 in 1959, through to state-of-the-art fibre-optic and wireline vertical-, offset-, and walkaway-VSPs (Vertical Seismic Profiles) in wells Kapuni-19 and Kapuni-20A in 2013 and multi-offset VSPs in Kapuni-21 and Kapuni-23ST1 in 2021 and 2022.

This presentation distils the lessons learned from over 60 years of borehole seismic surveying in the Kapuni field, and the invaluable insights gained for designing and operating surveys to maximise data quality and efficiency. This experience supports our feasibility assessment for using time-lapse borehole seismic to monitor CCUS in the Kapuni field and at other potential storage sites.

Reference:
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New Zealand Geopark Group

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In 2018 the New Zealand National Commission for UNESCO invited Expressions of Interests for the first time, to establish up to two UNESCO Global Geoparks in New Zealand. In response, the Waitaki Whitestone Geopark Charitable Trust was set up to actively seek UNESCO status for the Waitaki District. The intention being to build on the work of Prof. Ewan Fordyce from the Geology Department at the University of Otago, and the subsequent establishment of the Vanished World Centre in Duntroon over 20 years ago.

In 2023 Waitaki Whitestone Geopark became New Zealand's first UNESCO Global Geopark and is currently the only one in Australasia. A Geopark provides a unifying platform that links and celebrates the identity, history, culture and geological and natural diversity of an area. They are established by a 'bottom-up' approach that not only showcases features within it, but advocates for the protection of its geological heritage. The aim of the Waitaki Whitestone Geopark is to educate communities as well as visitors about our whenua/land, its heritage, and its stories so they may become kaitiaki or guardians of these treasures. Waitaki Whitestone Geoparks connections within the Global Geopark Network and international assessors during the UNESCO designation process, has highlighted the need for greater communication, advocacy, and support for potential, existing and developing Geoparks in New Zealand. It is here that we propose the establishment of the New Zealand Geopark Group. An online forum that meets quarterly, where enthusiasts, experts, knowledge holders from all backgrounds and disciplines can connect, share, and discuss challenges and learnings for the promotion and support of the establishment of Geoparks in New Zealand.

Mapping the geology of an underwater continent: example of 96% submerged North Zealandia

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Rock dredge samples have been obtained from c. 50 sites across the 3.5 Mkm^2 of North Zealandia. Dating and characterisation of these ground truth samples are combined with regional seismic, gravity and magnetic data. Aided by heroic assumptions and expansive interpolations and extrapolations, a tectonic and geological framework of the northern two-thirds of the Te Riu-a-Māui / Zealandia continent can be established. Nine geological units can be shown on a c. 1:18 M scale geological map of submarine North Zealandia:

CRYSTALLINE BASEMENT
(1) ?Precambrian to Paleozoic sedimentary-metamorphic terranes and associated plutonic rocks (NZ Western Province)
(2) Mesozoic subduction-related plutonic rocks (Median Batholith)
(3) Permian to Early Cretaceous sedimentary-metamorphic terranes (NZ Eastern Province)

VOLCANO-SEDIMENTARY COVER
(4) Twenty three Late Cretaceous to Pliocene sedimentary basins
(5) Western Oligocene-Pliocene Lord Howe Seamount Chain hotspot track volcanic rocks
(6) Late Cretaceous to Miocene rift-related intraplate volcanic rocks
(7) Eocene-Quaternary scattered intraplate volcanic rocks
(8) Eastern Paleogene ophiolitic allochthons
(9) Eastern Eocene-Quaternary subduction-related volcanic rocks

With the completion of the North Zealandia study, the geological framework of the entire, 5 M km^2, Te Riu-a-Māui / Zealandia continent has now been outlined in reconnaissance. The submarine shelves of Earth’s continents typically are mapped as separate, poorly characterised tectonic elements, uncorrelated with onland units. Despite being mostly underwater, Zealandia is the first of Earth's continents to have its crystalline basement, and volcano-sedimentary cover rocks fully mapped out to the continent-ocean boundary.

TenFor: An ensemble forecasting tool enabling time-dependent tsunami early warning

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New Zealand's tsunami forecasting relies on the Tsunami Expert Panel (TEP), which assesses data from ocean sensors and simulation data. The science advice informs the National Emergency Management Agency (NEMA) to support warnings and potential evacuation activity aided by issuing threat level maps. Central to this process is the tsunami threat map catalogue which provides hundreds of precalculated potential tsunami scenarios of different magnitudes and locations of origin. The catalogue considers uncertainties related to source location, scaling, slip distribution, and magnitude by conservative interpretation of the underlying simulation results. The catalogue provides very little information about the timing (e.g., 'start' and 'finish') of the unfolding event. This information is typically gained by running detailed simulations while the event unfolds.

Distant source tsunami (> 3hrs travel time) typically provide enough time for the established forecasting framework to function effectively. Regional source tsunami (approx. 0.75-3 hrs travel time) are close enough to significantly strain the established processes and produce considerable uncertainty around impact and temporal development. In most cases these are still too far away to generate a noticeable natural warning. Due to their short travel times most local source tsunami pose such an enormous challenge to our forecasting and warning framework that natural warning signs need to be relied upon ('long or strong - get gone').

To augment and improve our distant and regional tsunami forecasting capability, we have developed and will present here 'TenFor' (TsunamiENsembleFORcasting), a rapid response software system designed to enable time dependent tsunami early warning, within the RCET (Rapid Characterisation of Earthquakes and Tsunamis) programme. By combining near real-time inversions of NZ DART data and ensemble modelling, we can reduce and directly account for uncertainties in the tsunami source mechanism. This presents a pathway for adding information about the evolution of the hazard to the forecasting products.

Calibrating glycerol dialkyl glycerol tetraethers (GDGTs) as paleoclimate indicators in New Zealand lakes

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Branched glycerol dialkyl glycerol tetraethers (brGDGTs) are commonly used as paleotemperature indicators in aquatic and terrestrial environments. However, many challenges remain, including the limitation of data from New Zealand (NZ) in global calibration studies.

We have investigated the distributions of brGDGTs in surface sediments from 143 lakes across New Zealand. The lakes studied span a large diversity of lake and catchment sizes, water depths, geographic locations (latitude and altitude), productivity/trophic level, catchment vegetation and land-use. In comparison with temperature monitoring data, we have developed a NZ-specific temperature calibration and compared this with recently proposed, global lake calibrations. We also compared our new calibration with the previous NZ-lake-specific calibration of Zink et al. (2016), which at the time of its development did not allow for the distinction between 5- and 6-methyl-isomers.

The temperature calibrations were then applied to two lakes, Adelaide Tarn and Lake Bright, which are located in the northern (Tasman) and southern (Fiordland) parts of the South Island of New Zealand, respectively.

Reference:
Zink, K.-G., Vandergoes, M.J., Bauersachs, T., Newnham, R.M., Rees, A.B.H. and Schwark, L. (2016). A refined paleotemperature calibration for New Zealand limnic environments using differentiation of branched glycerol dialkyl glycerol tetraether (brGDGT) sources. Journal of Quaternary Sciences 31: 823-835. http://doi.org/10.1002/jqs.2908.https://doi.org/10.1002/jqs.2908

GeoNet strong motion network review in Canterbury Region

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The GeoNet strong motion network in Canterbury is a dense network of free-field seismic and structure monitoring stations. With the known active geological faults in the Canterbury region and the significant potential for strong shaking from an Alpine Fault earthquake, the seismic network configuration was designed with good spatial coverage to capture strong shaking across a range of environments. Data from the network provides valuable input for many applications related to ground motion studies and engineering seismology, with notable data records from permanent seismograph and additional temporary deployments for large earthquakes in the Canterbury Region between 2010 and 2016.

As part of GeoNet's ongoing network review efforts, Canterbury has been chosen as the first part of the strong motion network to examine. The goal of the network review is to determine if the network is over- or under-performing and whether any sites should be removed, moved, or added to optimise the network for its purpose.

The ongoing review process has engaged expert data users from across a wide spectrum of strong motion data applications. This consultation aims to understand the value of current sensor stations and the requirements for network data. The justification for continued operation of sites is informed by network geometry, population and infrastructure density, ground conditions, topography and structural influences, data records, and original site installation purpose. Information gathered in this network review is critically valuable for re-designing the network and ensuring it offers the greatest value while minimizing any over-investment. An inclusive communications approach is targeted for this review, reaching out to the strong motion community, agency partners and stakeholders for feedback and decision-making support. So far, expert feedback has contributed significantly to the network plan. Further feedback is welcome.

Performance of a national earthquake early warning system for Aotearoa New Zealand using a synthetic catalogue and synthetic seismograms

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Earthquake early warning systems (EEW) are valuable tools to minimize the impact of seismic events on communities and infrastructures. However, Aotearoa New Zealand, does not yet have a national EEW system. This study therefore began to evaluate the cost and benefits of an earthquake early warning algorithm for New Zealand. As a starting point, we focused our evaluation on the Canterbury region – a populated region that has experienced many earthquakes in the past decade and is monitored by a dense network of seismic instruments.

First, the latency of the current sensor network was analysed, and the communication latency was found to generally be less than 2 seconds. Synthetic seismograms were generated for all regional 459, 0.1° x 0.1° grid points and 33 sensor stations over the selected region and validated using the actual Darfield earthquake data recorded by the GeoNet sensor network.

Next, 100 different 100-year periods were randomly selected from the 220,000-year RNC2 catalogue, and the large magnitude earthquakes (M≥6.0) in those periods were extracted to represent possible events of the next 100 years. We are testing the PLUM early warning algorithm using synthetic seismograms of all these earthquake events. We are analysing the performance of the PLUM algorithm for the Canterbury region in terms of alert correctness and timeliness. This evaluation also takes into account the population density across the Canterbury region. Finally, we plan to investigate the impact of the sensor network density and location on EEW performance, particularly the effect of sensor or communication breakdowns, and the identification of optimal future sensor locations.

Tools and techniques for extending geoscience outreach into Early Childhood Education settings

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"He autō?" Is it magnetic? Geophysics is usually not considered a child-friendly outreach topic, and yet magnetic play is common in Early Childhood Education (ECE) settings. The Rocks for Tots participatory geoscience outreach programme, which was sparked by a parent education opportunity at Playcentre, demonstrates the synergies that can occur when geoscientists are open to connecting their expertise with what is relevant in the ECE space.

Our work aims to inspire geoscientists by demonstrating how rewarding it is to share geology expertise—of all types—in ECE settings, highlighting kaupapa Māori principles of taoka tuku iho (intergenerational transfer of knowledge) and ako (reciprocal learning) which are embedded in ECE. We have developed or adapted hands-on activities and participatory science inquiry that interweaves all five strands of Te Whāriki: He Whāriki Mātauranga mō ngā Mokopuna o Aotearoa (New Zealand's Early Childhood Curriculum)—wellbeing, contribution, belonging, communication, exploration. The activities address core ideas in geology and provide scaffolding experiences to support a capstone participatory inquiry project (environmental magnetism of Ōtepoti Dunedin). Can you think of ways to engage with young tamariki and their whānau? The resulting connections are amazing.

Earthflow dynamics and sediment load contributions in the Haunui research catchment

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Earthflows occur in Aotearoa's soft-rock hill country and may play an important role in catchment sediment dynamics and related water quality by providing a persistent source of fine-grained sediment to the channel network. A better understanding of their drivers, movement dynamics, and contributions to catchment sediment loads is needed to improve existing models for erosion mitigation planning.

We present insights into the dynamics and sediment load contribution of an 80,000 m^2 shallow earthflow located in the Haunui research catchment, a headwater tributary of the Manawatū River, from four years of monitoring. Complementary proximal sensing technologies provide data on sub-daily to multi-year displacement rates, annual volumetric change, and hydroclimatic conditions, allowing phases of earthflow displacement to be linked with hydrological drivers. Continuous GNSS, monitoring pegs, and pixel-tracking reveal displacements are greatest in the toe of the earthflow, with maximum displacements of 0.25 m day^{-1} and 17 m yr^{-1}. Annual displacements average between 6 m yr^{-1} in the head to 9 m yr^{-1} in the toe. A 3-fold variation in annual displacement is observed between monitoring years. This variation is reflected in preliminary estimates of sediment contributions to the stream network, which vary from 950 ± 4,900 to 19,000 ± 6,400 tonnes between years.

Phases of displacement coincide with sub-annual fluctuations in piezometric head measured at the failure surface, which remains saturated year-round. Continuous displacement is observed during winter–spring when piezometric head remains above a certain threshold. Accelerations follow higher-magnitude rainfall only when piezometric head exceeds this threshold. Displacement ceases over summer–autumn when the piezometric head remains low. Total displacement is determined by the magnitude and temporal distribution of rainfall during periods of elevated piezometric head. Our findings illustrate the importance of seasonal-scale hydroclimatic conditions in determining the dynamics and sediment load contributions of shallow earthflows in headwater catchments.

Northern Hikurangi deep marine processes between Pleistocene event beds: a study of background sedimentation

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In this study, the upper 24.17 m of the Integrated Ocean Drilling Program Hole U1526B, from the Tūranganui Knoll seamount is used to understand changes in the sedimentation and oceanography of the east coast of New Zealand over the past 1.2 million years. Hole U1526B provides a unique opportunity to study the paleoceanography, paleoclimate, and background process occurring at the northern Hikurangi Subduction Margin as it is located on top of the seamount, above a region that is dominated by downslope gravity deposits. Previous work has identified five hiatuses in this core during the Pleistocene which have become subsequently longer with time. Analyses of grain size and sediment provenance identified three major changes in sedimentary facies in the last 1.2 Ma which may relate to the hiatuses and changes in sedimentation processes. Oxygen isotopes measured from benthic and planktic foraminifera in the core are used to determine glacial-interglacial cycles to provide a chronostratigraphic constraint on the previously identified hiatuses. Intriguingly benthic foraminiferal assemblages provide evidence of sediment transportation from provenances significantly shallower than the study site throughout the core. There is also evidence of the last benthic foraminiferal extinction event which occurred over the Mid-Pleistocene Transition, providing age markers in the core. This will improve the understanding of changes in sea temperature and associated sedimentation processes over this period.

Testing and evaluation of earthquake rupture simulation for New Zealand

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We have tested and evaluated the output of a synthetic physics-based earthquake catalog for New Zealand. The catalog was generated using the Rate-and-State Earthquake Simulator RSQSim, incorporating the geometry and slip rate estimates of the 530 fault sources from the 2010 National Seismic Hazard Model (NSHM). The RSQSim utilizes rate and state dependent friction equations to simulate the initiation and propagation of ruptures, enabling the generation of long-term catalogs spanning hundreds of thousands of years. To address the stress singularity issues at fault edges, input fault slip rates provided by the 2010 NSHM were incorporated into RSQSim using a hybrid loading technique. We compared the RSQSim catalog with the 2010 NSHM in terms of their respective fault slip rates, magnitude-frequency distribution, and seismic moment rates. Finally, we compared probabilistic seismic hazard (PSH) estimates from the simulated earthquakes to those of the 2010 NSHM.

Our findings indicate that the slip rates derived from the hybrid loading technique, the seismicity rates obtained from the simulator, and the resulting PSH maps exhibit close agreement with the 2010 NSHM for faults located in the South Island, where deformation is primarily accommodated by crustal faults. However, slip rate discrepancies arise for faults situated on the North Island, where the Hikurangi subduction zone and overlying crustal faults accommodate most plate boundary deformation. This suggests that further refinement of the RSQSim simulator is needed before it can be used in any end-user applications.

An initial assessment of vertical land motion in the Indonesian archipelagoes

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From 2016 to 2021, Global Navigation Satellite System (GNSS) observation data spanning 23 co-located GNSS stations and tide gauges (TG) in Indonesia were analysed to ascertain the Vertical Land Motion (VLM) rates. Accurate corrections are pivotal for precise VLM determination and ensuring coherence when integrating VLM data with other datasets. This study investigates the impact of various ocean tide models to correct ocean loading effects. Specifically, we examined three finite element solution (FES) ocean tide models: FES2004, FES2012, and FES2014b, to deduce ocean tide loading (OTL) displacement at coastal sites in Indonesia. Disparities between the models were assessed using statistical measures. The variations in magnitude observed in these differences displayed a dependency on location, with the vertical component of the 3D parameters demonstrating the most pronounced disparity. Different OTL corrections in GNSS processing resulted in distinct GNSS site velocity rates. Notably, the velocity range disparity between FES2012 and FES2014b was comparatively smaller compared to other pairs, FES2004 vs FES2012 and FES2004 vs FES2014b. The pattern of VLM rates along the Indonesian coast reflects the dynamic behaviour of the coastal region resulting in either land subsidence or uplift. The sites are situated within the Indo-Australian deformation zone and experience anthropogenic processes and tidal dynamics. Furthermore, the research examined the correlation between displacement signals from tide gauges and OTL models at selected Indonesian sites. This preliminary study acknowledges the potential influence of long-term and seasonal variations on the velocity rates. F-test and correlation analysis between velocity rates and semi-annual and annual cyclic terms unveiled patterns linked to the temporal period of observations. In summary, this initial assessment lays the groundwork for comprehending VLM in Indonesia's coastal regions and its intricate relationships between oceanic and geodynamics.

One step ahead of extinction: quantifying extinction risk of New Zealand marine molluscs

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Extinction is a natural process that shows fluctuating intensity through time. Currently there is concern that anthropogenic factors are driving increasing rates of extinction that will surpass natural background levels. Today, as many terrestrial and marine species have gone extinct or are under severe threat of extinction, the question arises, are we approaching a large extinction event like the ones recorded in the fossil record. But to answer this question is extremely difficult, as there is no simple way to measure or accurately predict the magnitude or extent of an extinction until it's too late. However, the answer to future extinction lies in the past, with countless extinct species recorded in the fossil record providing thousands of extinction "experiments" to study.

This research aims to analyze New Zealand's rich marine mollusc fossil record to identify the key mechanisms and factors controlling extinction risk in the benthic marine realm, and how these factors vary between different taxonomic groups (e.g., bivalves and gastropods) and functional traits (e.g., size and motility). Macroevolutionary extinction rate calculations are used to visualize and interpret the fossil record to discern patterns of extinction. The influence of biological and environmental factors (e.g., sea surface temperature) on extinction will be used to calibrate future extinction vulnerabilities of New Zealand marine molluscs under a range of possible future climate change scenarios. These calibrations will serve to produce maps across New Zealand's marine estate displaying the distribution of extinction vulnerability for varying marine taxonomic groups, and to illustrate their possible responses to climate change over the coming centuries. Preliminary results show more volatile extinction patterns in gastropods than bivalves and small, motile, and epifaunal marine molluscs show shorter occurrence histories. This research will provide an improved understanding of extinction that will enhance our ability to conserve New Zealand's unique marine biodiversity.

Assessing the Pliocene–Recent erosion history of the eastern Southern Alps using cosmogenic radionuclides, tracer techniques and grain size analyses

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The Southern Alps / Kā Tiritiri o te Moana have attracted scientists to study the interactions between climate and tectonics for decades. It has long been argued that tectonic uplift of this orogen is approximately balanced by surface erosion. The prevailing westerly airflow at the latitudes of the Southern Alps has created a strong orographic effect with precipitation decreasing sharply across the orogen's main divide. The signature of this orographic effect is apparent in erosion rates that decrease from west to east, and from the dominant types of erosional processes that operate on either side of the orogen's main divide. Most studies quantifying erosion over geologic timescales have focussed on the wetter—but areally significantly smaller—side of the orogen. Here, we seek to quantify the Pliocene–Recent erosion history of the Southern Alps' much larger eastern side using cosmogenic radionuclides (^{10}Be and ^{26}Al), tracer techniques (U–Pb) and a grain size analysis on fluvial deposits in Canterbury that record concomitant erosion of this mountain range. Cosmogenic radionuclides provide a powerful tool to constrain erosion rates on timescales of 100–100,000 years, which is the temporal range at which tectonic and climatic forcings overlap and meso-scale stratigraphic architecture is created, thereby offering critical insights into the dynamics between tectonics, climate, and erosion. Detrital grain U–Pb analysis of the fluvial deposits will be used to establish the sediment's provenance, while a grain size analysis of the river sediments will provide insights into associated past stream dynamics. With this multi-method study, we seek to constrain both spatial patterns and catchment-scale rates of erosion of the Southern Alps, as well as their changes through time. Finally, this research will provide a benchmark for assessments of anthropogenically influenced erosion. Recent preliminary results from this research will be presented.

Textural implications for the magma mixing during the Waimihia eruption, Taupo

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The injection of new magma is one of the important processes that trigger eruptions. In this study, we focus on how the mixing and mingling of two different magmas affect the vesiculation process afterward. We examined the bubble and crystal textures of juvenile clasts from the 3.3 ka Waimihia eruption in Taupo. This eruption produced two contrasting plinian fall deposits followed by a volumetrically small ignimbrite. The juvenile clasts in the pumice deposits show various evidence of mafic-felsic magma interactions, such as mafic enclaves, banded pumices, hybrid grey pumices, and white pumices. Quantification of bulk densities reveals that the hybrid grey pumices are lighter than the white pumices. This result appears against a simple expectation that the mafic magma is generally denser than felsic magma. Scanning electron images demonstrate that the hybrid grey pumices are more vesiculated than white pumices. Besides, the hybrid grey pumices contain Fe-Ti oxide nanolites (and microlites) as well as amphibole nanolites, while the white pumice has a clear glass matrix. Given that amphibole which contains hydroxyl cannot form by decompression-induced crystallization, these nanolites in hybrid grey pumices might have crystallized during magma mixing. The Fe-Ti oxide is well known for being an efficient site for bubble nucleation as it reduces the interfacial surface barrier. We think the Fe-Ti oxide nanolites facilitate the volatile exsolution in hybrid magma and result in the formation of light grey pumices. In summary, the Waimihia eruption is a good example for understanding how nanolites crystallize in a magma chamber and affect the vesiculation during magma ascent.

Stress and structural controls on S-wave polarization anisotropy in the focal area of the Noto Peninsula earthquake swarm in Japan

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S-wave polarization anisotropy could provide us the information on stress and deformation. Seismic activity in the Noto region of Ishikawa Prefecture, central Japan, has increased since August 2020 and has continued as of August 2023. Stress changes due to subsurface sources and increases in fluid pressure are discussed as the causes of the seismic activity increase. In this study, S-wave polarization anisotropy was investigated by S-wave splitting analysis using temporary and permanent stations. We adopted the MFAST (Savage et al., 2010) for shear wave splitting detection.

The directions of anisotropy were generally NW-SE in the southern part of the focal area and east-west or north-south directions in the northern and other parts. The NW-SE anisotropy generally coincides with the direction of the maximum horizontal compression axis. Therefore, stress-induced anisotropy can be the cause of the observed NW-SE anisotropy. On the other hand, faults with strike directions generally east-west and north-south have been identified, and structural anisotropy may be another cause.

We examined the time variation of anisotropy at N.SUZH, one of the permanent stations. No significant time variation was observed in the direction of anisotropy. Larger anisotropy was observed, particularly for the activity in the western part of the focal area, from about June-September 2021 compared to the period up to the period.

We also investigated the seismic wave velocity structure in the source region by analyzing seismic wave velocity tomography (Zhang and Thurber, 2003 and 2006). A high Vp/Vs region was identified beneath the focal area, at a depth of 18 km. This high Vp/Vs region has slightly larger P-wave velocities than the surrounding area. Since Tertiary igneous rocks are distributed in the target area, the high Vp/Vs region may represent a magma reservoir, suggesting that fluids released from the magma reservoir are involved in this seismic swarm.

Reference:

Savage, M.K., Wessel, A., Teanby, N.A., Hurst, A.W. (2010). Automatic measurement of shear wave splitting and applications to time varying anisotropy at Mount Ruapehu volcano, New Zealand. J. Geophys. Res. 115: B12321, doi: 10.1029/2010JB007722.

The hazard beyond the horizon: a hybrid tsunami hazard model for Aotearoa New Zealand

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In Aotearoa New Zealand (ANZ), where most of the population lives within five kilometres of the coast, the potential risk of a devastating tsunami is of critical concern. The unique geographical location of ANZ within the Pacific 'Ring of Fire,' renders the region particularly susceptible to tsunamis, as it is where over 80% of the world's tsunamis occur. Over the past couple of centuries, ANZ has experienced over seventy tsunamis, with five events generating wave amplitudes exceeding five metres at the coast. Current research endeavours have predominantly concentrated on assessing the hazard from local tsunami sources since they pose the greatest threat to Aotearoa New Zealand. Nonetheless, for a comprehensive understanding and complete estimate of the hazard to ANZ, regional and distant sources must be accounted for as they pose a significant hazard over short return periods and have the potential to cause devastation to coastal communities, despite the lack of recorded events.

In this presentation, I will introduce our innovative hybrid tsunami hazard model, which combines geological and geophysical observations with physics-based methodologies, to determine the potential tsunami hazard to Aotearoa New Zealand. To do this, we estimated the accumulated earthquake slip on subduction zone faults across the Pacific and performed 3D dislocation fault modelling to calculate the sea-surface displacements from a diverse range of tsunami sources. We employed a finite difference code (COMCOT), which is proficient in solving linear and non-linear shallow-water-wave equations to simulate the propagation of tsunami waves from their source to ANZ's coastal regions. We recorded the range of expected wave amplitudes and arrival times of each of these potential tsunamis, to better understand some of the ‘worst-case’ scenarios and determine which subduction zones and potential tsunami sources pose the greatest hazard to Aotearoa New Zealand.

Discovery Deep, Antarctica, characterised by seismic and gravity surveys

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The Discovery Deep area of the eastern Ross Ice Shelf has been identified as a possible site for future paleoclimate drilling based on legacy regional-scale seismic studies and more recent satellite and airborne geophysical studies. To further assess the suitability of this target area, seismic reflection and gravity surveys were undertaken during the 2021-2022 summer.

A 30 km long seismic reflection profile is used to image the seafloor and underlying stratigraphy. A gravity survey with 2 km station spacing (1 km along the seismic line) is used to tie past regional gravity and bathymetry models in the region of the more detailed seismic profile.

The seismic survey provides new control for models of the bathymetry, sedimentary basin and local crustal units. The seismic data image a dipping package of sedimentary units. Furthermore, the absence of seafloor-draping strata indicates that there is very little Holocene sediment on the ocean floor where it is imaged. The seismic image shows no break in the slope of the seafloor which plunges shoreward (west) at about 0.4°, suggesting that the basin depocentre at Discovery Deep is yet to be imaged.

Gravity modelling along the seismic profile using Oasis Montaj indicates minimum basement depths of 4400 to 5500 m and a maximum depth of 5200 to 6350 m. Basement densities range from granitic (2600 kgm^{-3}) to mafic (3100 kgm^{-3}). The sedimentary package ranges in density from 1210 to 2200 kgm^{-3}.

A second seismic reflection survey was conducted along the central 2.7 km of the original survey using a 300 m long towed snow streamer. This method was about four times as efficient (in distance covered per day) as the traditional spiked geophone survey method. The quality of the stacks is comparable, the frequency content is lower, but the streamer data does not contain a source ghost.

Pre-and post-uplift shore platform erosion rates and patterns: implications for rock coast evolution in active regions (Māhia and Kaikōura Peninsulas, New Zealand)

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Recent erosion rates from tectonically active coasts provide evidence of rapid rock breakdown following coseismic uplift. These rates help solve puzzles regarding 'missing' marine terraces that prevent accurate reconstruction of past sea levels, earthquakes, and rock coast evolution. However, little scientific effort has been made to investigate the impact of tectonism on shore platform development (the precursor to a marine terrace). It is also unclear whether erosion records from one coast can be extrapolated to other regions with similar tectonic, geological, or geomorphic characteristics. We present shore platform downwearing rates and processes measured using a traversing micro-erosion meter (TMEM) and structure-from-motion photogrammetry from intertidal shore platforms uplifted by 3.1 m between 100 and 300 years ago. The site is a mudstone platform at Kahutara Point, Māhia Peninsula, North Island, New Zealand. Over 1.43 years, the mean annual downwearing rate was 1.94 mm/yr, while the total erosion at individual TMEM stations ranged from 0.29 to 8.31 mm. A lack of spatial pattern in cross-shore erosion rates, suggests equal efficiency of waves and weathering processes. Orthophotographs of the eroded rock surfaces support the combined role of marine and subaerial weathering processes, salt weathering, and biological activity in the erosion of mudstone platforms at Kahutara Point. The mean erosion rate of 1.94 mm/yr from the Māhia Peninsula is similar to the mean post-uplift rate of 2.25 mm/yr reported for the Kaikōura Peninsula, New Zealand, where platforms were uplifted by ~1 m in 2016. Results suggest a comparable pattern of erosion response at both sites following coseismic uplift and implies a centennial scale response time at Māhia that has implications for erosion timescales at Kaikōura. This work provides the first field evidence to support the comparison of the Kaikōura and Māhia shore platforms, thus helping to inform understanding of marine terrace development and destruction.

Cyclone Gabrielle impacts on seabed ecosystems off Te Matau a Māui/Hawke's Bay and Tairāwhiti/Gisborne regions

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Cyclone Gabrielle caused devastating and widespread impacts in catchments and coastal zone of the Te Matau a Māui/Hawke Bay and Tairāwhiti/Gisborne regions. The magnitude and duration of the storm event suggests that the extent and nature of impacts on marine ecosystems are potentially significant. However, direct observations offshore were logistically challenging to achieve in the aftermath and only recently have been documented. NIWA conducted boat-based surveys at priority coastal and shelf environments off Te Matau a Māui and Tairāwhiti to document changes in seabed geomorphology, cyclone-related sedimentation, fresh debris, and fisheries habitats and benthic communities. Survey effort mainly targeted priority areas where pre-cyclone multibeam bathymetry and biological data were available for comparison, but also extended to unsampled areas on the outermost continental shelf to map the possible extent of impact. In this presentation, we provide some preliminary results from these NIWA response surveys, including any evidence of geomorphic and habitat change, together with new benthic imagery and substrate observations. This project also includes a follow-up survey to monitor recovery, and modelling work to characterize the cyclone floodwater and sedimentation footprints and their possible impact on habitat-forming species.

Reservoir simulation workflows for hydrogen geostorage in Taranaki depleted gas fields

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Injecting and recovering green hydrogen from depleted gas fields could provide Aotearoa New Zealand access to enormous pore volumes to help realise its green hydrogen energy ambitions. During early derisking of specific sites, it is important to develop an accurate geological model to test whether the storage container has the desired volume and hydrogen deliverability. However, where seismic reflection and well data are limited, and/or the storage system is structurally complex, the resulting geological models may be non-unique. Therefore, injection and withdrawal simulations using different structural end members is critical to constrain how a hydrogen plume may flow within the container and interact with existing reservoir fluids.

Here we present workflows for modelling a multi-year injection and withdrawal cycle of hydrogen into a depleted gas field. We use data from the Tariki Sandstone Member of the Ahuroa field in the Taranaki Basin, currently used to store natural gas. This reservoir is located at 2 km depth at the crest of an anticline above the Tarata Thrust, with marine mudstones forming the top seal and low-permeability fault rock the lateral seal. With only mixed quality 2D seismic reflection lines and 11 wells, the precise geometry of the thrust fault and its relations to smaller secondary faults is poorly constrained.

To capture this uncertainty in our simulations, we have developed two geological models of the Ahuroa field in Leapfrog Energy 3D modelling software. We then use those geological models to conduct dynamic simulation of hydrogen injection and withdrawal using the massively parallel simulator PFLOTRAN-OGS. We develop simulations that allow us to, over a 10-year cycle, test for closure or spill into adjacent fields, and predict the amount of mixing with remnant natural gas and formation water. Finally, we reimport the results back into Leapfrog for visualisation of the hydrogen plume over time.

Emerging insights into the geological occurrence and morphology of New Zealand erionite

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In New Zealand, the presence of volcanic processes has led to the formation of diverse minerals that originate from volcanic activity, including a category of aluminosilicates referred to as zeolites. One such notable zeolite is erionite, which typically crystallizes through hydrothermal alteration or diagenesis of volcanic rocks, forming mainly in tuffs and basalts. Erionite possesses a fibrous crystal habit, similar to asbestos. And as with asbestos, erionite exposure has also been linked to cases of malignant mesothelioma- A significant epidemic was discovered in the Cappadocia region of Turkey in the 1970s. While undisturbed erionite fibres are not considered harmful to human health, the International Agency for Research on Cancer (IARC) has designated erionite as a Group 1 carcinogen due to its hazardous potential when disturbed or inhaled. Consequently, research is ongoing in New Zealand, employing various experimental and analytical techniques to detect and identify the occurrence of erionite. Some of the methods being utilized include Electron Microscopy, X-Ray Fluorescence, Electron Microprobe Analysis, micro-Raman spectroscopy, and X-ray powder diffraction with the Rietveld Method. These techniques aid in the characterization and identification of erionite in different regions of New Zealand. Notable findings so far include woolly erionite discovered in vesicles of rhyolitic rock at Mount Somers in the Canterbury region of the South Island, asbestiform erionite found in the Waitakere Group Volcanics in the Auckland region of the North Island and acicular bundles of erionite fibres found in tuff from the Timber Bay Formation in Kaipara. Due to the potential adverse health effects linked to erionite exposure, this research endeavours to enhance the understanding of erionite occurrence and aid in understanding how to minimise the dangers presented by this mineral.

Modelling the processes that may lead to phreatic eruptions, with comparison to Whakaari, New Zealand

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Phreatic, or steam-driven, eruptions are the most common type of volcanic eruption in New Zealand. They are notoriously difficult to forecast and have caused fatalities in New Zealand and overseas. We propose two mechanisms that lead to phreatic eruptions a) cracking of a hydrothermal seal that is trapping pressurised fluid, and/or b) an injection of hot magmatic gas interacting with cold groundwater that then flashes to steam. Testing these hypotheses can help to determine the subsurface processes and timescales leading to an eruption, a possible key to unlocking monitoring data for phreatic eruption forecasting.

We have collated conceptual models of Whakaari/White Island Volcano in New Zealand from the literature and turned them into generalised 2D numerical models of heat and multi-phase fluid flow in porous media. Using CSMP^{++}, we explore the pressure conditions and fluid flow associated with the build-up of fluids in a sealed hydrothermal system above a magma reservoir. Preliminary results suggest that the permeability of the volcanic edifice affects how quickly fluids move, but not the long-term pressure distribution. Our models show pressure increases beneath the hydrothermal seal, and we are exploring the conditions required for seal failure on timescales that are rapid enough to lead to large-scale decompression and eruption. We will then compare results of these models with field and experimental observations from Whakaari Volcano.

Detecting Hikurangi slow slip events through wavelet analysis of GNSS time series

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We use numerical modelling and wavelet analysis to study slow slip events (SSEs) along Hikurangi margin. The first part of this study is motivated by geophysical observations that suggest that temporal changes in pore fluid pressure correlate with SSEs at Hikurangi. These fluctuations in pore fluid pressure are attributed to fluid migration before and during SSEs, which may modulate SSE occurrence. To examine the effect of pore fluid pressure changes on SSE generation, we develop numerical models in which periodic pore-pressure perturbations are applied to a stably sliding, rate-strengthening fault. By varying the physical characteristics of pore-pressure perturbations (amplitude, characteristic length, and period), we find models that reproduce Hikurangi SSE properties (duration, magnitude, slip, recurrence). Our results indicate that large permeability values of $\sim 10^{-14}$ to 10^{-10} m^2 are needed to reproduce observed SSE properties. Such high values could be due to transient and localized increases in fault zone permeability in the shear zone where SSEs occur. Our results suggest that SSEs may arise on faults in rate-strengthening frictional conditions subject to pore-pressure perturbations. In the second part of this work, we use wavelet analysis, a mathematical tool for analysing time series, to study SSEs at Hikurangi. We apply a continuous wavelet transform to GNSS data from Geonet and identify the period range over which SSE signals are distinguishable (0.1 to 1 yr). Using an inverse continuous wavelet transform, we reconstruct displacement of GNSS stations over the given period range, stack them over different stations to increase signal-to-noise ratio and use them to identify SSE timings. Using this method, we build a catalogue of Hikurangi SSEs and compare it with independent SSE catalogues. We also study systematically the occurrence pattern of detected SSEs to characterize their periodicity. Our results indicate that wavelet-based detection methods are valuable for studying SSE recurrence patterns.

Large-scale experimental pyroclastic density current (PDC) seismoacoustic observations

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New Zealand is home to two dozen quaternary volcanoes with six observed/historically active volcanoes on the North Island. The hazards associated with these volcanoes include the most lethal and destructive: Pyroclastic Density Currents (PDCs). PDCs are challenging to study due to their complex dynamics, and difficulty in gaining field measurements. Seismology and infrasound monitoring research has demonstrated their use in tracking PDCs, however, the relationships between flow dynamics and signal generation are poorly understood.

Here we present research into the relationships between the seismoacoustic signals generated, and properties of the flows gained through experimental methods. The large-scale eruption simulator PELE (Pyroclastic flow Eruption Large-scale Experiment) at Massey University can generate high-energy currents of hot pyroclastic material and gas. This apparatus has been upgraded to include acoustic and accelerometer sensors to provide a series of signals in a controlled environment to improve our understanding of the signal generation mechanisms and relationships to the flows. There are three distinct observed phases in the acoustic and pressure data for each observed flow. These three phases correspond to an initial air wave produced by the simulation of column collapse, as material enters the confined channel, a phase of elevated pressure follows this, and finally, the highest amplitude signal arrives with the flow at the sensor.

Both the Whakaari 2019 and Te Maari 2012 eruptions produced PDCs and were recorded with the GeoNet seismoacoustic network. In order to better understand these signals a combination of results from the experimental observations and topographic effects must be considered.

Understanding the "Window of Vulnerability" in New Zealand's steepland plantation forests

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Harvesting of steepland forests results in a short period known as the 'window of vulnerability' (WoV), where the landscape is particularly susceptible to rainfall-triggered shallow landslides. It is a period in the forest's rotation where declining root strength coincides with changes in soil hydrology that results in low soil strength and the slope is susceptible to failure, particularly from intense rainfall. The WoV has been considered to occur up to 6 to 8 years following clearfelling.

We determined when maximum susceptibility to rainfall triggered landslides occurs within the WoV by examining three areas (Marlborough, Tasman, East Coast) where significant rain events (AEPs < 1%) between 2018 and 2021 resulted in many landslides on forest land harvested prior to those events.

Using forest company imagery, LiDAR and satellite information we manually mapped rainfall-triggered landslides for each study area. Landslides were 'tagged' to vegetation cover, time since harvesting and whether associated with forest infrastructure such as roads and landings, and their connectivity to streams.

Maximum landslide density occurred on land clear-felled 1 to 4 years (average 2 to 3 years) prior to the event and varied slightly between study areas. Landslides also occurred in older forest age classes (> 6 years) and on areas with different vegetation covers, i.e., mature indigenous forests, pasture, scrub, etc. Fewer landslides were associated with forest infrastructure such as roads and landings than 'natural' slope failures. On average, half the landslides were connected to streams and were thus able to deliver sediment and woody debris.

Better information on susceptibility to rainfall-initiated landslides following forest removal may help forest managers and regulators understand this hazard and what can and cannot be done to mitigate events that often result in 'disastrous' off-forest impacts as observed in New Zealand in recent years including Cyclones Hale and Gabrielle in 2023.

From Maruia to Milford Sound: extending our understanding of the Alpine Fault's seismicity

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The Alpine Fault poses significant hazard to people and infrastructure in New Zealand, with a high probability of rupture in coming decades. In order to accurately determine potential Alpine Fault rupture scenarios, reliable information on background microseismicity, and therefore of the seismogenic thickness, is required.

The Southern Alps Long Skinny Array (SALSA) is comprised of 56 seismometers every 10 km along the Alpine Fault and aims to provide continuous spatial and temporal coverage along its length. This dense, expansive network contributes high-quality data to detect and locate background microseismicity from Milford Sound to Maruia. However, to process all data manually would be very time-consuming, and would likely result in a biased and inconsistent catalogue. Rather, we use EQTransformer, a deep learning model for earthquake signal detection to create a more consistent microseismicity catalogue.

To ensure our catalogue is robust and highly complete, we conducted rigorous tests and carefully selected optimal parameters to achieve high-quality earthquake phase picks. These methodologies were successfully applied to data from over 80 stations during SALSA's operational period. In this presentation, we highlight the outcomes of these innovative techniques within a network that covers the entire length of the Alpine Fault, providing valuable insights into seismic activity in the region. Furthermore, our work demonstrates the potential of combining deep learning with high-quality data to enhance earthquake monitoring and hazard assessment in seismic regions.

Contrasting vegetation recovery and landscape responses in the Hawke’s Bay region and Waikato lowlands after the 1.8 ka Taupō eruption

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Lake sediment cores are valuable archives for assessing periods of past environmental change, landscape development, and climatic shifts through time. Using historical cores from Lake Tūtira (Hawke’s Bay) and Lake Rotokauri (Waikato), novel insights into the ecological impacts of the 1.8 ka Taupō eruption on proximal and distal ecosystems were provided through targeted, fine resolution sampling around thick (6-cm-thick) and thin (6-mm-thick) primary tephra deposits, respectively. Lake Tūtira is situated within a highly active and complex catchment that is sensitive to climatic, tectonic, and volcanic drivers, which have episodically disturbed the catchment and generated large volumes of sediments. Through a combined litho- and palyno-facies approach, the immediate volcanic impacts on the catchment landscape and vegetation from successive episodes of ashfall during the Taupō eruption were able to be distinguished from the devastating and prolonged effects of nearby ignimbrite emplacement. In contrast, coarse ash was deposited irregularly across the Waikato lowlands during the final and most explosive phase of the Taupō eruption. Immediately above the tephra is evidence of ashfall- and fire-induced forest disturbance, which reflects an opening-up of the podocarp-hardwood and kauri forest surrounding Lake Rotokauri from a combination of tephra deposition, lightning strikes, and burning both during and after the eruption. On a regional scale, forest recovery across the Waikato lowlands over a period of ~70 years was likely prolonged by the sporadic occurrence of fires under inferred arid, El Niño-like conditions, with compositional adjustments (i.e., increased kauri) likely reflecting an adjustment to drier climates accelerated by volcanic disturbance. These insights into the contrasting vegetation responses and timescales of landscape recovery were only possible due to fine resolution sampling, thereby demonstrating the value of millimetre-scale palaeoecological analysis for assessing past eruptive impacts on sub-decadal timescales that are comparable with observations following modern volcanic eruptions.

Engineering geological aspects of urban landslides in Gisborne, New Zealand

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Throughout Aotearoa-New Zealand, landslides are a widespread geohazard, often posing significant risk to infrastructure and/or human life. While residential development of hill slopes above floodplains means that the houses are more resilient to riverine flooding, they can be more at risk from slope instability. In Gisborne, urban areas have extended up-slopes and along ridgelines, increasing the exposure to landslide hazards. Gisborne is particularly prone to landslides due to the region's young, soft geology, steep topography, vulnerability to cyclonic weather events, seismic hazard, and history of land use change. The impact of Cyclone Gabrielle in February 2023 across the Gisborne region was profound: 52 houses were "red stickered", 270 houses were "yellow stickered", 12 bridges were lost (47 more were substantially damaged), state highways were closed at various locations, and 4 marae were severely affected. Numerous rainfall-triggered landslides occurred, and some of these have had lasting effects. The focus here is on the western end of Russell Street in Gisborne's Whataupoko suburb. The activation of the landslide complex, which is currently ongoing, has caused direct damage to at least two houses, with the slope vulnerable to reactivation from rainfall and/or seismicity. An engineering geological investigation was undertaken, including Cone Penetration Test (CPT) and Shear Vane to characterise subsurface material properties. Samples of the landslide materials were retrieved to characterise mineralogy, particle sizes and plasticity. Remotely piloted aircraft system (RPAS) surveys have been undertaken to track sequential changes in surface geomorphology at the site. Finally, numerical modelling is also being used to explore the potential effects of seismicity at the site under different groundwater conditions. This should provide insights into how intersecting geohazards can have a "layering effect" on resilience, important considerations within the government's Future of Severely Affected Land (FOSAL) categories and managed retreat.

Future availability of hydrogen, ammonia and liquid biofuels for heavy transport and aviation in New Zealand

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Hydrogen has been suggested as a fuel or energy carrier to replace fossil fuels, and the utopian idea of a low-emissions future where energy currently obtained from petroleum comes instead from 'green' hydrogen has been enthusiastically embraced. However, hydrogen is costly in terms of infrastructure and energy to produce and distribute. Each kilogram of 'green' hydrogen requires ~50 kWh of energy to produce via electrolysis assuming 80% efficiency but yields a product with a calorific value of only 39 kWh/kg. The more economical SRM synthesis route requires 11 kWh energy input, a natural gas feedstock (calorific value 52 kWh/kg) and emits ~10 kg CO_2eq per kilogram of hydrogen.

Furthermore, hydrogen cannot be easily compressed to a useful energy density and requires a heavy containment vessel which robs transport vehicles of payload.
For these and other reasons, hydrogen is far from ideal as an energy carrier or fuel for aeroderivative gas turbines or heavy transport vehicles.

Alternatives to hydrogen include ammonia, which is easily compressed to a liquid and can be co-fired with pilot hydrocarbon fuel in turbine, diesel or Otto cycle engines. However, low-emissions ammonia manufacture requires 'green' hydrogen feedstock. Production of enough 'green' hydrogen to completely replace New Zealand's annual consumption of diesel fuel with ammonia would require ~55 TWh which is ~133% of New Zealand's current electricity consumption.

Liquid biofuels can be produced from lignocellulosic feedstock, but solar insolation, photosynthetic efficiency, and intrinsically low manufacturing yields impose fundamental limits on potential production. Replacing all petroleum-derived fuels with liquid biofuels would require ~14% of New Zealand's land area to be cultivated for fuel crops.

The need to decarbonize aviation and heavy transport and the practical difficulties involved in meeting future demand for liquid biofuels will inevitably result in significant freight cost increases and may lead to future shortages of staple foods and essential supplies.

Tsunamis in Lake Taupō, New Zealand, on November the 30th 2022: observations, interpretation, and implications

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A magnitude 5.7 earthquake occurred under Lake Taupō in New Zealand at 11:47pm (local time) on the 30th November 2022. Local residents reported hearing unusually loud waves crashing on the beach after the earthquake, and the following day evidence of tsunami waves was discovered around the lake shore. Three water-level gauges also recorded tsunami waves. Surveys were made to record inundation heights and extents around the lake. Interpretation of the data suggests that there were at least two tsunami sources: (1) a largely sub-lacustrine landslide occurring in Four Mile Bay, adjacent to Wharewaka Point near Taupō township, and (2) movement of the lakebed near Motutaiko Island during the earthquake. The observed impacts of the landslide-caused tsunami appear to be largely confined to within a few hundred metres of the landslide source, while those generated by the co-seismic lake-bed movement are more widely distributed around the lake, particularly on the eastern side. Tsunami observations have been interpreted alongside seismic and geodetic data to better understand the source processes. Modelling and further work to quantify both tsunami sources are ongoing. We will describe the installation of new water-level instruments to better monitor lake water disturbances, e.g., caused by future volcanic unrest, and discuss the implications of this event for our understanding of the hazards and risks to the Taupō region.

Implementation of an experimental MEMS-based EEW sensor network supported by decentralised peer-to-peer mesh networking architecture: progress and future directions

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In contemporary earthquake early warning (EEW) networks data processing for detecting an earthquake takes place remotely at the cloud layer, and the warning is sent out as push notifications to the end-users. The processing of ground motion data at a central location provides the advantage of better control in the detection, collection, and processing of data during an earthquake and immediately afterwards. However, processing data centrally creates several technological bottlenecks. One of the main limitations is the risk of disruption in data transmission to a central location due to the failure of telecommunication infrastructure after a big earthquake. Data processing centres, intermediate data collection centres, and infrastructure to transmit data can be severely disrupted or destroyed after an earthquake. The unavailability of the central processing capability due to the loss of connectivity may hinder the issuing of time-critical warnings to end-users. Having recognised the limitations of centralised processing, national-level EEW system implementations across the globe have invested in redundancy solutions for data transmission and processing. However, the acquisition of data communication redundancies leads to a significant increase in both the EEW system implementation and operating costs. To overcome the limitation of centralised EEW systems, we have implemented a fully decentralised community-engaged MEMS-based EEW sensor network architecture in the Wellington region as a pilot project. This EEW network has been in operation for nearly three years helping us to evaluate the decentralised approach taken and providing an opportunity to experiment with the methods of data capturing, communication, and earthquake detection. With this approach, ground motion data is processed only at the edge layer with a lightweight intensity-based algorithm to detect earthquakes. In this presentation, we intend to share our learnings and experience since the initial implementation of the network including, opportunities, challenges, limitations and future trajectories of decentralised approaches to EEW.

Geoelectric structure of Northland, Auckland & Waikato Regions: a magnetotelluric survey in Aotearoa, New Zealand

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As an initiative to understand more about the conductivity structure of Aotearoa, New Zealand, a 52-site regional-scale magnetotelluric (MT) survey has been conducted along the northernmost land mass of the North Island. Among the methods for exploring the subsurface electrical resistivity of Earth, the MT technique remains the most efficient for obtaining information about the geoelectrical structure from the near surface to depths on the order of 100km. The surface impedance (Z) obtained utilizing the MT technique, is a key quantity in estimating how easily current moves through the earth. New Zealand being situated along subduction interfaces and surrounded by conductive oceans provides an intriguing yet challenging case study to analyse the influence of these features utilizing the MT impedances. This work briefly discusses the MT fieldwork/data acquisition and highlights the preliminary results from the MT data analyses. Additionally, the surface geoelectric fields are modelled to identify where the largest electric fields occur and are validated by the known geology and geophysics of the region.

Traditionally, the MT method is often employed for geophysical applications to delineate conductive boundaries and quantify fluids and partial melts. In this case, the MT data have been acquired to measure the electric fields that move along the earth structures and induce currents along man-made conductive pathways such as electric transmission lines, pipelines, and railways. The accumulation of these geomagnetically induced currents (GIC) can result in the degradation of transformers, and in extreme cases result in an electrical grid blackout. Ultimately, modelling the geoelectric structure of Northland, Auckland and the Waikato will provide insight to which portions of the electrical grid infrastructure are most susceptible to GIC.

GeoCamp and Tūhura Papatuānuku GeoNoho

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Since 2010 GNS Science has been running GeoCamp, a field-based learning experience that opens the world of science for local schools. The aim of GeoCamp is to give year seven to nine school children and their teachers the opportunity to learn from professional scientists about the scientific process, using content focused on geological forces and environmental processes that have shaped Aotearoa.

In 2020, partnership with Te Rūnanga o Te Rarawa and Te Aho Tū Roa led to a new initiative of noho-marae wānanga: Tūhura Papatuānuku. Tūhura Papatūānuku aims to enthuse Māori tamariki from rural areas about the possibilities of science prior to starting high school. Two important elements to achieve this outcome are place: holding the wānanga in a familiar and immersive noho-marae setting, and content: focused co-design and co-delivery with Māori knowledge-holders and educators to ensure integration of topical science content with te āo Māori. This includes Māori pedagogical approaches of engaging iwi with te taiao such as waiata, kemu Māori, whanaungatanga activities, karakia, and Maramataka Māori. In this way, we hope to create a space where Māori educators, hau kāinga, and GNS Science researchers collaborate to share the concepts and material they believe are important to this context.

Feedback we gather from educators and students in the form of informal debriefs and surveys is used to refine the programme over time. In our GeoCamp setting, we have also examined ‘attitude change’ to science and scientists, before, after, and in the 6-months following the camp experience.

He haerenga mōrearea - a hazardous journey; exploring Mātauranga Māori and volcanic hazards

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Mātuaranga Māori and mātuaranga-a-iwi are unique to Aotearoa that have guided a general understanding of our land as well as provided more specific insights into volcanism that parallel many of the of the problems we are trying to solve today within scientific research. Rūaumoko and expressions of Rūaumoko on the surface of Te Ika a Maui have shaped our cultural and physical landscape. This constant activity and changing surface have contributed to the development of new knowledge and mātuaranga since Māori first settled Aotearoa. The related mātuaranga recognises the source of magma deep inside the earth, its connection to the wider Pacific and the Pacific Ring of fire connecting Aotearoa to areas of volcanism to Rangitāhua and further afield to Hawaiki. Our whenua has been shaped by volcanoes that have power to influence the development of iwi and hapu and are seen as entities with specific personalities. The eruptions that have occurred over the last 1000 yrs. have guided our waka, provided navigational markers in the sky and create new fertile land for settlement. In recent times the tohu and environmental changes that occurred in our landscape were listened to and applied to provide forecasts of potential destructive activity. During the 20th Century several eruptions from Ruapehu has driven iwi, such as Ngati Rangi and Ngati Hikairo to participate in emergency management and decision-making roles to keep communities safe. A new form tangata tiaki has emerged to create new processes of disaster risk reduction based on mātuaranga-a-iwi to ensure the iwi maintains an equitable role in decision making and encouraging our young to solve problems using mātuaranga Māori, science, and technology.

Antarctic environmental evolution from a pollen and biomarker compilation

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High latitude records of terrestrial and ocean environmental change are key to understanding past Antarctic ice sheet changes, that inform predictions of the continent's contribution to future sea-level rise. Here, we combine pollen data from 50 years of sedimentary drilling of the Antarctic margin of the Ross Sea and Wilkes Land sectors, to create an 'Antarctic composite' pollen record of Eocene-Recent age and compare it to a composite sea surface temperature record from biomarker Tex86. Our composite pollen draws on 11 stratigraphic sections, and applies a consistent library of taxonomic names, collated into 2 million year time intervals. Our biomarker record draws on 7 sections. Pollen diversity is generally low for the entire record, and dominated mostly by *Nothofagidites* pollen, except during the early middle Miocene when *Podocarpidites* pollen is more abundant, coinciding with peak Neogene sea surface temperatures. In situ pollen are not recorded in samples younger than the base of Late Miocene time.

Present-day stress pattern of New Zealand

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Interaction of Australian and Pacific plates at New Zealand provides an ideal location to investigate the contemporary stress pattern. In this study, we compiled extensive stress data from six established methods to investigate the lithospheric stress pattern of New Zealand. To map the stress pattern, we compiled stress data from 289 boreholes, 4037 from earthquake focal mechanisms, 218 data records from formal inversion of focal mechanisms, and 72 stress orientations from neotectonic geological structures.

The database has been separated in two sets for above and below Moho depth to define the crustal and mantle stress maps. The crustal stress map reveals a consistent ESE-WNW orientation of the maximum horizontal stress SH_{max} in much of the South Island. The SH_{max} orientation throughout the South Island’s crust is at a high angle to the strike of major active strike-slip faults, indicating that major strike-slip plate boundaries are mechanically weak features. The crustal SH_{max} pattern in the North Island is variable and affected by the active subduction of the Pacific Plate.
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here are limited data for mantle depth in South Island so that no conclusive statements can be made. The mantle dataset in the Hikurangi Subduction Zone shows a variable pattern similar to the crustal stress. However, the mantle stress pattern in Taupo Zone is completely different from crustal stress suggesting a strong decoupling between mantle and crust.

In this study, we compared the neotectonic stress regime (inferred from fault database) with the stress regime (inferred from stress data) in 28 tectonic domains. In most of the domains there is an agreement between the observed faults, faulting style and the observed stress field, which indicates the activeness of these faults. However, in some domains there are discrepancies between the acting stress field and the observed faults which indicates non-optimal orientation of the faults.

Recent developments in medium-term earthquake forecasting in New Zealand and beyond

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EEPAS (Every Earthquake a Precursor According to Scale) is a NZ-developed medium-term forecasting model. It is based on the work of Evison and Rhoades since the late 1970s and was proposed as a generic statistical framework for producing earthquake forecasts in 2004. EEPAS has unique features and capabilities that distinguish it from conventional short-term forecasting models e.g., ETAS (Epidemic-Type Aftershock Sequence) and STEP (Short-Term Earthquake Probabilities). EEPAS is aimed at forecasting major earthquakes rather than aftershocks, with time horizons ranging from months to decades. It is internationally established and well-tested. It has been effectively used in NZ hybrid earthquake forecasting and the National seismic hazard model to enhance spatial representation of hazard for areas of concern, e.g., Christchurch.

There is a research and application gap between short-term aftershock forecasting and long-term hazard modelling in many scientific organizations within NZ and beyond. By providing a medium timescale of forecasting, EEPAS can fill this gap, yet it is not widely studied and utilized. We are in the process of creating an open-source version of the original EEPAS code. It will be available at no cost for research purposes. The original EEPAS code produces practical forecasts without a need of expert enhancement and is accompanied by a comprehensive manual to support its appropriate use in suitable applications. The full code has additional modules to include space-time trade-off and strain rate-precursor time relationship and to minimize effects of catalogue limitations in forecasts. Producing optimal forecasts with the full EEPAS code needs expert support. Therefore, we need time to complete implementing such developments. Until opening of the full source code, we provide access to the compiled code upon request. Open sourcing the original EEPAS should increase understanding and application of this model, facilitate innovative collaborations, and enhance natural hazard management and resilience.

Geological map products for Aotearoa New Zealand

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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, largely with Nationally Significant Collections and Databases funding. Ten geological maps in the series have completed map components, at continent/national, regional and urban extents, many of which have accompanying explanatory texts. The national datasets are GM1, the GIS-based Geological Map of New Zealand 1:250,000 dataset just released in its 4th edition and GM2, the 1:1,000,000 Geological Map of New Zealand close to release as a 3rd edition. Both releases incorporate improved geology and improved fault accuracy. GM11 is the 2020 dataset associated with the tectonic map of Te Riu-a-Māui/Zealandia poster at 1:8,500,000.

The regional geological products include GM4, a printed and digital geological map at 1:60,000 of the Tongariro National Park area (2017, 2020). The underlying GIS dataset has been upgraded with new interpretation of the Tongariro volcano. GM5 and GM6 are digital-only 1:50,000 geological maps and associated GIS data for the Middlemarch (2016) and Victoria Range (2019) areas respectively. Immediately west of the latter is GM10, a yet-to-be completed 1:50,000 geological map of the Reefton Goldfield. GM9 is the 2021 1:50,000 geological map of the Hyde-Macraes Shear Zone and Waihemo Fault Zone area. The GM8 1:130,000 geological map of the Taupo Volcanic Zone in production is focusing on the area's eruptive geology.

Urban geological map products include the GM3 urban Christchurch and eastern Canterbury (2015) digital-only product that includes a geomorphological map/GIS dataset and 3D geological and geotechnical models. GM7 Napier-Hastings at 1:75,000 (2020, 2022) and GM12 Pukekohe at 1:50,000 (2022, 2023) include printable geological maps, GIS datasets and 3D geological models with geomorphological maps pending. GM13 is a 1:30,000 geological map of urban Dunedin near completion focusing on improved Quaternary deposit resolution.

Governance of Māori geoscience data

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Since 1865, the New Zealand Geological Survey and the Department of Scientific and Industrial Research from 1926, acquired large quantities of geoscience data across Aotearoa New Zealand, onshore and offshore. Much of these legacy data were assimilated into GNS Science in 1992 who have continued to acquire and manage geological, geophysical and other geoscience data, primarily for scientific research.

In May 2023, Te Kāhui Rauranga (TKR) published a report on their Māori Data Governance Model for use across the Aotearoa New Zealand public service. The report provides guidance for the system-wide governance of Māori data, consistent with the Government's responsibilities under te Tiriti o Waitangi. GNS Science and the other Crown Research Institutes (CRIs) are collectively absorbing the content and implications of the report. According to TKR, Māori data is a taonga comprising "..digital or digitisable data, information or knowledge (including mātauranga Māori) that is about, from or connected to Māori. It includes data about population, place, culture and environment…". Our interpretation of this is data about place and environment connected to Māori covers all of Aotearoa New Zealand's land at and below the surface as well as the near-shore seabed.

This interpretation means the large quantities of Aotearoa New Zealand geoscience data held and managed by GNS Science (geological, geophysical, geochemical etc) are Māori data. TKR's culturally grounded model of protection and care of Māori data is already influencing GNS Science's ongoing management of geoscience data in recognising TKR's definition of Māori data governance as "…the inherent rights and interests that Māori have in relation to the collection, ownership and application of Māori data…".

The practicalities of sovereignty and governance of Aotearoa New Zealand's geoscience data held by GNS Science are beginning to be worked through in collaboration with other CRIs and GNS Science's Māori partners.

Walking backward into the future – what can Paleozoic bryozoans tell us about the future of modern bryozoans?

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Marine bryozoans are heterotrophic active calcifiers and are significant habitat forming invertebrates in modern temperate oceans, including the shelves surrounding Aotearoa. Marine bryozoans are susceptible to ocean acidification impacts, and as habitat formers this has potential consequences for other marine organisms. Modern marine bryozoans fall into two orders, the Cheilostomata, that originated in the Mesozoic, and the less abundant Cyclostomata, that are related to Paleozoic forms that were heavily impacted by the end-Permian climate-driven extinction. Understanding the response of ancient bryozoans to climate-driven change in carbonate saturation is important for predicting how modern forms may respond to future oceanographic change.

Analysis of Paleozoic bryozoan skeleton calcification and latitudinal distribution has revealed distinct differences between two orders. The Trepostomata (Ordovician to Triassic) and Cryptostomata (Ordovician to Permian) both show more calcified skeletons in lower latitude regions through the Ordovician to Devonian. This trend is in keeping with what might be expected given that carbonate saturation states are higher in warmer (lower latitude) waters. In the late Paleozoic (Carboniferous to Permian) each group behaves differently. The cryptostomes continue to show the same higher calcification at lower latitudes and are distinctly rare in higher latitude faunas of southern Gondwana. The trepostomes on the other hand dominate southern higher latitude faunas and show higher skeletal calcification. These southern trepostome bryozoans form larger colonies and also show increased feeding capacity over low latitude trepostomes. This suggests feeding capacity is assisting the trepostomes to metabolically overcome the lower carbonate saturation states typically associated with higher latitudes and colder waters. The dichotomy between Paleozoic bryozoan forms and their calcification response to saturation states indicates that modern groups should be assessed separately when considering how they may respond to changed oceanographic saturation states.

Using sediment cores to understand the environmental history of Aotearoa's lakes

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The health of Aotearoa's lakes is central to our environmental, economic and cultural wellbeing. However, the knowledge we have about their health is very limited because less than 5% of them are monitored nationwide. Additionally, we know nothing about what most lakes were like prior to human disturbances in the landscape. This makes modelling national scale water quality and setting informed restoration targets challenging. The 'Our lakes' health; past, present, future' programme, also known as Lakes380 (www.lakes380.com), is using a comprehensive suite of techniques to assess current health and reconstruct the environmental history of Aotearoa's lakes. The team has been collecting surface water and sediment samples and sediment cores from across Aotearoa. With the sediment cores the aim is to collect 1000 years of lake history, capturing change from before human settlement until the present day. This will assist in understanding what factors have impacted these ecosystems over time. To date the team has sampled 315 lakes ranging from alpine, coastal, lowland and highland sites. A suite of environmental indicators from lake sediments, such as pollen, hyperspectral data and environmental DNA, are used to reconstruct vegetation change, lake productivity, algal abundance and shifts in lake health. Here we present details of the workflow associated with this ambitious national scale project, including core preparation and storage, curation and tracking of samples, sampling methods and analytical techniques and description of specialised equipment that are used in the team's laboratories.

Reference:
https://lakes380.com/

Morphological evolution of the Hunga Tonga–Hunga Ha'apai submarine volcano caldera

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The unprecedent eruption of the Hunga volcano in January 2022 is considered the most powerful explosive event recorded in more than 140 years, drawing global attention to the risk of submarine volcanoes eruptions triggering destructive tsunami and compromising offshore infrastructures. Submarine eruptions are generally poorly understood and may lead to large calderas collapses, with the resulting morphologies providing invaluable information for understanding the processes during highly energetic and unpredictable eruptions.

Here we present unique pre- and post-eruption morphological analyses of the Hunga caldera, comparing repeat multibeam bathymetry acquired in 2015-2015, May 2022 and October 2022. The post-eruption morphology reveals a 4 km-diameter concentric circular basin with steep inner flanks, resulting from the caldera collapse down to ~850 m. The total loss volume calculated is of an order of 8.9 km^3 ± 0.1 km^3. More than 50 active gas plumes of up to 30 m high were observed inside the caldera 5-months after the eruption. The plumes located at deeper regions dissipated 10-months after the eruption, and little to nil subsidence was detected in the caldera basin, indicating the magmatic system in that area has degassed. Our observations suggest that the risk of future eruptions and consequent caldera wall collapses has reduced after one year of the eruption.

The unique high-resolution bathymetric datasets around Hunga volcano prior and post-eruption analysed here enables us to identify changes to the seafloor induced by the January 2022 eruption. This detailed information provides a first basis for targeting higher-definition research to identify volcano-ocean coupling via caldera collapse, pyroclastic flow/gravity currents and translate that information to provide a first-order hazard evaluation on other nearby potentially hazardous caldera volcanos.

Whale-fall scallops decode the Mid-Cenezoic – hunting down strontium dates across the Oligocene-Miocene Boundary and a review of Mid-Cenezoic chronostratigraphic data

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In the mid 20th century, a series of key bioevents were identified in the Oligo-Miocene marine strata of Zealandia and led to the formation of a structured framework of the New Zealand biochronostratigraphic stages. These have remained relatively unchanged to the current day, though the local NZ Stages exact relationships to international timescale and the stage boundary dates can do with further revision. Recent investigations into cetacean evolution during a 'dark age' in the earliest Miocene (Aquitanian, 23–20 Ma) led to the need to obtain high resolution dating for the NZ fossil cetaceans from around the Oligo-Miocene boundary. There is a lack of biostratigraphic resolution associated with the Oligo-Miocene boundary to precisely date local stratigraphy, especially in terms of resolution of bioevents (eg: low resolution of pericontemporaneous foraminiferan FAD/LAD bioevents). Here, we report 23 new strontium ($^{87}Sr/^{86}Sr$) dates from scallop (Pectinidae; Lentipecten) shells associated with 16 mysticete and 7 odontocete specimens, respectively. Of these, 8 fall within the Early Miocene and 7 – including 5 mysticetes – have their error weighted mean strontium isotope-derived dates specifically within the Aquitanian. The use of an updated marine strontium isotope curve coupled with comparisons of stratigraphic placements and microfossil assemblages shows that the Waitaki Valley's Late Oligocene to earliest Miocene stratigraphy and derived biozones are younger than currently reported. Various NZ stage boundary dates are discussed, with the takeaway point being the need for further analysis. The methodology of strontium isotope collection is discussed with the need for high precision sampling of unaltered shell material stressed to be of importance for high resolution dating.

Lacustrine charcoal as a proxy for prehuman wildfires in Central Otago, New Zealand

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Central Otago has been identified as one of the most at-risk areas regarding wildfire. This is, in part, due to an abundance of highly flammable vegetation and relatively arid summers. This study aims to provide a better understanding of climate change in the South Island of New Zealand by analysing charcoal from Lake Johnson and correlating variations with shifts in the climate. Lake Johnson is located within the Queenstown Hill "Red Zone", an area with a year-round fire ban due to its increased risk of wildfire within this already prone region.

As the aridity and mean annual temperature of a region increases, so does the extent and severity of local wildfires. These wildfires produce a significant amount of charcoal, which then accumulates over time in nearby lake sediment. Analysis of a contiguous charcoal accumulation rate (CHAR) can be used to compile a local fire history.

Previous studies have used CHAR to show changes in vegetation and biota in response to anthropogenic forcing. As New Zealand is unique in the fact that it was colonised within century, changes in the amount of charcoal accumulating in the bottom of our lakes may be able to tell us about large-scale variations in fire climate over time. Currently, our understanding of a natural wildfire regime is limited by a lack of high-resolution data prior to humans arriving in New Zealand. Furthermore, existing Holocene CHAR records from Central Otago are often discontinuous and not suited for in-depth analysis.

Here, we present an initial high-resolution (1 cm) analysis of CHAR from neighbouring Lake Hayes spanning the last ~1 ka. The preliminary data suggest evidence of wildfire within Central Otago prior to the arrival of humans.

Backtracking magma pathways from the eruptive vents down through the Earth's crust to locate the melt source feeding the Auckland Volcanic Field

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The mechanisms underlying the Auckland Volcanic Field, both in terms of why and where the melt is generated and what controls the scattered distribution of the eruptive vents, are still poorly understood. Here we use mechanical models of magma propagation through diking to backtrack magma pathways down through the lithosphere starting from the location of past eruptive vents. Conducting these simulations first requires establishing the elastic stress field in the wider region, in terms of active deformation, strength of host rocks, and other influencing factors such as recent surface load redistributions. We determine principal stress orientations through analysis of continuous and campaign GPS data and model surface loads redistribution through Boundary Elements models the dominant surface loading and unloading generated by rifting and sedimentation, especially in the adjacent Hauraki rift. Next, we simulate in reverse pathways of buoyant magma using a simple penny shaped crack subject to internal magma pressure and external stresses assumed to vary linearly on the surface of the penny and evaluating the direction of maximum stress concentration.

Magma pathways calculated in this manner dive subvertically below the AVF before becoming subhorizontal, directed to a poorly constrained lithospheric volume situated at depth ~30 to 70 km below the Firth of Thames. The shape of the trajectories, subvertical below Auckland and then subhorizontal at depth, imply slow dike propagation at depth after release, followed by accelerating ascent below Auckland. Work is ongoing to quantify expected dike ascent velocity along the pathways and assess the robustness of this model against relatively large uncertainties on regional stresses and sediment loading over space and time.

Small tsunami can represent a danger to navigation and persons in an apparently sheltered area: a case study of Mana Marina, Porirua.

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If threat posed by tsunami currents to navigation and persons in coastal areas is not a new concept, a recent study focusing on Porirua Harbour in New Zealand's North Island, and more specifically Mana Marina, underlines the issue for an apparently sheltered location. Analyses of Mana Marina sea level gauge data clearly reveal signals of six tsunamis in the past 12 years. Five of them were linked to powerful local, regional, and far-field earthquakes, i.e., the 2011 Tohoku (Japan) M_w 9.1, the 2015 Illapel (Chile) M_w 8.4, the 2016 Kaikoura M_w 7.8, the 2021 Matthew Island (New Caledonia) M_w 7.7, the 2021 Kermadec M_w 8.1, and one was triggered by the 2022 Hunga Tonga-Hunga Ha'apai (HTHH) volcano's submarine eruption in Tonga. To have a full picture of their impact inside and outside the marina, numerical simulations of these events were performed using COMCOT model and a dedicated high-resolution Digital Elevation Model (DEM) of Porirua Harbour. The generation of tsunami waves was calculated using source parameters from previous studies, except for the HTHH tsunami for which this study used combined source mechanisms. Simulation results of the past events show good agreements with their gauge records in terms of arrival times, wave amplitudes and polarities. With the same model configurations, further simulations of larger magnitude hypothetical scenarios reveal that in all these hypothetical scenarios tsunami currents could reach up to 10 m/s in upstream and downstream harbour channels outside the Mana Marina, where the inlets are narrow. In most cases of tsunami simulations in this study, the simulated tsunami currents could reach or exceed velocity threshold (1.5 m/s) for safe navigation inside the marina, and sometimes show persistent vortex patterns. This study does not consider dynamic interactions of tsunami waves with tides.

How often do subduction interfaces and overriding upper-plate faults rupture in the same earthquake (or close enough in time to be the same situation)?

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The New Zealand National Seismic Hazard Model separately assesses the probabilities of a wide range of earthquakes on upper-plate faults, on subduction interfaces (Hikurangi and Puysegur), and in subducting slabs. However, an elephant in the room is the possibility of a joint rupture– an earthquake (or sequence) featuring slip on both a subduction interface and one or more upper-plate faults. The worst-case-scenario earthquake for Wellington might be a joint rupture of the southern Hikurangi interface and the southern Wellington Fault: the first could pose a tsunami hazard, the second could rupture lifelines, and both would cause strong shaking. The worst-case scenario for Napier might similarly be a joint rupture of the central Hikurangi interface and the Napier Fault (which ruptured in the 1931 Hawke's Bay earthquake). The possibility that the Puysegur interface and the southwestern Alpine Fault could rupture together is also highly relevant given the high likelihood of an Alpine Fault rupture in the next century. However, few constraints exist on the frequency and likelihood of joint ruptures. Studies have disagreed on whether the 2016 M=7.8 Kaikoura, 1931 M~7.6 Hawke's Bay and 1855 M~8.2 Wairarapa earthquakes, which are mainly known for their upper-plate-fault slip, may also have involved slip on the underlying Hikurangi interface. In applications of physics-based earthquake simulators to New Zealand, joint subduction/upper-plate ruptures occur frequently, but it is uncertain how much this behaviour is controlled by modelling assumptions and details of model setup. To ground-truth the earthquake simulators, we look at the largest recorded subduction earthquakes around the world and examine how many of them also involved slip on upper-plate faults or were closely followed by large upper-plate aftershocks. We also examine potential interactions between subduction-interface and upper-plate seismicity in Hikurangi earthquake sequences in 1961 and 1990, and in recent earthquakes on the Puysegur subduction zone.

Widespread assimilation of altered crust in the Taupō Volcanic Zone

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Magmas with low $\delta^{18}O$ values, which require a contribution of isotopically light oxygen from hydrothermally altered rocks, are globally rare despite the common association of large-scale magmatism with intense hydrothermal activity. We considered this paradox in the central Taupō Volcanic Zone (TVZ), one of the most intense regions of magmatism and hydrothermal activity on Earth. We analysed phenocryst $\delta^{18}O$ values from 62 magma batches erupted since ~1.6 Ma, ranging from basalt to rhyolite, and matched these against existing and new Sr-Nd isotopic data. Basalt $\delta^{18}O$melt values (typically >+6.3 to +6.5‰) calculated from phenocrysts are mostly high relative to MORB, whereas basaltic andesites extend to +7.1‰. Rhyolite $\delta^{18}O$melt values are mainly +7.0 to +8.5‰, which is considered high-$\delta^{18}O$ in most settings. However, assimilation and fractional crystallisation (AFC) models show a mismatch between the amount of greywacke basement assimilation required to explain the Sr-Nd isotopic ratios and the $\delta^{18}O$ values of many TVZ rhyolites. We attribute this mismatch to assimilation of low-$\delta^{18}O$ altered rocks after prior assimilation of unaltered greywacke. This suggests that interactions between silicic magmas and shallow altered crustal rocks are common and widespread in the TVZ. The absence of low $\delta^{18}O$ magmas (<~+6.0‰) in the TVZ reflects the combined influence of high parental basalt $\delta^{18}O$ values inherited from the slab, and the limited isotopic leverage available to drive large ^{18}O depletions via alteration in this setting. The TVZ example suggests that interactions between magmas and altered rocks are probably important in many large magmatic provinces and not restricted to the sparse occurrences of low-$\delta^{18}O$ magmas. The lowest TVZ rhyolite $\delta^{18}O$melt values (+6.3 to +7.0‰) cluster along a western corridor of presently weak hydrothermal activity, implying that hydrothermal activity was more intense there in the past, and may have represented a focus of heat flow like the present-day eastern TVZ margin.

Heating temperatures of muddy country rock during dike emplacement

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Paleomagnetic methods can be used as a geothermometer to determine, for example, the temperatures reached in a volume of rock adjacent to an intrusion, emplacement temperatures of ancient pyroclastic deposits, and to understand the effect of surface heating by an overlying cooling lava flow. In all cases, heating produces partial to total remagnetisation of the surrounding rock, overprint that is then captured with step-wise demagnetization. In the case of planar intrusions such as dikes, applying this technique should therefore provide a profile of the maximum temperatures reached as a function of the distance from the intrusion.

Here we present preliminary results from a paleomagnetic study done on sedimentary rocks adjacent to eruption feeding intrusions from the Hopi Buttes Volcanic Field in Northern Arizona. Two dike-perpendicular profiles were done with samples collected from very fine-grained lenses within the mudstone-sandstone beds of the Petrified Forest member of the Chinle Formation, located at approximately 350 m below the eruptive paleo surface. Due to the nature of the country rock, oriented blocks rather than drilled cores were collected in the field. Subsequent sample preparation and analyses is being conducted at the Otago Paleomagnetic Research Facility at the University of Otago. Specimens will be step-wise thermally demagnetized at 25°C increments up to 650°C and magnetic moment measured using a 2G Enterprises pass-through superconducting magnetometer. Additional rock magnetic analyses will be done on the specimens using a Kappa bridge and VSM.

In combination with the results from analogue experiments and thermal models, we will use the results from this study to determine the thermal effect of magma flow in feeder dikes on the surrounding country rock.

Where will it flow? The relative effects of temperature, cross sectional area and wall defects on flow focusing in artificial fissure eruptions

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Here we present the results from our preliminary experiments focusing on the influence of feeder dike/fissure wall properties on near-surface transport of magma and subsequent eruption. In these experiments we inject molten wax into a slot at varying wax injection rates, and monitor flow behaviour with visual observations, particle tracking, and temperature measurements at the wax-wall interface.

Our observations show that flow diverts from narrow and colder sections of the fissure to wider and warmer segments in the early stages of an experiment. This is attributed to the susceptibility of the narrower sections to wax cooling and solidification, leading to flow-slowing and physical blockages within the eruptive fissure particularly at the downstream end. This behaviour is consistent with the numerical evaluations previously presented by other authors (e.g., Bruce and Huppert, 1990, Wylie et al, 1999). Furthermore, we can see the thermal effect of flow becoming focused into wider segments, where columns initially wider tend to be warmer compared to the rest of the fissure. Importantly, these results are consistently reproduced in our experimental setup.

In subsequent phases of our experimental approach, we are introducing defects such as cavities and blockages to assess the consistency of flow behaviour in a non-planar pathway. These obstacles represent wall-rock erosion, magma solidification and wall-rock collapse into the fissure and are placed strategically to look for interesting flow patterns and feedback effects. Results from this series will be extremely useful in assessing the predictability (or unpredictability) of fissure eruption evolution in early eruptive stages.

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Intraplate volcanism and characterisation of Caravel Granite in the Canterbury-Great South basins, New Zealand

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The geometry, size, distribution and age of igneous rocks provide insights into what are the driving mechanisms for magmatism, the longevity of the underlying magmatic activity, the relationship between plate-boundary processes and magmatism, and into sediment dispersal patterns around volcanoes. This study uses 2D/3D seismic, well and magnetic data to map the distribution of buried volcanics and intrusive igneous rocks within 105–83 Ma, 83–66 Ma, 66–34 Ma and 34–Recent intervals in the offshore Great South and Canterbury basins. Widespread igneous activity occurred during 105–83 Ma associated with crustal thinning and rifting. Igneous activity gradually decreased in the post-rift succession (since 83 Ma) and mainly show diffuse intraplate magmatism. Distribution of igneous bodies in these basins suggest that some of the magmatic activity occurred along the pre-existing basement terrane boundaries. Initial assessment of available magnetic data suggests that some of these buried igneous bodies have high magnetic anomalies.

This study also investigated detailed geophysical characterisation of Caravel Granite located offshore Canterbury Basin. We discuss the areal extent, structural pattern, age of granite and influence of regional stress pattern on the geometry of this granite. Caravel Granite is bounded by major rift faults and forms the basement rock in the recently drilled well Caravel-1. The top of this granite is highly reflective that differentiates it from the surrounding schist basement rocks. Major grabens developed on eastern and western side of this granite that host petroleum system.

Engineering geological study and runout analysis of urban landslides triggered from intense rainfall in Gisborne, New Zealand

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Landslides occur more frequently and cost more than any other natural hazard in Aotearoa New Zealand. Understanding landslide failure mechanisms and their impacts to urban surroundings, including runout, is important for hazard management.

Gisborne has some of the highest erosion rates in New Zealand, where Multiple Occurrence Regional Landslide Events (MORLEs) are extensive. To better understand the behaviour of rainfall triggered landslides in urban environments, we studied four urban Gisborne landslides initiated by MORLEs from November 2021 to February 2023. Contributing factors included slope morphology, geology, rock mass and sediment characteristics, and anthropogenic slope modification (including vegetation and poorly designed retaining walls). Numerical runout modelling in DAN3D used frictional and Voellmy models with varying parameters. Back analysis found the best fit models for each site. One landslide was forward modelled using the best-fit parameters to simulate a potential larger landslide. Other methods included desktop studies, field observations, laboratory testing, and geomorphic mapping.

We determined that slope angle at the four sites varied from gentle to steep, and that the slopes comprised a mix of alluvial deposits, Tolaga group sandstones and mudstones, and the Mangatuna formation. From our laboratory tests, the landslides contained medium plasticity silts and silty sand. The sediments have low moisture contents and exhibit flow-like behaviours, indicating low friction angles. Runout models were optimised when using low friction angles between 5-10° (frictional models) and low friction coefficient between 0.1-0.3 (Voellmy models).

Landslides in Gisborne’s urban area are commonly reactivations of relict slope instabilities, due to recent repeated high intensity rainfall. The resulting high groundwater tables and low moisture content of the sediments initiate failure in the form of tension cracking and flow-like landslides.

Unraveling the timescales and processes of hydrothermal alteration at Tongariro volcano, New Zealand

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Tongariro is an active composite volcano located in the southern Taupo Volcanic Zone in New Zealand. Its eruptive products range from basaltic andesite to dacite. Tongariro volcano hosts distinct hydrothermal systems, typically formed around actively degassing eruptive vents. Te Maari is one of the recently active vents on Tongariro's northern flanks that produced two small phreatic eruptions in August and November 2012, as well as a debris avalanche with a volume of 7.7×10^5 m^3. The role of hydrothermal alteration in the sealing and eruption mechanisms has been already documented, yet the timescale of alteration and sealing that can lead to such events remains to be reconstructed.

This study is based on fresh and altered sample pairs aiming to reconstruct alteration processes and timescales for mineral precipitation using field geology, petrography, stable isotopes, and thermodynamic modelling. The samples vary in mineralogy, geochemistry, porosity and related physical properties. The fresh samples have abundant plagioclase, pyroxene, and magnetite as primary phases, while the altered samples are characterized by secondary phyllosilicate minerals, including kaolin- and smectite-group minerals, and precipitation of cristobalite and native sulfur. The alteration minerals correspond to intermediate argillic alteration that is caused by acidic fluid flow at the near surface at 150-200 °C. Using samples that have stratigraphically and radiometrically well constrained aged from 45 kyr to a decade old, we show that hydrothermal alteration of the primary volcanic minerals and glass operates on timescales of decades to kyrs. Such rapid alteration may catalyse future flank collapses and phreatic eruptions by changing the mechanical and physical properties of the volcanic altered rocks, with implications for the development of more comprehensive hazard assessment strategies.

Hydrological controls on seismic velocity changes after earthquakes: the WELLington water WELL VELocity change project (WELLVEL)

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The Kaikōura earthquake in New Zealand caused both increases and decreases at water bore levels. We also found drops in seismic velocity at the time of the Kaikōura earthquake ranging from 0-0.2% for paths between temporary and permanent seismic stations, using a station-to-station noise cross-correlation technique. We attributed the drop to damage and cracks opening in the upper 5 km due to shaking during the earthquake, but the role of water in the velocity drops was uncertain.

The WellVel seismic network was deployed from March 2020 through April 2022 at sites of 11 water bores that operated in the Wellington region during the Kaikōura earthquake to determine whether smaller earthquakes would show similar velocity drops in single-station cross-component correlations, and what the relationship is between seismic velocity changes and water bore changes.

For most stations in the WellVel network, increases in water bore levels and decreases in temperature correspond to decreases in seismic velocity. The relationships are strongest in Kāpiti (correlation coefficients greater than 0.8), where a drop of 10% in the water level corresponds to an increase of nearly 0.2% in velocity. We infer that the cause of the seismic velocity drops are higher pore pressures, which lead to a decrease in the effective pressure of the rock and reduce the shear modulus. Temperature changes have a smaller effect. We have not found a strong difference between the seismic velocity response at water bores that increased or decreased during the Kaikōura earthquake, nor between water bores that are shallower or deeper than 50 m.

Correcting for velocity changes due to water level and temperature may allow us to better understand the velocity response of the ground to small earthquakes and possibly to slowly increasing stress due to plate boundary processes. The relationship to ground damage is unclear.

The response of Taupō Volcano to the M7.8 Kaikōura Earthquake

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Several studies suggest that large earthquakes (M>7.0) can act as external triggers for volcanic unrest, and even eruption. This triggering is attributed to either ground shaking (dynamic stresses) or permanent ground deformation (corresponding to static stress changes). However, large earthquakes are rare and testing these hypotheses has proven difficult. We use GNSS data to show that the 14th November 2016 Kaikōura earthquake triggered local deformation at Taupō volcano which lasted for approximately two weeks. Through geodetic modelling we determine that this deformation was caused by either aseismic fault slip or a dyke intrusion. We then use strong motion data from the Taupō area to show that the Kaikōura earthquake caused large dynamic stress changes in the area, despite occurring ~350 km away. We suggest that this dynamic stress change triggered the deformation at Taupō volcano.

Appropriate complexity of volcanic hazard models

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Accurate forecasts are needed to help mitigate the risks of volcanic hazards to society. Current approaches use probabilistic estimates based on sparse data, supplemented with expert judgment, to describe likely future eruption characteristics. These probabilistic eruption characteristics then inform input parameters required by hazard models.
This process requires a lot of simulations with varying input parameters to constrain uncertainty around a future eruption's hazards. This process is computationally intensive, and the outputs may quantify but do not reduce eruption uncertainty. As hazard models become increasingly more complex, so do the number of input parameters which increases uncertainty. As input parameters used for volcanic hazard models are fundamentally uncertain, how does this affect the reliability and utility of forecasts made using these modes?

This research explores the input space of volcanic hazard models to understand the interactions between model complexity and reliability of hazard model forecasts. We use the exemplar of a volcanic ash distribution model Tephra2 at Mt. Taranaki (50% chance of eruption in the next 50 years). Sampling strategies for Tephra2 were developed to make sure that input parameter space was fully covered and represented real-world values – both through independent and dependent sampling of parameters. For example, plume height is dependent on the amount of mass ejected during an eruption. A Global Sensitivity Analysis is presented here that explores which input parameters are contributing most to uncertainty through the statistical evaluation of variance using Sobol' indices and FAST (Fourier Amplitude Sensitivity Tests). The results also shed light on which inputs are vital to better understand/quantify before an event, and ultimately improve short-term and real-time hazard forecasting. Next steps involve running similar methods for Fall3D on the NeSI supercomputers.

A tectonic reconstruction model for Aotearoa-New Zealand from the mid-Late Cretaceous to the present day

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We present a mid-Late Cretaceous to present day tectonic reconstruction model for Aotearoa-New Zealand. Our GPlates model comprises 50 rigid crustal blocks grouped into regions with common deformation histories set within a well-defined Australia-Pacific-Antarctica plate circuit tied to a published global paleomagnetic absolute reference frame. Within the model, four distinct periods of deformation are recognised from both near- and far-field observations. A key model assumption is the continuity of basement terranes between North and South Zealandia prior to Middle Eocene rifting and Late Oligocene initiation of transform motion.

To complement the rigid crustal block model, continuously closing polygons show a ~25% decrease in plate boundary area since the Middle Eocene that has been compensated for by corresponding increases in crustal thickness. A kinematic fault-propagation fold model demonstrates the plausibility of post-Late Oligocene asymmetric oroclinal folding on both sides of the evolving transform boundary. ‘Missing’ areas of map section common to previous tectonic reconstructions can be reconciled through contraction, elongation and vertical-axis rotation of continental crust within the deformation zone ahead of northward propagation of the Alpine Fault. This tectonic reconstruction model provides an open, accessible, and testable foundation for current and future paleogeographic and tectonic studies across Zealandia.

Gabbroic insights into mafic magmatism beneath the K-Trig scoria centre, Taupō Volcanic Zone

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Basaltic volcanism in the Taupō Volcanic Zone (TVZ) is a volumetrically minor component, when compared to the TVZ's silicic volcanism, but plays a significant role in the formation of its silicic magmas. Understanding the deeper roots of the mafic systems is central to explaining why the TVZ is the locus for such intense silicic volcanism. Textural and geochemical analyses from a unique suite of gabbroic xenoliths from the K-Trig basaltic centre are used in this study to provide insights into TVZ mafic magmatism.

The K-Trig scoria centre is one of four monogenetic basaltic centres located off the NE side of Lake Taupō. K-Trig has been excavated by quarrying and the gabbroic xenoliths have been collected ex-situ from the quarry site, along with scoria samples. Mafic plutonics are very rarely found in the TVZ (never previously at a basaltic centre), and these samples are the most mafic compositions (~ 45 wt% SiO_2) recorded. Therefore, the K-Trig gabbros provide a unique opportunity to study the mafic roots of the magmatic systems(s) underlying the NE Taupō area.

The gabbros range in texture from crystal cumulates through to a non-cumulate "mushy" texture of vesicular interstitial glass between phenocrysts. Trace element analyses of gabbros show low ∑REE values (100-180) and the lowest La/Sm(N) ratios (subducted sediment component) of any published TVZ mafic rocks, suggesting these are derived from a depleted mantle source with little sediment input. Conversely, the gabbros and scoria contain low Fo(70-85) olivine and high An(<93) plagioclase, indicative of crystallisation in a water-rich magma, suggesting that aqueous fluids in the sub-arc mantle played an important role in the formation of the K-Trig melts. Strontium isotopic values for the K-Trig suite show little variation and are quite radiogenic (0.704853 – 0.704886) for a basaltic composition, indicating a consistent source of sediment and/or fluid contamination.

Three-dimensional inversion of magnetotelluric data from Mt. Ruapehu, New Zealand

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The andesite–dacite stratovolcano Mt. Ruapehu was formed ~230 ka ago at the southern termination of the Taupo Volcanic Zone (TVZ), a rifted arc and a centre of active rhyolitic volcanism. In the last century, Mt. Ruapehu has been frequently active with the last large phreatomagmatic eruption in 1995/96 and a steam driven eruption in 2007.

To improve the understanding of the magmatic system beneath Mt. Ruapehu, 40 magnetotelluric (MT) measurements have been acquired in the area between 2007 and 2009. 2-D and 3-D modelling shows the hydrothermal area, but due to the sparse site distribution and a code that does not incorporate topography, the resolution of the 3-D model is limited. This year, 28 new measurements have been acquired at Ruapehu to achieve a good coverage of measurements in order to derive a better conductivity model of the subsurface of Mt. Ruapehu.

Here, we present preliminary results of the 3-D inverse modelling of the complete set of MT data acquired at Mt. Ruapehu using the finite element toolbox, that has been developed together by the TU Chemnitz and the TU Bergakademie Freiberg. Thereby, we adapted the level of detailedness of the topography using an inverse distance weighting scheme.

The weird and the wonderful of Aotearoa's seismic network

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The 24/7 National Geohazards Monitoring Centre (NGMC) has been monitoring New Zealand's geohazards using the GeoNet seismic station network since December 2018. The NGMC was established primarily to monitor earthquake, tsunami, volcano and landslide hazards. However, because we have eyes on the seismic waveforms 24/7, a variety of non-tectonic events have also been detected and located since the NGMC began operating.

The NGMC has been able to locate events generated from various anthropogenic, terrestrial and extra-terrestrial processes. The signals of some of these events may mimic common local earthquakes, while others are noticeably different from the onset. For each weird and wonderful event, we will show you how we locate, recognise, and interpret their signals. We analyse characteristics such as amplitude and frequency, coda length, phase arrivals, location, magnitude and depth. Some of the events we will present include a gas explosion in Christchurch, landslides on Fox Glacier, meteorites, and mining/military explosions around the country.

24/7 monitoring and rapid response in Aotearoa: the story of the 2023 Kawerau Swarm

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The 24/7 National Geohazards Monitoring Centre (NGMC) was established in December 2018 to monitor and rapidly respond to geological hazards including earthquakes, tsunami, volcanoes, and landslides. On the 18th March 2023 at 4:30 am, over 5,000 felt reports associated with an ML_V 4.7 earthquake in Kawerau kicked off what would be a 6 day long response with over 1,000 located events by the NGMC. In the hour following this event, an earthquake was located by the centre every two minutes on average, including the largest of the swarm, an ML_V 4.9 occurring at 4:46 am.

Due to the high frequency of events detected on the seismic network, the main focus was put on producing continuous preliminary locations of earthquakes. This was complicated by energy overlapping from multiple earthquakes occurring within a short timeframe. During the initial response NGMC Geohazard Analysts juggled locating incoming events with refining the origins of the larger earthquakes in the sequence as well as communicating with on-call volcanic, seismic, and communications officers in addition to NEMA.

With a rapidly evolving situation in the first hours of a demanding response, the need for the centre to reliably analyse and disseminate data with speed is paramount. With the aim of highlighting the risk assessment techniques utilised in the centre during a response we will retrace our steps in real time. Here we present information to you in line with the timing of this response in order to underline the NGMC's purpose in rapidly assessing the risk presented by Aotearoa's geologically active landscapes.

A record of the Paleocene-Eocene Thermal Maximum in deep-sea fan deposits of the Gulf of Mexico, U.S.A.

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Ancient examples of rapid climatic warming, or hyperthermals, provide a valuable complement to numerical climate models in understanding how the Earth system will respond to future rises in temperature. The Paleocene-Eocene Thermal Maximum (PETM) may be the closest geological analog to anthropogenic climate change, with a geologically rapid onset and total duration of ~200 kyr. Although the PETM has been identified in over 100 sections from around the globe, there are relatively few records from deep-sea fan deposits that form the terminus of continental-scale (i.e., > 1×10^6 km^2) sediment-routing systems. This study presents a new PETM record from the deepwater Gulf of Mexico (U.S.A.) that is recorded within ~13 m of drill core from the Anchor 3 well, identified by a ~-2‰ decrease in organic $\delta^{13}C$ and acmes in the dinoflagellate *Apectodinium homomorphum* and calcareous nannoplankton *Rhomboaster cuspis*. Along with recently published data from ditch-cutting samples from other industry boreholes, these data show that the PETM was manifested by a shut-off in the supply of silt, sand, and terrestrial palynomorphs to the basin, after a lag, and a significant increase in rates of clastic sediment supply to the basin. Although many marine PETM localities record enhanced burial of organic carbon, total organic carbon concentrations decrease markedly during the PETM in the Anchor 3 core. Visual inspection of kerogen slides indicates an abundance of degraded, likely oxidized, terrigenous carbonized debris and inertinite during the PETM. We interpret these results to signify the combined effects of increased erosional denudation and rising sea level that effectively sequestered sand and silt-sized particles near the coastline but that allowed the influx of organic-poor terrigenous mud to the deep-sea. This study illustrates the profound effects of climatic warming on even the most distal reaches of Earth's sediment-routing systems.

Rainfall-induced shallow landslides in New Zealand hill country: a synthesis of findings from the STEC Endeavour programme

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Recent extreme weather has re-focused attention on landslide-triggering events and approaches for better targeting erosion control to reduce damage to land and degradation of receiving environments from excess sediment. In this context, we present a synthesis of findings from five years of research into rainfall-induced shallow landslides as part of the 'Smarter Targeting of Erosion Control' (STEC) MBIE Endeavour programme (2018-2023).

STEC enabled significant investment in mapping of shallow landslides from high resolution satellite imagery. The resulting landslide inventories were used to compare methods of data acquisition, including a) manual versus semi-automated mapping and b) event versus multi-temporal records. Despite mixed classification results using semi-automated mapping without manual refinement, the relative reduction in susceptibility model performance was low in comparison, and spatial patterns in susceptibility were generally similar. Model performance for event versus multi-temporal records was comparable, reflecting similarity in landslide densities between study areas.

High-resolution satellite imagery combined with calibrated weather radar enabled new event-scale analysis of rainfall and landscape factors influencing landslide susceptibility. Land cover and slope most influenced susceptibility ahead of intra-event rainfall intensities and pre-event rainfall accumulations. Of the rainfall variables, maximum 12-h rainfall normalised by the 10-y recurrence interval intensity and the 10-d pre-event accumulation normalised by mean annual rainfall had the most influence on susceptibility. Forest cover reduced the sensitivity of landslide spatial density to variations in slope, rainfall, and rock type, in contrast to pasture.

Regional LiDAR capture presents an opportunity to improve landslide susceptibility models. We demonstrated improvement in model performance using a 5-m LiDAR-derived DEM versus the national 15-m DEM for a case study in the Wairarapa. We also showed how LiDAR allows tree-level analysis of landslide susceptibility and connectivity, enabling quantification of the effectiveness of individual trees for mitigating landslides and sediment delivery to streams in pastoral hill country areas.

Characterising volcanic plume heights through the use of calibrated camera images

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Explosive volcanic eruptions can produce buoyant plumes, injecting tephra to high altitudes. Such tephra is then dispersed through buoyancy- and wind-driven advection, creating both airborne and ground-based impacts. Consequently, there is a need to forecast the associated tephra dispersion and fallout, commonly done through Volcanic Ash Transport and Dispersion Models. The inputs for these models, called eruption source parameters (ESPs) include the plume height and the mass eruption rate (MER). Thus, in order to produce timely and accurate forecasts, ESPs need to be rapidly and reliably constrained.

Webcams are a common monitoring tool at volcanoes worldwide. However, in order to accurately quantify plume height from the acquired images, a calibration relating image coordinates to physical locations needs to be applied. In this study, we present a calibration which accounts for a) the geometric configuration created by the vent location and camera position and alignment; b) the intrinsic camera properties; and c) deformation of the volcanic plume by atmospheric wind. We demonstrate the use of the calibration for two-different eruption styles: sustained plumes from Mount Etna, Italy, and Vulcanian explosions from Sabancaya volcano, Peru. These case-studies show that the method is computationally cheap and, therefore, has potential application for real-time volcano monitoring. Finally, we discuss the limitations of the method, including an analysis of the effect of input data uncertainty, and a consideration of different imaging conditions. We conclude that camera images can be a relatively rapid and inexpensive tool for obtaining accurate quantitative constraints on volcanic plume heights, but the suitability of the method depends on the lighting and weather conditions at the time. Therefore, such webcams should form part of an integrated network for eruption characterisation, along with other instruments and datasets that provide complementary information.

Understanding the dangers of large flying rocks around Ngāuruhoe: quantifying the outsized ballistic ejecta from recent eruptions

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Ballistics are the most common cause of fatal incidents at volcanoes within 5 km of the crater (Brown et al., 2017). It is important to understand the hazard extent of these molten (bomb) or solid (block) projectiles, especially at volcanoes like Ngāuruhoe/Tongariro, which has high numbers of visitors reaching over 140,000 per year through areas like the Tongariro Alpine Crossing. Large ballistics with diameters over 1 m have been measured at over 1.5 km from the crater (in plan view), intersecting the track of the Crossing, which were ejected in recent eruptions including the 1954-55 and 1974-75 events. There is evidence that many of these large ballistics continued to roll and bounce after landing, reaching greater distances than would be accounted for by ballistic models. We present a preliminary survey of large landed ballistics at Ngāuruhoe, focusing on the distribution of large ballistics and morphological evidence of post-flight processes. Our results show that evidence of rolling and bouncing includes the peeling of outer layers, flattening, smearing, and embedding of other clasts in the surface. In addition, some ballistic impacts have been observed to produce secondary ballistics upon impact, with a 'shotgun-blast' style of smaller fragments ejected forward of the primary ballistic's trajectory. In our ongoing work we intend to quantify the hazard from large ballistics around the flanks of Ngāuruhoe, accounting both for final impact locations and prevalence of indicators of post-flight movement and shape changes. Additionally, historical accounts, photographs, aerial surveys, and video are incorporated to understand the extent of the ballistic hazard around this popular hiking trail.

Urban geophysics and seismic hazard assessment in the Wellington CBD

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Many of our cities are built on sedimentary basins. Both the depth and shape of the basin will influence, and generally enhance the level of shaking. Our focus is the Wellington CBD, where we use seismic reflection and gravity methods to assess the depth and shape of the basin. An initial gravity survey of the Wellington CBD is interpreted to show sedimentary thicknesses of up to 450 m in the CentrePort area, and 200 m in much of Thorndon. But these interpretations depend on an assumed density contrast between sedimentary and basement rock. We use both P and S wave seismic reflection imaging, at discrete localities in the CBD to constrain or benchmark our gravity interpretation. For controlled source seismic work, we ideally need grassed areas, but these are rare in most CBDs. We report new results from three sites: Wellington Girls College hockey field, Waitangi Park and Miramar Polo Ground park. Strong S-wave reflections are recorded at all sites, and basement depths are 220, 210 and 55 m (±10%) respectively. To obtain these depths from two-way travel time we adopt shear-wave velocity versus depth data furnished from two logged, >100 m deep, bore holes in the Wellington CBD, and from surface wave dispersion studies.

The gravity survey of the Wellington CBD highlights the importance of the subsurface expression of the Lambton Fault, which strikes NE beneath the railyards, and dips steeply to the SE. Together with the parallel Aotea fault, the Lambton fault has created a bath-tub shape for the Wellington basin which will have consequences for amplified seismic wave shaking due to basin edge-effects, constructive wave interference and resonance.

Forecasting relative sea level change within an active plate-boundary zone: New Zealand tide gauge and GNSS time series

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Measurements of vertical land motion are critical to understanding the impact of ongoing and future sea level rise due to rapid climate change. We assess the applicability of measurements based on short term satellite-based global positioning (GNSS and InSAR) time series, focusing on subsidence rates of major cities in New Zealand. GNSS and InSAR measurements between 2003-2011 show rates of subsidence for Auckland and Wellington typically between 2 and 5 mm/y, yet tide gauge time series near the same sites, for the period 1900-2022, when compared with eustatic sea level curves, show that virtually no vertical motion is required. Auckland tide gauge time series in particular, prior to the early 1990s, reveal an excellent match to the Global Mean Sea Level (GMSL) curve. The tide gauge time series also faithfully replicates the enhanced sea level rise (~ 5 mm/y) in the Southern Ocean as suggested by satellite measurements of the sea surface for the ~ 30-year period of 1993-2022. In view of these results, we consider whether there has been a rapid subsidence of New Zealand in just the last few decades due to elastic loading of glacial melt water in the Southern Ocean, affecting both land and ocean, or whether the satellite measurements of onshore sites are biased due to other causes. Our analysis favours the latter, but we cannot rule out the former playing a role. Thus, on time scales of both 30 and 100 years, tide gauge time series provide a key test of the meaning and applicability of vertical velocities derived from GNSS time series, as well as validating satellite measurements of rising sea levels.

Trace metal micronutrients: regulating the Southern Ocean's carbon sink during the last glacial-interglacial cycle

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The expansive Southern Ocean controls global climate by drawing-down atmospheric carbon dioxide into the ocean's interior via marine primary production within the 'biological pump'. This process is limited by the supply of trace-metal 'micronutrients', such as iron and zinc, but future-climate projections are constrained by traditional 'macronutrient'-based productivity tracers that are not ideally suited to Southern Ocean climate reconstructions.

We are applying a suite of newly calibrated micronutrient isotope tracers, based on the iron, zinc and cadmium stable isotope systems, to fossil-plankton extracted from a basin-wide, latitudinal transect of Southern Ocean marine sediment cores to reconstruct micronutrient uptake and demand by primary producers as a time-series across the 'last glacial cycle'. This interval spans the global warming and cooling transitions of the past 140 thousand years and includes similarly abrupt climate reorganisations as those occurring today. We are interfacing our micronutrient-focussed records with an Earth-system climate model that uniquely integrates micronutrient-limitation of marine primary production to directly quantify the influence of trace-metal micronutrients on marine productivity, assess the efficiency of Southern Ocean carbon dioxide removal during major climate reorganisations, and provide important boundary conditions for improving future-climate projections.

Cretaceous sedimentation patterns in the Aotea Basin

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We report results from a multidisciplinary study of Cretaceous strata in five wells (Romney-1, Hoki-1, Tane-1, Matuku-1 and Maui-4) located in the proximal Aotea and western Taranaki basins. The study involved a full biostratigraphic and paleoenvironmental reassessment of Cretaceous well sections, integration of regional seismic mapping, and wireline log facies analysis. Five proximal to distal facies associations are defined, and sequence stratigraphic analysis was undertaken from well correlations constrained by miospore and dinoflagellate zones, and seismic mapping.

The Cretaceous section in Aotea Basin has been divided into six main sequences (S_K30–S_K96) bound by regional seismic horizons, representing low order sequence boundaries and/or transgressive surfaces (K50 to P00). The youngest four sequences are further subdivided into ten higher order sequences based on log stacking patterns, biostratigraphy and geochemical data. The regional K80 reflector, drilled only at Romney-1, corresponds to the top of the 'late syn-rift'. The new name Romney Formation is suggested for the unit between K80 and K90 and is divided into a lower Merino Member (S_K80), with fully marine shallowing to marginal-marine facies, and an upper Coopworth Member (S_K85), dominated by coastal plain facies. Maximum regression in the Aotea Basin occurred at the top of S_K85 (below K90).

The interval above K90 is overall transgressive, with local volcanics occurring towards its base, and with regressive units developed in the upper parts of higher order sequences. Significant marine influence across the whole study area is apparent above K96, with strata dominated by marine mudstones and maximum transgression occurring in the latest Cretaceous. Correlation between Aotea and Taranaki basins is more difficult in older units (S_K90). Higher confidence correlations above K96 are due to greater abundances of dinoflagellate cysts and the gradual decline in active faulting and extension in proximal parts of the study area.

Mapping CO_2 outgassing over volcanic regions using hyperspectral imaging

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Magmatic degassing is often the main driving force of volcanic eruptions and governs whether they are effusive or explosive, exsolving from the magma as it rises. Elevated CO_2 flux from a volcano can indicate the movement of magma deep in the system, displaying a potential eruption precursor, demonstrated by recent eruptions including Te Maari (2012), Villarrica (2015) and Stromboli (2019). Active degassing can further induce hydrothermal alteration of primary volcanic lithologies, due to magmatic heat and (acidic) fluids passing through permeability zones. Studying these aspects of volcanic activity improves our understanding of their relationships and allows for the development of multi-dimensional maps and models that can contribute to hazard mitigation efforts. Hyperspectral remote sensing presents a unique opportunity to explore both volcanic outgassing and associated hydrothermal alteration. CO_2 spectral absorption features are present in the SWIR region of the electromagnetic spectrum at 1.4–1.6 µm and 1.9–2.0 µm, these signatures can be used to detect pixelwise CO_2 emissions and estimate atmospheric columnar abundance.

We present CO_2 detection methods that exploit gas absorption features in the 1.9–2.0 µm wavelengths of airborne and satellite hyperspectral scenes of Tongariro (New Zealand) and Ambae (Vanuatu), inspecting point source and diffuse CO_2 emissions. To validate our methods, we used mineral spectral library data and MODTRAN atmospheric modelling to generate synthetic radiance data where ground truth CO_2 values are pre-set, simulating the spectral signals of typical volcanic/hydrothermal environments. We use this synthetic data to conduct sensitivity analyses, investigating the influence of atmospheric water vapour, aerosol content, surface albedo and mineral absorption features on measuring CO_2. The mapped CO_2 emission and sources are discussed and integrated with existing geophysical techniques such as aeromagnetic datasets to detail the connection between surface signatures and hydrothermal alteration depth.

Earth science, energy transition, reserves, exponential growth bias, and supply chains: our responsibility to advise

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The biggest challenge humans face is the need to shift from fossil fuels to renewable energy, but it is happening quicker than people think. The COVID-19 pandemic has both obscured and provided insight into the challenge we face. The rate of change related to energy transition is accelerating and may have passed a critical threshold of no-return. The challenge that earth scientists face is not whether our planet has enough of any specific material to achieve energy change, but rather whether we can provide useful advice now that will result in good decisions and planning, so that supply chain problems do not delay transition. I will summarize data related to energy transition and show that good advice is needed right now if we are to avoid delays and obfuscation caused by those that have vested interests to delay change; and, ironically, also those that are most vocal about wanting change. Will anybody listen? How should we advise? I would like feedback.

Exploring factors influencing decision-making in tsunami evacuation

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In Aotearoa New Zealand, a significant portion of the population resides, works, or engages in recreation within tsunami evacuation zones. The coastal communities in these regions face potential tsunami threats, underscoring the necessity to comprehend evacuation protocols and the most effective strategies for relocating sizable populations during emergencies. Our project seeks to understand tsunami evacuation behaviour in Aotearoa New Zealand, by combining computational modelling techniques and social sciences. Agent-based modelling is used to simulate the movements of individuals using statistical methods to model people's decision-making processes. To ensure that the modelling represents the actual environment and people as realistically as possible, we look to improve the models by incorporating factors that affect people's decision-making when evacuating. As part of this process, we held a series of workshops with subject-matter experts to explore an array of variables for decision-making during a tsunami evacuation. These included parental/carer responsibilities, mobility constraints, urban/rural considerations, risk perceptions, options for vertical evacuation, modes of transport, and blockages and rerouting. Existing peer-reviewed evidence regarding how to model these factors is currently being evaluated, the outcomes of which will progressively enable them to be integrated into the agent-based models. This paper summarises the findings from the workshops and highlights considerations and future research questions for understanding decision-making in tsunami evacuation scenarios.

Technology adoption of an earthquake early warning system through a continuance intention model

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This study investigates technology adoption of earthquake early warning, focusing on the Android Earthquake Alert (AEA) system in New Zealand, analysed through a continuance intention model. The research aims to investigate the model's implications by investigating the public's perceptions and attitudes towards the AEA system, specifically emphasising continuance intention and its influencing factors. This study utilises Structural Equation Modelling; it uses data collected from the public after alerts were sent out during two separate earthquake events. The results reveal partial support for the continuance model, emphasising the significance of perceived usefulness and perceived trust in driving continuance intention. By investigating the theoretical underpinnings of the continuance intention model and interpreting the findings in the context of the AEA system, this research contributes to a deeper understanding of technology adoption. The implications of these results hold promise for advancing EEW technologies and refining technology adoption strategies, ensuring their sustained relevance and impact. The poster presentation will elaborate on the theoretical framework and show the importance of perceived usefulness and perceived trust in shaping the AEA system's continuance intention. The poster also discusses the potential implications for EEW system design and implementation, fostering a more resilient and user-centred approach to earthquake early warning efforts.

Revised NZ volcano threat levels and instrumentation recommendations for the next decade of volcano monitoring in NZ

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This presentation will cover Version 2 of the New Zealand Volcano Early Warning System (NZVEWS) volcano threat level updates and instrumentation recommendations for New Zealand's volcanoes. Volcano threat is estimated using the product of hazard, exposure, and vulnerability factors which together represent the relative likelihood and consequence of the volcanic hazards at each volcano and uses updated population and infrastructure data. Volcanoes are categorised into threat groups based on the ranked distribution of their threat scores. Ōkataina and the Auckland Volcanic Field are the two highest threat volcanoes.

To determine monitoring instrumentation commensurate with each volcanoes threat levels, a consultation exercise was undertaken with the NZ volcano science community using USGS instrumentation recommendations as a starting point and updating them for NZ community requirements.

Instrumentation levels are assigned to each threat group with increasing numbers and diversity of instruments and types of data required for higher threat volcanoes compared to lower threat volcanoes. During the consultation exercise data users were requested to develop the instrumentation recommendations and were then invited to design sensor networks based on the NZVEWS recommendations. We synthesise these designs into minimum and maximum recommended networks for each volcano. The full set of instrumentation recommendations include both instrumentation counts and network maps, network design principles, and recommendations for future developments in technology use.

NZVEWS form a key contribution to the wider dialogue around GeoNet sensor network development and has already formed a cornerstone in network planning, drawing the focus of GeoNet to the Auckland Volcanic Field which is a high threat volcano with a relatively low sensor network capability.

Fossils from South Taranaki reveal Aotearoa New Zealand as a long-term 'hot spot' for seabirds

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In the last five years, six seabird species have been described from the three-million-year-old sedimentary deposits of South Taranaki. These include a shearwater (*Ardenna davealleni*), an albatross (A*ldiomedes angustirostris*), a crested penguin (*Eudyptes atatu*), a petrel (*Procellaria altirostris*), a giant petrel (*Macronectes tinae*) and a little penguin (*Eudyptula wilsoni*). The shearwater is as large as the largest living shearwaters but closely related to the more delicate Buller's shearwater (*Ardenna bulleri*). The crested penguin is considered to be a very early member of the genus, with a thinner beak, indicating a different feeding ecology to living species. The albatross is unlike any living species, being notably smaller with a uniquely narrow beak, indicating a more piscivorous diet. The Procellaria is a large species, closely related to the Westland petrel (*P. westlandica*) and white-chinned petrel (*P. aequinoctialis*). The giant petrel is smaller than living species of giant petrels, with features of the humerus providing new evidence for a closer relationship with some of the smaller fulmar species. The little penguin is similar to living taxa but has a more slender skull. Together these fossils reveal a rich diversity of seabirds. They provide a glimpse into the fauna just prior to the onset of cooling in the Pliocene. The richness of the fauna and the beautiful state of preservation of many of the fossils from this site make it one of the most important for understanding the evolution of seabirds both locally and globally.

Automated image acquisition, processing and recognition of microfossils

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Identification of microfossils usually requires manual identification of thousands of specimens by taxonomists, under a microscope, which is very tedious and time-consuming. Furthermore, identification may differ between operators, biasing reproducibility. Recent technological advances in automated microscopy and artificial intelligence now enable to develop automated workflows from microscope image acquisition to image processing and taxonomic identification.

A new workflow was recently developed and installed at GNS for automated image acquisition, processing, and identification. Several hundreds to thousands of specimens per slide are captured using stacking and segmentation techniques. Each individual specimen of microfossil is then automatically classified by a convolutional neural networks (CNNs) trained on radiolarian, pollen or diatom datasets for example. For each image, numerous morphometric measurements are also provided, enabling the investigation of new paleoenvironmental indices based on some microfossils shape or size, as well as their evolution through time.

Trained CNNs usually have an overall accuracy of about 85 - 90 % and contain up to about 150 classes. The whole procedure is entirely automated and takes approximately 1h per sample. Census data count, morphometric measurements, and classified images are automatically exported and saved. This new workflow paves the way for the analysis of long-term, microfossil assemblages- and morphometric-based paleoclimatic and paleoenvironmental reconstructions.

Coseismic slip profiles

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Characterization of coseismic slip profiles is useful for computing rupture forecasts, fault slip rates, and fault displacements. We investigate these gross features of coseismic slip, using rupture models of past earthquakes and measurements of surface ruptures. We find that the along-strike average slip profile is well approximated by a power-of-sine function with index = 1/2 (i.e., a sinesqrt function). Although the down-dip average slip profile also corresponds to the sinesqrt function, whereas that for surface rupture events (with rupture aspect ratio > 1.5) has less tapering to the surface. For the latter, the average surface slip for an event is comparable to the average slip of the overall rupture area. We also demonstrate that a generalised extreme value distribution best describes the surface slip variability at along-strike locations on the fault rupture. These findings are envisaged to improve the modelling of slip distributions for seismic hazard analysis.

Shallow shear wave reflection surveys in urban environments

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New seismic reflection data are used to estimate basement depth, identify fault structures, and image the general shape of the Wellington CBD Basin. This data can be used to estimate the seismic shaking potential from both local and distant earthquakes. We experimented with generating and recording both S- and P-wave energy with the former being favoured for near-surface imaging as the slower velocity S-waves interfere less with other arrivals in shallow (<200 m deep) sediments. We use an optimised S-wave seismic acquisition survey geometry that allows for the rapid collection of high-quality data in urban environments. A purpose-built aluminium shear wave seismic source was designed and manufactured for this project and data were recorded using a multichannel system with 48 horizontal,40 Hz geophones. Anthropogenic noise in urban settings can mask the seismic signal and we apply frequency and F-K filtering methods to enhance signal-to-noise ratios.
We present seismic imaging results from three sites: Wellington Girls College (WGC); Waitangi Park (WP) and the Miramar Polo Ground (MPG). Existing downhole shear wave seismic data are used for two-way times to depth. At WGC the depth to basement is ~200 m, which is ~25% deeper than the previously modelled estimates used in earlier studies of earthquake shaking. Data from WP also suggest a basement depth of about 200 m and complex faulting and deformation structures that are likely linked to the onshore extension of the Aotea Fault. The seismic record at the MPG shows a previously unmapped reverse fault with 5m of vertical offset in the Greywacke basin. Seismic structures in these locations have been independently tested by modelling residual gravity anomalies across the basins.

Taranaki Maunga: it's older than you think

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Quaternary igneous rocks of the Taranaki Peninsula are grouped within the Egmont Volcanic Centre deposits, ranging in age up to ~2 Ma, with Taranaki Maunga itself thought to be less than 0.2 Ma. Fourteen recent $^{40}Ar/^{39}Ar$ ages from subsurface samples of the Taranaki Peninsula ring plain reveal an older history of volcanism than previous estimates.

Subsurface samples from the western tip of the peninsula returned ages of 2.9 and 2.3 Ma, older than the out-cropping Sugar Loaf Andesite (~2 Ma). Three subsurface samples from below the outcrop area of the Maitahi Formation, which surrounds the Pouakai and Kaitaki edifices, returned ages of 1.1, 0.8 and 0.6 Ma, which contrasts with previous estimates of 0.6 to 0.2 Ma. The 1.1 Ma sample, from 215 m below sea level in the Warea-1 well, gives a minimum age for the onset of volcanism resulting in the present topographic form of the peninsula. Seven $^{40}Ar/^{39}Ar$ ages from near the base of the Taranaki ring plain (previously <0.2 Ma) ranged from 0.52 Ma in the Kapuni-15 well on the south side of Taranaki to 0.39 Ma in Rahotu-1 on the western side.

These ages are in broad agreement with an age estimate based on the time required to deposit the volume of igneous rock present. The present study, based on petroleum wells and seismic reflection data, estimates a total igneous volume of the Egmont Volcanic Centre to be ~800,000 km^3, the majority of which is the products of Kaitaki and Taranaki, accumulated over 1.1+ Myr. Previous estimates of eruptive volumes of individual events indicate volcanic production rates for Taranaki of ~0.53 km^3/kyr for the last 100 kyr. Assuming a uniform rate through time, about 1.5 Myr is required to accumulate the present volume of the ring plain and volcanic centres.

Evaluating the confluence test on the southern Hikurangi margin using historical earthquakes

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Turbidite paleoseismology has produced some of the longest and most complete records of subduction zone earthquakes globally. However, many of the techniques that underpin turbidite paleoseismology have been vigorously debated. One such technique is the confluence test, which argues that if the number of turbidites present both above and below a submarine canyon confluence are equal, then this provides evidence for synchronous earthquake triggering of turbidity currents in discrete sediment distributary systems along a margin. To date there have been no definitive assessments of the confluence test using turbidites emplaced following observed earthquakes. Here, we critically evaluate the confluence test using turbidites emplaced on the southern Hikurangi margin in response to two well-documented large historic earthquakes, the 2016 M_w 7.8 Kaikōura Earthquake, and the 1855 M_w 8.2 Wairarapa Earthquake. Using a dense network of TOPAS lines and ~65 multi-cores, the spatial distribution and sedimentary structure of the 2016 Kaikōura event-bed (KEB) was examined to identify optimal coring locations for turbidite paleoseismology. This examination of the KEB demonstrated that core sites on canyon wall terraces above the canyon floor can provide good locations for turbidite paleoseismology. Multi-cores from these sites contain a single core-top event bed, the KEB, and at least one underlying turbidite, separated by approximately 14-46 cm of hemipelagite. Precise ages for these older turbidites were determined at locations above and below the confluences of three major canyon systems, and the Hikurangi Channel using short-lived naturally occurring (^{210}Pb) and anthropogenic ($^{239,240}Pu$) radionuclides. Preliminary ages for the penultimate turbidite indicate that it likely correlates with the Wairarapa Earthquake, allowing this event bed to be traced through multiple confluences. We show that the Kaikōura and Wairarapa earthquakes produced deposits that adhere to the confluence test, providing some validation to the approach as a viable method to establish synchronicity of turbidite deposition.

Understanding the ancient glacial history of Canterbury

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Significant research into the timing and causes of past glaciation in Canterbury, New Zealand including systematic surface exposure dating and extensive geomorphic mapping, has improved our understanding of climate change for the region over the last glacial cycle. However, older glaciations associated with the major river valleys in Canterbury, that extended well beyond the mountain front, have not been extensively researched despite the identification of these advances in earlier publications. This project looks at identifying, mapping and interpreting the more cryptic glacial features to develop our understanding of these older advances with a focus on the Rakaia Valley in Canterbury. Geomorphic mapping using high-resolution LiDAR and digital analysis, supported by GPR, drone surveying, and sediment analysis have all been used to investigate cryptic older glacial features on the Canterbury Plains seaward of Rakaia Gorge. The identification of glacial fluting over the Woodlands Moraine and onto the outwash beyond the moraine suggests a previously unidentified glacial advance that over-ran the Woodlands Moraine sourced from the main Rakaia Glacier but not representing ice coming from Rakaia Gorge. Instead, the orientation of these features suggests ice within the High Peak valley extended over the High Peak hill range and down onto the Canterbury Plains. The latest results will be presented.

Full waveform inversion reveals high-resolution crustal structure within the Southern Hikurangi Margin: implications for physical conditions along the megathrust

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Along the Hikurangi Subduction Margin, recent seismic imaging studies (e.g., Crutchley et al., 2020; Arnulf et al., 2021) have revealed marked down-dip variations in physical properties near the plate interface over narrow (10 km) length scales with implications for megathrust slip behaviour. In this study, we apply a Hybrid optimization-based Full Waveform Inversion (FWI) scheme to a 90-km-long multichannel seismic (MCS) seismic reflection profile (05CM-38) that transects the southern limit of the region which hosts shallow slip-slip at this margin.

To perform FWI, the MCS data (12 km maximum offset) are first downward continued from sea level to 75 m above the seafloor. A Hybrid optimization FWI scheme is then performed using three simple starting models, all of which converge to a similar background model. These results are then averaged and used as the starting model for a local optimization-based FWI, which reveals the high-resolution structure. We simultaneously invert all events without muting any energy, including free surface multiples. As a result, phases arriving later than multiples are preserved and are utilized to help recover the deep (4-9 km depth) structure that was masked during a previous application of FWI to this profile (Arnulf et al., 2021).

Beneath the inner accretionary wedge, our new model resolves a distinct reduction in Vp (~ 0.5 km s-1) within the subducting plate immediately below the plate interface at depths of 7-9 km. Preliminary numerical modelling shows that the position of the low-velocity zone is consistent with predictions for fluid release from the smectite-to-illite mineral dehydration reaction. It follows that the low Vp region may represent a zone of elevated pore-fluid pressure and low effective stress and we explore the implications for interface slip behaviour.

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Shear-wave velocity structure of Aotearoa New Zealand's upper mantle from surface wave dispersion of an amphibious dataset

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Aotearoa New Zealand lies on the continent Te Riu-a-Māui Zealandia lying mostly beneath the ocean. Aotearoa New Zealand's two subduction zones between the Pacific and Australian plates have opposite polarities. Between them lies the Alpine Fault, which extends along most of Te Waipounamu South Island. This unique plate configuration poses fundamental questions about how the plates are accommodated in the upper mantle and their influence on subduction zone seismicity. We attempt to answer these questions by developing a three-dimensional shear-wave velocity model of Aotearoa New Zealand using Rayleigh-wave data from distant earthquakes recorded by an amphibious network of broadband seismometers. With this dataset, submerged portions of the continent are included, providing a more complete picture of the tectonic boundary. Cross-correlations of Rayleigh waves from earthquakes that align on a great circle path with two stations from the amphibious network are used to observe the phase spectra of each station pair. These phase spectra are isolated for unique periods that are sensitive to upper mantle depths. These inform a Bayesian inversion which probabilistically estimates path-averaged 1D shear wave velocity structure between stations pairs. Combining data for all station pairs, we use these path-averaged models as input for a series of 2D interpolations at discrete depth slices in order to produce a pseudo 3D model of Aotearoa New Zealand with associated uncertainties. The relationship between the Pacific Plate and Australian Plate beneath the Alpine Fault and the structures associated with the subduction zones are examined.

Data-driven shallow landslide connectivity analysis to reduce sediment delivery to streams

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To achieve national freshwater objectives and reduce sedimentation, higher-resolution data on sediment delivery by shallow landslides to streams is needed. Data-driven landslide connectivity analysis may help to address this by identifying areas where future landslides are more likely to reach streams.

Initial work on statistical landslide connectivity in New Zealand focused on pastoral hill country landscapes using a dataset of over 1,200 landslide deposits (Spiekermann et al. 2022). However, there remains a need to identify the spatial drivers of landslide connectivity at high resolution across a wider range of land covers and lithologies, underpinned by expanding regional LiDAR coverage.

We mapped shallow landslide source areas and debris deposits across a 3,062 km^2 study area in northern Hawke's Bay affected by intense rainfall in March 2022 that produced over 35,000 landslide features. We used stream networks derived from a LiDAR DEM with a range of channel initiation thresholds as landslide targets. A binary logistic regression model with automated variable selection was trained on the landslide dataset. Predictors included morphometric factors, land cover, and lithology. Our results revealed a strong dependency of connectivity on the overland flow distance to the target. Regardless of the initiation threshold, the probability of reaching the target stream was higher than 0.5 if the landslide source area was located within 30 m of a stream. Moreover, landslides occurring in pastoral landscapes are more likely to be connected compared to other land cover classes.

The data-driven landslide connectivity model can be used with susceptibility analysis to identify areas that are likely to produce landslides that reach the stream network. This will enable more cost-effective targeting of mitigations to reduce landslide erosion and sediment delivery to streams.

Reference:

Spiekermann et al. (2022) Development of a morphometric connectivity model to mitigate sediment derived from storm-driven shallow landslides. Ecological Engineering 180: 106676.

Quantification of geothermal carbon dioxide fluxes using radiocarbon

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Geothermal systems degas carbon dioxide (CO_2) into the atmosphere, with consequences for the climate and for our understanding of geothermal systems. Geothermal power stations increase degassing as fluids are brought to the surface. The direct power plant CO_2 emissions are readily quantified and counted towards national anthropogenic CO_2 emissions under the Paris Agreement. Importantly, geothermal power stations have been moving towards re-injection of the degassed CO_2 and have even proposed to use geothermal systems for carbon capture, making them carbon neutral or even carbon negative with respect to their direct emissions. However, the rate of natural CO_2 degassing from geothermal fields is poorly known, and the consequences of geothermal power generation and re-injection on natural degassing rates is almost entirely unknown.

Flux chamber measurements are typically used to quantify the natural degassing rate from the CO_2 buildup into a small chamber placed over the ground. Yet the degassed CO_2 is composed of a mixture of CO_2 from geothermal and biospheric respiration. If the biogenic CO_2 flux is uncertain, this will bias the geothermal flux estimates; particularly problematic when the geothermal flux is low.

We use radiocarbon (^{14}C) measurements to partition the degassed CO_2 into geothermal and biogenic components, and demonstrate that at the Tauhara geothermal field, the biogenic CO_2 flux rate is significant and spatially variable. Further, the ^{14}C measurements can discriminate even tiny geothermal CO_2 contributions, allowing more robust mapping of the limits of geothermal degassing. We also examine ^{13}C as an alternative partitioning method, and show that while it is generally effective, uncertainties in the end member $\partial^{13}C$ values, and the presence of both C3 and C4 plants can make interpretation complex. Our preliminary study demonstrates the intricate complexity of calculating emissions in volcanic area and should provide recommendations for future monitoring regulations.

Most recent rupture on the Boulder Creek Fault triggered bedrock landslides in the Nooksack watershed, Whatcom County, Washington, USA

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Catastrophic bedrock landslides with volumes ranging from 10^6 to 10^8 cubic meters contribute to rapid landscape evolution, often resulting in erosion rates that exceed the long-term average rates caused by tectonic uplift. Assessing spatiotemporal trends of large bedrock landslides helps us understand previous drivers of landscape evolution and predict how the landscape will respond in the future. The Nooksack watershed, Washington, is particularly susceptible to large slope failures because of its high relief, seismic activity, local geology, and relatively abundant precipitation. Specifically, folded and faulted bedrock as well as recent surface rupturing earthquakes on the Boulder Creek fault are both probable mechanisms for widespread landsliding. To determine the relative importance of these driving mechanisms, we investigate spatiotemporal trends of 447 landslides in the Nooksack watershed using a calibrated relationship between lidar based surface roughness and age. We compare the temporal patterns in the resulting landslide chronology to simulated landslide frequency histories with and without coseismic landslide pulses at the times of the two most recent geologically constrained earthquakes on the Boulder Creek fault. We assess spatial patterns by conducting a regional kinematic analysis to define areas susceptible to planar sliding and toppling failures. Our resulting landslide frequency history best matches a simulated landslide frequency history that includes preservation bias and coseismic landslide pulses. Our regional kinematic analysis demonstrates almost half the landslides in our inventory overlay hillslopes where planar sliding and/or flexural toppling are kinematically feasible. These findings together support the conclusion that surface rupturing earthquakes and bedrock orientations, specifically those conducive to flexural toppling, primarily control the spatial and temporal distributions of landslides throughout the Nooksack watershed. These findings are important for hazard assessment and planning throughout the region and suggest the evolution of the Nooksack watershed is heavily influenced by coseismic landslides.

Sediment source fingerprinting in New Zealand fluvial environments: an overview of recent applications

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Sediment source fingerprinting is a geochemical tool for determining the proportional contributions of eroded soil from different catchment sources to sediments in downstream receiving environments. The technique involves: (a) selecting tracers that discriminate sources based on their biogeochemical or isotopic properties and (b) applying statistical mixing models to quantitatively determine source contributions to downstream sediments. Tracers may include geochemical, fallout radionuclides, or compound specific stable isotopes (CSSIs). Tracer suitability varies depending on the characteristics of the study catchment and the soil property or erosion processes being targeted. For instance, the spatial variation in soil geochemical properties is largely determined by underlying geological and pedogenic processes, whereas CSSIs utilise $\delta^{13}C$ isotopic properties of fatty acid biomarkers that bind to soils and vary based on plant communities associated with each land cover.

Thus, sediment fingerprinting applications vary considerably, which can make the technique challenging to understand for non-specialists. Additionally, although the basis for discriminating sediment sources is reasonably well understood, research has drawn attention to limitations and uncertainties associated with source discrimination, tracer selection, non-conservative behaviour, and mixing model performance. Here, we present an overview of selected sediment fingerprinting studies in New Zealand catchments and summarise key findings and implications for future research and application. The selected studies relate to: (1) characterizing suspended sediment sources using geochemical tracers in New Zealand hill country catchments; (2) understanding temporal and spatial sediment source dynamics during rainfall events; (3) determining source contributions to overbank sediment deposits; and (4) evaluating the impact of geochemical and CSSI tracers on the accuracy of source contribution estimates.

Unearthing slickenlines on the 2016 rupture of the Kekerengu Fault: testing the veracity and utility of the rupture-propagation-direction / curved-slickenline hypothesis

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Earthquake rupture propagation direction is known to influence the distribution and intensity of damaging ground shaking, especially for long strike-slip ruptures. Recently, Kearse et al. (2019) and Kearse & Kaneko (2020) proposed a new paradigm - based on spontaneous dynamic rupture modelling and grounded in geological field observations - that links patterns of curvature of slip striations (slickenlines) on fault surfaces to the direction of rupture propagation. To test this slip striation paradigm, we set out to unearth slickenline data on a fault (the Kekerengu Fault) that ruptured with a known propagation direction during the 2016 Kaikōura earthquake. At the same time, we wanted to learn how to best excavate along a fault in order to preserve, expose and document fault-rupture slickenlines.

In undertaking our work on the Kekerengu Fault we learned – by trial and error – successful techniques and approaches to exhume fault surfaces to reveal a preserved record of slickenlines.

In our four excavations of the fault, we observed slickenlines of variable plunge. This observation, as well as others globally, indicate coseismically inscribed curved slickenlines at the ground surface are widespread and typical. At three of our four excavations of the Kekerengu Fault, we documented slickenlines of the same sense of convexity as was observed on fault scarp free faces immediately following the 2016 Kaikōura earthquake; this convexity is consistent in its polarity with model-based expectations for a northeastward rupture propagation direction. At the fourth site curved slickenlines were also found but could not be compared to 2016 field observations. We infer that in shallow excavations the sense of convexity of curved slickenlines can be used to constrain the rupture direction of recent large paleoearthquakes on the fault in question. This is potentially a big advance towards better characterization of earthquake ground shaking hazard.

References:

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Melting glaciers and climate change: what can we do?

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Glaciers around the world are losing mass rapidly. Glaciers in New Zealand are losing mass especially quickly - a global study found that the ~3,000 glaciers in Aotearoa New Zealand are thinning at a rate faster than any other region globally. However, in that study, New Zealand glacier measurements have higher uncertainties and lower spatial coverage compared with other regions.

To better understand how glaciers in New Zealand are changing, we monitor glaciers at a variety of scales and using a range of methods. These include using field measurements and photogrammetry for individual glaciers, a photographic survey for a subset of 50 New Zealand glaciers, and numerical modelling for glaciers nationwide.

Results of these studies show high melt for New Zealand glaciers, especially in the past decade. Melting glaciers have impacts in New Zealand and around the world. Global sea level has risen 10 cm in the last 30 years, a quarter of which is due to glacier melt. Glacial lakes are growing, which increases the risk of damage caused by glacial lake outburst floods. At the same time, less water is available in some regions with diminishing glaciers, particularly during drought years.

By the end of the century, glaciers will look different than today. In New Zealand, we might lose ~40% of glacier volume, or we could lose ~90%. Furthermore, melting glaciers are only one of the many impacts of climate change. However, we can still make choices to avoid the worst impacts of climate change.

Faulted terraces and recurrence behaviour of the Pisa Fault

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The Otago region is one of low seismicity due to its position to the east of the boundary of the Pacific and Indo-Australian plates. The faults of the Otago Range and Basin province have long recurrence intervals, typically 10,000 years or more. The Pisa Fault is a west-dipping reverse fault that runs along the western edge of the upper Clutha Valley and bounds the Pisa Range and the Cromwell-Tarras Basin. The fault is assumed to have been quiescent for about 30,000 years, but this assumption is largely based on conjecture rather than actual data.

The central objectives of our study are: (1) to use a combination of field mapping and cosmogenic and optically stimulated luminescence (OSL) dating methods to constrain the ages of five fluvioglacial terraces in the area of the Pisa Fault; (2) use observations of faulted terraces and ages from (1) to determine the long-term slip rate of the Pisa Fault; and (3) use the slip rates from (2) and newly-developed magnitude-fault area scaling relations to estimate the magnitude and long-term recurrence interval of the fault. These estimates are paramount for understanding the hazards that may be present and provides information for assessing the risk associated with infrastructure and population that are in proximity of the fault. The towns of Cromwell and Wanaka have grown alongside the fault and would be significantly damaged by future Pisa Fault earthquakes.

Reconstructing southern hemisphere Maunder Minimum and Satellite Era relative changes in surface UV-B flux based on sporopollenin chemistry

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Elevated levels of surface UV-B flux can have a negative impact on life. The amount of UV-B that reaches the surface varies through time. However, few avenues exist for reconstructing past UV-B levels. Sporomorphs (pollen and spores) contain UV-B absorbing compounds (UACs) in the sporopollenin biomacromolecule forming their outer walls. Empirical and experimental studies have determined that UACs are ubiquitous in sporopollenin, and that the quantity increases with increased exposure of the parent plant to UV-B. Because sporomorphs are abundant in the fossil record and their UAC content stays stable over time, they offer an avenue for the reconstruction of surface UV-B flux through time. This technique has been applied in limited studies in Northern Hemisphere or equatorial locations, but not yet in New Zealand or the wider Southern Hemisphere.

We have used Fourier Transform infrared microspectroscopy to measure UACs within sporopollenin of Prumnopitys taxifolia pollen retrieved from sediments of Lake Ohau (44°16.782'S, 169°55.480'E). We have targeted two periods: (1) 1977 – 2010 (approx.), representing the period in which we have satellite measurements of solar activity, and (2) the Maunder Minimum (MM; 1645 – 1710 CE). We compare the UAC-based record of relative UV-B variation against the satellite measurements to evaluate the strength of the correlation between solar radiation and UAC variation. Our record of UAC levels over the MM are an opportunity to explore the dynamics of surface UV-B in New Zealand during this recent period of low solar activity. Our preliminary data indicates variation in UAC levels at Ohau, suggesting that UV-B and solar activity during solar minima may be more dynamic than once thought. This corresponds with our recent work in Türkiye, using the same method, which suggests that the 11-year cycle did persist during the MM, counter to what has been indicated by sunspot cycle records.

Simulation of the 2012 Te Maari debris avalanche from failure to impact.

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Volcanic debris avalanches are natural phenomena that involve complex mass movements initiated by the collapse of an unstable part of a volcanic edifice. Debris avalanches are a common feature of New Zealand's stratovolcanoes, altering landscapes and impacting populations and infrastructures nearby. The 1914 event at Whakaari destroyed the sulphur factory and killed 10 miners, while the 2012 event of Te Maari triggered a complex multi-stage eruption. Current modelling strategies for debris avalanches are plagued by large uncertainties in model input parameters. Considering the entire multi-stage process of a debris avalanche, assumptions in a preceding stage can greatly influence the next. Therefore, we focus on improving the accuracy of debris avalanche hazard assessment through a modelling methodology accounting for the entire multi-stage process. We have evaluated the influence of material properties and slope failure model on flow dynamics using the well-characterized 2012 Te Maari debris avalanche as a case study.

The presence of a hydrothermal system beneath Te Maari weakens the strength properties of rocks and promotes collapse. Our preliminary failure simulations highlight the importance of input accuracy (in strength parameters, failure criterion, groundwater detection), in determining the location and magnitude of the collapse. In the Te Maari case study, the use of a finite element method to establish the forces acting on the slope appears to improve prediction accuracy for the 2012 failure. This suggests that this failure was associated with deformation which can potentially impact the initial velocity of the flow. We demonstrate that the use of the refined mass failure conditions from finite element modelling as inputs for flow simulations can potentially improve subsequent simulations of the kinematic characteristics and runout of the debris avalanche.

Knowledge, perceptions, and behavioural responses to earthquake early warning in Aotearoa New Zealand

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Aotearoa New Zealand (NZ) experiences frequent earthquakes, with a history of damaging and fatal events, but currently does not have a national, official earthquake early warning (EEW) system. Since April of 2021, Google's Android Earthquake Alert System has operated independently in NZ. While recent work has identified general public support for such a system, it is important to assess public knowledge of EEW as well as typical responses to receiving an alert. The protective actions "Drop, cover, and hold" are recommended and taught in NZ and previous research found strong intentions to undertake these and other protective actions in response to an alert. However, it is important to explore a range of responses to these novel EEWs, including how much people know about them, what actions they took in response to the warning, and their overall judgment of the system including its usefulness. We undertook surveys following two widely received alerts from the Android Earthquake Alert System to assess public knowledge, perceptions, and responses to these alerts with a total sample size of 3,150. While most participants who received the alert found it useful, knowledge of both EEW generally and the Android System was low and few participants used the time to protect themselves from shaking. These findings reiterate the importance of education and communication around a warning system, so that the public know how to act when they receive an alert.

Risk perception, attitudes, and behaviour when considering both earthquake and tsunami: an experimental survey

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Our understanding of the effects of multi-hazard contexts on risk judgments and behaviours is limited. Past studies tend to test which of multiple hazards people choose to think about and act on. In a novel approach, we use an experimental survey where groups of participants from Wellington, Aotearoa New Zealand are asked to consider tsunami and earthquake in isolation, concurrently, or subsequently. Participants perceived significantly less threat from tsunami after thinking about earthquakes, and vice versa. Intention to prepare for tsunami were also lower if the participants had already been asked about earthquakes; however, intention to prepare for earthquakes was higher if participants had already been asked about tsunami. Generally, these findings reflect a decrease in risk perception of the second hazard, suggesting that people's risk perception can be overloaded. However, the results showing that differences in the pattern of effects depend on which hazard was presented first suggest that hazard salience is also important to consider. These findings have important implications for public education efforts around tsunami evacuation. Communication to encourage tsunami evacuation, particularly in the context of local source tsunami, should take into consideration that people will still be processing the psychological impacts of having experienced a severe earthquake during the window where they are expected to decide to evacuate.

Reactivated coastal hot springs, Waiwera Geothermal Field

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Waiwera is a small town located on the east coast of the North Island about 35km north of Auckland City. The area has a pre-European history of Māori using natural artesian hot springs located on the foreshore and intertidal zone at the south end of Waiwera Beach. Development of the geothermal system since European settlement led to over 70 bores being drilled in the area, encountering geothermally influenced waters at depths of 200 m to 400 m bmsl. These developments increased direct use of the geothermal system, drawing down water levels that then led to the coastal hot springs ceasing to flow in the ~1960's. Gradual curtailment of consented water allocations since 1980's by the Auckland Regional Council caused the aquifer water levels to stabilise but not sufficiently recover to allow artesian flow.

The main user of the geothermal water in the area, Waiwera Thermal Resort, ceased pumping and closed in 2018. There is now evidence of the geothermal system recovering pressure and causing existing users bores and abandoned bores to overflow. The results of a 2022 aerial thermal infrared survey show evidence that the coastal hot springs have returned to an artesian state. Hot water flows up fractures to the surface as several small seeps along the intertidal rock platform. Results of geochemical analysis of geothermal groundwater will be provided and implications of observed flow rate from overflowing bores will be discussed regarding the possible full recovery of the coastal hot springs.

5 Minute: volcano - co-designing games about geological disaster risks with and for children

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This research will present an example of an applied game that supports children's learning. 5 Minute Volcano is a game co-designed with children educated in the bi-cultural environment of Aotearoa New Zealand to communicate coastal volcanic risks. It is a collaborative game to identify hazards based on Aotearoa volcanoes, science structures, and society using native and cultural imagery and concepts, such as animals and Taniwha to represent characters and hazards.

Volcanoes are an integral part of New Zealand's history. Even so, these hazards can pose risks to our communities and people should be aware of such risks. Children are especially vulnerable as they rely on competent adults around them. However, children also have the potential to make changes in their communities through education.

Appropriately designed risk communication resources (including games) can reduce children's vulnerability to natural hazards. Applied games can be an effective instrument for children to learn, but research and design practice gaps are extensive. To address these gaps, the authors worked alongside a Māori language kura to co-design an applied game for tamariki about volcanic risk communication. Our qualitative research allowed us to collect perspectives from different stakeholders, including the kaiako and tamariki, to inform the game's design process. This co-design process aimed to align learning goals from scientists with the school context, and to address the children's learning needs and game preferences as a target group.

The results of this process highlight the design principles of these games to communicate important knowledge and skill goals, help children with their core competencies, and must be usable to promote resilience to natural hazards with both Western and Māori elements. The goals of ongoing research will explore the effectiveness of game principles in volcanic risk communication, and how to incorporate Māori elements in a culturally appropriate and effective manner.

The quest for commercial low enthalpy geothermal resources in New Zealand

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Modern technology promises to make the heat of the earth available anywhere. Away from the known high temperature geothermal fields of TVZ and Northland, there are numerous records of warm water or rocks across NZ, some of which are strategically located close to energy intensive industries.

In Taranaki, geothermal gradients measured in numerous deep oil and gas wells are commonly 30°C/km, which is consistent with a number of operating geothermal power stations in Europe. Recent modelling indicates 600 kW can be extracted from a typical pumped well completed in fractured carbonates of the Tikorangi Limestone. Deeper sandstone reservoirs typically lack porosity and permeability. Elsewhere, there are few deep (>3km) sedimentary basins onshore NZ, especially beneath major population centres.

Greywacke basement forms part of the geothermal reservoir at Ngawha and Kawerau, however its thermal characteristics elsewhere require more research. Limited data from Waikato suggests that elevated geothermal gradients may exist, and that where faults are intersected, sufficient fracture permeability may be present. Little is known of the thermal properties of other basement lithologies, with the DFDP drilling into the Alpine Fault being the only well documented occurrence of warm basement lithologies.

In the Hauraki Graben, extensive data indicates regional heating of the sedimentary succession, likely controlled by faulting. Geothermal gradients of 60-100°C/km can be demonstrated from drillholes, however these are limited to <350m depth, and nothing is known about the deeper structure, basin fill, or underlying basement, other than indirect geophysical measurements.

Presently, development of novel low enthalpy geothermal resources in NZ is viewed by industry as risky, due to uncertainty about deep geology, lack of temperature and fluid flow data, and absence of precedents. Policy levers need to be developed to address these risks, with current funding mechanisms requiring too short a time frame to be an enabler.

Spatial-temporal development of paleo-pockmarks on the Chatham Rise from 3D imaging with subbottom profiler data

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Seafloor depressions, sometimes known as pockmarks, are commonly observed features on the ocean floor. Their shape and size can range from small, circular indentations (10s m) up to large, often irregularly shaped depressions (several kms in diameter). The origin of pockmarks is often attributed to focused fluid or gas seepage at the seafloor, but their formation mechanisms (e.g., gas/fluid composition, timing, physical processes) remain ambiguous in many cases. On the Chatham Rise, offshore New Zealand's South Island, seafloor depressions cover an area >50,000 km^2, and appear to be bathymetrically controlled. For this region, it has been hypothesized that episodic release of geological CO_2 resulted in the recurring formation of pockmarks at glacial terminations. High-resolution seismo-acoustic surveys using hull-mounted, parametric subbottom profilers allow the investigation of potential fluid-flow pathways and buried paleo-pockmarks. A voyage in 2020 acquired an extensive grid of densely spaced (~25 m) 2D subbottom profiles over a dense pockmark field on the Chatham Rise. Those profiles were used to create a comprehensive pseudo-3D cube by utilizing a recently developed processing workflow. Based on this generated cube, we perform an analysis of seafloor and buried pockmarks in the shallow subsurface up to 150 m below the seafloor. Here we present preliminary insights into the recurrence of pockmark formation at different geological times and an assessment of morphological changes and varying spatial locations over time.

A quantitative assessment of GeoNet earthquake location quality in Aotearoa New Zealand

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Tens of thousands of earthquakes are catalogued by GeoNet across Aotearoa every year. Each earthquake's hypocentral location (latitude, longitude and depth) is a fundamental catalogue parameter constrained by an inversion method which uses earthquake phase-arrival information from a network of stations. However, nationwide disparities in station coverage, varying spatial distributions of earthquakes - especially with depth - in contrasting tectonic regimes, alongside other data processing factors mean geographical variability in the location quality of seismicity exists throughout the GeoNet catalogue.

To investigate this, we consider simple, established 'rule of thumb' criteria for assessing the quality of GeoNet earthquake location precision. By considering station azimuthal coverage, minimum station distance, phase arrival coverage and fixed location criteria, we score earthquakes on a Quality Score (QS) scale from QS0 (unconstrained) to QS6 (best constrained) to quantitatively assess location quality.

Significant variation in QS exists nationwide; 48% of North Island earthquakes score QS6, versus only 20% for the South Island. The Hawkes Bay region scores well (68% QS6) followed by other Hikurangi regions including Gisborne and Wellington (54% and 59% respectively). However, several regions score extremely poorly, with Fiordland, West Coast, Nelson, Otago-Southland and Auckland-Northland regions having ≤5% QS6 events and >75% of events scoring QS3 or lower. Low quality scores mostly arise from failure of minimum distance quality criteria, whereby the closest station is too far from the earthquake to provide sufficient depth control.

Our analysis quantifies the impact of network heterogeneity on earthquake catalogue location quality across Aotearoa. This work should form an important part of driving discussion around weak-motion network expansion in critically under-instrumented regions, especially those with high seismic hazard, such as the late-interseismic Alpine Fault. Importantly, our analysis forms a baseline reference, against which proposed network expansion can be tested to gauge improvements and optimise impact.

The South Westland Alpine Fault: what's down there and how does it make earthquakes stop?

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Approximately half of past major Alpine Fault earthquakes have arrested close to the transition from the listric Central Segment to the sub-vertical South Westland Segment near the Martyr River. Here, the fault undergoes notable changes in geometry, slip rate, kinematics, bounding lithology, resolved stress, seismogenic behaviour and frictional properties, all of which have the potential to influence through-going rupture behaviour. Unravelling which factors contribute to observed conditional rupture arrest here – and therefore assessing likely future rupture behaviour – requires a combination of detailed observations about the fault’s physical state to inform realistic, physics-based earthquake rupture models.

Recent work to produce precise relocations of thousands of earthquakes and their focal mechanisms has illuminated the structure and microseismic behaviour of the segment boundary leading to improved quantification of the spatial variability in physical factors mentioned above. Here, we build on this work by using those local earthquake phase-arrivals to produce 3D tomographic models of the segment boundary in unprecedented resolution. We present preliminary Vp, Vs and Vp/Vs models revealing large-scale changes in crustal structure across the segment boundary, high-velocity bodies associated with the Dun-Mountain ultramafic terrane and Livingstone Fault and compare these with newly relocated seismicity to identify active structures.

Our full suite of observations are then used to inform a series of 3D finite-element dynamic simulations of earthquakes along the fault. Iterative geometric and stress parameterisations allow us to assess the relative role different physical factors play in allowing ruptures to either propagate through or terminate at the segment boundary. We find that successive on-fault stress changes from a series of earthquakes around the geometrical boundary can reproduce rupture arrest consistent with the paleoseismic record and surface slip values.

Tsunami early warning system in New Zealand

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New Zealand's (NZ) entire coastline is at risk of tsunami from local, regional and distant sources. With more than 75% of New Zealanders living or working within 10 km of the coast, our tsunami risk is significant.

The Rapid Characterization of Earthquakes and Tsunamis (RCET) research programme is being undertaken to better understand, mitigate and respond to tsunami events in NZ. Under this programme, a system has been developed to deliver next-generation tsunami early warning products within about 30 minutes of origin of the tsunami.

This system involves a step change in the amount of information provided in early warning forecasts. It aims to present a forecast of the evolution of the tsunami threat, rather than a static picture of its maximum amplitude. We call this time-dependent tsunami early warning (TiDeTEW). One key challenge in producing this tool is the need for development of the rules that bridge the numerical forecast with the end-user early warning product. These rules must be co-created through careful collaboration between scientists and end-users including the emergency response sector and affected coastal communities.

My PhD focuses on facilitation of this process by conducting research that provides a basis for comparing levels of conservatism of the forecasts with levels of risk tolerance in the end user community. I will present recent results from this work focussing on testing past and synthetic scenario tsunamis.

CO_2 emissions of the Taupō Volcanic Zone and complexities in estimating subaqueous degassing

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New Zealand's North Island is globally recognized for its high concentration of volcanic and hydrothermal regions in the Taupō Volcanic Zone (TVZ). Of the approximately 20 active hydrothermal systems, 6 have been measured comprehensively for their diffuse CO_2 emission. We show that the CO_2 emitted from several well-studied systems (e.g., Rotorua, Rotomahana, and Rotokawa) rivals that of NZ's active volcanoes, and that the CO_2 emission rates correlate well with published heat fluxes for the subaerial systems. Using this correlation, we estimate a new minimum total emission rate of ~ 5500 – 7000 t/d CO_2 for 17 hydrothermal systems in the TVZ. This estimate is an order of magnitude higher than the previous estimate of ~ 4.7 x 10^9 mol/yr, or ~570 t/d (Seward and Kerrick, 1996) based on degassing of upwelling hydrothermal fluids.

The relationship between CO_2 emission and heat fluxes for subaqueous systems is more complex than for the subaerial systems. Both lakes where CO_2 fluxes have been measured show emission rates higher than what would be expected based on the CO_2:heat relationship observed for subaerial systems. We note that extrapolation procedures (e.g., GSA vs. sGs) can greatly influence the emission rate calculated, and we calculate a new, lower, CO_2 emission rate for the Rotomahana lake system of 345 t/d. Yet, this estimate still exceeds what would be expected. Lakes may in fact act as a condenser of all emission from the hydrothermal system, where subaerial emission rates may only represent the diffuse component, suggesting the subaerial emission rates are underestimated. Alternatively, lake fluxes that are measured in winter may represent the degassing of a CO_2 load that has built-up beneath the summer thermocline. Ongoing work aims to unravel these natural and methodological influences on CO_2 emission rates to better constrain activity associated with NZ's hydrothermal systems.

SWM: Stochastic Weather Model for precipitation-related hazard assessments

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Long-term hazard and risk assessments are produced by combining many hazard-model simulations, each based on a slightly different set of inputs to cover the uncertainty space. While most input parameters for these models are relatively well-constrained, atmospheric parameters remain problematic unless working on very short-time scales (hours to days). Precipitation is a key trigger for many natural hazards including floods, landslides, and lahars. This work presents a stochastic weather model that takes openly available ERA5-land data, and produces long-term, spatially varying precipitation data that mimics the statistical dimensions of real-data. Thus, allowing precipitation to be robustly included in hazard-model simulations.

The stochastic weather model (SWM) comprises three steps: Data conversion, block construction, and stochastic weather generation. Due to the relative simplicity of the model and exploiting some coding efficiencies in the R package dplyr, 10 years of hourly data can be generated across a 10 by 10 cell grid (~110 km by 110 km) on a standard desktop computer in < 5 seconds.

Building an enhanced earthquake catalogue for Aotearoa: applying an automated workflow with cutting-edge machine learning methods to mine New Zealand's seismic data.

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The nationwide seismic catalogue produced by GeoNet is primarily focused on ensuring fast hazard communication and response. The focus on hazard response, combined with the inconsistent nature of the New Zealand seismograph network can mean events are mis-located or not located at all. We propose and develop a cutting-edge automated workflow to generate research-grade earthquake catalogues. This workflow will expand and improve the catalogue and enable further research into New Zealand's tectonic settings. This workflow will allow uniform identification, classification and location methods to be applied to the entire catalogue, reducing errors and uncertainties introduced by inconsistencies in the current catalogue.

We use the now well-tested EQTransformer AI seismic picker to efficiently and accurately pick events in a uniform manor. Initially we have re-picked all events within the GeoNet catalogue and will later use EQTransformer as a detector to identify new events within raw seismic data. We locate all events using NonLinLoc with the Eberhart-Phillips NZWide 2.3 Velocity Model, producing accurate locations and robust uncertainties. In this presentation we present the results of initial testing on five distinct regions around Aotearoa. We find that the effect of automatic picking in comparison to manual picking is negligible in determination of final location and that the improved velocity model has a much larger influence. In all test regions, the majority of events locate deeper than initially estimated by GeoNet, this is particularly the case in Fiordland and Taupō where average depth increases of 10.8 km and 9.1 km are observed. In more densely monitored regions with less complex velocity structures we see a smaller change in location (averaging 2.1 km change in depth in Canterbury). Future work will extend this cataloguing throughout Aotearoa to develop a self-consistent high-quality earthquake catalogue to enable an enhanced understanding of seismogenesis, fault structure and hazard throughout New Zealand.

A revised record of late Quaternary activity on the Settlement Fault, Otago, New Zealand

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The Settlement Fault is a ~23 km long southeast dipping reverse fault in the Catlins area near the southeast coast of the South Island. Based on radiocarbon dating of an uplifted Holocene marine platform and shallow sediment cores from Catlins Lake adjacent to the fault, at least one, and possibly two, Settlement Fault surface-rupturing earthquakes since ~3,600 years ago have been previously proposed. To refine the Settlement Fault paleoseismic record, we excavated a trench across a ~3 m high Settlement Fault scarp on a small alluvial fan ~3 km northeast of Catlins Lake. The ~3-m deep trench exposed a sequence of gritty-silt to sandy-silt fan alluvium, with clay lenses. The upper part of the sequence is grey-brown, and rests on a blue-grey lower part. The entire sequence is uniformly deformed by a ~15-m wide, ~3-m high monocline. We therefore infer the sediment package was deposited within one earthquake recurrence interval and subsequently deformed by one or more surface ruptures; based on the scarp's height, a reasonable case for two ruptures can be made. Four Optically Stimulated Luminescence (OSL) dates from the base to upper part of the exposed sediments all returned ages of ~20ka. We therefore interpret that that the alluvial fan sediments were deposited relatively rapidly ~20ka. Given the 2.7 m vertical offset of the fan surface across the scarp, the OSL results suggest an uplift rate of 0.14 mm/yr. By comparison, a marine terrace remnant from the last interglacial period (~125 ka) near Catlins Lake lies 10-15 m above sea level. Assuming the last interglacial peak sea-level was 5 m higher than present, this implies a long-term Settlement Fault uplift rate of 0.04-0.08 mm/yr. This increase in Settlement Fault uplift rate over the late Quaternary is consistent with observations from other faults in the southeastern South Island.

Active faulting and seismicity in low strain rate regions: new perspectives from the southern South Island

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Investigating tectonic deformation in low strain rate regions (i.e., regions with fault slip rates <~1 mm/yr) is challenging as it is inherent that there are fewer historic and instrumentally recorded earthquakes, and the surface rupture expressions of low slip rate active faults are less likely to be preserved in the landscape. In this contribution, we synthesise results emerging from a multidisciplinary study of deformation peripheral to the Australian-Pacific plate boundary in southeastern parts of Otago and Southland. These results include updated active fault mapping, which is aided by the recent release of widespread lidar coverage in Southland. This highlights several discontinuous scarps that commonly follow pre-existing faults and show a diverse range of orientations. From a growing paleoseismic record in the Otago range and basin reverse fault province, we document temporal slip rate variations across individual faults. Finally, we present preliminary results from the Southland-Otago Seismic Array (SOSA), a dense 12 month seismic array that extends east-west from the Clutha District to Fiordland. Cumulatively, our results highlight two features of active deformation in the southern South Island: (1) clustering of earthquakes at a range of spatial and temporal scales; for example, although close to 50 active or potentially active faults are mapped in the Otago range and basin reverse fault province, most late Quaternary (i.e., since ~50 ka) surface rupturing earthquakes have been on three faults at its eastern edge, and (2) the role of structural inheritance in active deformation, including -but not limited to- the reactivation of pre-existing crustal weaknesses, and possible strain rotations across rheologic contrasts at terrane boundaries. Comparisons to other slowly deforming regions indicate these may be ubiquitous features of crustal deformation in low strain rate regions.

Uncovering the influence of data resolution on quantifying landslide volumes

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Submarine landslides are a potentially hazardous phenomenon that occur beneath the ocean's surface. These events involve the sudden movement of large volumes of sediment, rock, and other materials along underwater slopes or canyon walls. When triggered, submarine landslides can have significant consequences, including the generation of tsunami that can pose a possible hazard to coastal communities.

Landslide scars occur along all canyons around Aotearoa New Zealand, e.g., Kaikoura Canyon and Pegasus Canyon, where numerous, different-sized scars are detectable in bathymetry data.

In 2020, we collected high-resolution bathymetry and closely spaced sub-bottom data to map a submarine landslide on the Pegasus Canyon using equipment mounted on an AUV. This landslide was previously thought to have happened recently; however, these data revealed that the landslide is blanketed by a thick layer of sediment, indicating an older event.
When estimating the potential tsunami risk from a submarine landslide, a key factor is the volume calculation of the released material. Using existing lower resolution data on the above-mentioned landslide, this volume would be significantly under-estimated. We demonstrate, using this new and unique high-resolution multibeam dataset, how much the resolution of the seafloor data affects the volume assessment, and therefore what impact this has on the calculated tsunami risk of underwater landslides. Combining it with sub-bottom data by mapping the sediment layer will further aid the calculation accuracy of the landslide volume.

With over 2,200 underwater landslides identified on the seafloor along the Hikurangi Margin, could the risk of a tsunami be much higher than we thought?

Landslide dams in Aotearoa: a national database to characterize their formation, longevity and breaching behaviour

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The multiple recent extreme weather events impacting Aotearoa New Zealand and their consequences have demonstrated how dynamic our environment and landscapes are. Numerous landslide dams formed during these events as part of the hazard cascade, posing a risk to downstream infrastructure and communities.

Landslide dams form when landslides fully or partially block a watercourse, potentially resulting in damaging flooding if they fail rapidly. Despite their potential consequences, they are under-researched. Their formation, longevity, and breaching behaviour are not well understood, which is critical information needed for effective risk management.

We present v1.0 of the New Zealand Landslide Dam Database (NZLDD), compiling pre-historic and historic natural dams. The database includes over 1000 landslide dams and is a major step towards improved understanding of this natural hazard.

Several case studies, including from recent severe weather events, will be discussed to showcase features of the database and the complexity of landslide dams. These have been studied in detail using multiple field and remote sensing campaigns – including field mapping, RTK surveying, drone photogrammetry, and LiDAR.

The database is currently being analysed to quantify local factors influencing dam formation, longevity, and breaching behaviour. These analyses and observations will be used to characterize the otherwise poorly understood landslide damming processes, enabling improved prediction of the magnitude and reach of their hazards, as well as their management.

New windows on the world – Part II: extended reality experiences to support geoscience field trips

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As the era of spatial computing gains momentum, and mobile hardware options become both higher quality and lower cost, virtual and augmented (collectively, extended) reality (XR) applications are proving to be valuable supplements to the geoscience field experience. Interacting with field-relevant spatial datasets in a natural and intuitive way can facilitate 3D visualisation and provide alternatives to traditional ground-based perspectives. Three XR applications have been developed to complement undergraduate field courses.

Drone photogrammetry and 360° photography are harnessed to replicate outcrops in virtual reality (VR). A flight locomotion system allows sites to be examined from any angle, altitude, or distance. Due to accessibility and safety constraints, students can often only take detailed observations of the lowermost section of outcrops in the field. They can now explore the full exposure in VR and measure all key litho- and cyclostratigraphic boundaries using a virtual measuring staff that is locked to a local stratigraphic datum.

VR-based aerial stereoscopy combines decades-old analogue photography with a modern XR platform for the convenient and effective delivery of 3D imagery. Initially, overlapping areas of consecutive aerial photographs are aligned in open-source illustrating software. Annotated 8K stereoscopic equirectangular images are then generated in Final Cut Pro X and navigated using the Unity game engine. VR aerial stereoscopy can be prepared for any New Zealand field location using freely available historical imagery in the Retrolens website.

An iPad-based augmented reality (AR) exercise helps prepare 200-level students for their first field mapping course. The 'Rule of Vs' and its various exceptions are demonstrated using eroded semi-transparent stratigraphic block models, annotated with topographic contours and drainage directions. Students can examine how subsurface stratigraphy interacts with topography to produce predictable field relationships. The model space fills an expansive communal area on campus, encouraging physical movement and providing an immersive collaborative experience.

The thermal properties of the Central Alpine Fault, New Zealand

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The Alpine Fault is New Zealand's largest onshore source of seismic hazard, is late in its seismic cycle, and has regularly ruptured in magnitude 8 earthquakes. Temperatures within fault zones strongly influence fault behaviour before, during, and after earthquake slip, yet little is known about the thermal properties of fault rocks themselves. This study quantifies the thermal properties of the Alpine Fault zone, which consists of a ~50m-thick sequence of fault gouge and cataclasite that grades eastwards into an ~1km-thick mylonitic sequence derived from the protolith Alpine Schist. 130 thermal conductivity and diffusivity measurements were made in situ of the fault gouge, cataclasites, and footwall fluvioglacial gravels using a linear heat source double-pronged needle probe. 40 foliated mylonite and Alpine Schist samples were collected and measured in the laboratory with an electronic portable divided bar in orientations parallel and perpendicular to foliation. Preliminary results show a significant decrease in thermal conductivity with proximity to the Alpine Fault principal slip zone. Mylonite and Alpine Schist samples exhibit strong anisotropy in thermal conductivity, with higher values obtained from measurements made parallel to foliation. Future research aims to quantify the physical properties and processes that control the thermal properties and construct a predictive model for the thermal properties of given lithologies. Data will also be used to investigate the evolution of temperature with slip during an earthquake and the heat signature of the fault at various depths. Findings from this study may also have implications for future exploration and development of unconventional geothermal resources.

The chemical effect of preservation methods on crustacean body burden: implications for biomonitoring and analysis of essential metals

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The marine environment is facing increasing pressure from anthropogenic activities such as ocean acidification and pollution. Biomonitoring studies, using organisms such as Crustacea, are an important means of assessing the exposure of toxic metals in the environment as well as assessing recovery and compliance. However, prompt analysis is difficult and organisms can be preserved and handled in different ways prior to analysis, which may alter body burden chemistry.

To understand the effect of these processes on body burden chemistry we have analysed 35 elements in shell and tissue from two specimens of the crayfish *Jasus edwardsii*, sampled on consecutive days in Te Whanganui-a-Tara/Wellington. The samples were preserved as frozen, and using three commonly used fixatives (ethanol, isopropyl alcohol and formalin), and analysed periodically over 2 years.

Fresh samples were processed using both a metal (stainless steel) and ceramic knife, with the former showing higher contents of many metals in the shell. Partitioning between shell and tissue for many elements was similar, although some metals preferentially partitioned into shell (e.g., U, Pb, Y) and others into tissue (e.g., Zn, Cu, As). The effects of preservatives were complex and varied over time, possibly related to decomposition and subsequent re-calcification of carbonate in the shell, and absorption of trace metals from the preserving fluid. Formalin-preserved specimens are generally too compromised to be useful, whereas specimens preserved in ethanol are less compromised and faithfully record a range of metals. Frozen samples show the least variation in shells compared to fresh samples, but in tissue there were still significant changes in many elements, suggesting deterioration of the tissue and remobilisation of elements between tissue, shell and fluids. Our results highlight the importance of metal free handling of specimens, and although even frozen samples may be suitable for many elements, some are compromised, especially in tissue.

Geometry and density of fractures in Taranaki seal rocks

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Hydrogen is projected to account for at least 10% of the global energy system in 20 years and is a critical component of the future zero-emissions energy system. Aotearoa New Zealand (ANZ) uses a high proportion of renewable electricity. Underground storage of green hydrogen will take advantage of intermittent surplus of renewables at low cost, accommodate peaks in energy demand, and provide a strategic reserve of energy. Underground hydrogen storage (UHS) provides a means to balance seasonal fluctuations in energy supply and demand. Current surface hydrogen storage facilities, such as pipelines or tanks, are unlikely to have the sufficient capacity for future projected demand. This poster is part of a larger research programme primarily focused on investigating the potential for UHS in subsurface porous rock formations of Taranaki, ANZ. Here, we explore the geological conditions for storage in depleted gas reservoirs with particular focus on seal integrity.

Seal integrity is key for economically storing and recovering hydrogen in the sub-surface. In this project the overarching goal is to improve understanding of whether mudstone seal strata have the potential to prevent leakage of hydrogen from Taranaki reservoirs. The primary focus is to characterise the geometries of fracture systems in seal strata, their impact on its bulk permeability and to identify the pressure conditions required to promote the loss of seal integrity. In this poster I use Formation Micro Imagery (FMI) from wells and interpretations of seismic reflection lines in onshore Taranaki to constrain the densities and orientations fractures in seals. I explore the impact of macro-scale faulting and folding on different seal strata. The poster outlines results to date, proposed research pathway and invites discussion.

A controlled environment evaluation of smartphone and low-cost multi-GNSS, dual frequency sensors for deformation monitoring

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Global Navigation Satellite Systems (GNSS) deliver precision measurements (at the millimetre level) and high temporal resolution (1 Hz or higher data sampling) in crustal deformation monitoring. However, the substantial cost (exceeding tens of thousands of dollars for each geodetic-grade GNSS receiver) is a major factor that contributes to a low density of continuously operating GNSS (cGNSS) sites, particularly in a diverse New Zealand plate boundary zone, where site spacing can exceed 10 kilometres. Low spatial density limits our ability to detect short wavelength variations in ground movements and especially for localised deformation effects. Although campaign-based GPS surveys and Interferometric Synthetic Aperture Radar (InSAR) observations contribute towards improving the spatial density, there is still a challenge when it comes to addressing the temporal gap. The term "temporal gap" refers to instances of deformation movements that occur frequently but exhibit short durations, such as aseismic creep, which requires continuous monitoring instrumentation. This study investigates the feasibility of using smartphone and low-cost multi-constellation, dual-frequency, GNSS receivers as viable alternatives to augment the existing cGNSS network in New Zealand. The receivers we are investigating consist of Android-based smartphones and low-cost uBlox receivers, which are benchmarked against geodetic-grade Trimble NetR9 receivers. We also undertake positioning performance tests in a controlled setting by simulating lateral movements on a sliding platform for all GNSS receivers. Our findings demonstrate that these economically accessible GNSS receivers provide a comparable ability to their geodetic-grade counterparts to detect such movements. This suggests the potential for supplementing geodetic networks with cost-effective receivers, enhancing the performance in deformation monitoring.

From picks to pixels: practicing field skills in virtual reality

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The best geologist is he who has seen the most rocks. However, the infrequent opportunities to attend field trips in undergraduate geology courses often limits the number of rocks each student is exposed to.

We have developed a virtual reality tool for providing students ongoing access to practical skills training outside of regularly scheduled field trips. Sites of interest are virtually replicated through a combination of 360° video and 3D scans, allowing students to learn on-site without the logistical and economical overhead of physical travel.

We present the results of a preliminary study where 25 second-year students were virtually taught how to measure the strike and dip of a bedding plane. Testing on a real-world surface before and after exposure to the virtual lesson showed a statistically significant improvement in students' ability to perform this measurement accurately, while also doing so significantly faster. Interviews with students afterwards showed great support for the ongoing integration of this tool into regular coursework for a range of tasks including practical skills testing and 3D visualisations. We discuss these findings and their future implications for geoscience education.

Origin of crystals in mafic to intermediate magmas from circum-Pacific continental arcs: transcrustal magmatic systems versus transcrustal plutonic systems

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Complex zoning in crystals is characteristic for arc magmas and occurs in response to closed-system changes in magmatic P-T-fO_2 conditions and open system processes such as magma mixing and degassing or regassing. However, over which time frame do such changes occur? Do zoning patterns record changes occurring during the polybaric ascent of magmas that carry the crystals, or alternatively indicate the uptake of antecrysts that experienced long periods of cold storage in plutonic precursors? A priori, these scenarios are endmember models, with the former transcrustal magmatic systems, where the crystals record the changing conditions during magma ascent, traditionally preferred over the latter, which we here term transcrustal plutonic systems, where aphyric parental melts acquire their entirely antecrystic crystal cargo during ascent from plutonic protoliths, and where only crystal rims may be related to the host magma. We discuss the evidence for dominantly plutonic antecrystic cargo in some continental arc magmas, identified by considering mineral phase proportions and evidence for hydrothermally altered cargo picked up by fresh melts. We then turn to two-pyroxene thermobarometry and review the evidence for plutonic antecryst dominance revealed by this method in SW Japan and the southern Taupo Volcanic Zone. We provide additional data from the Andes, the Cascades, and northern Taiwan, corroborating that the uptake of crystals by aphyric to scarcely phyric melts is prevalent in continental arc magmatic systems. Thus, in many cases transcrustal plutonic systems seem to dominate, implying that a significant proportion of parental melts of continental arc magmas are felsic, too hot to carry crystals, and typically too hot and not hydrous enough to be generated by differentiation in frequently postulated lower crustal hot zones, as we will demonstrate. Our data indicate that in continental subduction zones, the mantle wedge is the source of a diversity of melt compositions.

Source parameters of crustal events in New Zealand from generalized inversion

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In this study, we perform spectral decomposition of the Fourier amplitude spectra (FAS) of ground motions in the New Zealand Ground-Motion Database (GMDB v3.0) compiled during the National Seismic Hazard Model (NSHM) 2022 update project. We apply a non-parametric generalized inversion technique (GIT) to isolate source, path, and site effects from 20, 813 ground motions from 1200 crustal events recorded by 693 sensors at 439 unique locations. Each channel is treated as an independent "site". We then parameterize the high-quality observational dataset of nonparametric source spectra using classic source models in the Fourier domain and address questions regarding source scaling in an NZ context. We found a very mild earthquake magnitude-dependence of stress parameter Δσ (assuming a Brune-type circular rupture model) for crustal events and a slight increase in Δσ with focal depth. Δσ exhibits a statistically significant spatial clustering, which can potentially be utilized to improve ground-motion predictions at high frequencies.