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Brine-reactivity for studies of injecting CO_2 and H_2 in New Zealand rocks

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New Zealand’s commitment to a carbon neutral economy by 2050 requires reducing emissions of anthropogenic CO_2 into the atmosphere as well as developing clean energy resources. Geosequestration of carbon dioxide (CO_2) entails to capture greenhouse gases from the source points (e.g. industry emitters, direct air capture) followed by injection into appropriate subsurface rock formations. The most common approach consists of injecting the CO_2 in its pure supercritical state or CO_2 dissolved into water, which in both solutions disturb the reservoir's native fluid(s). Such approaches are ongoing in the geothermal sector, but opportunities exist for other CO_2 point sources such as the Huntly and Glenbrook plants and petroleum fields.

Hydrogen is a potential future fuel for New Zealand, and if large volumes of the fluid are produced these would need to be stored somewhere to match our energy supply-demand cycle. The MBIE-funded Pūhiko Nukutū project is exploring the potential to store hydrogen in the subsurface, just as the energy industry has successfully implemented for years with methane. For both applications, CO_2 and H_2 injection into subsurface rocks, rock-fluid reaction experiments in the laboratory are critical to understanding the potential and/or limitation of such technologies. The experimental approaches can be summarised as: mono-mineralic powder reactions in batch reactors to maximise surface reactions for kinetics purpose by instance, and whole rock reactions with native or synthetic fluids to seek the time-scale of reaction in realistic reservoir conditions (reactive transport by instance).

Performing whole-core reactions with CO_2-brine and H_2-brine requires using a brine chemical composition that mimics the reservoir's native fluid to avoid inducing unnecessary brine-rock reactions. We show approaches to using and creating synthetic brines for such experiments. We also illustrate how chemical imbalance of the brine and/or original drilling fluid components within cores can change the physical properties of Taranaki sandstones.

Rapid aftershock cataloguing: A Kafka story

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In the aftermath of significant seismic events, geohazard analysts often prioritise the analysis of larger magnitude aftershocks. However, a more complete and near-real-time earthquake catalogue is essential for comprehensive hazard assessment and response. This work aims to complement existing real-time aftershock cataloguing methods by enhancing early aftershock detection immediately following a main event. By leveraging interchangeable and containerized detectors, associators, location algorithm and velocity models, all connected to a central Kafka broker, we develop a near-real-time pipeline capable of generating more comprehensive earthquake catalogues.

To integrate these capabilities into an Ideal Earthquake Catalogue Framework, the pipeline is designed to be easily adaptable and modifiable. All details, including parameters and Kafka topics, are documented, ensuring reproducibility of the results. This standardisation facilitates comparison by providing consistent I/O formats and empowers users to adapt the pipeline to their specific needs. We will demonstrate the pipeline using the 2016 Kaikōura earthquake sequence as a case study.

Ultimately, our goal is to deliver a robust, flexible system that enhances real-time seismic analysis, contributing to more informed decision-making during geohazard responses. This pipeline is not only designed for aftershock analysis but also includes modules focusing on Earthquake Early Warning (EEW) systems, specifically a P-wave detector tailored for the Central Weather Administration (CWA) in Taiwan.

Towards an automated detection and characterisation of slow slip events along the Hikurangi subduction zone using graph neural networks

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Slow slip events (SSEs) play a crucial role in the seismic cycle by influencing earthquake timing and stress accumulation, making their detection and characterisation essential for understanding and mitigating seismic risk. The Hikurangi subduction zone, a region with significant SSE activity, currently lacks an automated monitoring system for these events in Aotearoa New Zealand. Existing approaches often depend on visual inspection, tedious pre-processing, and time-intensive inversion algorithms.

In this work, we explore the application of geometric deep learning models to both synthetic and real GNSS time series. By leveraging the spatial and temporal relationships within the data, our approach aims to automatically and efficiently estimate, for example, the daily amount of slip along the interface of the Hikurangi subduction zone. This represents a significant step toward rapid, automated SSE characterisation tools for Aotearoa New Zealand.

Structural analysis in the actively deforming western foothills in southwestern Taiwan: Fault-related folds versus mobile shale processes

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The Taiwan mountain belt is an active orogen formed in response to the oblique convergence between the Eurasian plate and the Philippine Sea plate. The convergence results in a west-verging fold-and-thrust belt deforming a Plio-Pleistocene foreland basin sequence, which becomes muddier towards the south. In southwestern Taiwan, the 3-4 km-thick Gutingkeng mudstone has similar characteristics to mobile shales, such as high overpressure conditions, sourcing mud volcanoes and possibly mud diapirs. In the foothills, uplift rates as fast as 2 cm/yr measured using geodetic techniques have been observed mainly on the footwall of steep thrusts. One of these thrusts is the northeast-striking Gutingkeng Fault, which is lined with mud volcanoes. We have integrated surface observations near the Gutingkeng Fault with regional subsurface data to construct an upper crustal cross-section and examine the roles of fault-related folding and mobile shale processes in the deformation of southwest Taiwan. Field observations show steep and well-preserved bedding on both the hanging wall and the footwall, and a wide zone of distributed black shear zones, most likely reverse, corresponding to the Gutingkeng Fault zone. No distinct structures explaining footwall uplift were found at the outcrop scale. At the scale of the cross-section, surface geology and subsurface data suggest a structural style involving fairly narrow anticlines with steep limbs, growing above a relatively deep detachment. These geometries are difficult to account for with traditional fault-related fold models. We infer that the Gutingkeng Fault is inactive, and that uplift is caused by folding of the footwall through thickening facilitated by the weak mudstone rheology. Mobile shale processes within fold cores may lead to rock weakening or plastic flow causing thickening and inflation of the fold cores without clear evidence in the surface geology, besides mud volcanism and increased surface uplift.

Statistical insights regarding the relationship between seismicity and slow slip events in the Hikurangi subduction zone

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The Hikurangi subduction zone (HSZ) is a large plate boundary system that extends beneath the North Island of Aotearoa New Zealand and generates a diverse range of activity including mainshock-aftershock sequences, seismic swarms and slow slip events, along with the historic and impending risk of megathrust earthquakes. Examining the recurrence of and interaction between such behaviours is a crucial step in improving our understanding of underlying fault processes and the future of the Hikurangi region. Slow slip events are a kind of slow-motion earthquake and have been associated with both large earthquakes and seismic swarms in the HSZ. Seismic swarms are spatially and temporally clustered sequences that do not display typical mainshock-aftershock decay: several events may have similar magnitudes and the largest event often occurs in the middle of the sequence. Although the boundary between mainshock-aftershock and swarm activity is not clearly defined, swarms rely less on earthquake to earthquake triggering and are generated by diverse mechanisms including slow slip, fluid movement, melt migration, and geothermal processes. We implement statistical techniques to systematically uncover the relationship between slow slip events and seismic swarms. Analysis of their complex relationship has previously been restricted by the available data, thus we greatly benefit from the utilisation of recent catalogues of seismicity and slow slip events, developed using matched filter and wavelet analysis, respectively. Relevant seismic sequences are identified and classified into 2D spatial subregions. Within these subregions, correspondence with three key regions of slow slip (occurring shallowly off the East Coast, in Kāpiti/Manawatū, or deep beneath the Kaimanawa Mountains) is analysed. We also use point processes to model event recurrence patterns across seismic sequences and distinguish mainshock-aftershocks from seismic swarms. The epidemic-type aftershock sequence model captures the triggering relationships of mainshock-aftershock activity, while swarm-like sequences are better described using renewal processes.

It's not just paleovegetation: Sporomorph chemistry-based insights into UV-B radiation and solar activity from lake sediment records from Aotearoa and Türkiye

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Paleoenvironmental proxies provide a crucial avenue for determining how our climate, oceans and other environmental parameters have changed through geological time. Pollen and spores, collectively termed 'sporomorphs' have traditionally been used for reconstructing vegetation change, and, by inference, climate change. Recent work has demonstrated that sporomorphs also record a signal from UV-B radiation in the chemical makeup of their outer sporopollenin wall, through variations in levels of UV-B absorbing compounds (UACs). Because sporopollenin is extremely stable, and sporomorphs can be preserved for multiple millennia under the right conditions, it is possible to measure UAC levels in ancient pollen to provide a proxy record of relative surface UV-B radiation receipts. We have harnessed this technique to address a number of research questions relating to solar activity and UV-B radiation through time, as well as further demonstrating the robustness of the UAC proxy.

Using sediment records with exceptional, annually-resolved age models we have been able to examine how UV-B radiation varied during the most recent solar minimum (Maunder Minimum, MM) from approximately 1645-1715 AD. Our results from our Turkish record demonstrate that, contrary to inferences from sunspot records, the 11-year Schwabe cycle of solar activity persisted through the solar minimum. Results from our Aotearoa site (Lake Ōhau) are somewhat more cryptic, which we attribute to a more dynamic sedimentary environment and mixing of pollen from multiple years and locations.

We also present the first multi-species sporomorph UAC record. We have compared UAC values from sporomorphs of three different plant taxa from different habitats (tree, shrub and grass) over the same timeframe. We see a strong correlation in the trends in UAC levels across the three taxa, demonstrating that the UAC proxy is consistent across different plant taxa.

National fault-induced river avulsion hazard model

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Surface-rupturing earthquakes can trigger the sudden avulsion of river channels, causing rapid and continual coseismic flooding of previously unaffected areas. This occurs when a fault rupture results in significant vertical or horizontal displacement, altering the topography of the river channel. The importance of understanding fault-induced river avulsion (FIRA) for hazard analysis was underscored by the 2010 Darfield and 2016 Kaikōura earthquakes, during which FIRA events occurred on the Hororata River and the Waiau Toa Clarence River, respectively.

This study uses New Zealand national river (NIWA River and Flood Maps) and fault databases (GNS Science New Zealand Active Fault Database and the New Zealand Community Fault Map) to create a regional-scale methodology to quantify the relative hazard of FIRA events. Using the 'F-index' proposed by McEwan et al. (2023), it identifies the magnitude of potential earthquake-induced overbank flow by considering the flow-dependent river channel depth, and the expected fault vertical displacement.

Preliminary testing of this methodology indicates a greater proportion of FIRA-significant fault-river intersections in the North Island compared to the South Island. The outcome of this study is a regional hazard model that provides a preliminary assessment of earthquake-induced flood hazards. As a result, this includes the identification of FIRA event susceptible regions and specific fault-river intersections to inform and prioritise site specific modelling. Additionally, the study will inform how changes in rainfall affect the relative risk of FIRA events, highlight regions that should prioritise emergency response management plans to account for FIRA events, and advance the understanding of fault displacement hazards.

From science to operation within the Rapid Characterisation of Earthquake and Tsunami (RCET) Program

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The Rapid Characterisation of Earthquakes and Tsunami (RCET) programme is a large GNS Science-led multi-year public initiative to better prepare for and respond to natural disasters. This has included implementing and testing a set of near real-time tools for use in event response. While the scientific approaches across the suite of tools aim to enrich the event information that can be provided (e.g. through improved accuracy or better uncertainty characterisation), the operationalisation seeks to reduce the time taken to compute and deliver this critical information from days to hours or minutes.

This challenge of taking science into operation requires its own infrastructure and processes, selecting a platform for method development, testing, deployment and monitoring, as well as visualisation and dissemination of results. These challenges are well known globally in geohazards monitoring, and program like GeoNet have developed excellent practices to meet requirements for robust and reliable 24/7 delivery of data and products to a wide and diverse audience. However, the paradigm for RCET is different. The novel and relatively low maturity tools are still under active development, testing or re-configuration, so processes are ideally accessible, agile and modular. While high reliability is desired, results often only need to be delivered to small expert user groups, so parts of the system can leverage simpler and less robust solutions.

Here we present an overview of some of the approaches taken (and lessons learned) within RCET to achieve operational capability. We present the ecosystem of response tools created, some of the scientific and technical pathways connecting them, and some of the products created to meet the goal of enhancing rapid scientific information during the next event response.

Integrating machine learning in geoscience and engineering education: A multihazard approach

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We developed an educational framework for teaching machine learning (ML) techniques focusing on geohazard prediction and management. The course integrates ML across various geoscience applications, preparing future professionals to address complex environmental challenges. This was part of a course for 4th-year civil engineering students on data modelling from physics-based and modern data-driven approaches.

The curriculum follows a multihazard approach, with weekly labs covering diverse topics, for instance, exploring meteorological data and wildfire occurrence, clustering analysis of seismic stations by geotechnical characteristics, and neural network prediction of streamflow and flooding.

The flood prediction module, which received positive student evaluations, forms a core component of the course. This module focuses on a case study involving river flow data from New Zealand's Mohaka catchment. Students explored the implementation of ML models such as Neural Networks for flood prediction. Students engage with a partially implemented pipeline, covering data preprocessing, feature engineering, model training and testing, and hyperparameter tuning. They apply these models to demonstrate principles such as peak flow estimation and real-time forecast updating.

The hands-on approach provides insights into data quality, feature engineering, and ML applications across various geohazards. Students grapple with concepts like data leakage, cross-validation, and the distinction between parameters and hyperparameters. Learning from model deficiencies was also emphasised.

This educational framework equips future geoscientists and engineers with advanced analytical tools and interdisciplinary knowledge, preparing them to address evolving challenges in various geological domains. By focusing on skills application and recognition of limitations, we build confidence in students' abilities to tackle real-world challenges using modern methodologies, contributing to more effective geohazard prediction and management.

Improving eruption forecasting through transfer machine learning: A global approach utilising models trained on 24 volcanoes

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Volcanic eruptions threaten human lives and infrastructure, yet the accuracy and reliability of automated forecasting methods remains challenging due to the lack of robust historical data for individual volcanoes. Our research explores using datasets from well-instrumented volcanoes to train generalizable machine learning (ML) forecast models using seismic data, potentially identifying eruption precursors for volcanoes with limited historical records.

We tested ML models on seismic data from 24 volcanoes to distinguish imminent eruptions from non-eruptive phases. Our approach targets pre-eruptive signals using random forest models trained on diverse data subsets. We employ cross-validation, dividing eruptions into testing and training sets and averaging model performance across out-of-sample eruptions.

In pseudoprospective tests, our generalised models showed high accuracy for volcanoes with more than three eruptions (85%) and were useful (75%) for those with fewer. Notably, these models can match or exceed the performance of tailored models when applied to out-of-sample volcanoes, leveraging the ergodic properties of volcanic systems to address data scarcity at individual sites.

Compared to seismic amplitude-based approaches, ML models display performance gains of 47%. Our results indicate that predictive skill depends on the number of volcanoes in the training pool, with performance improving for larger ensembles and saturating beyond twelve volcanoes.

This approach harnesses transfer learning to shift from non-ergodic to ergodic hazard modelling, tackling the persistent issue of data scarcity in forecasting low-frequency, high-impact events. The technology shows potential for enhancing eruption forecasting at under-resourced observatories, volcanoes with limited eruption records, or newly established monitoring systems.

A catchment-scale risk analysis of coseismic landslide dams Aotearoa New Zealand

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Landslide dams have historically caused significant losses and changes to landscapes globally. Yet, they are under-researched, relative to other natural hazards, given their potentially devastating consequences. There is high uncertainty on the formation and potential longevity of landslide dams, making them a complex, coseismic hazard. Given Aotearoa New Zealand's seismic hazard, and abundance of areas suitable for dam formation, we need to understand landslide dam hazards better to inform resilience planning and emergency response capacity.

In the South Island, a future M8+ Alpine Fault (AF8) rupture is likely and expected to cause hazardous landslide dams in the many steep and narrow valleys of the Southern Alps. Given the high likelihood of an Alpine Fault rupture in the near future, locating where landslide dams may form and cause hazardous outbreak flooding is imperative to improving earthquake resilience for Aotearoa New Zealand.

Our approach assesses landslide dam risk at a catchment scale. More specifically, it is an assessment of hazard, exposure, and vulnerability, and how these combine to produce an overall risk score. To establish hazard, the characteristics of slopes and rivers will be assessed. This includes an assessment of landslide susceptibility, available landslide material, and stream power. Exposure will be gauged based on the presence of people and infrastructure situated on the valley bottom. The vulnerability of communities will be evaluated by assessing building characteristics and modelling outbreak flooding.

At present, there is no consensus on how best to assess landslide dam risk. Our novel approach uses a combination of factors that contribute to hazard, exposure, and vulnerability. The goal of this research is to rank and locate the South Island catchments with the highest risk for an AF8 event. This will inform future directions for landslide dam research and inform resilience strategies around landslide dam risk in Aotearoa New Zealand.

Scraps from a paleobotanist's bench: Novel Cenozoic fossil plant treasures from Zealandia

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Previously unreported leaves, cuticles and ecological interactions from a range of mid-Cenozoic fossil sites across the South Island, New Zealand, are highlighted from ongoing work into the past floristic diversity of the region. Silicified wood from a small tree trunk associated with late Oligocene Pomahaka estuarine deposits exhibits the characteristic anatomical features of *Agathis*, while a fossil flora of early Miocene age associated with a thin amber-bearing lignite exposed in a clay pit at Hyde has yielded a rich diversity of well-preserved cuticular fragments and a few identifiable leaves. Some leaf fragments are identified as *Coronelia*, an extinct conifer genus only known previously from Paleogene sites in Chile and Tasmania. Leaf tooth hydathodes reported from *Laurelia* at Foulden Maar show the antiquity of these structures in the New Zealand flora. A small, flattened stem from Miocene oilshale deposits in the Nevis Valley yielded phytoliths with characteristic palm morphology, similar, but not identical to nīkau, our only modern palm. A small moss shoot of similar age from Bannockburn is the oldest fossil of its kind reported from New Zealand. A leaf bed of Late Pleistocene age at Round Hill goldmine on the Southland coast near Orepuki yielded dozens of the distinctive leaves of *Nothofagus menziesii* with excellent cuticular preservation. The implications of the presence of these fossils in Cenozoic Zealandia for understanding their evolution and biogeography is discussed.

Southern Alpine Fault segmentation and potential earthquake ruptures

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With length of >800 km, maximum slip rate of ~27-31 mm/yr accounting for up to 80-90% of Pacific-Australian relative plate motion, and paleoseismic evidence of recurrent large and great earthquakes, the Alpine Fault is the most significant seismic hazard in the South Island of Aotearoa New Zealand. At a plate-boundary scale the fault onshore is remarkably straight and unsegmented, a characteristic of mature continental faults globally. The southern (Fiordland) trace of the fault however is geometrically more complex, exhibiting multiple sections between km-scale pull-apart basins and releasing bends. Such fault segmentation spanning 250 km along strike may potentially arrest future earthquake ruptures, limiting magnitude, and leading to stress interactions and triggered earthquake sequences. We outline the structure and geomorphology of the southern Alpine Fault using bathymetric and seismic reflection data. Nine traces are distinguished, along with six significant geometric irregularities. The dimensions and geometry of fault releasing bends and pull-apart step-overs are generally consistent with global field data and laboratory experiments of strike-slip faults. The geometry of fault linkage between linear segments and the distribution of slip rate derived from dated offset submarine geomorphology constrain pull-apart basin evolution and may provide important clues as to the magnitude-frequency distribution of past earthquake ruptures. To gain further insights into potential Alpine Fault earthquake behaviour we investigate a catalogue of synthetic earthquakes derived from numerical simulations using a physics-based Rate-and-State Earthquake Simulator (RSQSim). These simulations draw on the 3-dimensional fault architecture of the New Zealand Community Fault Model (NZ CFM v1.0, Seebeck et al., 2023), in which Alpine Fault structure is underpinned by our structural and slip rate observations. Preliminary assessment of the synthetic catalogue supports a model in which segment boundaries impact the magnitude and frequency of seabed-rupturing earthquakes on the southern Alpine Fault.

Geology of the Dunedin urban area, coastal Otago: A map-based resource of geoscientific information to assist habitation, economic activities and informed development

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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 builds upon several previous geological maps, published between 1939 and 1990 at scales ranging between 1:63,360 and 1:25,000. Although the shapes of the geological unit polygons remain relatively generalised, the availability of LiDAR has enabled the very precise positioning of geological unit boundaries, especially for Quaternary-age fluvial and coastal deposits, as well as human-made deposits. The draft updated map brought forward the widely-used Benson (1968) Dunedin volcanic stratigraphy, with geological unit positions corrected onto a modern, largely LiDAR-based, topographic base. However, reviews of the draft map highlighted concerns about the robustness of aspects of the Benson stratigraphic scheme, and whether the detailed stratigraphy could convincingly be placed accurately on a modern basemap. In response to the reviews, the volcanic geology was greatly simplified for this map, beneficially resulting in a more concise legend for the volcanic strata. The only differentiations from a generalised Dunedin Volcanic Group unit are notable occurrences of tephra-dominated strata and volcanogenic alluvial/colluvial strata.

The new Ōtepoti Group stratigraphic framework, emphasising Quaternary geology and geomorphology, comprises eight formations, defined variously by provenance and/or depositional environment. Mapped where these units are of sufficient extent relative to the map scale, the framework's strength is that it is also designed for use in site-specific settings. It thereby provides nomenclature for Quaternary deposits at any scale, whether or not they appear at that location on the Dunedin map.

Along with revised interpretations of faulting and folding on the map and cross sections, a map text formalises the new stratigraphic components, explains structural interpretations, summarises geological history, and describes the geological units in both lithological and geotechnical terms.

Enriching the Alpine Fault paleoseismic record using curved slickenlines to constrain paleo-epicentres

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The Alpine Fault's spatiotemporally-rich 300 km/20 earthquake/4 kyr paleoseismic record offers an incredible opportunity to anticipate characteristics of the next Alpine Fault earthquake but leaves us wondering about others. This record reveals a highly regular temporal recurrence of surface rupture (giving us high confidence in the timing of the next earthquake), but it also indicates high spatial variability in rupture extent (leading to lower confidence in the next earthquake's magnitude, rupture extent, rupture direction, slip distribution, and shaking intensity). Of these properties, we currently have the least constraint on nucleation locations (i.e. epicentres) of paleoearthquake ruptures. The epicentres of the past several Alpine Fault paleoearthquakes are a desirable input into multi-cycle dynamic rupture modelling that can constrain the current stress state and more accurately forward model a realistic next earthquake. To better constrain the rupture direction of past earthquakes, we observed curved slickenlines on principal slip surfaces of the Alpine Fault at two outcrops spanning the Central-South Westland 'earthquake gate' region. At Hokuri Creek and Martyr River we observed both convex-up and convex-down curved slickenlines on or adjacent to a common principal slip surface, providing evidence for past ruptures from the northeast and southwest of these locations. At Martyr River relationships suggest the most recent event (e.g. 1717 AD) ruptured from the southwest. Based on our proof-of-concept pilot study, we suggest there is considerable value in densifying curved slickenline observations in outcrops and trenches along the Alpine Fault to further enrich our paleoseismic record and aid earthquake scenario modelling efforts.

The southern extent of active Hikurangi subduction: Insights from 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 across the Marlborough Fault System from oblique subduction to transpression on the Alpine Fault. 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 geodetic data raise the possibility of an active interface beneath Marlborough in the northern South Island. 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. We also compile a catalogue of well-constrained earthquake locations and focal mechanisms from the literature. These hypocentres are compared to the Williams et al. (2013) model of the subduction interface to identify earthquakes that could be associated with active subduction and intra-slab faulting. The data indicates that the Benioff zone and active subduction extends beneath North Canterbury and at least 80 km south of the seafloor expression of the subduction thrust. Rupture of the subduction thrust could pose significant seismic and tsunami hazard in the northeastern South Island.

Cracking the code: Empirical analysis of damage fracture occurrence, abundance and morphological complexity for natural and experimental volcanic ash particles

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Fractography, the study of fractures in materials, components, and structures, is a critical tool in multiple disciplines for understanding the mechanisms behind material failure and damage. Two key rules in the field of fractography are that 1) the more energy exerted to break a material, the more fractures are created, and 2) the higher the energy release rate, the more complex the fractures become. Based on these fundamental rules, we developed and conducted an empirical analysis of different ash particles, created both in eruptions and analogue experiments, to investigate different damage fracture types and abundances on particles created by different fragmentation processes. Damage fracture types and abundances were observed and recorded using high resolution, high magnification images of 4 phi ash captured with the Backscattered Electron Detector of a Zeiss FEG-SEM. We combine this fracture analysis with particle morphology analysis using pySilTo (python-silhouetting-tool), PARTISAN and DendroScan. Particles created by experiments represent thermal granulation and FCI process, abrasion and by shattering Prince Rupert Drops. These are compared with natural samples created by eruptions of Surtsey, Havre, Hunga and Sakurajima, among others. We present a Damage Fracture Intensity (DFI) index that considers the prevalence of fractures, their relief and complexity, and whether they transcend or terminate at glass-crystal boundaries. DFI values then allow inference of relative energy densities and energy release rates from different fragmentation processes, recorded by the resulting particles. Overall, we observe that there is far less variation of DFI for individual samples created by experiments, compared to those from eruptions, due to the greater range of processes active in natural eruptions compared to experiments. Also, experiments are often geared towards investigating specific, single, fragmentation mechanisms. For both natural and experimentally created samples, samples subject to magma-water interactions displayed a larger proportion of particles with severe to extreme damage.

Lithic clasts show conduit structure during explosive eruptions of the basaltic-andesite Panitahi Fanthams Peak at Taranaki Mounga

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The physical properties (strength, porosity, permeability) of conduits can directly influence eruption dynamics, making understanding conduit structure important for hazard assessment. Differences in the mineralogy and textures of lithic clasts can be used to infer the structure of a volcanic conduit. We systematically sampled lithic clasts variation in a series of airfall deposits from Panitahi Fanthams Peak, the most prominent satellite cone on Taranaki Mounga, to infer the changing structure of its conduit during the basaltic-andesitic explosive Manganui eruption sequence (~3000-1600 BP).

Bulk samples were collected from each Manganui member and dry sieved at 1 phi intervals from -5 to +5 phi. Lithics were distinguished based on crystallinity and mineralogy. Five end-members were identified: type 1 glassy basalts, type 2 crystalline andesites, type 3 completely hydrothermally altered lithics, type 4 intrusives, and type 5 sedimentary lithics. Types 1 and 2 have hydrothermally altered sub-types.

The lower airfall deposits are dominated by type 3. Lithic clasts in the middle deposits, including the sub-Plinian D member, are predominantly fresh types 1 and 2. The final deposit of the Manganui sequence contains high amounts of altered types 1 and 2, as well as some types 4 and 5.

We interpret that the initial eruption phases were vulcanian in style as the conduit was being cleared and established. As the eruption progressed the conduit stabilised, ejecting a higher proportion of fresh juvenile glassy lithics from the conduit margins. The conduit became unstable again in later eruption units, as the vent closed and reopened in sequences of dome forming and vulcanian explosions.

Our model links lithic proportions and types with conduit processes that are important for eruption style changes and pyroclastic flow development, helping our understanding of potential hazards from future eruptions from Panitahi Fanthams Peak.

A marine MT array for imaging the magmatic systems beneath near-shore volcanoes (Whakaari and Tūhua) in New Zealand

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As part of a New Zealand government funded Endeavour Research Program called 'Beneath the Waves: Preparedness and Resilience to New Zealand's Nearshore Volcano Hazards' 183 marine MT measurements have been made across the Bay of Plenty, with arrays of data centred around Whakaari White Island, and Tūhua Mayor Island. These nearshore volcanoes pose a risk to coastal communities in the Bay of Plenty and surrounding region (including Auckland, New Zealand's largest city) through ashfall and/or volcano-induced-tsunami. However, they are not well understood and the tragic events at Whakaari in December 2019 highlight the need to better understand the risk and potential hazard posed by New Zealand's near-shore volcanoes.

Over four separate voyages from 2022 to 2024, marine MT data were acquired around Whakaari and Tūhua to image their underlying magmatic systems. Resistivity models of these MT data will be used, in combination with other data, to develop conceptual models of these volcanoes that can be used to inform decision making during periods of unrest.

Initial phase tensor analysis of the marine MT data indicate that areas of high conductance occur at short periods beneath and south of Whakaari, the latter consistent with the location of the submarine Calypso Geothermal Field. At longer periods, an area of high conductance is indicated northwest of Whakaari near Te Paepae o Aotea (Volkner Rocks), which is thought to be the remnants of an older volcano.

Assessing dredge spoil dispersion on the inner shelf off the coast of Tauranga Harbour, Aotearoa New Zealand

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With an ever-growing population, the pressure on ports and harbours around the world is expanding and bringing with it an increase in the size of ships carrying food and supplies to cities. These larger ships necessitate deeper and wider channels for safe passage, requiring dredging at regular intervals to maintain. The dredged material must be disposed of, commonly, by depositing it into open water in a process known as spoiling. This maintenance of shipping lanes, however, needs to be balanced with environmental considerations resulting from the removal and displacement of sediments.

In Te Awanui Tauranga Harbour, the largest port in Aotearoa New Zealand, dredging began in 1919 and continues to the present day. Several studies in the past have considered the fate of disposed material offshore in the Bay of Plenty, but it has been more than three decades since this was investigated in detail. In this presentation, we showcase new data collected from the offshore dredge-sediment disposal site outside Tauranga Harbour to answer the question: has climate change and its impacts on sedimentary processes resulted in redistribution of sediment on the continental shelf? Analysis of shallow seismic surveys, vibracores, and surface sediment samples shows a sand-dominated sediment mound in the study area that is 1.5 m above the pre-deposition seafloor, with no discernible surface features or bedforms. The results suggest that despite any potential changes in hydrodynamic conditions over the past few decades, sediments deposited in water depths of 20-30 m are stable on the sea floor. This study provides an updated baseline of sedimentary characteristics that can be used in the future to assess environmental change.

Developing the GNS Science incident management system in preparation for Rū Whenua and the next large earthquake

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GNS Science holds the official mandate to deliver rapid geoscience advice to the National Emergency Management Agency (NEMA) and support a coordinated response to natural peril emergencies. Since the Mw7.8 2016 Kaikōura earthquake the way this role functions has evolved. The National Geohazards Monitoring Centre (NGMC) is part of the GeoNet programme, which monitors perils (earthquake, volcano, tsunami, landslide) in 24/7 capacity and now with other 24/7 operations in Aotearoa, most importantly the NEMA Monitoring, Alerting and Reporting Centre (MAR), GNS Science required a more coordinated approach to deliver science advice.

Following a review of GNS Science incident management arrangements in 2023, a bespoke Incident Management System (IMS) has been established with science functions at its core. The GNS Science IMS is based on national standards and is tiered across four levels (L1-4) and scalable to any size event. The Science Function comprises NGMC, 24/7 peril Duty Officers and Scientist-in-Charge (SiC) roles plus expert panels across all perils. GNS Science expert panels are different and complementary to the national science panels hosted by NEMA. Response is supported through additional functions incorporating social science, impact and geospatial teams, operations, logistics and continuity, etc.

Co-ordinated incident management optimises scientific and emergency response efforts during major events. The GNS Science IMS has been tested through real events (Taupō unrest, Cyclone Gabrielle, 2024 Papua New Guinea landslide) and GNS Science began a program of exercising and improvement to assure the IMS capability, connections, and roles across the institute. Exercises were developed around an Mw8 Alpine Fault rupture scenario which has a high likelihood of occurrence in our lifetime. GNS Science led its own 'AF8' exercise in 2023 and fully participated in the NEMA-led Exercise Rū Whenua held mid-2024. This talk will introduce the concepts above and expand on how this work supports the wider science community.

New Zealand National Seismic Hazard Model revision 2022: Hazard changes with respect to NZ NSHM 2010

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Revision of the New Zealand National Seismic Hazard Model (NZ NSHM 2022) represents a significant change not only in hazard results but also in terms of methods and processes in comparison to NZ NSHM 2010. The changes span over the entire model components such as seismicity rate model (SRM), ground-motion characterisation model (GMCM) including modelling of site-effects. One important change is the quantification of the plausible range of epistemic uncertainty in hazard estimates. This is achieved by using multiple (alternate) models within the full SRM and GMCM logic trees.

In this study, we present a systematic comparison of hazard results from NZ NSHM 2022 against those from NZ NSHM 2010. It demonstrates the impact of changes in GMCM and SRM individually. Additionally, the comparisons are illustrated in terms of hazard sensitivities with regard to a few modelling and parameter choices in GMCM and SRM.

Our results show that on average the hazard increases by a factor of 1.5-2.0 depending upon the vibration period and location across the country. In high hazard regions such as the eastern part of the North Island the change in GMCM dominates the change in hazard while in low hazard regions (the north-western part of the North Island and the south-eastern part of the South Island) the change in SRM is the dominating change. These changes are further dissected in terms of changes originating from different source types (or tectonic types) both in ground-motion characterisation and seismicity rate models.

How greywacke faults heal: Results from hydrothermal friction experiments

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During an earthquake, faults slip, weaken, and release stored elastic energy as seismic waves. Afterwards, chemical and mechanical processes cause faults to regain strength, a phenomenon called frictional healing. Frictional healing influences key earthquake source parameters including stress drop, recurrence interval, and radiated energy. In the laboratory, frictional healing is investigated using slide-hold-slide (SHS) experiments, which simulate the seismic cycle. We report the results of hydrothermal SHS experiments performed on Pahau Terrane siltstone and greywacke sandstone collected from the Leader Fault in North Canterbury.

Experiments were performed at 75 MPa effective normal stress (σn') and temperatures (T) between 20°C and 500°C. Siltstone and sandstone gouges were deformed at a sliding velocity (v) of 1 µm/s for ~6 mm, a shear strain of ~6, after which a SHS sequence commenced with successive hold times of 10^0 to 10^5 seconds. Following each hold, the gouges were re-sheared. During the re-shear, peak friction (µpk) was measured and compared to the steady-state sliding friction (µss) before the hold.

Experimental results show that the change in friction (Δµ) is log-linear with hold time (th), conforming to established friction theory. Results were fit with the equation $\Delta\mu = \beta\log(1 + th/\alpha)$, where β is healing rate and α is a cut-off time beyond which the trend in Δµ is log-linear (generally less than ~500 s). Results show that healing rate depends on temperature. At T <300°C, the mean healing rate for sandstone and siltstone is similar (β=0.00783 ± 0.00147; n=6). At T ≥300°C, healing rate markedly accelerates and displays a lithology dependence, with siltstone (β=0.0396 ± 0.00532; n=5) healing twice as quickly as sandstone (β=0.0197 ± 0.00351; n=3).

Modelling the next Alpine Fault earthquake: Why measurements matter

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The central Alpine Fault is a long-lived structure that accommodates 70-75% of the total relative Australian-Pacific plate deformation. Exhumation of a complete fault rock sequence (mylonites-cataclasites-gouges) from ~35 km depth provides us with an unparalleled opportunity to identify the weakening mechanisms underpinning the fault's remarkable efficiency. In this presentation, we summarise results of geological, geophysical, and rock mechanics research that provides the numerical constraints needed to model the next Alpine Fault earthquake, with a focus on the properties that control seismic slip.

Rupture models show that fault strength, frictional stability, and dynamic stress drops govern earthquake rupture nucleation, propagation, and arrest. Rock mechanics experiments reveal that the brittle fault comprises predominantly frictionally strong (μ >0.6 at T ≥140°C), velocity weakening (negative a-b at 140°C ≤ T ≤ 450°C) gouges and cataclasites. Cataclasis and fluid-rock interactions have formed low-permeability (k ≤10^{-18} m2) principal slip zone fault rocks. The near-ubiquitous presence of juxtaposed, low-permeability fault core gouges and cataclasites promotes dynamic (coseismic) weakening mechanisms such as thermal pressurisation. New measurements of thermal conductivity show that it decreases with increasing proximity to the principal slip zone from 2.15 ± 0.36 W/mK in cataclasite to 1.37 ± 0.19 W/mK in fault gouge, further promoting strong coseismic weakening and short critical slip distances of <15 cm in gouge.

Models also show that the elastic properties of rocks surrounding the principal slip zone affect near-fault principal stress orientations, earthquake rupture propagations, speed and directivity, earthquake hypocentral depths, and strong ground motions. Porosity, density, and elastic wave measurements reveal that the hanging wall cataclasites remain compliant (E <64 GPa) throughout the seismogenic zone. Persistently compliant wall rocks surrounding frictionally strong, velocity weakening, impermeable gouges with low thermal conductivity favour strong slip localisation, with potentially large dynamic stress drops and amplified strong ground motions.

Where in Fiordland does subduction terminate?

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South of Fiordland, young oceanic crust subducts obliquely along the Puysegur trench. North of Fiordland, plate motions are accommodated through oblique slip along the Alpine Fault and distributed deformation off the fault. Seismicity to 150 km shows contortion of the slab as it collides with strong Pacific lithosphere. Across northern Fiordland, geodetic strain rates transition from the narrow Alpine Fault plate boundary to a broader region.

We use traveltime data from permanent and temporary seismograph deployments to image the 3D Vp and Vp/Vs properties of Fiordland. We interpret these 3D images in conjunction with seismicity to elucidate the nature of plate motion partitioning in Fiordland.

In the crust, seismicity is distributed from the offshore Alpine Fault to eastern Fiordland, with partitioning along a number of structures including reactivated shear zones. Below the crust, our results show the seismicity and the top of the subducted plate bending northeast.

At Secretary Island there is a sharp change in crustal properties associated with abundant seismicity and high Vp/Vs. These results and previous large earthquakes are consistent with the transition to partitioned deformation. South of Secretary Island, a moderately dipping slab with overlying high Vp/Vs suggests subduction related dehydration.

In northern Fiordland, our model suggests crustal thickening between the George Sound and Indecision Creek shear zones with exhumed orthogneiss overlying mid-crustal low Vp. Abrupt termination of intermediate depth seismicity suggests the edge of the slab lies near the Indecision Creek shear zone. A 60-150 km deep zone with elevated seismicity just south of the inferred slab edge is associated with high Vp/Vs, suggesting a narrow impact zone with high strain rate and fluid release. At 30-60 km depth above the zone of elevated slab seismicity, seismicity is sparse. Discontinuation of the Benioff zone suggests that deformation there is no longer akin to subduction.

Sill emplacement of the Waiareka-Deborah Volcanic Field and the oddity Mt Charles Bow-Alley Creek

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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. This is a feature that is not present in the nearby but younger Dunedin Volcanic Group. By looking into the different variables of sill emplacement, like the tectonic setting, this difference will be explained.

The Bow Alley Creek outcrop has a distinct difference in whole-rock REE pattern between rocks exposed here and samples taken elsewhere throughout the field. The outcrop near Bow Alley Creek 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 Bow Alley Creek compared to the rest of the volcanic field.

The total alkali and silica content of Bow Alley Creek classes it as a basanite, while the Mt Charles sill is classed as a basaltic andesite. This indicates Bow Alley 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, indicating a component of more primitive origin.

Modelling of the crystallisation pressures of different sills gives deeper values for Bow Alley Creek. This indicates mixing took place followed by a relatively rapid ascent of the magma.

Mine geology experiential learning as we charge towards Net Zero: Field trip to two operating open-cast mines

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Fieldwork is perceived to be at the heart of geology, viewed by many as a ubiquitous element of geological higher education, considered by both academics and students to be an extremely effective experiential (i.e. 'learning by doing') teaching and learning method. Often, this takes the form of observational fieldwork, augmented by measuring dip, strike and plunge, leading to map and cross-section production. In engineering geology, much of the learning pedagogy is focused on applied problems such as dams, tunnels, mines, state highways and landslides, dealing with issues of 'ground risk'. Due to the obvious safety (and legal) implications of students visiting high hazard operational worksites, these applied learning experiences are often confined to PowerPoint slides in university classrooms, or sometimes virtual field trips using a range of technologies. This can produce challenges to fostering engagement, given the pedagogically established notion that students learn best 'by doing', in an active learning setting, using experiential learning approaches. Here, the development of a one-day graduate-level engineering geology field class based at two operating open-cast mines is presented. The trip is structured to develop the students' awareness of the first priority of such workplaces, health and safety. The students then follow a mini 'Cook's Tour' led by mine staff, around the open-cast mines, recording geological features, and are prompted to think about consequent potential engineering hazards relating to the geology. The students then log core in the mine core shed, observe and record the stratigraphy and significant features such as defects, and strength variability. Post-trip, the students analyse borehole geophysical logs and undertake kinematic analysis and limit equilibrium modelling of highwall stability, incorporating this into an assessed report. Opportunities, barriers and challenges to further developing such field trips are also discussed.

Advancing peril-specific deep learning applications within the Interferometric Synthetic Aperture Radar (InSAR) processing chain

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The adaptation of state-of-the-art deep learning models for earth science applications is growing in certain disciplines (e.g. earthquake seismology) yet for geodetic techniques such as InSAR and GNSS remains largely untapped. The lack of openly available labelled benchmark datasets and the consequent difficulties in applying unsupervised/self-supervised learning frameworks to complex and irregular spatiotemporal data structures are just a few examples of the prevailing issues contributing to this trend.

Here we look to advance the application of deep learning within select outputs of the InSAR processing chain via a two-stage approach. Initially we focus on two dimensional InSAR outputs such as raw interferograms and line of sight secular velocities, before extending our understanding to three dimensional persistent/distributed scatterer (PS/DS) spatiotemporal outputs. This approach is designed to leverage deep learning applications that are well suited for the identification of ongoing and transient patterns associated to peril-specific natural hazards (tectonic/volcanic/landslide) throughout Aotearoa.

We will consider multiple InSAR datasets including the international Hephaestus interferogram dataset, a nationwide PS/DS time series dataset, and an eye to future intentions to produce large scale, synthetic, multi-label geodetic datasets.

Preparing New Zealand for natural hazards: Implementation of real-time GNSS and G-FAST for a fast earthquake characterisation

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New Zealand's unique tectonic setting is the source of various natural hazards such as earthquakes and tsunamis. Previous studies have shown that tsunamis driven by slip at shallow depth during earthquake rupture are extremely dangerous to coastal populations. Therefore, a rapid characterization of earthquakes and their tsunami generation potential is needed. In the framework of the RCET (Rapid Characterisation of Earthquakes and Tsunami) program, a major multi-year public initiative led by GNS Science, we explore new techniques for rapid estimation of earthquake rupture characteristics.

In this context, the use of continuous GNSS has demonstrated its efficacy in addressing these types of challenges. For instance, unlike velocity records, it does not saturate, and unlike accelerograms, it does not require a complex correction. In this study, we present the current status of the implementation for New Zealand of the G-FAST algorithm. This algorithm is capable of estimating the geodetic moment magnitude, a moment tensor solution, as well as the fault geometry and the corresponding slip. We demonstrate the capabilities and limitations in the context of New Zealand. This is relevant since different fault geometries are present along New Zealand, including the strike-slip Alpine Fault, and the Hikurangi subduction zone.

We present the results for a series of historic earthquakes and a synthetic case study simulating a Mw8.1 earthquake along the Alpine Fault. We simulate real-time GNSS data for historic events using the GeoNet network, which comprises approximately 50 GNSS real-time streaming stations. The results demonstrate that the G-FAST algorithm is applicable to the majority of the geometries presented in the context of New Zealand's geological setting. However, there is considerable uncertainty for some strike-slip geometries that are entirely offshore. Although the results are satisfactory, the use of multi-dataset tools is essential to capture the full range of fault geometries in New Zealand.

Late Holocene sedimentary processes of Doubtful, Dagg, and Dusky Sounds, Fiordland, New Zealand

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Fjords act as large efficient traps preserving high-resolution sediment archives, often deposited without disruption. Several studies worldwide have used fjord sediment archives to resolve the timing and impact of rapid climatic and tectonic events, particularly within the Holocene. However, Fiordland remains a very understudied environment. Complex biophysical sedimentary processes have shaped the submarine sediment record in Fiordland throughout the Holocene. Understanding these processes will help to unravel the climatic and tectonic history of New Zealand's temperate fjords.

Here, we use sediment gravity cores from Patea Doubtful Sound, Te Rā Dagg Sound, and Tamatea Dusky Sound to reconstruct active depositional processes. The selected fjords span a range of tectonic and geomorphic settings from central to southern Fiordland. We integrate high-resolution multi-proxy sediment analysis, multi-beam bathymetry and geochemical analysis to develop a detailed sedimentological facies model. Initial results suggest that the sediment record is dominated by silts and fine sands, with rare coarse sand layers mixed with large amounts of plants and shell fragments.

This research contributes to interpreting the onshore-to-fjord basin sedimentary processes, revealing the interplay between terrestrial and oceanographic influences on New Zealand fjords' depositional environment.

Correlation or causation? Influences of topography, heat sources, and geology on regional-scale geothermal fluid flow in the Taupō Volcanic Zone, New Zealand

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The Taupō Volcanic Zone (TVZ) is one of the most geothermally active regions on Earth, discharging ~4200 GWh of heat through 23 high-temperature geothermal systems. Seven of these systems provide almost 20% of New Zealand's electricity production, with plans for expansion. To find new geothermal resources and to ensure sustainability of the ones that we are using, we need to understand what influences the locations of these systems and how they evolve over time.

Geothermal fluid flow requires an underlying heat source and permeable pathways through the crust, but several other interesting correlations have been noted in the TVZ. For example, the tops of many systems are located in topographic lows, and are outside of the densely faulted Taupō Fault Belt, rather than being associated with major surface faults. We can gain new insights into these potential relationships by merging the results of increasingly extensive geophysical and geological surveys of the central North Island of New Zealand into numerical flow models.

We created generalised numerical models of heat and fluid flow using TOUGH2 software to investigate large-scale influences on geothermal circulation in the TVZ. The locations of seven of the nine geothermal systems in our study area can be explained by TVZ-scale convection influenced by localised deep heat sources and hydraulic gradients due to topography. At three geothermal systems, geological influences such as more permeable volcano-sedimentary cover or a region of intense faulting that acts as a recharge zone for cold downwelling fluid also seem to be important. Modelled upflow does not correspond to surface geothermal activity at Te Kopia or Haroharo volcanic centre, which we hypothesise is related to uplift along the Paeroa Fault and impermeable shallow lava domes respectively. Given the widespread faulting and volcanic activity in the TVZ, these would be interesting targets for future study.

Opportunities for integrated multi-discipline monitoring of New Zealand's Southern Alps

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New Zealand's Southern Alps are a dynamic environment characterised geologically by high-uplift rates along the Alpine Fault which are in turn balanced by high erosion rates. There is significant opportunity to better understand the Alpine Fault before the coming earthquake, and enhanced instrumentation must play a role in this. However, to only consider instrumentation for earthquake science outcomes would be to miss a broader opportunity to understand the interaction between solid-earth processes, geomorphology, glaciers, hydrology and ecosystems.

Recent work to monitor glacier movement using global navigation space systems (GNSS) and optical imagery has highlighted significant variations in rates of motion on timescales from hourly to annual. In combination with other observational datasets such as passive seismic data, a more accurate picture of the deformation processes may be possible. Similarly, often our only evidence for when major landslides events occur in the Southern Alps comes from somewhat ambiguous seismic recordings - and some of the largest landslides move slowly over periods of years, generating little seismic energy, but transporting large amounts of sediment which challenge human infrastructure and visitor management. Combining seismic, GNSS, optical imagery and climate observations with other data would provide a better understanding of the range of deformation processes within the Southern Alps.

Less obviously perhaps, the monitoring of native and introduced fauna in the Southern Alps has been vital to pest management. Despite the disparate nature of the outcomes of work within the Southern Alps, multiple monitoring efforts are underway and have similar requirements in terms of power, communications, and long-term robustness: coordination of these efforts could lead to more productive outcomes. In this presentation we highlight some recent findings relating solid-earth processes and landslides and glacier movement, discuss opportunities for collaboration, and propose a straw-person multi-disciplinary monitoring network for the Southern Alps.

Enhanced earthquake detection enables advancements in our understanding of earthquake physics

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How earthquakes start, stop and interact with other fault-zone processes remains difficult to understand. One key to understanding these phenomena lies in consistent and detailed records of seismicity over a range of timescales. For more than a decade, our group has been developing enhanced earthquake catalogues in Aotearoa New Zealand aiming to shed light on the fundamental physics of earthquake processes. This work has been built on continuous, high-quality seismic recordings from around New Zealand, including hard-won data from temporary and semi-permanent deployments in remote regions.

Detailed analyses of these continuous seismic datasets using advanced techniques, developed or extensively tested by our group, have provided some of the most detailed and robust regional earthquake catalogues globally. From these catalogues we have made discoveries of fault zone processes illuminated by repeating earthquakes, low-frequency earthquakes, foreshocks and aftershocks. Additionally, our long-duration catalogues provide a better understanding of the background rate of seismicity in New Zealand and how and why these rates vary in time and space.

This talk addresses some of the key findings on fault-zone processes and earthquake interactions enabled by these enhanced earthquake catalogues and exemplifies how these findings have been applied. We will also discuss possible next steps in earthquake monitoring for understanding earthquake physics in Aotearoa. Finally, we will emphasise key areas of ongoing and future fundamental observational research upon which seismic hazard analysis and other areas of applied research critically depend.

Early warnings on a budget: Harnessing community power and low-cost tech to detect earthquakes

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Can an effective Earthquake Early Warning (EEW) system be implemented at a low cost in earthquake-prone regions? This study explores this critical question by demonstrating the feasibility of a low-cost experimental EEW system hosted by the general public in the Wellington region of New Zealand. The system leverages decentralised processing to operate two versions of the EEW algorithm: (1) NZ-PLUM, an adaptation of the Propagation of Local Undamped Motion algorithm tailored to New Zealand's seismic context, and (2) NZ-PLUM-P, an enhanced version that incorporates P-wave detection for earlier alerts. While the NZ-PLUM algorithm triggers alerts based on S-wave detection using horizontal acceleration thresholds, the NZ-PLUM-P algorithm provides a longer warning window by detecting the initial P-waves. The performance of this community-based network was assessed using data from three recent earthquakes on 22 May, 3 June, and 6 July 2024. Results show that the NZ-PLUM-P approach significantly increased warning times compared to the NZ-PLUM approach, with average gains of 2.6, 1.25, and 7.6 seconds, respectively. These findings indicate that the community-engaged EEWS effectively detects and provides timely warnings for these earthquake events.

Estimating radiated seismic-energy of Aotearoa

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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, 1998).

Naturally, this is a topic worth exploring to contribute to the Rapid Characterisation of Earthquakes and Tsunami (RCET) project, a GNS Science-led project whose goal is to characterise a seismic source within 10 minutes of its occurrence, improve the estimation of an earthquake damages and impacts, as well as determine resulting hazards such as tsunamis and landslides, and build local communities' knowledge and resilience.

We followed Convers & Newman's (2011) method to estimate radiated energy at teleseismic distances. We are building a seismic-energy-estimation tool to use in a near-real-time approach and making an Aotearoa seismic energy catalogue.

Based on this catalogue, we want to bring to light some local variation in the tectonic regime of New Zealand, to either confirm or refine what we already know from a geological perspective. Those results will also serve as a reference for future attempts at implementing near-field-based methods (Boatwright et al., 2002).

We will present the current state of these efforts.

Geomechanical properties of zeolitized East Coast Bays Formation, Waitematā Basin, and implications for tunnelling

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This project aims to investigate the influence that zeolitisation has on the geomechanical properties of subsurface East Coast Bays Formation (ECBF) beneath the Auckland urban area. Here, we evaluate the geomechanical and mineralogical properties from a suite of rock core from the Auckland Light Rail (ALR) project. Zeolites are expected to have an impact on the geomechanical properties of the ECBF, due to the cementation they often provide, which strengthens these sedimentary units, and therefore may impact tunnelling approach and performance of the chosen tunnelling methods. A comparison of the effects of zeolitisation is undertaken by comparison of four different units of ECBF: (1) Parnell Volcaniclastic Conglomerate (PVC), (2) well-cemented sandstone, (3) a thinly to moderately thinly interbedded siltstone and sandstone, and (4) zeolitic ECBF. Sample cores from these four facies are tested for the following properties: particle-size distribution, unconfined compressive strength (UCS), tensile strength, Young's modulus, Poisson's ratio, and triaxial testing. The mineralogy of zeolitised ECBF is also being evaluated to determine the exact zeolite minerals that comprise the cement, using x-ray powder diffraction (XRD) and scanning electron microscope (SEM). From the tests, a comparison of the differences in geomechanical properties is being undertaken, and related to mineralogy, particle-size and cementation. Taken together, this will be used to determine the effect of zeolitisation on rock properties and the possible impacts of zeolitisation on tunnelling projects, including excavation methodology, project costs, and health and safety aspects.

Illustrating uncertainty in natural hazard science advice: Evidence informed guidance for Aotearoa New Zealand

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Uncertainty is a fundamental aspect of geoscience and geohazard data, and visualising this uncertainty can enhance how information is interpreted and used. The design of these visualisations, including choices related to colour and visual emphasis, can significantly impact risk perception and confidence in forecasts. For instance, factors such as colour saturation can influence how confident people feel about uncertain forecasts, and the choice of colour can alter the interpretation of probabilistic data, such as ashfall predictions. Studies have shown that uncertainty visualisations in weather, wildfire, earthquake, climate change, and volcanic data can affect interpretation. However, there is a gap in research on how to best communicate geohazard uncertainties to diverse stakeholders, particularly in New Zealand.

While there are numerous studies and reviews focused mainly on communicating uncertainty in political and health sciences, there is limited guidance on how best to visually communicate uncertainty within geoscience data and the effectiveness of each method at conveying the intended messages. Providing clear and effective visualisations of uncertainties is an ongoing and significant challenge across geosciences.

We present the results of a literature review on uncertainty visualisation approaches and their different impacts on effectiveness. Developed from this review, we will also share an initial set of guidelines for communicating uncertain geoscience data in Aotearoa New Zealand. Further work over the next six months will explore the public's appetite for uncertainty, as well as how different people interpret and perceive uncertainty based on different visualisation approaches.

Seismic structures beneath an ophiolite nappe in New Caledonia: Implications for Eocene tectonics in Zealandia

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We image crustal and lithospheric structures beneath southern New Caledonia, southwest Pacific, using seismic waveform data from a network (ITOPNC) of permanent and temporary stations from October 2018 to November 2019. Rayleigh wave dispersion indicates a 1-2 km thick ophiolite nappe on top of sedimentary basins beneath the east and west coasts, and basement rock in the centre of the island. A 1D velocity model derived from local earthquakes has high V_P of 5.5-6.0 km/s beneath the ophiolite in the centre of the island. V_P is 7.4 ± 0.2, 7.9 ± 0.3 and 8.1 ± 0.2 km/s at depths of 27-31, 31-35 and 35-40 km, respectively. Receiver function imaging reveals an upper-lower crust boundary at 12 km depth beneath the centre of the island, but this rises eastward to near the surface at the eastern edge of Lake Yate. The base of the crust is sub-horizontal at 27-30 km depth beneath western and central parts of the island, shallows to <10 km near the east coast. A conversion imaged at 20 km depth beneath the east coast deepens westward to 65 km and is interpreted as a fossil subduction zone. The low (<4°) taper angle of the ophiolite requires it to have a weak base during emplacement. The source of the ophiolite was just east of the coast, where the Moho beneath eastern Grande Terre projects to the surface. Eocene subduction beneath Grande Terre was west-dipping and the ophiolite can be classified as Cordilleran in nature, i.e. low-density rocks within the hanging-wall drove uplift and emplacement.

New Zealand's mineral resources for the low carbon emissions future

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The transition to low carbon emissions energy requires substantial quantities of minerals for manufacturing wind turbines, solar panels, batteries for EVs and solar panels, and emerging new technologies. Minerals are also required in emissions reduction, e.g. platinum and palladium in exhaust catalytic converters. Although manufacture of the end use products is likely to be mostly overseas, New Zealand has the opportunity to contribute to the resources required as part of the effort to reduce World carbon emissions. This has prompted an assessment of potential resources of relevant minerals in New Zealand including recent exploration for:

1. Rare earth elements (REE) in carbonatites and alkaline igneous complexes on the West Coast (e.g. Hohonu Batholith) and in Marlborough (e.g. Mt Tapuaenuku) and northern Canterbury (e.g. Mandamus Complex);
2. Lithium in West Coast pegmatite dikes and hydrothermally altered rhyolitic clays in the Taupō Volcanic Zone;
3. Platinum group elements in ultramafic rocks in east and south Nelson (e.g. Mt Baldy), and Southland (e.g. Longwood Complex); and
4. Silicon from quartz gravels in Southland (e.g. Pebbly Hills).

Additional exploration is needed to determine the prospectivity for:

a. Nickel and cobalt in ultramafic rocks of western South Island (e.g. Riwaka Complex), and with iron and manganese in seafloor ferromanganese nodules (e.g. Campbell Slope); and
b. Copper in porphyry copper type deposits of Northland and the Coromandel Peninsula (e.g. Ohio Creek), and in volcanogenic massive sulfide deposits of Northland and East Cape (e.g. Lottin Point), and offshore in the Kermadec arc (e.g. Brothers volcano).

New Zealand currently produces iron and byproduct vanadium from titanomagnetite ironsands at Waikato North Head and Taharoa on the west coast of the North Island, and increased production is proposed from mining offshore deposits near Patea. Mining of heavy mineral sands near Westport, mainly for ilmenite, also has byproduct REE-bearing monazite.

Refining the subduction earthquake record of the southern Hikurangi subduction zone: Overview of preliminary results from recent studies

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The southern Hikurangi subduction zone has a record of four past subduction earthquakes but this paleoseismic record is short (spanning ~2 ka) and limited to single-site studies. To improve this record we have been undertaking field studies at five new sites across the lower North Island and upper South Island. Our aims are to narrow the age uncertainty ranges on known past earthquakes, extend the record back in time and gather multi-site evidence. The studies at Wairau Lagoons, Cape Palliser, Lake Kohangapiripiri, Puakimuri Stream and Glenburn are in various states of progress from complete to just beginning. Near Cape Palliser up to four Holocene marine terraces have been mapped, and radiocarbon ages obtained from the youngest terrace date the timing of uplift to 860-560 cal yr BP. Modelling suggests the terraces could be uplifted by earthquakes on the Palliser-Kaiwhata Fault or the Hikurangi subduction interface. On the eastern Wairarapa coast, new terrace ages have been obtained from trenching, and several sediment cores from wetlands upon uplifted terraces show potential for constraining terrace ages as well as possible paleotsunami deposits. New sediment cores in the Wairau Lagoons have helped refine the age of the penultimate earthquake and provide new information on the spatial extent of the accompanying tsunami. This presentation will give an overview of studies at these five sites and our progress toward integrating these into a more comprehensive record of large earthquakes on the southern Hikurangi subduction zone.

At a crossroads: A paleoseismic investigation into intersecting faults in the Te Mihi area, Wairakei Geothermal Field

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Intersecting faults have been observed in a range of geothermal settings including the Basin and Range (USA), Iceland, and the Taupō Volcanic Zone (TVZ) in Aotearoa New Zealand. They are often associated with perturbations in the stress field, increased rock fracturing and productive fluid flow conditions. Here we present paleoseismic observations from the Te Mihi area of the TVZ to investigate earthquake activity on a set of obliquely intersecting faults. This work informs a larger study that is aimed at understanding the major controls on crustal deformation and permeability in this area.

The Te Mihi area makes up the northwest part of the Wairakei Geothermal Field. As is typical of the TVZ, extension is accommodated across many distributed faults, which in this area include the Kaiapo, Whakaipo, and Te Mihi faults. Most of these strands (Whakaipo and Kaiapo faults) are northeast/southwest striking, however there is a smaller subset (Te Mihi Fault) that strikes east-northeast/west-southwest. This combination of fault orientations means that in some locations strands of the Te Mihi fault obliquely crosscut strands of the Whakaipo and Kaiapo faults.

Paleoseismic trenching of one strand of the Te Mihi Fault south of the Te Mihi geothermal power plant was undertaken to assess its faulting history. From faulting relationships, liquefaction features and tephra, a paleo-rupture history for the Te Mihi Fault was developed at this location. Results from this trenching are compared with results from a trench excavated across the nearby Kaiapo Fault to explore whether there was any synchroneity or relationship in the timing of earthquake activity between these intersecting faults. The results of this work will feed into ongoing investigations into the effect of fault intersections on permeability and dilatancy, a key component of understanding hydrothermal fluid flow in this and other productive geothermal reservoirs.

Eocene spiny fruits and seeds from the Waihao Greensand, New Zealand

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An assemblage of fossilised drift seeds and fruits mostly from the Late Eocene (Priabonian: 37.2-33.9 Ma) Waihao Greensand, South Canterbury, South Island, New Zealand is summarised. Fossil spiny drift fruits and seeds of *Pseudoanacardium* are reported, representing both the first record from New Zealand of this otherwise South American Oligocene taxon and the oldest fossils to date for the genus. The abundant New Zealand specimens of this spiny-fruited fossil at the site represent a new species and the possible affinities of this enigmatic genus are discussed. Although these fossils superficially resemble the fruits and seeds of the pantropical drift-seed leguminous vine *Guilandina bonduc* L. (Fabaceae, formerly *Caesalpinia bonduc* L.), there are several differences and as propagules from members of several other angiosperm families also share features with the fossils, definitive family placement is problematic.

Carbon loss from earthquake-induced landslides in Fiordland

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Fiordland is a carbon sink, and the influence of landslide events on carbon transport and sequestration in the region needs to be understood. Landslides triggered by two earthquakes in Fiordland were mapped using Google Earth Pro satellite imagery (eye altitude of 1.5-2.5 km, enabling ±50 m precision). Ground acceleration during the Mw7.2 2003 Secretary Island earthquake resulted in at least 1852 landslides. The larger Mw7.8 2009 Dusky Sound earthquake had lower accelerations, producing only 313. Both events dislodged large swaths of native forest, grassland vegetation and soil, some landing in rivers and fjords. The landslide maps and magnitude-frequency distributions show close similarity to a published Global Forest Loss dataset derived from 2001-2022 satellite imagery. Assuming forest loss here is predominantly landslide related, it enables the more-precise earthquake-induced landslide mapping to be placed in a longer-term context of other vegetation loss, mostly rainfall-induced landslides, during the past two decades. The total area of forest loss during the 2003 earthquake was anomalous, whereas during 2009 the earthquake losses were similar to areas of forest loss assumed to be rainfall-induced landslides throughout Fiordland each year. Carbon concentrations of landslide vegetation were calculated by defining vegetation types from a published Land Cover Database, and soil organic carbon concentration from a 1 km resolution raster dataset. Total carbon loss from earthquake-induced landslides amounts to 2.05 Mt for the Mw7.2 2003 earthquake and 0.217 Mt for the Mw7.8 2009 earthquake. By way of comparison, New Zealand's total annual carbon sequestration was 6.3 Mt in 2020, and CO_2 emissions were 9.2 MtC. Multiple-occurrence regional landslide events can account for changes in carbon storage and sequestration in areas of dense vegetation, such as Fiordland. Processes of landscape disturbance are significant for carbon accounting and could be included in estimates of national greenhouse gas emissions.

Dunedin City's shallow groundwater and multi-hazard flood forecasts as sea-levels rise

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Dunedin City has a large number of assets and critical infrastructure sitting on a low-lying coastal plain that is underlain by a largely unseen and relatively poorly understood hazard. Shallow groundwater in this area limits the unsaturated ground available to store rain and runoff, promotes flooding and creates opportunities for infiltration into stormwater and wastewater networks. Groundwater levels are expected to rise as sea level rises, causing greater frequency of pluvial flooding and/or direct inundation from below once it nears the ground surface.

Knowledge of coastal hydrogeology and hazards as groundwater responds to sea-level rise (SLR) have been improved locally in Dunedin through installation of shallow groundwater monitoring piezometers and continuous observations. Interpolation of site data enabled mapping of the present-day state of groundwater level (GWL), depth to groundwater (DTW), their temporal statistical variation, and differing spatial responses to tides and rainfall. Future depth to shoaling groundwater and its variability can be projected under increments of SLR, with assumptions and caveats, to show where and when episodic and/or permanent inundation can be expected. Shoaling groundwater's contribution to pluvial flooding and groundwater emergence have been compared with potential for coastal inundation in a multi-hazard forecast for Dunedin. Changes in relative land exposure with SLR shows evolution in flood hazard from current pluvial-dominated events, into 'flooding from below' and groundwater emergence, in advance of any overland coastal inundation.

Dunedin exemplifies how groundwater transfers effects of sea-level rise surprisingly far inland, but the lowest-lying or shoreline-proximal suburbs are not necessarily the most vulnerable. Unlike coastal inundation, shoaling groundwater is unconstrained by protective topography and presents as a creeping hazard, or contributor to hazards such as pluvial flooding, which can be widespread, occurring already and difficult to defend against.

A water cycle diagram to highlight the importance of liquid water, hydrological and hydrogeological processes on, in and around Antarctica

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A water cycle diagram has been constructed to visually highlight the multidomain, interconnected, fluid systems of Antarctica including groundwater, subglacial water, and surficial meltwater. It was generated in response to a growing interest and increasing awareness of the importance, and climate sensitivity of liquid water on the continent. The simplified diagram aims to depict key processes of liquid water involvement across the continent within, and between, the atmosphere, cryosphere, biosphere, geosphere and oceanic hydrosphere. Although water cycle diagrams have been previously constructed for continents and processes at lower latitudes, the circulation of water within and from Antarctica is unique and deserving of special attention. Liquid water is fundamental for the origins of life and influences biogeographic regionalisation, ice dynamics, and surrounding oceanography. Changes to the water cycle are inevitable with climate change and will cause widespread impacts on the Antarctic continent locally. As basal melt increases and shifts to groundwater occur, an understanding of changes to meltwater and subglacial fluid flux to the marine environment will be essential to our accurate prediction of oceanographic processes, carbon sequestration, and even sea-level rise. Knowledge gaps include the extent to which ice-melt will emit greenhouse gas, destress sub-glacial sediment and continental bedrock, enhance sub-ice deformation and alter ice-dynamics, or increase infiltration to groundwater. How much groundwater can be stored beneath the ice sheets and within bedrock porosity before the continent's capacitance is full, leading to accelerated runoff that ultimately contributes to sea-level rise? The latest version of the water cycle diagram is provided at the poster session. The authors welcome feedback (via scribbles, sticky notes, or email) on any key processes that may have been missed or overlooked, as they aim to provide an overview and outreach tool describing the key pools and fluxes of water on, in and around the icy continent.

Geodesy, a fundamental but often invisible tool for geoscience

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Geodesy underpins modern life. There is general awareness on how reliant modern systems are on Global Navigation Satellite Systems (GNSS) positioning, navigation and timing services. But, outside of the geodetic community, there is a lack of awareness on how much modern technologies rely on the underpinning science of Global Geodetic Reference Frame definition and the geodetic infrastructures, products and experts that are vital to it. This 'global geodesy supply chain', which underpins modern geoscience (landscape and climate studies, mapping, tectonic and hazard research and monitoring and more), is globally degrading and suffers from lack of dedicated funding. Numerous organisations worldwide work every day to demonstrate the importance of geodesy to policy makers, funding agencies and the general public.

In 2020 the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) agreed to establish and host a Global Geodetic Centre of Excellence (UN-GGCE). The UN-GGCE, launched in 2023, aims to "assist UN Member States and geodetic organisations in coordinating and collaborating to maintain, enhance, access, and use an accurate, accessible, and sustainable GGRF in support of science, society, and global development". GNS Science is represented as part of its International Advisory Committee.

Through its GeoNet programme, GNS Science has a long history of partnership to support Toitū Te Whenua Land Information New Zealand in defining the National Reference Datum and its relation to the Global Geodetic Reference Frame. GeoNet operates the national Global Navigation Satellite System (GNSS) infrastructure and the free and open, real-time geodetic data products enables New Zealand to stay connected – nationally and globally.

Here, we would like to share the UN-GGCE activities and existing connections with the international geodetic community. There is a need to build an Aotearoa New Zealand geoscience community, more effectively engaging with the United Nations and international forum.

Breaking the outreach barrier

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Societal education of the sciences is the responsibility of the scientific community. This thinking around outreach isn't quite right. Not all scientists are equipped to deal with the public, yet not all educators think they are equipped to teach science.

Let's change the narrative. Life is science. Or plainer still…Life is.

Instead of studying ways to engage the public in our chosen earth science platform, we could build an idea of the world that surrounds the community's everyday life. It is time to take a philosophical step back and consider what outcome we are searching for, as a collective and as individuals. Think a little broader.

Outreach. Academics and professionals extending our knowledge outside of working environments to the community. The outreach concept has been marketed by many out of concern for the future pool of expertise shrinking through lack of interest in study of the sciences. We are 'reaching out' to community to impart an idea of what the world is and could be over time. To what end? To secure funding for our jobs? To secure funding for our schools? To ensure another generation of world-ready workers to tackle the implications of the changes we see around us now: rising sea levels, high energy prices, hotter climates, less land for habitation?

SeisMomentum's process challenges this narrative. We are 'reaching in', exploiting opportunities to educate and focussed on how to stir the passion of people in life. We are targeting two groups: primary schoolchildren and retirees. Harness the young who have time with unquestionable passion and their grandparents who have time and are passionate about their legacy.

SeisMomentum will walk you through our thinking process; the fails and wins that are spurring us along as we tackle breaking down the barriers around the community's perception of science.

Spatio-temporal variability in disaster exposure: Insights from the Alpine Fault earthquake scenario (Rū Whenua)

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Emergency Management exercises are key tools in preparing for significant disaster events. Yet, these rarely consider the fluctuation in population exposure to the hazard across macro spatio-temporal scales, and the implications for the response. We consider a national-scale exercise (Exercise Rū Whenua) for a highly probable large (M8+) earthquake on the Alpine Fault, likely to generate significant ground shaking impacting a large geographical area. Here through applying multidimensional asymmetric techniques, we build a macroscale population model to inform the scenario-based planning. We consider the application of our modelled approach to understanding macro-scale spatio-temporal fluctuations in population mobility. Here we show how spatial and temporal variance significantly changes to the spatial distribution of people, which has implications for the impacts of a disaster. We show variations in populations across time and space and consider their subsequent exposure to ground shaking in an Alpine Fault event. In doing so, it is demonstrated that there are significant changes in populations exposed to different ground shaking hazard. In some areas, 20,000 more people are exposed to damaging shaking. Further, this changing exposure is spatial and temporally independent, whereby the time of the maximum of exposure varies by location. Our methods provide dynamic population models that can inform disaster risk models and scenarios. As we demonstrate, there is a clear need to understand time in emergency response planning, so we can understand how impacts and appropriate response vary through time.

Radiocarbon analysis of rapidly deposited layers within fjord sediments

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Fjords are hotspots of carbon burial and currently unaccounted for in New Zealand's carbon budgeting. Large amounts of terrestrial organic carbon (OC) are thought to be delivered to fjords through landslides and rivers. Atmospheric inversion modelling suggests that Fiordland's indigenous rainforest draws down significantly higher quantities of atmospheric CO_2 than previously thought. It is hypothesised that low frequency, high magnitude deposition events are the main process for efficient sequestration of the carbon.

We present preliminary results of using unique radiocarbon and geochemical measurements on rapidly deposited layers (RDLs) from Tamatea Dusky Sound to better understand the mechanisms of carbon sequestration in high magnitude deposition events. These events are largely due to earthquakes and flooding, and this sedimentation process has previously been overlooked in carbon cycling analysis of fjord sediments in Aotearoa New Zealand. We are conducting ongoing ramped pyrolysis oxidation radiocarbon dating and pyrolysis-gas chromatography-mass spectrometry to study the composition, degradation state and age of different OM pools while total organic carbon analysis has been used to quantify carbon stocks. This has enabled high resolution interpretations on two identified RDLs within a singular 1.5 m gravity core from the Bowen Channel, Dusky Sound. Our analyses are intended to constrain the timing of the high magnitude events, the sources and chemical makeup of the deposited carbon, differences from lower rate deposition in these locations, and the contribution of these events to carbon accumulation in the fjords. Importantly, this research provides temporal and spatial insight into the role fjord margins play in carbon cycling and storage, particularly lateral catchments and submarine fans.

I raro i ngā ngaru: Beneath the waves of Lake Wānaka using multibeam echosounders

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Lake Wānaka is a significant site for tangata whenua, believed to have been carved out by Waitaha explorer Rākaihautū along with all the other lakes of Te Waipounamu (South Island). Now a popular international holiday destination, the shores of Lake Wānaka are busy year-round with food festivals, wineries, adventure races, and airshows, drawing in hundreds of thousands of visitors annually. Although people have resided along the shores of Lake Wānaka for hundreds of years, little is known about the lake's bathymetry and geomorphology. Due to the geographic location of Lake Wānaka within a steep glacial-carved valley and its local proximity to the Alpine Fault, the lake and wider region has been significantly impacted by anthropogenic, climatic, and tectonic forces.

The first known map of Lake Wānaka was drawn in 1844 by the southern Ngāi Tahu leader Te Huruhuru, with the first bathymetric map being produced more than 100 years later by the New Zealand Oceanographic Institute (NZOI) in 1976. Since then, incomplete multibeam, single beam, and seismic surveys of Lake Wānaka have provided incremental improvements to our understanding of lakebed geomorphology and sediment transport processes, however, no complete multibeam survey had taken place. In March-April 2024, NIWA undertook the first complete multibeam echosounder survey of Lake Wānaka using a Reson T20-R system. Results from this survey provide significant opportunities to understand lake-floor morphology, past glacial processes, modern sediment transport processes, and to identify any potential natural hazards. Here we present an overview of the acquired survey data and provide wider context around the geological and human connections to Lake Wānaka.

Scratching the surface: A catalogue of recognised human impacts across New Zealand's nearshore marine/freshwater environments

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The people of Aotearoa New Zealand have a close connection to the awa (rivers), roto (lakes), and moana (ocean) with ~65% of all residents living within 5 km of a coastline. Although multiple agencies and institutions have been actively researching and surveying the shallow marine and lacustrine environment across Aotearoa, each of these surveys has involved a variety of different acquisition techniques (e.g. towed cameras, multibeam echosounders, sub bottom profilers) and survey output requirements (e.g. hydrographic surveys vs. ecological habitat assessment). Many surveyed marine/freshwater settings around New Zealand have shown a broad range of anthropogenic features in processed bathymetric surfaces. Although quickly detected in real-time, many of these features can be quickly 'smoothed' out due to their relatively fine scale (<10 m), resulting in either a lack of ability to reconcile features, or the mischaracterisation of features as other natural phenomena (e.g. rock outcrops or other rugose features). Additionally, even if human impacts are detected in one dataset type (e.g. multibeam echosounder), it may not be evidently clear how these features are modified or preserved through time. As such, it is essential that the ability to extrapolate out identified instances of detected human impact can be undertaken.

Here we present an overview of observed human impacts across New Zealand, synthesised from multiple research/hydrographic multibeam echosounder surveys in both marine and freshwater environments. We discuss how reprocessing hydrographic multibeam data, where possible, may be required to best identify anthropogenic features and how incorporation of other data processing techniques, such as structure-from-motion photogrammetry, may provide additional information outside of conventional morphometric analysis.

The structure of the Puysegur subduction zone: A study using detailed multi-year earthquake catalogues

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The Puysegur subduction zone is a young and steeply dipping subduction zone. It is a key site for studying early subduction stages as the subduction zone is thought to be on the brink of becoming self-sufficient. Despite its globally unique situation, the current knowledge regarding the structure and stress state of the Puysegur subduction zone is limited due to the remoteness of the region and the subsequent lack of instrumentation. Few earthquake studies are currently available for the region, and the permanent GeoNet network in most of the South Island is too sparse to accurately constrain the region's seismicity.

This study aims to resolve the structure and stress state of the Puysegur subduction zone beneath Fiordland by using data from a combination of temporary deployments and the permanent GeoNet network. Data from these networks is used to construct highly detailed, multi-year earthquake catalogues using automated earthquake detection and association coupled with manual evaluation and P-wave polarity determination. Accurate earthquake locations are obtained using NonLinLoc and the 3D nationwide velocity model and refined by relative relocation. Further analyses of the catalogues will be conducted using moment tensor inversions, focal mechanism analyses, and stress inversions. The hypocentral locations in our catalogues delineate the geometry of the subducting slab underneath on- and offshore Fiordland and enable the identification of active faults in Fiordland. A limited number of focal mechanisms and moment tensor solutions provide additional constraints on these structures and on the regional stress state.

Seismic stratigraphy of Lake Whakatipu

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Glacial lakes that formed after the Last Glacial Maximum are large sediment traps that preserve a record of environmental change in the catchment area. Seismic surveys have been conducted in lakes in the Northern Hemisphere to identify changes in sedimentary composition and depositional structure to make interpretations of environmental conditions at the time of deposition. In New Zealand there is a lack of this type of research being conducted especially in lakes south of the Mackenzie Basin with only a few studies utilising seismic data. Good quality seismic data have been collected from Lake Whakatipu along 63 lines in November 2021 and November 2022. The 24 lines located in the Glenorchy Arm are the focus of this study due to their proximity to the Rees Dart River Delta. These lines were processed using GLOBE Claritas and imported into S&P Kingdom where surfaces corresponding to the lake floor, basement and sedimentary strata were identified to build a depositional model. The sedimentary bedding is all shallowly dipping away from the delta. Slump deposits have been identified at depth in the lake basin. Multiple paleo lake channels indicate periods of high erosivity and sediment transport in the deeper parts of the lake. The occurrence of gas pockets is interpreted to increase towards the head of the lake and the top of the gas is shallower than the paleo channels. This possibly indicates a change in the amount of organic material being deposited as part of the sediment, corresponding to a change in environment. These findings show the usefulness of lacustrine seismic data to interpret changes in catchment conditions resulting from seismic activity or vegetation development since the last glaciation. Lacustrine seismic surveys also identify areas of interest for collecting sediment cores, which can be used to determine the age of different events.

Lead isotope tracing of heavy metal contaminants in the environment

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The waters, soils and sediments of Aotearoa New Zealand's streams, estuaries and harbours are pressured by increasing levels of heavy metal contaminants from nearby transport, construction, agricultural and horticultural activity. Rapid expansion of land-use activities through population, primary-industries, construction-sector and tourism growth is only expected to intensify these adverse effects. Heavy metal contamination is traditionally monitored using metal concentrations, however, there are major gaps in our knowledge of where anthropogenic heavy metals come from. To help overcome this shortfall, we are developing a toolkit in metal-isotope 'fingerprinting' based on the isotope systems of Pb, Cu, Cd, Zn and U to offer improved discriminatory power over metal concentrations alone for quantifying the sources, transport-pathways, and sinks of heavy-metal contaminants as they move through the environment. Here, we present heavy metal concentration and Pb isoscape maps for soils collected from c. 70 sites located 2-4 km apart on a grid across central and west Auckland that span a range of land-use activities. Samples from the surface and subsurface, respectively, representing modern and pre-industrial metal distributions were obtained. The results for soil extracts show (i) Pb concentrations ranging between 3 and 392 mg/kg, and (ii) significant variations in Pb isotopic composition, which can be explained by variable mixing between natural Pb inherited from the basement lithologies and anthropogenic Pb sources. We combine the Pb isotope signatures of the soils with those determined for known Pb-containing pollutants (e.g. wheel weights, road dust, landfill leachates, and paints) to quantify the extent to which historic and modern sources of anthropogenic Pb have accumulated in Auckland soils and elucidate the contribution from each source.

Advancing uncertainty communication of the scientific model - using 'Uncertainty Doughnut'

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Uncertainty is integral to the process of knowledge creation through scientific models. The failure to communicate uncertainty to the decision-makers has led to the collective inability to tell a coherent story about scientific modelling, where the lack of an effective communication mechanism for scientific models is hugely discussed as the root of this uncertainty communication problem. Hence, this study builds upon these research gaps and draws reflexive insights from in-depth qualitative interviews with 17 decision-makers and 15 scientists.

Based on the reflective analysis of these interviews, this research proposes a novel 3D framework, 'Uncertainty Doughnut,' designed to address communication challenges by offering a structured approach to classifying, prioritising, and visualising uncertainties. This 'Uncertainty Doughnut' facilitates uncertainty discussions between scientists and decision-makers. The development of this 'Uncertainty Doughnut' involved an iterative and rigorous process where, after the tool's initial development, we sought feedback through 11 additional feedback interviews and two focus group discussions (FGD). Results from this feedback described 'Uncertainty Doughnut' as a valuable tool. Both scientists and decision-makers expressed this as an innovative tool. They suggest this tool stimulates meaningful discussions between scientists and decision-makers, helps scientists go beyond traditional communication methods, and reduces discomfort.

The global geoethics infrastructure

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In recent years, the involvement of a growing number of scholars from diverse disciplines has significantly advanced the theoretical foundations and practical applications of geoethics. This has been achieved by creating spaces for sharing reflections, discussions, results, and study materials. Scholars have developed both physical and conceptual spaces to maintain conceptual consistency in geoethical thinking by grounding reflections in the discipline's historical evolution and encouraging further developments through open analysis and contributions from various fields. Today, a complex research infrastructure on geoethics has emerged, serving as a convergence point for diverse cultural and scientific experiences.

At the core of this infrastructure is the International Association for Promoting Geoethics (IAPG), established in 2012. Recently, two new entities have enhanced this infrastructure: the Commission on Geoethics of the International Union of Geological Sciences (IUGS), established in 2023, which serves as the IAPG's supporting branch to the IUGS and addresses geoethics and social geosciences; and the Chair on Geoethics of the International Council for Philosophy and Human Sciences (CIPSH), established in 2024, which aims to expand and strengthen an international research network to foster interdisciplinary initiatives bridging geosciences, humanities, and social sciences through geoethics. The research infrastructure on geoethics has been enriched by two editorial initiatives: the SpringerBriefs in Geoethics series by Springer Nature, founded in 2020, which discusses the ethical, social, and cultural implications of geosciences; and the Journal of Geoethics and Social Geosciences, a diamond open-access publication founded in 2021. Lastly, the School on Geoethics and Natural Issues ('Schola'), founded in 2019, complements the research infrastructure. The 'Schola' teaches and promotes geoethics principles and values, providing the knowledge and evaluation skills necessary to understand the relationship between human actions on ecosystems and geoscientific decisions that impact society.

To access information about the global geoethics infrastructure, visit https://www.geoethics.org.

One tune, many tempos: Faults trade off slip in time and space to accommodate relative plate motions

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Analysis of incremental slip rates from the four major strike-slip faults of the Marlborough Fault System (MFS) provides a first-ever record at the scale of an entire plate-boundary fault system of how relative plate motions are accommodated in time and space. This record, which spans the past ~400 m of relative plate motion and ~13 ky, demonstrates that the fault system collectively accommodates a steady plate-boundary slip rate, with the MFS faults ‘keeping up’ with the overall rate of relative Pacific-Australia plate motion at relatively short displacement (10’s of metres) and time (10^2-10^3 yr) scales. These results affirm the often-assumed but until now unproven assumption that the relative plate-motion rate provides a robust basic constraint on both geodynamical models and analyses of system-level seismic hazard at these scales. In marked contrast, the incremental slip rates of each of the four main MFS faults are highly variable through time, marked by coordinated accelerations and decelerations spanning 4-6 earthquakes as the faults trade off slip to accommodate a steady relative plate motion rate. Interestingly, the periods of fast slip on the MFS faults exhibit ~20-25 m of displacement, suggesting that these may record periods of fast slip on a weakened fault/ductile shear zone that continues until it uses up all locally stored elastic strain energy, thus approaching local complete stress drop, albeit during a few tens of metres of rapid fault slip during multiple earthquakes. These results emphasise the need to analyse the collective behaviour of the entire fault system, rather than just individual faults, to understand the mechanics of the system. Moreover, these patterns suggest a potential path forward for more accurate estimation of time-dependent seismic hazard, with the possible incorporation of the current position of a fault within a fast- or slow/no-slip period into the probability analysis.

Pleistocene paleoenvironmental reconstructions from the Pacific Sector of the Antarctic Circumpolar Current: Diatom and sediment geochemistry proxies from IODP 383 Site U1539

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The Mid-Pleistocene Transition (MPT) marks a fundamental shift in Earth's climate system from ~41 ky lower amplitude glacial cycles to higher amplitude ~100 ky cycles. The Antarctic Polar Front (APF), which maintains strong control on upwelling and productivity in the Southern Ocean, is known to migrate over time, with notable shifts during major climate transitions. Previous studies have identified changes in APF position and associated changes in the biological pump across the MPT, but data from the Pacific Sector of the Southern Ocean are sparse due to difficulty of access. Here, we present new diatom and geochemical records from IODP Site U1539, located at 56°09.0655'S in the Pacific Sector of the Antarctic Circumpolar Current (ACC). At Site U1539, a shift in the diatom assemblage across the MPT indicates a northward shift of the APF around 750 kya. The pre-MPT assemblage is dominated by Thalassiothrix antarctica mats (10.3-46.7%), transitioning to a more diverse assemblage post-MPT. The post-MPT assemblage notably records cyclicity in the relative abundance of Eucampia antarctica (0-11.1%), with peaks in abundance coinciding with glacial periods. Throughout the 1.4 Myr record, summer sea surface temperature (SSST) and weight % biogenic silica (wt.% BSi) vary cyclically with the global benthic oxygen isotope stack indicating sensitivity to glacial-interglacial change. Higher wt.% BSi and cooler SSSTs occur during glacials while lower wt.% BSi with warmer SSSTs coincide with interglacials. Siliceous productivity is notably low in marine isotope stage (MIS) 11, where the sediment is characterised by nanofossil ooze. The diatom record at U1539 also contains isolated peaks in % Chaetoceros resting spores, most occurring during glacial-interglacial transitions with the highest abundance (53.6%) following MIS 31.

Call me a magnetician: Digitising New Zealand's historical magnetic field data

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Magnetic variometers, operating in stations in or near Christchurch, have been recording the variation in the magnetic field in New Zealand for over 100 years. Prior to 1991 daily high-resolution records were collected on paper (magnetograms) and hourly mean averages were compiled into annual reports. Some of the hourly data has been captured digitally, but little high-resolution data has been captured from these magnetograms prior to the Solar Tsunami Endeavour Programme starting.

The Solar Tsunami Endeavour Programme is an international collaboration led by the University of Otago to understand how New Zealand's energy infrastructure will be impacted by an extreme space weather event (https://solartsunamis.otago.ac.nz/).

One of GNS Science's contributions to the Solar Tsunami Endeavour Programme is to digitise some of the historical magnetograms. The historical record is very important for characterising the likelihood and intensity of future magnetic storms since we don't have many very large storms and no massive storm in the digital collection era (1990 onwards).

Digitising the line data proved to be a challenge due to things like faint lines and overlapping lines. We used a combination of automatic and manual digitisation methods. The most interesting and challenging part of the project was finding and working with the historical records (e.g. notebooks and physical worksheets) to reconstruct how the data were processed.

So far, we (GNS Science and University of Canterbury) have captured minute data from the largest storm days (K7 and above) and the weeks either side of the storm days from 1950-1990 (~1500 days total). We are now working on lesser storm days (K6 and below).

Mountains to sea in 3D: Fiordland plutonic block is key to the southern South Island New Zealand plate boundary

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In southwestern Zealandia, the plate boundary transitions from the Puysegur oblique subduction zone to the 600 km long dextral Alpine fault and Southern Alps uplift zone. Utilising abundant earthquake observations, we construct a 3D seismic velocity model to 130 km depth that demonstrates that the strong lithosphere of the Fiordland block defines the character of deformation along the plate boundary zone. Highly oblique convergence combined with the relatively weak young Puysegur slab enables sharp slab bending as it is translated northward around the Fiordland block.

The Fiordland block contains plutonic rock from the 500-100 Ma Gondwana Cordillera, and its Grebe shear zone is a long-lived boundary, with a geochemically indicated Precambrian lithospheric keel underlying the Eastern Domain. The Grebe shear zone is imaged as a boundary to 80 km depth, with Eastern Domain lithosphere abutting the deeper Australian slab, where it bends to vertical below 75 km depth. Western Fiordland Orthogneiss lower crust, uplifted in the Miocene along reactivated shear zones, is imaged as a rigid/strong high-velocity feature pushed up above the 30-70 km depth Australian slab.

In southernmost Fiordland, south of Dusky Sound, the Puysegur slab maintains its moderately dipping subduction continuous with its offshore extent, and the overlying Pacific plate shows moderate seismic velocity material with the deep keel located further east than the slab. In northern Fiordland, the impacting Pacific lithospheric base has an additional strong component, with Cretaceous underplated Hikurangi igneous plateau. This collision further steepens the young Australian slab which exhibits abundant deep seismicity 70-150 km depth consistent with high strain-rate. Overlying the deep vertical slab, from 20-50 km depth, lower-crustal ductile thickening is inferred from a localised low-velocity region, under overthrust Western Orthogneiss.

Next generation tools for volcanotectonic numerical modelling in the TVZ

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New Zealand's Taupō Volcanic Zone (TVZ) hosts the world's most frequently active caldera supervolcano system. In the TVZ, interactions between faults, seismicity and volcanoes have occurred historically, with small to moderate earthquakes associated with volcanic unrest (periods of enhanced seismicity and surface deformation). The geologic record contains numerous examples of fault slip predating, contemporaneous with, or just post-eruption, as also observed historically for global examples. Hazard assessment of unrest often relies on simple elastic inversions to estimate the location and size of magma bodies, even though complexities such as fault slip can substantially change volcanic unrest signatures. We will outline new methods being developed to unravel the interactions between faults and volcanoes to determine potential triggering mechanisms. These methods use advanced numerical modelling tools (developed locally and internationally) to improve our physical understanding of mechanical interactions between TVZ's caldera volcanoes and nearby faults. These tools can test the influence of magmatic fluids, fault geometry, crustal structure and tectonic deformation on the pathway from minor volcanic unrest to earthquakes and volcanic eruptions. We will present some preliminary results and the outcome of discussions with the TVZ volcanotectonic research community on case studies from the central TVZ that can be used to test model assumptions.

Over the misty mountains – Fiordland's climatic development during the Holocene

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There are few terrestrial sites in the mid- to high latitudes of the Southern Hemisphere that can represent undisturbed paleoclimate archives. Providing nearly undisturbed conditions for sediment accumulation and the formation of ecological niches, lakes can capture and store small-scale environmental variations. However, land use and land transformation leading to overfertilization, increased weathering rates or drainage not only puts ecosystems at risk but may also override archived information, limiting potential for paleoclimate interpretations. Nested within the rugged terrain of central Fiordland, remote alpine lakes are therefore rare and ideal locations to study past climatic changes over the Holocene.

We present the outcomes of a study of two adjacent lake catchments in central Fiordland (Lake Bright and Lake Laffy). We apply a multiproxy approach utilising non-destructive x-ray fluorescence core scanning, and the analysis of plant lipid biomarkers and carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) bulk isotopes to determine changes in sediment provenance. Changes in temperature and moisture are derived from glycerol dialkyl glycerol tetraethers (GDGTs) and compound-specific isotopes of leaf wax n-alkanes.

Our Lake Bright stratigraphy was compiled by the MBIE-funded Lakes380 programme and presents a highly resolved picture of the last 4200 years, exhibiting changing hydroclimatic conditions over the course of the late Holocene. With the core from adjacent Lake Laffy, we reach further back in time to unveil the intricate interplay of climate and environmental changes since the end of the last glacial extent in Fiordland about 17,000 years ago. Our results indicate that the early Holocene in Fiordland was characterised by a cold and humid climate. Over the mid-Holocene temperatures increased and more arid conditions may have prevailed. Whilst humidity generally increased in the late Holocene, our results indicate that the last millennium was shaped by a trend to overall drier conditions.

Unravelling the vertical land motion and relative sea level rise in Sumatra, Indonesia

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Sumatra Island in Indonesia has been undergoing significant deformation changes since the major earthquake in 2004. This region has experienced several significant geological events, including the 2004 M9.1 Aceh earthquake and the 2023 eruption of Marapi volcano. These events rank among the most catastrophic in modern history, resulting in over 227,000 deaths and 24 fatalities, respectively. We analysed the movement of continuous Global Navigation Satellite System (GNSS) stations along the Great Sumatran Fault and Sunda Trench from 2010 to 2023. Our dataset includes the GNSS Continuously Operating Reference Stations (CORS) data from 44 Sumatran GPS Array (SUGAR) sites and 27 Indonesian CORS (Ina-CORS) sites, respectively managed by research institutions and government agencies. We processed this data using Bernese software version 5.2 and applied the Finite Element Solution 2014 (FES2014) tidal loading correction for improved accuracy.

Our research reveals that despite the data spanning from 2010, earthquakes occurring before 2010 still impact some GNSS sites, indicating ongoing post-seismic effects. Due to the location of monitoring stations in the subduction zone, these GNSS CORS are significantly affected by earthquakes, especially those with magnitudes above 6.5 that occurred during the data collection period. We identified one station in east Sumatra, which has less significant seismological impact, but it showed notable land subsidence due to peatland degradation.

Furthermore, we observed significant land subsidence along the subduction zone and the west coast of Sumatra, except for the northern part of the island, which is experiencing an uplift. Additionally, we found a high correlation between sea level rise and vertical land motions at several co-located tide gauges and GNSS stations. These findings emphasise the importance of considering vertical land motions when addressing sea level changes, particularly in seismically active regions.

Do active faults' clay mineral compositions affect whether earthquake ruptures they host will displace the surface?

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The tectonophysical paradigm that earthquake ruptures should not start, or easily propagate into, the shallowest few kilometres of Earth's crust makes it difficult to understand why damaging surface displacements have occurred during historic events. The paradigm is supported by decades of analyses demonstrating that near the surface, most major fault zones are composed of clay minerals – particularly extraordinarily weak smectites – which most laboratory physical measurements suggest should prevent surface rupture if present.

Previous analyses along the Alpine Fault Zone (AFZ) have demonstrated that weak clay minerals, such as smectite are only found in some gouges from near surface outcrops; in others smectite is absent. This may explain why this fault was able to offset the surface in some places in past events while other locations (e.g. Fox Glacier township) lack evidence for recent displacement. This sort of heterogeneity in rupture propagation to the surface would have important implications for seismic hazard assessment. It would therefore be valuable to examine the relationship of gouge mineralogy to evidence for surface displacement. However, various other factors may also influence gouge mineralogy, such as protolith, and length of surface exposure (therefore weathering).

To explore how gouge clay mineralogy varies in relation to some of these factors, we analysed gouge samples from surface exposures at six locations along the AFZ with XRD and XRF. The results reveal the presence of smectite at four locations (Cascade River, Robinson Creek, Waikukupa River, and Darnley Creek) correlating with a depletion of chlorite, an increasing metamorphic grade and higher uplift rates towards the central AFZ. In these samples, smectite was most common in steeply dipping fault segments (>54°). The mineralogy is comparable to fault gouges of other weak faults, e.g. San Andreas Fault and Mejillones Fault, showing aseismic creep.

Recrystallized grain-size and subgrain-size piezometer for ice with application to natural ice in Antarctica

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Recrystallised grain-size piezometers were developed as a way to statistically link deformed features within rocks to stress (Cross et al., 2017; Goddard et al., 2020; Platt, 2023; Shimizu, 2008). Generally, this involves identifying the grain-size of subgrains formed during deformation and statistically differentiating them from larger relict grains. Experimental grain-size piezometers have been created for various minerals such as quartz, olivine, pyroxenes, and feldspars (Cross et al., 2017; Platt, 2023; Speciale et al., 2022; Stipp and Tullis, 2003). These models have demonstrated success when comparing experimentally deformed samples to naturally deformed samples. We aim to produce a foundational piezometer model for synthetic ice which will improve understanding of grain-scale deformation processes at various stresses and initial grain sizes. This model will then be fine-tuned using natural Antarctic ice data, which will allow us to create a model of microstructural deformation processes with depth, and further our understanding of natural ice mechanics.

Kyeburn moa footprints and the Maniototo Conglomerate

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In March 2019 a trackway of seven moa footprints was found at a riverbank outcrop of Maniototo Conglomerate in the Kyeburn River, Central Otago. This project allowed the first interaction of the local Māori with footprints similar to what their tipuna (ancestors) would have used for tracking and hunting several species for mahinga kai (food gathering) before their extinction some 500 years ago.

These footprints were the first to be found and recovered in the South Island Te Waipounamu. Here we present our results of the trackway measurements and dimensions and how big these moa were alongside the results of the cosmogenic nuclide dating of the Maniototo Conglomerate which overlies the trackway. This helps put these footprints into an evolutionary context.

The footprints of the trackway were ~46 mm deep, 272-300 mm wide and 260-294 mm long. There was also an associated separate footprint that was 448 mm wide and 285 mm long. Cosmogenic nuclide dating of adjacent overlying beds from the same formation establishes a mean minimum age of burial age for the tracks of 3.57 Ma (+1.62/-1.18 Ma) with a mode of 2.9 Ma, which we interpreted to be Late Pliocene, with a conservative age range of Pliocene to Early Pleistocene.

Comparing 2D and 3D models of Antarctic ice shelf rift fronts

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Rifts are large, through-cutting, laterally propagating fractures in ice shelves. They propagate in response to the stress-state at their fronts, splitting the floating ice and creating new internal boundaries, or rift walls, on either side. Both glaciostatic and hydrostatic pressures act on these rift walls, and due to their differing depth-dependence, a net inward push from the ice overburden is generated. Rifts are often observed to be filled with mélange – a mixture of frozen seawater, glacier ice blocks, and accumulated snow – typically an order of magnitude thinner than the surrounding ice shelf.

2D representations are commonly used for modelling rifts in ice shelves. In such models, the rift tip is represented by a point, implying a vertical or near-vertical rift front. This study examines the limitations of 2D models in capturing the stress conditions at the rift front by comparing them with a 3D idealised rift model. In the 3D model, different contributors to the force balance on the rift walls are incrementally added and their impact on rift propagation is evaluated. Finally, the investigation explores theoretical rift front geometries that are stable and how these are influenced by the presence of mélange.

A study of the transition in eruptive styles at a scoria cone in the Hopi Buttes Volcanic Field, Arizona

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Understanding the eruptive behaviour of monogenetic volcanoes in volcanic fields remains an important focus of volcanology in New Zealand, particularly due to the Auckland Volcanic Field and its related hazards.

At a site called Crazy Waters, located in the Miocene aged Hopi Buttes Volcanic Field, Navajo Nation, Arizona, there is excellent exposure of the entire eruptive history of a scoria cone with phreatomagmatic base surge deposits at its base. This volcano partially overlaps an older maar lake. Despite their proximity, the two vents are likely unrelated. The bombs erupted from the scoria cone landed in sand dunes that had formed when the older maar lake had dried up, and geochemical and petrological data suggest two different batches of melt. The sequence of beds related to the scoria cone represent a good opportunity to study the complete life of a monogenetic volcano in a volcanic field, in particular the transition in eruptive styles, with a focus on describing the growth of the scoria cone, and interpreting whether the transition was gradual, or rapid.

At this particular volcano, this transition was gradual. The presence of scoria increases with height at most outcrops, eventually culminating in a welded scoria cap. At some cliff faces, this scoria became so well welded that columnar jointing became the cooling mechanism. The base surge deposits at the base of the phreatomagmatic sequence contain the same mix of lithic clasts from the three main sedimentary lithologies below the cone; the Bidahochi Formation, the Chinle Formation, and the Moenkopi Formation. This transition is likely the result of an increase in magmatic flux over time, rather than a 'drying up' of the eruption.

Utilising machine learning methods to enhance grainsize distribution maps of Aotearoa's surficial marine sediments

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Sediment characteristics such as grainsize are vital for understanding benthic habitat distributions, marine organic carbon sinks, and sediment provenance. Previous grainsize maps for Aotearoa's marine realm, comprised of over 10,000 datapoints (Bostock et al., 2019a, b, NZJGG 62), used traditional kriging interpolation methods to create surfaces for mud, sand, gravel, and carbonate percentage. Owing to limitations with this interpolation method, these sediments grainsize data layers have had limited application for predicting habitat suitability for benthic fauna (e.g. Anderson et al., 2016, Deep Sea Res. 115). Here, we test multivariate machine learning methods that utilise non-correlating bathymetry derivatives (from Lecours et al., 2017, Environmental Modelling & Software 89) such as depth, slope, easternness, northerness and bathymetric point index (BPI) to explore and compare results.

Furthermore, the grainsize layers could be used to improve machine learning models for mapping seafloor sediment geochemical signatures. Geochemical maps of offshore Bay of Plenty have been created previously using Random Forests, utilising local surface currents, distance from the coast, gravity anomalies and magnetic anomalies, and bathymetry derivatives as covariates; however, strong linear relationships between some elements and mud percentage (e.g. Rb, R2 = 0.74; K, R2 = 0.61) suggest models for some elements could be improved with the addition of grainsize as a covariate. Thus, using a combination of grainsize and geochemical data layers in benthic habitat models that utilise machine learning techniques has potential to improve our understanding of both marine ecological and geological processes.

Comprehensive physics-based multi-hazard and multi-risk modelling for Aotearoa New Zealand: A progress report

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Within the recently completed RNC2 Earthquake and Tsunami Programme, we have developed a framework to use earthquake cycle simulators to generate hundreds of thousands of synthetic earthquake scenarios. Critically, our simulations have shown us that the biggest events are typically complex events involving multi-fault ruptures. This discovery has widespread implications for future multi-peril models. Cascading multi-peril impacts can be calculated for each of these scenarios. Collectively, they present an enticing physics-based pathway to develop probabilistic multi-hazard risk models and suites of pre-calculated impact products that will allow us to assess uncertainty in impact forecasts during future event response.

In a first proof-of-concept application, we have applied the comprehensive multi-hazard framework to a 30,000-year event catalogue affecting central New Zealand. For each event in the catalogue, we develop ground motion models including both dynamic shaking and static displacement. We then use these models to assess hazard, including cascading impacts of tsunamis and earthquake-induced landslides. We are in the early stages of creating loss metrics for the modelled impacts. This work is aligned with Stage 1 of the new National Tsunami Hazard Model that focusses on the Wellington region. We will present current model progress as well as highlight opportunities for collaboration of the wider community in this effort.

Exploring future Alpine Fault earthquakes using ambient seismic noise analysis

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The Alpine Fault is the primary seismic hazard in southern New Zealand since it has been demonstrated that M7+ earthquakes occur as regularly as every ∼300 years. The Alpine Fault last ruptured 307 years ago, which makes it urgent to understand as much as possible about the fault and constrain the range of shaking possible in the coming earthquake. Empirical information on the shaking resulting from Alpine Fault earthquakes does not exist, as no Alpine Fault earthquake has been recorded instrumentally.

Ambient seismic noise analysis is a valuable tool for modelling realistic Alpine Fault earthquake ground shaking, as it allows wave propagation to be studied without relying on earthquakes or explosions. Ambient noise cross-correlation, coherency and deconvolution functions between stations can reveal coherent energy travelling between stations and approximate the Green's function between pairs of stations.

We use 15 months of ambient seismic records from the temporary Southern Alps Long Skinny Array (SALSA) of 43 broadband stations deployed every ∼10 km along the Alpine Fault and GeoNet stations to compute surface-to-surface coherency functions between every station pair. We calibrate the ambient noise coherency functions for depth and focal mechanism using moderate-magnitude (M4-M5) earthquakes occurring in different segments of the Alpine Fault to obtain calibration factors that we later use to simulate M6+ earthquakes.

In this presentation, we show three M5+ earthquake simulations of real earthquakes occurring in the three Alpine Fault segments. The comparison between the real earthquake waveforms and our simulation is outstanding between specific frequency ranges (0.1-1 Hz). This approach will allow us to simulate higher magnitude earthquakes anywhere along the fault and investigate the ground shaking variability as a function of rupture and a wide range of rupture scenarios in the next phase of the SALSA project.

A minerals strategy for New Zealand

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Around the world governments are navigating energy transitions and the associated geopolitics of critical minerals essential to a global low carbon energy future. In New Zealand this presents both challenges and opportunities.

New Zealand already has a highly renewable electricity system but in the medium term it remains critically dependent on baseload thermal generation. Domestic gas production has been in decline and can no longer fully meet demand from industrial and electricity markets resulting in unsustainably high gas, and consequently, electricity prices. When hydro lake levels are low, the baseload generation gap is currently met by importing coal. The short-term energy outlook remains negative and electricity markets will continue to be heavily influenced by hydro lake inflows.

The policy response to these energy challenges includes proposals to facilitate investment in renewables by streamlining consenting, the development of regulatory settings supportive of investment in offshore renewable energy and to ensure New Zealand plays a role in the supply of critical minerals.

The Government recently consulted on a draft Minerals Strategy to enable a long-term, strategic approach to how we develop our mineral resources. The strategy is built on 3 key pillars; Enhancing prosperity for New Zealanders, Demonstrating the sector’s value, and Delivering minerals for a clean energy transition. Achieving the strategies’ objective of doubling mineral exports to $2 billion by 2035, playing a role in global supply of critical minerals, and navigating the energy transition all require open access to geoscience data.

New Zealand Petroleum & Minerals, the regulator of the Crown owned minerals, holds significant collections of geoscience data, technical reports and samples. These are discoverable and accessible publicly via the regulator's Geodata Catalogue service on their website. Recent improvements are set to expose all elements of the collection, much of which is now available for immediate download.

Modelling building amplification of earthquake ground motion, Wellington, New Zealand

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The GeoNet Building Array Programme has provided an extensive collection of strong motion data from instrumented structures across New Zealand, progressively including more buildings since starting in 2007. In this study, funded by the Natural Hazards Commission (NHC) Toka Tū Ake, building array data from three mid-to-high rise buildings in Wellington's central business district are used to model the dynamic behaviour of buildings in a region of heightened seismic hazard. Our objectives are to document and model the internal amplification effects of large multi-storey buildings in response to ground motions produced by earthquakes of varying magnitudes and distances, including the 2013 Cook Strait, 2013 Lake Grassmere, and 2016 Kaikōura earthquakes.

A comprehensive building array dataset has been compiled based on a catalogue of 800 earthquakes recorded in central New Zealand since 2010. We use deconvolution interferometry to decouple building responses from soil-site interaction, Fourier analysis to investigate the distribution of dominant frequencies and building periods, and strong motion analysis to derive the amplification response in various directions, based on peak ground acceleration and peak floor acceleration.

The new knowledge gained from this research will provide valuable insights into building performance and better anticipate structural responses to earthquake ground motion.

Deformation history of the Waimea-Flaxmore Fault System in Nelson-Tasman Bay (New Zealand): Implications of alternative restorations

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The Waimea-Flaxmore Fault System (W-FFS) controls the range front in onshore Nelson but remains below sea level along the eastern margin of Tasman Bay. Recent interpretations based on offshore seismic lines tied to onshore transects portray mid-Miocene reverse reactivation of inherited east-dipping normal faults, with Plio-Quaternary propagation of the W-FFS in Nelson versus inactivity of its Tasman Bay strands since 7 Ma. Northward diminution of activity on the W-FFS has relevant implications for seismic and tsunami hazard assessments, but poor imaging of offshore seismic lines and erosional removal of the Neogene cover sequence in the W-FFS hanging wall do not allow unique interpretations. Two end-member scenarios are envisaged: 1) reverse reactivation of inherited east-dipping normal faults, with folding of the Neogene cover sequence followed by erosional levelling of the W-FFS hanging wall anticline in eastern Tasman Bay since 7 Ma; and 2) folding of the offshore Neogene sequence during reverse reactivation of west-dipping normal faults west of the W-FFS, followed by post 7 Ma propagation of the east-dipping W-FFS decapitating earlier inversion structures.

In the first scenario, segmentation of the W-FFS and its diminishing activity in eastern Tasman Bay occur at the transition from the Nelson contractional domain to the northern Marlborough strike-slip domain, driven by large-scale kinematics of the Pacific-Australia plate boundary. In the second scenario, sets of Late Cretaceous-Paleogene syn-rift faults are presently buried in the footwall of the W-FFS, consequent on Quaternary shortening and thrusting along the W-FFS in both Nelson and Tasman Bay. Both scenarios are admissible and restorable but require different chronology of fault activity, as well as different erosion and deformation rates. Available data do not provide a clear-cut solution and new subsurface information and stratigraphic control are needed to fully unravel deformation style and timing of activity of the W-FFS.

Investigating late Holocene climate change and carbon sequestration in Fiordland

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Fjords are globally recognised as significant carbon burial sites due to their ability to trap and preserve organic carbon. Deposition and preservation of carbon in the fjord basins through time is influenced by changing climate, which impacts rainfall and fjord circulation. Paired records of past climate and carbon accumulation can provide an insight into how climate change affects carbon burial, and how this may change in the future under projected climate conditions.

The deep basins in Fiordland contain sedimentary sequences that potentially extend back to the Last Glacial Maximum, including periods when climate was similar to future projections. Our research aims to provide a comprehensive high-resolution reconstruction of past climate and carbon burial in Fiordland. This requires multi-proxy analysis of sediment cores collected from the fjords. Here we use sediment cores collected from Te Awaroa Long Sound to examine multiple different analysis techniques, including Itrax XRF core scanning, hyperspectral imaging, CT scans, carbon concentrations, and physical properties, to determine which analysis best contributes to key research questions and where there may be replication. The aim of this comparison is to identify key analysis techniques for fjord sediment cores that can answer critical science questions, while at the same being efficient and cost-effective.

Correlating sequestered organic carbon provenance and age in the southern New Zealand fjords using geochemical and radiocarbon methods

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In coastal marine sediments, lateral transport and burial of organic matter are critical components to controlling release or sequestration of carbon in the environment. Principal sources of carbon sequestered in coastal marine sediments include primary productivity in the water column, lateral transport of resuspended matter, and significantly for fjords, eroded terrestrial organic matter. Heavy rainfall, earthquake-driven landslides, gullying and mass wasting processes occurring in the steep, friable geologic structure of the New Zealand fjords generate high sedimentation rates and resultant high carbon burial rates. This land-derived material is composed of a mixture of modern plant debris, soil mixtures of composite ages, and ancient rock.

Using ramped pyrolysis oxidation radiocarbon (RPO-AMS), lipid biomarker, pyrolysis-gas chromatography-mass spectrometry (Py-GC-MS), and compound specific radiocarbon (CSRA) analysis methods, we have developed a chemical composition fingerprint of buried carbon preserved in surface sediments at the head and mouth of Tamatea Dusky Sound, Patea Doubtful Sound, and Isthmus Sound within Rakituma Preservation Inlet. Biomarkers and CSRA isolate individual compounds to inform the age, provenance, and chemical composition of the sequestered carbon, providing specific, detailed information about a few key compounds in the sediment matrix. RPO-AMS and Py-GC-MS complement this by partitioning carbon thermochemically, determining the age and stability of all compound classes present in the sediment, giving a more holistic representation of the sequestered carbon. This characterisation of organic carbon composition in three unique fjord settings allows us to gain insight into the processes that drive the transport and sequestration of carbon into the sediment.

Education of the next generation of geotechnical engineering and engineering geology professionals in New Zealand

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Recent developments in the geotechnical industry in Australia and New Zealand have highlighted challenges related to the education of geotechnical engineers and engineering geologists, industry expectations of university graduates, and a workforce shortage.

In response to these developments and concerns, the Australian Geomechanics Society (AGS) and the New Zealand Geotechnical Society (NZGS) held a panel discussion at the Australia and New Zealand Conference on Geomechanics in Cairns, which aimed to understand the perspectives of different stakeholders and to formulate a plan forward. The panel included a young geotechnical professional (YGP), an industry representative and an academic from both Australia and New Zealand. During the panel discussion the fundamental question was posed: Is geotechnical engineering/engineering geology education and training meeting the needs of graduates and the industry? The panel discussion saw strong engagement from the audience.

Following the successful and engaging panel discussion in Cairns, the NZGS committed to continuing this project in collaboration with the AGS. A roadshow was subsequently organised with the panel discussions held in Wellington, Christchurch and Auckland to research the opinions on the state of geo-education in New Zealand. The panel for these discussions consisted of two academics, an industry representative, and a YGP. The discussions were aimed to capture the views on the current state of geo-education, as well as suggestions for future improvements, from a wide range of people including those working in the field and stakeholders working with people in our field.

This presentation will focus on the research completed leading up to the Cairns conference, key findings from the four panel discussions completed to date, and the planned next steps. While the discussions to date have been focused on the geotechnical engineering and engineering geology fields, similar issues may apply to other earth science disciplines, and similar debates may be stimulated.

Geological model of South Dunedin, New Zealand: Understanding local coastal change

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South Dunedin is a densely developed urban area built on low-lying, partly reclaimed tidal mudflats, salt marshes and sand dunes at the head of Otago Harbour. A ground elevation typically less than 2 m above sea level means groundwater is close to the surface, making the area susceptible to flooding, which is expected to be exacerbated by climate change. Using recent and historical subsurface investigations and geophysical surveys, an interpretive three-dimensional (3D) model of the subsurface geology has been developed. Bedrock beneath South Dunedin comprises Miocene-age strata of the shallow marine Caversham Sandstone in places overlain by volcanic rock (Dunedin Volcanic Group). Quaternary-age sediments overlie an irregular erosion surface (St Clair channel) cut across the bedrock to a depth of as much 60 m or more below sea level. The erosion surface is a former river valley floor that drained generally southeast through the South Dunedin area most likely formed in the late Pleistocene during glacial periods and infilled before the most recent sea level lowstand. Variations in the character of the Quaternary sediments, together with radiocarbon dating and paleo-environmental analyses using microfossils, provides a basis for differentiating older Pleistocene valley-fill sediments from overlying Holocene marginal marine sediments. The Holocene sediments are concentrated in the inferred St Kilda channel further east incised into the Pleistocene sediments during the most recent sea level lowstand, and was drowned, and subsequently infilled with sediment up to 25 m deep during the latter stages of the post-glacial sea level rise. The 3D geological model is intended to inform future modelling of the impacts of sea-level rise scenarios on groundwater and flooding and other engineering or planning initiatives.

Mapping the contemporary active channel evolution of braided rivers in New Zealand

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New Zealand's braided rivers are known for their dynamic nature, which is shaped by both current and historical river channels. The active channel consists of braided channels, clean gravels, low islands, and river margins that get inundated during floods. It is important to understand that this active channel is part of the larger braid plain and shifts within it over time. In our study, we utilised a comprehensive approach to analyse the changes in the contemporary active channel of braided rivers in New Zealand by using optical and radar imagery spanning the last 30 years. Through this approach, we produced frequency maps of occupancy and developed longitudinal graphs to effectively document and analyse the evolving dynamics of these river systems. We aimed to understand how large braided rivers change over time by studying the variability in width of the active channel. Using satellite remote sensing time series, we were able to determine patterns of expansion and contraction related to different hydrological conditions and sediment transport dynamics. This analysis provided insights into the changes in the active channel width over time and helped us understand the overall evolution of the braid plain. Our findings highlight the delicate balance between disturbance and stabilisation processes, providing valuable insights into the constantly changing mosaic of habitats within these river systems. This research offers significant contributions to fluvial geomorphology and has the potential to inform conservation and management strategies for riverine ecosystems.

Geophysical constraints on the seafloor geology of KIS3 drill site oceanward of the Kamb Ice Stream grounding line, Ross Ice Shelf, Antarctica

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The seafloor stratigraphy underlying the Ross Ice Shelf in the vicinity of the Kamb Ice Stream grounding line plays an important role in evaluating past advances and retreats of grounded ice in West Antarctica through the Quaternary. This region is critical for assessments of the stability of the West Antarctic Ice Sheet and is an ongoing focus for research efforts that involve melting through the ice shelf and recovering sediments from beneath the seafloor. Seismic (and to a lesser extent gravity) methods have played a critical role in assessing a possible stratigraphic framework for these sediments. Approximately 73 km of seismic data were collected in this region during three seasons since early 2015, complemented by finely sampled gravity transects and a coarser regional gravity grid. These data provide higher-resolution information on sub-ice geology in a region where ROSETTA-Ice airborne-gravity data identified a gravity low. Seismic acquisition parameters have varied from survey to survey, but all involve explosive charges frozen into hot-water-drilled holes that are recorded by conventional surface-deployed geophones. Processed seismic data show at least 200 m of sub-horizontally layered seafloor units underlying the ocean cavity containing mappable unconformities that are identified as distinct reflective horizons in the seismic data, as well as reflection terminations and pinchouts in overlying and underlying units. These unconformities could correspond to past glacial erosion episodes as the position of the grounding line in this region has migrated landward and oceanward. Gravity modelling suggests that the thickness of the sedimentary basin in the region is variable – beyond what we see in the upper few hundred metres of the seafloor.

Exploring Pleistocene warm periods through carbonate-rich continental margin sediment in offshore Patagonia

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Understanding the nature of millennial-scale climate change on a regional level is a necessary step in understanding the drivers of climatic change globally. The Antarctic Circumpolar Current (ACC) is a major influence on climate in the Southern Hemisphere. During the Pleistocene, the narrowest extent of the ACC was proximal to the Patagonian Ice Sheet in southern South America. Consequently, sediments from the Chilean continental margin may preserve sensitive records of regional interactions between the ACC and glacial-interglacial cycles in the eastern South Pacific.

Paleoclimate records from offshore Patagonia have been limited in the past by low deposition rates, erosional processes, and relatively short temporal scales. Here we present a profile of lithologic facies in sediment core collected from the upper continental slope of the southernmost Chilean margin by IODP Expedition 383 in 2019. The 249 m composite core has an average deposition rate of >30 cm/ka and offers a temporal record of sediment deposition in the region potentially ten times longer than previous studies (±700 ka). The core contains several carbonate-rich facies correlated via biostratigraphy to several significant periods of Pleistocene warming, notably marine isotope stage (MIS) 11 (424-374 ka). By examining these interglacial sediments and their surrounding units in detail, we aim to gauge past changes in current speeds and sedimentation on the Chilean margin as the climate cycled through glacial and interglacial conditions.

These facies were constructed through detailed core logging using x-ray and image data of the core. Laser diffraction particle size analysis of detrital sediment allows estimates of current velocities and ice proximity to be made. Correlation with existing geophysical data, as well as stable carbon isotope data, strengthens these conclusions.

Chimaeroids to *Carcharodon*: Ewan Fordyce's contributions to expanding the New Zealand fossil record of chondrichthyans and bony fishes

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Recent decades have seen great advancements in our knowledge of fossil marine vertebrates from New Zealand, in large part a legacy of Ewan Fordyce's extraordinary career and the many students he mentored. While particularly noted for his research on marine mammals and penguins, Fordyce's interests were varied and encompassed other groups across a broad span of geologic time. His contributions, which this author was privileged to collaborate on, include important additions to the New Zealand record of Mesozoic and Cenozoic chondrichthyans and bony fishes. Among the discoveries we reported are the first basal 'palaeoniscoid'-grade actinopterygian from New Zealand (Early Triassic), and a Late Triassic chimaeroid egg capsule that indicates chimaeroids reached southern Gondwana ~100 million years earlier than previously realised – and employed a reproductive mode identical to that of their living relatives. A new tarpon-like elopomorph teleost from the Paleogene of Pitt Island (Rēkohu Chatham Islands) preserves spectacular 3D morphological detail, and is the most complete fossil elopomorph recovered from the Southern Hemisphere. The Oligocene limestone country on the South Island, well-known for cetacean and penguin fossils, has also yielded important shark finds – the most impressive being an associated specimen (165 teeth and 32 vertebral centra) of the 'megatoothed' lamnid shark *Carcharodon* (= *Carcharocles*) *angustidens*. Oligocene teleosts represented include a new genus and species (*Megalampris keyesi*) of giant lampridiform ('moonfish') with a total length of ~4 m – twice the size of extant *Lampris*, and the first fossil lampridiform reported from the Southern Hemisphere. Finally, a new morphologically distinctive xiphioid billfish (*Aglyptorhynchus hakataramea*) is clearly placed within an otherwise exclusively Northern Hemisphere fossil billfish genus. Taken together these records span over 200 million years and encompass considerable systematic diversity. They exemplify the fundamental nature of Ewan Fordyce's scientific contributions and are a notable part of his remarkable legacy.

A Pliocene boxfish (Tetraodontiformes, Ostraciidae) from New Zealand – a harbinger of near-future environmental change?

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We report on an articulated fossil boxfish (Tetraodontiformes, Ostraciidae) collected recently from the Pliocene of the North Island of New Zealand, which represents the first Southern Hemisphere fossil occurrence of the group. The specimen was recovered from the mid-Pliocene (c.3.0-3.4 Ma) Tangahoe Formation in South Taranaki, which has produced a diverse marine vertebrate fauna including cetaceans, seals, penguins, seabirds, bony fishes and sharks. The fossil boxfish is preserved in right lateral view and including the caudal fin (which is not preserved) would have measured c.13-14 cm in total length. The covering of tightly connected hexagonal to sub-hexagonal hydroxyapatite plates is nearly intact and rigidly encases the body, as is characteristic of boxfishes. The configuration of the plates and the dorsal and ventral spines along the body, and the rectangular cross-sectional shape of the 'box,' suggest that the specimen is assignable to the extant Indo-Pacific genus *Tetrosomus*, which occurs today in tropical Australian waters. Recent reports from divers note that boxfish and several other tropical Pacific fish species are now being seen in northern New Zealand waters – the Pliocene boxfish thus reflects likely near-future environmental change as continued ocean warming reverts New Zealand back to 'warm world' conditions more like those that prevailed during the Pliocene.

Improving earthquake forecasting in New Zealand: The development and implementation of the Hybrid Forecast Tool (HFT)

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Earthquake forecasting is crucial for estimating the likelihood of seismic activity within specific regions over designated timeframes, leveraging historical data and patterns from past events. In New Zealand, the GeoNet programme within GNS Science has been the principal source of geological hazard information, providing earthquake forecasts publicly since the Darfield earthquake in September 2010. Traditionally, generating and updating these forecasts have demanded significant time and expertise from specialists. To address the growing need for efficiency and reduce dependency on manual input, a robust software solution, known as the Hybrid Forecast Tool (HFT), has been developed. The HFT integrates various forecasting models that span multiple timescales: short-term (ranging from a few hours to several years, based on aftershock decay patterns), medium-term (from years to decades, reflecting increased seismic activity before major earthquakes), and long-term (covering decades to centuries, using data on fault slip rates, spatial distribution of earthquakes, and geodetic strain rates). These models, initially developed in different programming languages such as Fortran, Java, and R, and on separate operating systems, are now unified within a single platform using a Docker container. This approach overcomes software library compatibility issues and streamlines integration. The HFT features a graphical user interface (GUI) and a command-line interface, facilitating user-friendly configuration of automatic and periodic forecast runs. This integration enhances GNS Science's capability to deliver timely and consistent forecasts, thereby improving responses to significant seismic events and advancing New Zealand's progress toward automated earthquake forecasting. Although tailored for New Zealand, the HFT’s framework, implementation, and containerisation strategy also offer potential benefits for earthquake forecasting efforts in other regions.

Mineral resource estimation for gold mining at Macraes mining area, Hyde-Macraes Shear Zone, Otago, New Zealand

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Mineral resource estimation is an essential stage of any mining project and is where a geological model and assay samples are combined to provide a quantitative representation and distribution of tonnes and grade used for mine design and production scheduling.

Resource estimation at Macraes utilises a range of methods that vary based on style of mineralisation and mining method.

Open pit mining utilises large panel (25 x 25 x 2.5 m) recoverable resource estimation using Multiple Indicator Kriging (MIK). This technique provides a reliable estimate of minable resource within the open pits, with higher resolution grade-control block models at 5 x 5 x 2.5 m scale used for ore/waste delineation on the pit floor.

Where the resource is to be mined using underground methods, the spatial location of the mineable ore needs to be defined in advance of mine development. The accuracy of the geological model is crucial in providing this and identifying those mineralised domains with continuity between drill holes is a key step in the estimation process. Disruption to continuity by post-mineralisation faulting presents challenges to accurately showing the ore location and modelling methods used for the underground mines need to reflect this.

This presentation will outline the range of resource estimation methods used at Macraes and the importance of geological data to the final outcome.

Structural reinterpretation of the McKee field using a thrust-fault growth and linkage model

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The McKee field in the Taranaki Basin has been an energy resource for ~40 years. Initially developed as an oil field, it now provides natural gas to support New Zealand's energy demand.

The McKee field is contained within a thin-skinned thrust block of McKee Formation. The deformation was caused by Oligocene to Miocene compression on the crustal scale Taranaki Fault to the east, resulting from the evolving Australia-Pacific plate boundary and onset of Hikurangi margin subduction. The late Eocene McKee Formation has been transported several kilometres westward on decollements within upper Mangahewa Formation coals, and then uplifted several hundred metres on the Tarata Thrust fault ramp to form the McKee structure.

Development of McKee has been challenging due to its complex structure and poor seismic imaging. We have reinterpreted the field using newly reprocessed seismic and dip data from well logs. New observations include 1) the inconsistency between Tikorangi and the McKee Formation dips seen on seismic and well data, 2) varying thickness of Otaraoa Formation along strike, and 3) variation in structural relief. To explain these observations a model of thrust fault growth through segment linkage has been adopted, rather than a single fault plane interpretation.

The structuration is now interpreted to represent an evolution of deformation whereby smaller thrust faults coalesced to create a larger composite fault system. Observations suggest that thin-skinned deformation was initially accommodated on a series of smaller thrusts in the early Oligocene. By early Miocene these were connected, first through soft linkage and then hard linkage, and coalesced to form the Tarata Thrust.

This conceptual model is analogous to other studies of thrust fault development and helps characterise spatial variation in dynamic field behaviour: the initial thrust fault segments now bound distinct production regions of the field: the Tuhua, Pouri, Central McKee, and Toetoe blocks.

Rediscovering and cataloguing previously undocumented Otago and Southland earthquakes, 1855-1929

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Historical earthquakes are often overlooked as a source of information about the seismicity of Aotearoa New Zealand. Over the last 60 years historical seismology research has primarily focused on the most significantly damaging earthquakes since organised European settlement commenced in the 1840s. Although this approach is logical from a seismic hazard perspective, it has resulted in a sporadic historical earthquake catalogue, with entire years lacking any catalogued seismicity as late as the 1920s.

The Otago and Southland regions have been particularly neglected in historical seismology research. The earliest earthquake recorded in the National Earthquake Information Database for these regions occurred in 1876 – about 30 years after the beginning of European settlement – and records are only complete after about 1942. Yet these two regions have experienced some of the largest earthquakes to strike Aotearoa New Zealand since European settlement, including the Mw7.1 1938 Charles Sound earthquake, the Mw7.2 2003 Fiordland earthquake, and the Mw7.8 2009 Dusky Sound earthquake.

We have used newspaper articles between 1846 and 1929 from the National Library of New Zealand, and contemporary felt reports from GNS Science's archive, to document approximately 75 years of forgotten earthquakes in Otago and Southland. Our initial study demonstrates the potential to expand the historical record of large (M≤7.2) and damaging (MM VII+) earthquakes, although defining the seismic parameters through macroseismic studies for these earthquakes poses a significant challenge. It is hoped that further work, for Otago, Southland, and other regions, will enable a substantial expansion of the existing National Earthquake Information Database, assisting future evaluations and revisions of existing seismic hazard assessments.

Database development for volcanic tsunami threat levels

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When the Hunga Tonga-Hunga Ha'apai (HTHH) volcano in Tonga erupted in January 2022, it generated a tsunami that reached the New Zealand coast. At that time, no precomputed volcanic tsunami scenario was readily available to assist with the tsunami response. The Tsunami Experts Panel (TEP) relied on expert judgements from observed tsunami data from DART buoys together with existing tsunamigenic earthquake scenarios to assess the potential threat of the HTHH tsunami to New Zealand. In this work, we developed a database that provides tsunami threat levels (e.g. no threat, beach and marine threat, and land threat) from a limited number of volcanic tsunami source scenarios for 28 volcanoes located in New Zealand and the Kermadec Ridge south of 25°S. During a volcanic eruption, multiple tsunami source mechanisms can occur. They can be categorised into two main groups: (1) localised sources such as underwater explosions, pyroclastic flows, caldera collapses, volcanic earthquakes, and flank failures/landslides; (2) continuously propagating sources such as atmospheric Lamb waves. Our focus was on localised source mechanisms to evaluate tsunami threats from the selected volcanoes for this source type. The simulation results were used to make tsunami threat level maps, tsunami travel time estimates, and waveform plots at coastal gauges and offshore DART (Deep-ocean Assessment and Reporting of Tsunamis) stations. The maps, plots, and estimates produced in this study were designed to enhance the capability of TEP members and the National Geohazards Monitoring Centre (NGMC) in responding to future volcanic tsunami events. Real-time monitoring from the seismic and sea-level networks is another key component for mitigating tsunami hazards. The data is used alongside the pre-computed results for the tsunami threat level assessments and to issue timely warnings.

Investigating greywacke fault zone architecture of the central Southern Alps of New Zealand

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Across typical greywacke fault zones in New Zealand, tectonic deformation has produced highly deformed bedrock with variable physical properties. Continental collision between the Australian and Pacific plates has produced the Southern Alps orogen. The Alpine Fault is the major structure in the region and current estimates suggest that it is responsible for accommodating up to 75% of relative plate motion. However, potentially active faults east of the central Alpine Fault control the location of the highest peaks found in the Southern Alps. The mountainous terrain here receives high levels of precipitation, and when paired with high rates of uplift, an actively evolving landscape is produced. This results in excellent exposures of exhumed fault zones that are typically found at seismogenic depths.

Field work conducted on such exposures of the Liebig and Ostler-Great Groove faults revealed fault cores with abundant calcite veins and ultracataclasite-filled transpressional faults. To document the elastic properties of the rocks comprising the fault zones, we collected field samples of Rakaia Terrane greywacke sandstone, siltstone and cataclasite. These samples were combined with Rakaia Terrane samples in a reference set previously collected around the Wellington and the central Southern Alps regions. Our research documents the results of field mapping of hanging wall bedding, footwall bedding, and principle slip zone orientations and measurements of the samples' elastic wave properties. Initial bench top measurements yielded mean P-wave speeds of 5.1 ± 0.530 km/s in sandstone and 5.3 ± 0.450 km/s in siltstone. These results will inform a numerical model of the behaviour of elastic waves in a representative greywacke fault zone where bedding orientations are parallel or oblique to fault zone orientations. This work aims to provide the fundamental geophysical and geological data needed to better investigate and understand complex faulting in greywacke bedrock across Aotearoa New Zealand.

High-resolution seismic imaging and stratigraphic analysis of the Discovery Deep Basin: Implications for climate records and basin geodynamics beneath the Ross Ice Shelf, Antarctica

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The Discovery Deep Basin is the deepest basin underlying the Ross Ice Shelf (RIS), Antarctica. Recovery of sediment cores at this location could yield records that are essential for enhancing climate change models since the Last Glacial Maximum (LGM). We present the results of an explosive-source seismic exploration of the basin in the summer of 2023/24, with the primary objectives of identifying the basin's deepest point, assessing the presence of high-resolution sediment build-up, and elucidating the subsurface structure and stratigraphy. Surface-detonated Cordtex detonating cord sources (10 m lengths at 10 g/m) and a 300 m long 96-geophone snow streamer was used to record reflecting and refracting seismic waves, which are processed into seismic images in GLOBE Claritas. Faulted, glacially carved, unconformably lying sediment cover is identified at a site with a maximum depth of 1650 m, and is characterised by well-preserved, thick sediment layers. The identified stratigraphy and sediment accumulation offer insight into past oceanic and climatic conditions which show how the ice sheet has recovered since the LGM, but also the geological processes that have shaped this region, including glacial, tectonic, and oceanic influence. Given the depth and substantial sediment accumulation, this site may offer the highest resolution climate record in Antarctica. Furthermore, our study provides a critical bathymetric tie for the ROSETTA model presented by Tinto et al. (2019) and Tankersley et al. (2022) by confirming a greater basin depth than previously modelled and relocating the deepest point of Discovery Deep towards the northwest. These findings will contribute to an improved understanding of RIS basin geodynamics, ice sheet stability, ocean currents, and tectonic activity and emphasise the importance of future exploration drilling to refine our knowledge of past climate conditions.

Scoring the FAIRness of GeoNet's Data in 2024: Lessons learnt and progress made since 2021, and how to cite GeoNet data

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The FAIR data principles are based on the primary importance of data and datasets being Findable, Accessible, Interoperable and Reusable (FAIR). Taken together, these principles enshrine what good, modern data custodianship should be, and they have been widely incorporated across scientific practices. GNS Science, its Nationally Significant Collections and Databases (NSCD) and GeoNet are committed to achieving FAIR implementation, and a key indicator is assessing and scoring how FAIR data is. To that end, GeoNet and overlapping NSCD datasets have been scored in 2021 and in 2024 using an Australian Research Data Commons scheme. Those scores are presented, and compared to elucidate key trends.

Evidence of progress can be seen in quite a few datasets, and minting DOIs, using web-based csv data dissemination, and TILDE have improved FAIR scores. For example, now converted and publicly available as a csv (from reports), the eruption history database has boosted its FAIR scores across the board (FAIR2021 = 50%, FAIR2024 = 72%). Others show large steps forward in Findability through the addition of a dataset DOI, like our acoustic dataset (F2021 = 50%, F2024 =100%). Thirdly, the development and implementation of TILDE has raised the Accessibility, Interoperability and Reusability of several datasets, largely through its modern Application Programming Interface and use of open dataset formats, which enhances machine usability of that data. Some datasets, however, appear to be plateauing in terms of FAIRness. Additionally, having DOIs for datasets has led to a revolution in how GeoNet data should be cited.

FAIR scores were used in 2021, and will be once more in 2024, to highlight areas of improvement for GeoNet data. We'd also be keen to hear from users of our data what their suggestions are to keep moving in a 'FAIR'-er direction; potentially exploring other data principles.

Accumulation at Patriot Hills, West Antarctica, over the last half century

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The Ellsworth Mountains lie proximal to the grounding line of the Filchner-Ronne Ice Shelf, an area of the West Antarctic considered vulnerable to future ocean-warming induced mass loss. Caught between the Weddell and Amundsen-Bellingshausen seas, the mountains currently appear to exhibit East Antarctic-like climate despite being situated at the base of the Weddell Sea Embayment. Records from nearby ice cores offer a means to reconstruct regional accumulation, temperature and elevation history into the past, providing critical context needed to anticipate future change. Modern firn records covering the satellite era allow for direct interrogation of the sub- and interannual climate processes that influence regional temperature and accumulation, and the preservation of these parameters in longer ice records.

We report a 47-year record of accumulation from Patriot Hills at the southern edge of the Ellsworth Mountains. Our record is derived from a pair of firn cores that together cover the full length of the satellite record up to 2022. Stable water isotopes (δ^2H, $\delta^{18}O$) and major ion chemistry are used to provide chronological control. We additionally reconstruct a parallel modelled atmospheric transport history for the site using a suite of continuous trajectory model runs. What climatic modes, if any, exert an influence on the southern Ellsworth Mountains? Is the apparent stability in the region linked to climate dynamics that may change in future?

Modelling coseismic landslide impacts on infrastructure system in Wellington

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The proximity of the Greater Wellington Region (GWR) to numerous active faults poses a sizeable earthquake hazard that has implications for the whole of Aotearoa New Zealand. While the seismic hazard is relatively well-studied, the cascading hazards, particularly landslides, are less well understood. How landslide impacts might vary across a range of scenarios is a critical question in a region with such high seismic hazard. This study assesses the variability in coseismic landslide hazard and resulting impacts in the GWR for a plausible earthquake scenario ensemble. We use a statistical landslide model, applying fuzzy logic within GIS to determine landslide hazard. This empirical model applies conditioning factors of landslides and shaking intensity data to determine landslide hazard, which we apply to ten earthquake scenarios across the GWR. We then assess the exposure of the road network to landsliding across the earthquake scenario ensemble, to assess potential disruption to key routes and emergency water access, and how this might vary between earthquake events.

Our results show that maximum hazard values varied between 0.97 and 0.71 across the ensemble, with the highest values observed in ruptures of the Hikurangi, Ohariu, Wellington, and Wairarapa faults. High disruption values on State Highway 2 from Ngauranga to Petone and between Māhina and Days Bays were observed in eight of the ten scenarios. Plausible disruption was observed for 19 of the 21 posited Community Water Stations, with high disruption in Days Bay, Huntleigh Park and Karori. This work shows the importance of utilising earthquake scenario ensembles to assess variability in the range of plausible impacts of seismic events. Identifying impacts which occur irrespective of the earthquake scenario allows for consideration of comprehensive mitigation strategies in key areas. Bespoke approaches for scenario-specific impacts can also be implemented more equitably, with greater appreciation of specific versus holistic coseismic impacts.

New Zealand's earliest geological maps and the argument they generated between Hochstetter and Heaphy

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The earliest 'geological' maps in New Zealand were simple outlines with comments on the presence of certain rock types written on them. Two pre-1860 unpublished maps have recently been located that we claim are the earliest New Zealand geological maps. Both maps have coloured areas corresponding to the outcrop of different rock types and both have the same title 'Sketch of the geological formation of the Auckland District'. The earliest, dated 1857, annotated in brackets 'corrected up to February 1859', was made by Charles Heaphy and presented to the Auckland Mechanics' Institute on 9 February 1857. This newly discovered map is in the library of the Geological Society of London having been sent by Heaphy in 1859 to accompany his manuscript on the volcanic geology of Auckland. A black and white lithograph of the central portion of this map was published with his article in the QJGSL in 1860.

The second map was made by Ferdinand Hochstetter based on his fieldwork in early 1859 and was drafted by William Boulton in the Auckland Survey Office. This map was left in Auckland in July 1859 for the use of the Provincial Council and is now held in the Auckland Museum. Hochstetter's recently-translated diary and other documents indicate that soon after arriving in Auckland Hochstetter borrowed Heaphy's map from the Mechanics' Institute wall and traced it as a guide for his fieldwork.

Hochstetter was angered by Heaphy's submission of his 1857 (1859) map to London for publication, and in a fit of pique wrote "The map … by Heaphy … is a very incomplete copy of my observations and maps ... that gentleman introduced his own observations …, but without possessing even the most elementary knowledge necessary for making a geological survey." (Hochstetter and Petermann, Geology of New Zealand, 1864).

Magmatic processes and the obsidians of Tūhua (Mayor Island)

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Tūhua (Mayor Island) is New Zealand's only active pantellerite volcano and is offset ~80 km westward of the Taupō Volcanic Zone. Tūhua's volcanic deposits are dominated by a mixture of obsidian and pumice, which suggests a series of transitions between apparently effusive and clearly explosive behaviours that include significant caldera-forming Plinian events. The mechanism controlling this variation in eruptive style remain enigmatic. Investigation of the bulk chemistry of the deposits suggests they are all a similar composition, hence other variables must be more important. These could be related to volatile and crystal content of the magma, but more subtle differences might also create divergent behaviour. One such variable could be the oxidation state of iron in the melt, exerting an important control on melt viscosity and the formation of nanolites. These might be very dynamic variables and, therefore, difficult to identify in the preserved rock record.

One striking feature of the obsidian is the variety of colours found in the field. Here, we piece together textural and analytical observations on obsidians from Tūhua and further afield, to explain what might contribute to their characteristic appearance. Experiments are used to test the effect of oxidation state and cooling rate, in an attempt to reproduce synthetic natural obsidians. This information is essential to understand the magmatic/shallow conduit processes governing changes in Tūhua's eruption styles.

3-D inversion of long period magnetotelluric measurements in Northland and Southland, New Zealand

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Long period magnetotelluric (MT) measurements have been acquired in the Northland and Southland regions of New Zealand within the framework of the 'Solar Tsunamis' project to study geomagnetically induced currents. The surveys consist of 62 measurements in Southland and 53 measurements in Northland with an approximately 25 km site spacing.

Phase tensor maps in both areas show that data is good quality and can be used for 3-D inversion from 20 s to 10000 s. 3-D inverse modelling of the data has been carried out using the finite element code FEMTIC, incorporating topography and bathymetry.

First results in Southland show the thick and very resistive crust and upper mantle being most resistive in the Fiordland area. A deeper conductor is seen at 120 km depth shallowing to 80 km in the north-westernmost part of the survey below the area where seismic tomography detected the edge of the subducted Hikurangi plateau. In the shallow part of the model, the thick sediments of the Moonlight tectonic zone can be clearly seen in the model. The Dun Mountain Ophiolite belt is seen as a resistive feature.

In Northland, a conductor exists at 40 km depth in the northern part deepening to the south. This conductor is shallowest where the Northland basaltic fields and the Ngawha geothermal field is located.

Enhancing geophysical monitoring through low-cost ground-based GNSS-Reflectometry technology

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The Global Navigation Satellite System (GNSS) is used in today's positioning, navigation, and timing. GNSS signals scatter and reflect off the surfaces, creating noise due to aliasing. This noise, commonly known as multipath, cannot be completely removed but can only be mitigated through an optimal stochastic model. However, this noise, recorded as signal-to-noise ratio (SNR), carries valuable information about the reflective surfaces. By utilising the SNR, remote sensing techniques like GNSS-Reflectometry (GNSS-R) can be used to monitor and analyse various geophysical parameters such as soil moisture, water levels (in lakes or seas), and snow depth. First proposed by Katzberg and Garrison in 1996 and further demonstrated from an aircraft in 1998, GNSS-R has expanded from airborne and spaceborne platforms to ground-based platforms. One notable ground-based technique developed in the past 15 years is GNSS Interferometric Reflectometry (GNSS-IR). Recent improvements in algorithms for multipath extraction from standard geodetic GNSS antennas have made it possible to apply GNSS-IR to various geophysical studies, producing results comparable to conventional measurement techniques. For example, analysis techniques such as Lomb-Scargle periodogram, wavelet analysis, inverse methods and parametric models like cubic and quadratic analysis are used to retrieve measurements from the SNR. With the availability of low-cost GNSS antennas in affordable receivers and smartphones that have poorer multipath suppression, a new opportunity is presented to retrieve the SNR for ground-based GNSS-R. This study focuses on the analysis of the SNR data using low-cost antennas and receivers, including smartphones and uBlox receivers. By utilising these technologies, this research has the potential of providing an alternative and ubiquitous approach to geophysical and environmental monitoring, making advanced remote sensing more accessible.

Glacial-interglacial uranium isotope systematics of coccolithophore from the Southern Ocean: New insights for ocean temperature, pH, carbonate ion concentration and redox reconstructions

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Marine carbonate sedimentary records of uranium (U) concentration (U/Ca) and isotopic composition ($^{238}U/^{235}U$) have been applied as proxies of ocean temperature, carbonate ion concentration (or pH), and oxygenation in order to reconstruct past ocean biogeochemistry. These reconstructions are crucial for deconvolving interactions between the ocean-atmosphere system and global climate through geologic time, from the Cambrian climate events early in Earth's history to the glacial-interglacial cycles of the last 2 million years. However, different carbonate archives (eg. surface ocean coccolithophore, foraminifera and corals) give conflicting U/Ca results. Moreover, the U isotope ratio of surface ocean carbonate has been applied almost exclusively as a paleo-redox tracer; however, there is growing evidence that other factors such as environmental conditions, variable deposition of carbonate polymorphs, and post-depositional alteration could play a role in fractionating the U isotope system. We present coccolithophore-based records of U concentration and U isotopic composition for the last 32 ka in the Southern Ocean that spans the glacial conditions of Marine Isotope Stage (MIS) 3 and the Last Glacial Maximum, rapid climate warming through the last deglaciation, and the Holocene interglacial warm period. This period records substantial temperature change and CO_2 concentration variations in the atmosphere and the ocean, but stable and well-oxygenated ocean redox conditions. Coccolithophore are unique amongst calcifying organisms, as they secrete their carbonate shell (coccolith) intracellularly, which involves physiological control of parameters, such as pH and carbonate ion concentration. Our new records show elemental and isotopic fractionation of U, and have implications for the use of U/Ca as a robust paleotemperature proxy and $^{238}U/^{235}U$ as a paleo-redox tracer, so far thought to be independent of biological processes during carbonate formation from seawater.

Linking the biological pump and CO_2 drawdown in the Southern Ocean: Diatoms as a recorder of surface ocean trace metal micronutrients

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The expansive Southern Ocean controls global climate by drawing down atmospheric carbon dioxide (CO_2) into the ocean's interior via primary production within the so-called 'biological pump'. The efficiency of this process is limited by trace metal micronutrients such as iron (Fe), zinc (Zn) and cadmium (Cd), but future climate projections are constrained by past-climate records based on traditional macronutrient tracers (nitrate and phosphate) that are not ideally suited to the High Nutrient Low Chlorophyll Southern Ocean. Therefore, sedimentary records of trace metal micronutrient tracers are needed to reliably reconstruct the efficiency of the past biological pump and improve the predictive performance of future-climate projections. South of the subtropical zone, diatoms dominate the sediment and provide a record of surface Southern Ocean biogeochemistry (e.g. nutrient regime, temperature, ocean circulation). In this study, a protocol was developed to extract diatoms from sediment for precise Fe, Zn and Cd isotopic measurement. This protocol has been applied to core top sediments spanning the Southern Ocean from the Polar Front (55 to 60°S) to the Ross Sea to produce a latitudinal intercalibration that links the Fe, Zn and Cd isotope signatures of diatoms to those of the seawater in which they grew. Once calibrated to diatoms, these methods will be applied to two sediment cores from offshore Antarctica and around the Polar Front. These records will be used to understand how trace metal micronutrients have regulated marine primary productivity, the efficiency of the biological pump, and the ability of the Southern Ocean to regulate atmospheric CO_2 levels over the last glacial-interglacial cycle, with a focus on warming and cooling transitions, as well as the last interglacial period, which is considered to be a good analogue of current global warming caused by anthropogenic activity.

The GeoNet benchmark seismic dataset for AI

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The rapid advancement of artificial intelligence (AI) and machine learning (ML) in the past decade has ushered in new possibilities for seismic data analysis, particularly in the realms of earthquake detection and phase picking, and subsequent catalogue creation. A number of state-of-the-art ML earthquake detection and phase pickers such as PhaseNet and EQTransformer are readily available through the SeisBench toolbox for machine learning in seismology. These models are trained on benchmark datasets from international monitoring agencies (e.g. GEOFON, ETHZ).

Seismicity in Aotearoa New Zealand is variable and fundamentally different to other active regions due to the unique tectonic setting we are in. Therefore, using ML models trained using benchmark datasets from other regions would not allow us to realise the full potential of these ML earthquake detection and phase picking algorithms, hindering their implementation in routine earthquake monitoring. Developing a benchmark dataset for New Zealand would allow the training and benchmarking of the existing ML algorithms for the New Zealand setting and could be used by researchers for training novel ML models.

Here, we present a benchmarked seismic dataset to address this shortcoming, hosted and developed by GeoNet, to explore potential applications. Our dataset is based on the GeoNet earthquake catalogue and comprises a diverse collection of seismic records from earthquakes, volcanic events, landslides and covers a range of magnitudes, depths, and seismic noise conditions. It includes meticulously labelled P and S phases that have been verified through multiple quality control steps, providing a robust ground truth for training and evaluation of ML models. To facilitate AI research and development, the dataset is formatted for compatibility with SeisBench. We invite the community to explore the dataset, contribute to its expansion, and engage in collaborative efforts to push the boundaries of what AI can achieve in the field of seismology for New Zealand.

Geological assessment of underground hydrogen storage prospectivity, Taranaki Basin: A multi-criteria decision-making approach

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Seasonal underground hydrogen storage (UHS) in porous media provides an as yet untested method for storing surplus renewable energy and balancing our energy demands. This study, which forms part of the larger 'Pūhiko Nukutū: a green hydrogen geostorage battery in Taranaki' programme, investigates the technical suitability of sites for UHS in Taranaki Basin. Assessment of suitability for UHS was carried out based on open file geological data, and only accounts for geological factors (i.e. social, environmental and economic factors were not considered). Most assessed sites are depleted hydrocarbon fields, with one undeveloped discovery and one deep aquifer site also included.

Prospective sites were assessed using two approaches. A decision tree approach was first undertaken, providing a 'fast-track' method for identifying potential sites based on sites passing a series of criteria in sequence. Secondly, a decision matrix approach was used for ranking optimal sites, which assessed 18 relevant parameters, which were weighted and normalised to provide a numerical ranking. Based on expert elicitation, the most important factors to consider for UHS in Taranaki are storage capacity, reservoir depth, and parameters that affect hydrogen injectivity/withdrawal and containment. The quality of available data also has a large impact, and the relative ranking of sites could change with new data becoming available.

Results from both approaches suggest that Paleogene reservoirs from gas (or gas cap) fields provide the best option for demonstrating UHS in Taranaki Basin, and that New Zealand's projected 2050 hydrogen storage demand could be exceeded by developing one or two high ranking sites. Lower priority is assigned to finer grained, labile, clay-rich and heterolithic Miocene oil reservoirs, and to deep aquifers that have no proven hydrocarbon containment.

Detailed mapping of the structure and topology of a brittle-ductile fault swarm near Franz Josef Glacier, New Zealand

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We present detailed surface and structural models of a swarm of subparallel faults exposed in a glaciated outcrop near Franz Josef Glacier in New Zealand's Southern Alps. These faults in the hanging-wall Alpine Schist are inferred to have moved under brittle to ductile conditions when ~20 km deep and above the Alpine Fault. High-resolution outcrop imagery collected across the exposed rock outcrop has been modelled to create a digital surface model and orthophotograph with a ground sample distance of less than 1 mm. By employing field mapping to locate faults and measure structural orientations, we can combine the outcrop observations and the high-resolution digital surface model to precisely map the network of brittle-ductile faults displacing the Alpine Schist compositional layering. The detailed mapping allows us to investigate the topology, permeability, and mechanics of the fault swarm during its formation. These observations can be combined with recent field mapping where we have located the upper and lower boundaries of the fault array, to show that it formed as an isolated zone of semi-brittle deformation surrounded by more ductile crust.

The detailed field mapping also allowed us to compare geological observations with those identified from high-resolution digital outcrop data. We found that while digital imagery offers rapid and detailed data acquisition for rock outcrops, particularly in inaccessible areas, some field-observed features were not easily discernible in the digital datasets. Thus, combining high-resolution 'digital-twins' of outcrops with field observations, as demonstrated in this study, proves to be an effective hybrid mapping technique.

Linking oceanographic-driven sediment and organic carbon flux to geologic records in Antarctic submarine canyons

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Globally, submarine canyons are dynamic deep-sea settings that can be biodiversity hotspots and direct routes for water, sediment, and organic carbon transport to the deep ocean. Submarine canyons in Antarctica may play a key role in ocean circulation and future sea-level rise by serving as pathways for dense shelf-water cascading and warm water incursions. Such sites, however, are challenging environments for sample acquisition and seafloor imaging, with limited information available. Recent studies elsewhere have demonstrated the potential to quantify sediment and organic carbon transport in canyons, but they have yet to address dynamics in high latitude canyons. To date there have been no near-seafloor water column samples collected from Antarctic submarine canyons to aid in deciphering their role in global ocean sediment transport, and ecosystem functioning.

The deployment of an oceanographic mooring system in Wilson Canyon, on the edge of the western Ross Sea, provided a unique opportunity to acquire near-seafloor time-series oceanographic and sediment flux data over the course of a year (2022-23). Using these data, we aim to investigate linkages between sediment transport, lateral organic carbon fluxes and oceanographic processes. By correlating these data with regional oceanographic studies, we can draw some initial interpretations of the relative importance of oceanographic and sediment density flows in transporting and depositing sediment through Antarctic canyons. Furthermore, using sediment trap data paired with seafloor sediment cores, we will provide a preliminary quantification of the sediment and organic carbon fluxes within Wilson Canyon, which provide fuel for benthic ecosystems or are exported to the deep sea.

Plio-Pleistocene paleoceanographic changes in the southern North Island: Implications from strontium isotope ($^{87}Sr/^{86}Sr$) stratigraphy

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The application of strontium isotope ($^{87}Sr/^{86}Sr$) stratigraphy, along with paleotectonic reconstructions and paleontological assessment of molluscan faunal assemblages in late Pliocene-early Pleistocene sedimentary successions in the Wairarapa, Hawkes Bay, and Whanganui Basin has enabled the timing and distribution of changes in marine paleotemperatures to be resolved, and further tuning the timing of the requisite development of basin architecture in order to enable the influence of colder, deep-marine currents. Previously, it has been difficult to precisely date sequence-stratigraphic and tectonostratigraphic events in the late Pliocene-early Pleistocene sedimentary succession in New Zealand, which have proven notoriously difficult to date due to widespread shallow marine settings, coarse lithologies, and multiple unconformities. High-resolution dating of selected sequences has resolved integrated paleogeographic and oceanographic changes, made possible through the application of $^{87}Sr/^{86}Sr$ isotope stratigraphy on marine carbonates, and supported through corresponding tephrochronological data.

This study largely focuses on the Nukumaruan boundary succession (c. 2.46 Ma) and adjacent strata spanning Marine Isotope Stages MIS 96-102, with $^{87}Sr/^{86}Sr$ isotope stratigraphy applied to date significant unconformities and facies transitions. Additionally, these data identify the timing of the first occurrence of *Psychrochlamys delicatula*, notable as a cold-water index species. Importantly, the first occurrence (FO) of *Ps. delicatula* was assumed to be coeval across the East Coast and Whanganui basins, however $^{87}Sr/^{86}Sr$ isotope stratigraphy, detailed age models, and comparison with the Old West Road Nukumaruan type section in the Whanganui Basin confirm the FO of *Ps. delicatula* occurs as discrete events between basins, with marine water temperatures, rather than time, being the ultimate control on the occurrence of *Ps. delicatula* assemblages. This in turn, has significant implications for the identification of, timing, and distribution of cold-water currents, and in conjunction with stratigraphic, sedimentological, and paleontological data, provides insight into the development of basin architecture.

Climate of the tropical South Pacific during the Last Glacial Period: Insights from the speleothem archives

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The South Pacific Convergence Zone (SPCZ) is the largest feature of Southern Hemisphere atmospheric circulation. Its size and position control the distribution of rainfall across a large area of the tropical South Pacific. Modern satellite and instrumental records show that the SPCZ responds to seasonal and interannual climate variations by migrating as a continuous linear feature. Pacific island nations depend on rainfall for fresh water, and a persistent shift in the position of the SPCZ will have profound effects on the long-term viability of those nations. The modern record gives little insight into how the SPCZ might respond to rapid global scale climate perturbations such as global warming.

We can look to the past for insight into how the SPCZ might respond to the rapid climate change that we see today. Ice core records from both the Northern and Southern hemispheres show periods of rapid warming during the Last Glacial Period.

Speleothems are known as the ice cores of the tropics because of their ability to preserve high-resolution climate records over long time periods. Here we present a series of coeval speleothem paleoclimate records for the Last Glacial Period from Niue, the Cook Islands and French Polynesia that make up a zonal transect spanning over 2000 km. This transect is ideally placed to capture the dynamics of the SPCZ, and these new records reveal changes in rainfall that are synchronous with rapid warming in the Northern Hemisphere. Furthermore, the spatial distribution of these changes in rainfall suggests that the response of the SPCZ to rapid global climate perturbations may be more complicated than previously thought.

Conduit establishment and evolution at Taranaki Mounga

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Volcanic conduits play an important role in modulating eruption dynamics by influencing outgassing of ascending magma and the density of eruption plumes. Inhibiting outgassing of magma during ascent promotes explosivity. Increasing the density of plumes through conduit wall erosion increases the likelihood of plume collapse and pyroclastic density current generation. Here, we combine textural and physical property data with componentry analysis and field relationships to describe the initial structure and subsequent evolution of the shallow conduit during the 1655 AD Burrell eruption.

Five end-member lithic types are distinguished: crystalline andesites are derived from the shallow conduit and are either fresh (type 1), hydrothermally altered (type 2) or brecciated and sintered (type 3). Lithic types 2 and 3 are interpreted to be remnant lining from pre-Burrell effusive activity. Glassy andesites (type 4) are juvenile lavas from the initial effusive phase of the eruption. Banded vitrophyres (type 5) are sintered and compacted juvenile material accumulated in the shallow vent during the explosive-effusive transition.

Permeability and Dynamic Young's Modulus of lithic types correlate with porosity, except for sintered/altered lithics which show lowered permeability (i.e. outgassing potential) and increased Dynamic Young's Modulus. Componentry analysis of fall deposits shows crystalline andesites (types 1-3 combined) are the most abundant lithic type throughout, suggesting most erosion occurred within the shallow conduit during the explosive phase. Glassy andesites are a significant component at the bottom and top of the fall deposit, implying the eruption had an effusive beginning and end.

These results are important for understanding explosive activity following repeated cycles of dome-forming eruptions, commonly seen at andesitic stratovolcanoes worldwide. The development of a relatively strong, lined shallow conduit that inhibits outgassing likely contributed to the Burrell eruption's explosivity. Removal of the lining during the sub-Plinian phase may explain Taranaki Mounga's return to cycles of effusive activity since.

Recent inflation episodes beneath Taupō volcano

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Taupō volcano lies within the Taupō Volcanic Zone which is rifting as a result of 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. In the last 150 years, 18 episodes of minor to moderate unrest have been documented at the volcano.

Continuous GNSS measurements have been conducted around Taupō volcano since 2002 but are limited by the presence of Lake Taupō. The GNSS measurements have revealed a complex pattern of deformation, with regional (inflation sources, faulting) and external sources (large earthquakes and slow slip events) impacting the volcano. In the last five years Taupō has experienced two moderate unrest episodes (2019, 2022-23), with increased seismic activity and deformation. The GNSS measurements are consistent with inflation occurring at around 4-8 km depth beneath the centre of the lake. Estimated uplift at Horomatangi Reef was about 10 mm/yr during the 2019 inflation episode but exceeded 50 mm/yr in 2022. The modelled volume increase during the 2022-23 inflation episode was an order of magnitude faster (~0.015 km^3/yr) than during the 2019 inflation (~0.0018 km^3/yr). In this presentation we compare the two inflation episodes and investigate how the observed external deformation sources might contribute to observed seismic activity.

GNSS geodetic measurements along the Alpine Fault, then and now

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The first GNSS geodetic measurements to study the Alpine Fault in the South Island of New Zealand were conducted in 1992 when a network of 70 benchmarks was measured from Hokitika to Christchurch. With time the GNSS network was expanded to cover the Alpine Fault from Fiordland to the top of the South Island. Measurements of the GNSS network were repeated every few years to evaluate interseismic deformation along the fault. In addition, parts of the network have been measured in response to regional earthquakes, e.g. the M6.7 1994 Arthur's Pass, M6.2 1995 Cass, M7.8 2009 Dusky Sound, M7.2 2010 Darfield, M6.2 2011 Christchurch, M6.2 2015 Wilberforce, M7.8 2016 Kaikōura, and M6 2023 Geraldine earthquakes.

The first continuous GNSS station along the Alpine Fault was installed in Hokitika in 1998. In 2000 a profile of continuous and semi continuous GNSS stations was set up across the central Southern Alps to better determine vertical deformation associated with strain accumulation along the Alpine Fault. Since then, the network of continuous GNSS stations has grown slowly, with over 45 stations currently in operation in the South Island of New Zealand to study and monitor natural hazards.

In this presentation we give an overview of GNSS measurements along the Alpine Fault, present main findings, challenges and look to the future.

Using citizen science Raspberry Shake seismometers to enhance earthquake location and characterisation: A case study from Wellington, New Zealand

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The recent development of low-cost citizen seismometers has opened new avenues for improving seismic detection and location capabilities. We explore the integration of Raspberry Shake citizen seismometers with the national GeoNet seismic network to improve the precision of earthquake locations in Wellington, New Zealand. Our findings demonstrate that using Raspberry Shake seismometers in conjunction with the GeoNet network is effective for both the locating and characterisation of seismic earthquakes. Notably, we find that precise station locations are less critical for precise earthquake location, a significant factor given that the publicly available Raspberry Shake locations are obfuscated to protect user privacy. These results suggest that citizen seismometer data can be a valuable tool in seismic monitoring and improve earthquake location capability, whilst remaining cost-effective.

The Wairakei Earthquake and Tomography Array (WĒTĀ): A nodal seismic array for investigating seismicity at Wairakei Geothermal Field, New Zealand

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The development of self-contained seismic nodes has the potential to revolutionise the way seismic data are acquired. Seismic nodes are small, portable, and cheap in comparison to most traditional seismometers, allowing high-density seismic arrays to be deployed quickly for a variety of applications. As part of a project funded by the Natural Hazards Commission Toka Tū Ake and AuScope from the Australian Government via the National Collaborative Research Infrastructure Strategy (NCRIS), and with the support of Contact Energy, seismologists from Victoria University of Wellington and the Australian National University deployed the Wairakei Earthquake and Tomography Array (WĒTĀ) in September 2023, a temporary nodal seismic array targeting the Wairakei Geothermal Field in Taupō. The array consisted of 96 short-period and 51 broadband nodes from Australian National Seismic Imaging Resource (ANSIR) facility, distributed over a 25 × 35 km area from early-September to mid-October. From mid-October to late-November, the array consisted of 24 short-period and 50 broadband nodes that were recharged and redeployed. Using a machine learning-based approach to detect seismicity on the nodal and GeoNet data, we have created an earthquake catalogue for Wairakei from September to November 2023. Earthquake locations, focal mechanisms, and magnitudes were analysed to find patterns in seismicity within the study period. The dense seismic array allowed us to reliably detect M<2 earthquakes and to better constrain earthquake locations, particularly at shallow depths. We show that precise characterisation of seismicity is useful for enhancing the exploration, monitoring, and management of geothermal fields, and that nodal seismic arrays provide an effective, low-cost means to achieving this.

Unravelling the sediment signature of the lake tsunami: The potential of lake sediment records to reconstruct magnitude and frequency

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Reconstructing past landslide-generated tsunamis in lakes is crucial for understanding the extent and frequency of this hazard. Current approaches involve identifying large landslide deposits preserved on the lakebed and analysing landslide dimensions and dynamics to estimate tsunami magnitude. However, this evidence is often eroded or becomes buried over time, limiting our ability to reconstruct long-term tsunami records. We hypothesise that lake tsunamis leave diagnostic sedimentary imprints in the stratigraphic record of lakes that can be used to develop long-term records of tsunami frequency. The hypothesis is tested by examining the sedimentological signature and spatial heterogeneity of deposits produced by a coseismic tsunamigenic delta collapse in Lake Rotoroa (South Island) through extensive bathymetric mapping, seismic imaging and sediment coring. By linking deposit sedimentology to numerical tsunami simulations and sediment transport principles, we developed a facies model for lake tsunami deposits. The diagnostic sediment signatures include anomalously thick megaturbidite sequences with erosive basal contacts, discontinuous laminae in the upper deposit, and thick fine-grained sediment caps, with interbedded coarser and organic sub-units. Our findings illustrate that lake tsunami deposits can be differentiated from seismic turbidites and mass transport deposits, demonstrating that lake sediment records can be used to reconstruct the frequency of lake tsunamis over long time scales. This research shows promising progress towards a quantitative assessment of lacustrine tsunami hazards and has the potential to enhance our understanding of the frequency of hazardous lake tsunamis in New Zealand and globally.

A geoethical vision for Aotearoa New Zealand

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Establishment of the Aotearoa New Zealand (ANZ) chapter of the International Association for Promoting Geoethics enables geoscientists, engineers and other domain specialists to join a diverse scholarly community exploring the theoretical foundations and practical applications of geoethics, with its values-based approaches to human-Earth system interactions. Due to its unique South Oceania location and historical trajectories of human settlement, ANZ is well-placed to contribute to the global geoethics discourse. Geoethics provides a framework for integrating the physical and social sciences and addressing societal issues including those with often-competing values over natural resources, development and landscapes. To operationalise the geoethical principles articulated in the Cape Town Statement on Geoethics, sound geoscience must be coupled with respect for diverse communities, ontologies and epistemologies. Primary among these partner ontologies/epistemologies are those of Te Ao Māori (the Māori world) and Mātauranga Māori (Māori knowledge systems), which have been increasingly interwoven with earth and environmental sciences.

Geoscientists work to address many of the environmental challenges of our time, challenges with significant societal implications. Accordingly, we propose an ANZ geoethics work programme that will: develop a geoethical conceptual framework relevant to the ANZ context; encourage geoscience community participation in education and outreach; promote policies and actions that protect the environment, ensure sustainable economic development, and mitigate geohazard/geo-risk; map ANZ geoscience strengths and deficits to the Sustainable Development Goals; ensure ethical conduct during post-disaster scientific and engineering reconnaissance missions; promote geoethical principles in engineering sectors involved in landscape modification; value geodiversity, geoheritage and geotourism; and partner with colleagues across Oceania, around the Pacific Rim and beyond to explore geoethical theory and applications in a range of developmental and socio-cultural contexts. As a basis for operationalising geoethical practice, our chapter will suggest mechanisms for professional geoethical accreditation for geoscientists, akin to codes of ethical conduct in the engineering sector.

A new consistent and high-precision earthquake catalogue for the Taupō Volcanic Zone

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We present a newly developed earthquake catalogue for the Taupō Volcanic Zone spanning sixteen years from 2007-2023. This earthquake catalogue is consistent in methodology, allowing analysis of temporal changes, and has high-precision hypocentre locations. The 86,000+ earthquakes show previously documented volcanic unrest and eruptive episodes, as well as revealing many other examples of magmatic, geothermal, and tectonic seismicity. We present this catalogue in the hope that it will be used for a wide variety of research purposes in the future.

New insights into the fossil record of sea pens (Octocorallia) based on a new find from the mid-Cretaceous of New Zealand

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Sea pens (Cnidaria: Octocorallia: Pennatulacea) typically have well-mineralised skeletons represented by calcified axial rods, but their fossil record is surprisingly poorly understood. This group appears suddenly in the fossil record in the latest Campanian-Early Maastrichtian (~72 Ma) with multiple diversified finds across the Northern Hemisphere (Europe, North America, Central Pacific) many of which are confined to relatively shallow-water environments. Molecular analyses, however, indicate that the sea pens should have a more ancient origin, dating divergences of the main clades back to the Early Cretaceous. In turn, analysis of recent diversity points to the Central Indo-Pacific continental shelf as the most probable centre of origin, however, without clear consensus.

Herein we report a new find of a small fossil, collected in 2024 from the tectonised mid-Cretaceous (presumably early Albian, ~110 Ma) sequence exposed on Red Island, on the coast south of Hawke Bay. The fossil has a match-like shape, quickly narrowing at one end, with an indistinct radial structure resembling a poorly preserved belemnite. Examination of its microstructure, closely resembling that known for recent pennatulacean genera *Stylatula* and *Veretillum*, allows confident recognition of its octocoral affinities. This is the oldest pennatulacean axis known so far, extending the known stratigraphic range of the group by 38 myr.

Our find indicates that sea pens were already present in the paleo-Pacific in the mid-Cretaceous time. The only record available so far originates from the deposits confined to an ancient seamount of the Hikurangi Plateau, which was located somewhere in the middle latitudes of the Southern Hemisphere. The seeming absence of Early and mid-Cretaceous records elsewhere is probably a result of the late expansion of sea pens to the Northern Hemisphere and poor knowledge of the paleontology of the paleo-Pacific, from one side, coupled with the unremarkable appearance of their axes, from another.

Millennial-scale instability of the Antarctic Ice Sheet and impacts on New Zealand climate in the mid-Pliocene Warm Period

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Late Pleistocene climate records show rapid onset (decades to centuries) and high amplitude climate changes every few millennia (1,000-10,000 years). Over the past million years, these events have been most pronounced during transitions between glacial and interglacial states, and it has been proposed that they were triggered or amplified by ice-ocean feedbacks from the marine-based Northern Hemisphere Ice Sheet (NHIS). With the marine-based NHIS now largely absent, the focus is on the marine-based Antarctic Ice Sheet (AIS), which still has significant regions vulnerable to marine ice sheet instabilities in warmer climates. However, it is unknown if future marine-based AIS collapse could trigger abrupt millennial-scale climate events similar to those driven by the past NHIS. To address this, I will examine the response of the AIS and its impact on global climate during the mid-Pliocene Warm Period (mPWP: 3.3-3.0 million years ago), a period when global temperatures were 2-3°C warmer than pre-industrial levels.

This study provides new direct records of AIS variability via CT-scan-based ice-rafted debris counts from the International Ocean Discovery Program site U1524 in the Ross Sea during the mPWP. The implications for New Zealand's climate resulting from AIS variability will be assessed by developing climate records from the Siberia-1 core in Whanganui, using the biomarker-based proxies during the mPWP. Both sediment core records contain high-resolution stratigraphy enabling the identification of millennial-scale climate changes. Our preliminary results provide the first known evidence of millennial-scale AIS variability during a warmer-than-present climate.

Avoiding fault: Two decades of surface fault rupture hazard management on the Ostler Fault, Twizel, South Canterbury

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We present a study of surface fault rupture hazard management in an area of rural-residential development across the Ostler Fault in the Mackenzie Basin, immediately west of Twizel. The ~80 km long Ostler Fault is one of the most active reverse faults of the eastern Southern Alps, with very complex surface expression including km-scale lateral stepovers and broad distributed deformation of the hanging wall. In the Twizel area, a succession of glacial outwash plains is spectacularly deformed with vertical displacements ranging from ~200 m (~200 ka plain) to ~20 m (~18 ka plain). Estimated surface rupture recurrence interval is 3000+/-1000 years with the most recent event ~3600 years ago.

GNS Science assessed the surface fault rupture hazard for developers in 2005 as part of an application for a subdivision spanning the fault deformation zone near Twizel. The assessment followed the freshly minted 2003 MfE guidelines ‘Planning for development of land on or close to active faults’ but recommended an innovation of different width Fault Avoidance Zones (FAZs), greater on the hanging-wall (100 m) than the footwall (50 m). GNS Science undertook further surface fault rupture assessments for nearby rural residential subdivisions in 2007, 2009, 2017 & 2019.

In 2010 GNS Science developed a FAZ for part of the Ostler Fault to inform a district plan change, which became the Ostler Fault Hazard Area in the Mackenzie District Plan. In 2023, aided by LiDAR obtained in 2015, Environment Canterbury updated the fault mapping and FAZ for the Mackenzie District Plan review, incorporating and expanding on GNS Science assessments.

The MfE guidelines focus on life-safety in buildings and avoiding fault deformation, but the Ostler Fault work highlights a need for guidance on foundation design as an option to mitigate surface fault rupture hazard, and appropriate subdivision across an area of complex deformation.

24/7 monitoring and rapid response to landslides in Aotearoa New Zealand

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The 24/7 National Geohazards Monitoring Centre (NGMC) was established in December 2018 to monitor and rapidly respond to the geological hazards of earthquakes, tsunami, volcanoes, and landslides in Aotearoa New Zealand.

Of these hazards, landslides cost the most economically to New Zealand and result in the highest number of fatalities. With the increase in extreme weather events and glacial retreat, the frequency of societally significant landslides is forecasted to increase. As such, effective landslide monitoring is increasingly important.

Since the advent of the NGMC, a number of developments have occurred in this space, including:

- Landslide seismic signals are being manually detected more often, leading to a growing database of landslide-associated seismicity.
- Earthquake and Rainfall Induced Landslide forecasting tools have been developed.
- The NGMC has deployed a purpose-built ArcGIS Online tool for their daily reporting, a move that supports the development of an active landslide resource.

In this presentation, we will discuss the development of NGMC's capability to monitor and respond to landslides, as well as future opportunities for growth.

An evaluation of citizen science approaches to monitor landslides and reduce the associated community risk in coastal cliff environments

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Coastal cliffs, constituting 50% of the world's coastline, are highly susceptible to landslides due to substrate weathering, wave action undercutting, and triggers from seismic or meteorological events. How much climate change will exacerbate the landslide and erosion hazard along coastal cliffs is largely unknown, necessitating comprehensive investigations into the relationships between environmental changes and landslide occurrence.

Traditional landslide monitoring approaches are expensive and cannot always provide reliable and comprehensive data acquisition in coastal cliff environments, due to the challenges of site inaccessibility and the harsh (corrosive) environments. This research addresses these challenges by exploring the potential of integrating citizen science principles into landslide monitoring programs in coastal cliff environments.

Focusing on three distinct regions, Cape Kidnappers in Hawke's Bay, Urenui and Onaero in North Taranaki, and Mairangi bay in Auckland City. This project aims to assess the effectiveness of citizen science in enhancing landslide monitoring and risk reduction efforts. These regions offer diverse geological settings, marine weather conditions, and beach users, providing a test for how different citizen science methods can be applied across different coastal cliff environments.

The study will evaluate a range of citizen science data sources for collecting landslide inventory data, identifying landslide precursors (e.g. incipient failures), and increasing the understanding of coastal cliff behaviour. Additionally, it considers the bidirectional impact of citizen engagement, assessing changes in hazard identification accuracy and hazard avoidance behaviour among participants of landslide hazard monitoring initiatives.

By leveraging citizen science, this project seeks to bridge knowledge gaps associated with coastal cliff erosion, triggers, failure magnitudes, and event frequencies. The findings aim to contribute to improved risk management strategies, enhancing the safety of both local communities and tourists exploring these captivating yet hazard-prone environments.

A new magmatic phase of eruptive activity at Whakaari White Island

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In May 2024, a new eruptive episode began at Whakaari White Island after relative quiescence since 2019. Here, we summarise initial observations and present an interpretation for driving processes.

Eruptive activity began on 24 May with a steam-driven eruption creating a plume to ~2.5 km above sea level. Observations from an overflight found a thin, narrow ash deposit on the north flank and that the crater lake level had noticeably dropped. Further steam-driven events occurred over the ensuing days. In the following weeks, the steam plume above Whakaari was unsteady and pulsatory. Simultaneously, CO_2 and SO_2 fluxes were elevated (eventually reaching 2587 and 2975 t/day, respectively, on 14 August) whilst the crater lake level continued to fall, largely disappearing in early July. Satellite data and aerial imagery captured from 8-12 July showed a new vent had been created, with vigorous steam and minor ash emissions; ballistic impact craters up to 250 m from the vent; and a more widespread, but thin, local ashfall deposit. On 9 August, a continuous large and vigorous plume was observed, with low-altitude airborne volcanic ash detected in satellite imagery for the first time, extending 10s of kilometres downwind, occasionally reaching over the mainland. Observations on 13-14 August showed that the activity had migrated to a new vent slightly west of that active in July, with the latter now shut-down. Airborne ash samples serendipitously collected during an overflight on 14 August were extremely fine grained (~5-30 µm), consisting of fresh volcanic glass and crystals, free of hydrothermal interaction.

The observations suggest that magma ascended beneath the volcano, evaporating the lake and driving the initial vent-clearing, gas-driven eruptions. Fragmented fresh magma was entrained into the plume, producing small amounts of fine, fresh ash. This activity represents the onset of a new magmatic eruption episode at Whakaari.

Fiordland saltmarshes: Sediments, salinity, and vegetation

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Fiordland saltmarshes are distinctive in their landform setting, lesser salinity than elsewhere in New Zealand, humic freshwater layer, cool climate, relative shelter and shade. At fiord heads that lack sediment-trapping lakes upstream, elongated deltas of large rivers have braided watercourses, while smaller stream mouths have fan-shaped deltas with distributary channels. Studies at 22 sites (12 in Doubtful Sound) show how plant communities are related to elevation within the c. 2.5 m tidal fluctuation, as well as to substrate particle size: seagrass meadows on subtidal silt, a lower tidal zone of cobbles with marine algae and lichens, then, with limited overlays of sand and silt, successive zones of turf plants: Poa grassland, Oioi rushland, Toetoe tussockland, Carex sedgeland, and low shrubland, towards a forest edge.

Bay heads closer to the outer coast, being more exposed to wind/wave action, have gravel beaches with driftwood, and upper zone sedgeland only. Sutherland Sound is unique, being partially blocked by a sandy estuary overlying moraine. Lagoonal estuaries and tidal river marshes, common in Westland, reach northern Fiordland only.

The flora includes some particular Fiordland components, but lacks species typical of saline and hypersaline communities elsewhere in New Zealand, and those of warmer latitudes. Few naturalised plants are present, and no troublesome weeds. Enhanced freshwater influence near the Manapouri power station tailrace at Deep Cove is indicated by the colonisation of additional turf species from the freshwater shores of Lakes Te Anau and Manapouri. These studies form a baseline in expectation of rising sea level and sea temperature, tectonic events, impacts of browsing animals, weeds, invasive marine organisms, tourism, recreation, and fire, and possible threats such as oil spills from cruise ships or water-export vessels.

The history of earthquake and tsunami monitoring on Rēkohu Wharekauri Chatham Islands from 1932 to 2024

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Earthquake monitoring on the Rēkohu Wharekauri Chatham Islands dates from the early 1930s, with the installation of the first seismograph in 1932 and running until 1941. In December 1966 the station was re-established, running until April 1994. It was again re-established as part of the new GeoNet Programme in December 2007. An enhanced network, including geodetic Global Navigation Satellite System (GNSS), continues to operate from several locations on the island as a part of GeoNet. A sea level monitoring gauge was installed at Waitangi in November 1989 as part of the Global Sea Level Observing system (GLOSS) and operated until 2010. This gauge was important for the Pacific Tsunami Warning and Mitigation System (PTWS) because few observations were available in the region. A sea level gauge was re-established at Owenga Wharf in December 2007, again as a part of the GeoNet system. An education 'seismometers in schools' programme has been running since 2018, with new equipment installed in Te One, Kaingaroa and Pitt Island schools in 2021. Further developments and upgrades are planned across the entire network.

Enhancing rapid earthquake response with new RCET products: Examples for the Rū Whenua Exercise M8+ Alpine Fault earthquake scenario

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The RCET programme is developing and testing a suite of new rapid earthquake characterisation tools to enhance situational awareness for responders in the minutes to hours following a major earthquake (and tsunami). These tools characterise the fault rupture extent, direction, duration, magnitude, focal mechanism, energy release, aftershock distribution and shaking (i.e. GNS Science Shaking Layers developed in partnership with GeoNet). Many of these tools are now running in-house at GNS Science in real-time. They produce outputs that can be reviewed and interpreted by expert responders, significantly speeding up the process of generating bespoke advice.

The 2024 Rū Whenua exercise hosted by the National Emergency Management Agency provided an opportunity to simulate best-endeavours rapid science delivery ahead of a major M8 Alpine Fault earthquake. We present examples of the products simulated using our tools and the timelines in which they could be delivered during a real response. We also include the effects of GeoNet network outages that could occur immediately following a major event.

A key point we illustrate is that advanced rapid earthquake characterisation (e.g. through new tools such as FinDer, RTEQcorrscan, W-phase) is critical to correct significant inaccuracy in automated Shaking Layer models generated following our largest earthquakes. Through the inclusion of 3D fault rupture extent (even if rough), meaningful Shaking Layers models can be generated, which in turn allows additional products such as landslide forecasts and loss models to be confidently delivered.

The 2022 New Zealand National Seismic Hazard Model applied in the Wellington Basin

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Sedimentary basins are well-known to amplify ground shaking; the Wellington Basin is one of many examples in New Zealand. Capturing complex site amplification effects in national seismic hazard models (NSHMs) is an ongoing global challenge. NSHMs are based on statistical averages and commonly tie hazard results to a single site parameter (or limited number of parameters), which also ensures that they can be consistently and pragmatically applied in seismic design codes.

We provide an overview of the application of the 2022 NZ NSHM in the Wellington Basin. The 2022 NZ NSHM revision includes a general increase in calculated hazard for high-hazard areas of New Zealand, including Wellington. It also adopts Vs30 as the single site parameter, replacing NZS1170.5 subsoil class, marking a substantial change in the treatment of amplification effects. These changes are reflected in the newly proposed draft Technical Specification (TS) TS1170.5:2024 for seismic design. We show that the draft TS increases spectral design values by a factor of ~1-2.5 times, with the degree of increase depending critically on the local site conditions. The largest increases occur at intermediate spectral periods at the softest NZS1170.5 class C and class D sites.

We also compare the amplification models adopted in the 2022 NZ NSHM with basin-specific amplification models developed for Wellington through NSHM research. Results highlight that average amplification behaviour (Vs30-scaling) observed in the wider Wellington region is not substantially different from global statistical averages represented in the NZ NSHM 2022. However, individual sites can exhibit strongly peaked amplification that is underpredicted by NSHM mean ground motion models.

Future work to capture localised site effects in NSHM, will need to consider the treatment of uncertainties, particularly those associated with nonlinear effects at high shaking intensities that dominate the hazard.

Achieving carbon neutrality in geothermal energy: A model for high-emission industries

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The 2023 UN's COP28 pledge aims to triple global renewable energy capacity by 2030 to limit temperature rise to 1.5°C. This commitment emphasises the role of geothermal in advancing sustainable and climate-friendly energy systems.

To shift towards a net-zero carbon future, there is growing interest in reinjecting non-condensable gases, including CO_2, H_2S, and CH_4, from geothermal power plants back into reservoirs for safe and long-term storage. Upon injection, CO_2 can be stored in a reservoir through trapping mechanisms. Beyond assessing storage potential, it is important to carefully evaluate technological challenges, process issues, and reservoir management risks. Potential resource management risks, such as breakthrough and surface leakage during testing and concerns about long-term resource performance, must be addressed. Additionally, the impact of CO_2 on fluid characteristics and reservoir pressure may affect geothermal production.

We used numerical models to evaluate the carbon storage potential in a representative geothermal reservoir. In the initial stage, a reservoir flow model incorporating critical parameters like permeability, fluid production and reinjection rates, and carbon dioxide reinjection rates to predict the behaviour of injected CO_2 was used. The second phase involves analyses using a reactive transport model to assess the potential for permanent carbon storage, considering its transformation into stable mineral forms and associated effects. Sensitivity analyses were conducted to explore the impact of various parameters on reservoir performance.

The impact of land dynamics on the terrestrial carbon cycle in Fiordland

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Fiords such as those found on the southwest coast of New Zealand are known to be important carbon sinks globally. The dynamic landscapes in New Zealand's fiords create ideal conditions for a net carbon sink through erosion and burial of organic material on the seafloor. A critical pre-conditioning of the sink potential is provided by the rapid colonisation of disturbed landslides and debris by the prolific nitrogen-fixer *Coriaria arborea*. This rapid nitrogen accumulation is expected to drive optimal rates of plant growth in Fiordland's cool, year-round maritime climate.

Atmospheric inversions of CO_2 fluxes over New Zealand support suggestions of a strong C sink linked to carbon uptake by native forests in the Fiordland region that is greater than process-based terrestrial carbon cycle models predict. However, models do not typically include the impact of land disturbances or the succession from nitrogen-fixing grasses/shrubs to young native forest. In order to better quantify the sink potential of New Zealand's fiords, we need to develop ways to incorporate dynamic landscapes in carbon cycle models.

To do so, we explore the new World Research Institute (WRI) Canopy Height dataset, which provides a new window into both the stability of landscapes and the carbon cycle in Fiordland. This dataset is publicly available at 1m resolution and includes time of collection. We validate the potential for use of this data in Fiordland using LiDAR data from Milford Sound and then use the dataset to characterise landscape stability. With this new information, we explore the incorporation of dynamic landscape processes into carbon cycle simulations with the Biome-BGC MuSO model, focusing on the impact of disturbance and rejuvenation (e.g. landslides/flood deposits), succession and the presence of N fixers, and slope and aspect.

Identifying concealed structures in urban areas: Insights from Tāmaki Makaurau Auckland, Aotearoa New Zealand

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Locating faults can be challenging in urban environments and in low strain regions with long earthquake recurrence intervals, where surface expressions of faulting are erased by anthropogenic and surface processes between seismic events. Detection of concealed faults in urban areas is nonetheless critical for hazard assessment and mitigation, as earthquakes on unidentified faults can have serious consequences (e.g. 2010-2011 Canterbury earthquake sequence). Common geophysical methods for identifying concealed subsurface faults are challenging to implement in urban areas due to difficulties identifying appropriate locations and gaining permits, and the high signal interference from city noise. However, urban development can provide rich resources, such as geotechnical boreholes and high-resolution LiDAR topography, which can be used to identify concealed faults.

The Tāmaki Makaurau Auckland area of Aotearoa New Zealand represents the country's most populated urban region and sits in a relatively tectonically stable area. Here, intense urbanisation and Quaternary Auckland Volcanic Field deposits mask potential faults. Previous work by Kenny et al. (2012) examined borehole, geophysical and outcrop data to identify concealed post-Miocene fault structures. We expand on this work by developing a new methodology and workflow to identify the location and assess reliability of concealed structures in Auckland. From a database of 8,000+ boreholes we identify 43 post-Miocene structures, including 8 likely and 23 possible faults. Our new workflow lends greater certainty and reliability to structural interpretations compared to previous works. For example, several previously published QMAP faults could not be substantiated following our workflow, and the 64 faults from Kenny et al. (2012) were reduced to 31 likely or possible faults. We provide a new QGIS database of borehole and fault data for Auckland, enabling further refinement of our interpretations in future studies. This work shows how data associated with urbanisation can be leveraged to complement traditional methods of identifying concealed faults.

A fossil hydrothermal system within the Wahianoa Formation, Mt Ruapehu, New Zealand

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Andesitic composite volcanoes can have hydrothermal systems over their lifespan. Hydrothermally altered rock can further exert influence on magma degassing, eruption styles and mass flow initiation. This study investigates the type and extent of hydrothermal alteration within the Wahianoa Formation (160-80 ky) of Ruapehu volcano in New Zealand by integrating field observations, Scanning Electron Microscopy (SEM-EDS), Shortwave Infrared (SWIR) reflectance spectroscopy, X-Ray Diffraction (XRD), sulphur isotope systematics and Inductively Coupled Plasma Mass Spectrometry (ICP-MS), thermodynamic modelling and airborne geophysics. Ruapehu shows a diverse suite of weathering and hydrothermal alteration minerals formed in relation to the present and fossil hydrothermal systems. Wahianoa Formation is one of the oldest formations, showing remarkable diversity of hydrothermal alteration that has never been studied before. The distal rock has only supergene alteration with abundant goethite, hematite and phyllosilicate mineral associations, while the hydrothermally altered rock are rich in phyllosilicates, Fe-oxides, pyrite, jarosite, alunite, gypsum anhydrite, and native sulphur. The latter is interpreted to be formed under intermediate and advanced argillic alteration conditions (>150°C and low pH). In contrast, the some of the exposed outcrops within the upper Wahianoa valley show distinct mineralogy, that is rich in quartz, pyrite, illite(-chlorite) and tourmaline, indicating a transition from the advanced argillic conditions toward more phyllic alteration type (>220°C and more neutral pH). Our results indicate a complex hydrothermal system developed within the Wahianoa Formation between 150-80 ky, providing a great example to study vertical and lateral mineralogical changes. A new model has been proposed to integrate hydrothermal alteration history into Mt Ruapehu's evolution that can better depict ongoing alteration processes and triggers for flank instability and volcanic hazards associated with hydrothermal systems.

Linking hydrothermal alteration to rock mechanics: Comparative analysis of andesitic volcanoes in Aotearoa New Zealand

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Volcanic hydrothermal systems are common to andesitic composite volcanoes in New Zealand and internationally. The hydrothermal systems and deposits on each volcano are unique, with different mineralogy, spatial distributions, and pervasiveness. Hydrothermal systems induce complex physical and chemical changes to the primary volcanic host rock. The feedback between hydrothermal alteration and rock properties are vital to constrain volcanic hazards, such as phreatic eruptions and volcanic flank stability.

In this study, we present mechanical and mineralogical data from Whakaari, Tongariro, and Ruapehu, selected to complement existing data on Whakaari and Ruapehu while providing the first mechanical data on Tongariro. The samples cover a range of alteration type, including (advanced) argillic and phyllic alteration with varying pervasiveness. Laboratory measurements of porosity, permeability, elastic wave velocity, and uniaxial compressive strength were used jointly with SEM-EDS and reflectance spectroscopy to quantify hydrothermal alteration history and physical properties. Our data is consistent with published data, showing trends of decreasing rock strength and elastic velocity waves with increasing alteration, while porosity and permeability increases with alteration. For the same porosity (~10%) and lithology (lava), we found a reduction in strength from ~100 MPa unaltered samples, ~80 MPa intermediate argillic samples, and ~30 MPa advanced argillic samples. Some samples show opposite trends, with increasing rock strength from ~100 MPa to ~150 MPa due to silicic alteration, but these are only found on Tongariro. While the overall trends in mechanical and alteration data are consistent across all three volcanoes, the alteration pervasiveness and styles differ. Ruapehu and Whakaari have crater-hosted systems, with highly pervasive alteration within these selected areas, and Tongariro has a dispersed hydrothermal system resulting in lower alteration degrees over a wider area. Our data has implications for how hazards such as phreatic eruptions and flank stability are modelled and highlights the importance of having individualised data for each volcano.

Building a high-resolution model of the Wellington Basin: A seismic and gravity survey of Wellington central business district

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Sedimentary basins create localised amplification of earthquake shaking. This was demonstrated by the Mw7.8 2016 Kaikōura earthquake, which caused significant damage to mid-rise buildings in Wellington City despite originating ~90 km away. The trapping of low-velocity, high amplitude surface waves in the Wellington Basin caused extensive damage in the Port and central business district (CBD) area. The interval of shaking was prolonged, and the degree of site amplification exceeded current site class building codes by 2 times. Mapping the basin's depth and shape is essential for forecasting localised amplification effects.

In 2021 Stronach and Stern published a gravity survey of the Wellington CBD showing a model with up to 100% differences in sediment thickness compared to the pre-existing Wellington Basin model. However, gravity interpretations are non-unique, and it is important to develop a complementary method to constrain them at discrete locations. The most widely adopted method to pair with gravity interpretations are controlled source, multichannel seismic methods because of their high depth resolution when compared to other geophysical methods.

We focus on the Thorndon-Centreport and East Te Aro/Waitangi Park regions. These are key areas for seismic risk due to large projected thickness of sediment, paired with critical vulnerable infrastructure and basin-bounding fault structures. We present new seismic and gravity data from Sky Stadium, where the gravity inversion suggests the basin is deepest (450-500 m). New seismic and gravity data from Waitangi Park has been collected in order to determine the onshore location of the Aotea Fault. Our new map will feed into the computer-based shaking models that are being developed by the earthquake engineering community, to quantify seismic site effects in Wellington, and to reduce earthquake related hazards.

Estimating shallow magma body depths from volatiles dissolved in glass recovered during drilling at the Puna Geothermal Venture wellfield, Hawaii

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In 2005, dacitic magma was unexpectedly encountered during the drilling of injection well KS-13 at the Puna Geothermal Venture wellfield, Hawaii. The magma was quenched to glass in the drilling mud and recovered, providing a unique window into the extreme and unknown environment of magma chambers. Similar encounters with shallow silica-rich magma bodies during drilling in the Krafla geothermal wellfield in Iceland have demonstrated the potential for high power outputs produced directly from magma. However, these shallow magma bodies can contain magmatic volatiles that profoundly affect melt and hydrothermal fluid properties. Hence, understanding volatile behaviour could inform future geothermal development drilling directly into magma bodies.

H_2O and CO_2 have been measured in the KS-13 glass chips by micro-Fourier transform infrared spectroscopy (micro-FTIR). H_2O contents range from 1.5-3.2 wt% (average 2.1 wt%), while CO_2 was only detected in one sample (12.5 ppm). Average H_2O-CO_2 saturation pressures of 34 MPa, for 800°C, and 40 MPa, for 1400°C, have been estimated for the KS-13 glasses using MagmaSat with the available major element composition for the KS-13 glasses (Teplow et al., 2009, Geotherm Res Council Trans, 33, 989). This is equivalent to 1,338 and 1,579 metres below surface (mbs), respectively. These modelled depths are shallower than the magma intersection depth (2,488 mbs), suggesting that the dacitic magma body was undersaturated. This indicates that either the magma never reached H_2O saturation, or it has degassed. A selection of samples will be analysed by high-resolution synchrotron radiation (SR)-FTIR at the Australian Synchrotron to check for H_2O and CO_2 diffusion, which, if present, will reveal the timescales of magmatic processes in response to changes induced by drilling into magma. Results from this study will be compared with those from the Krafla geothermal wellfield in Iceland, where drilling also intercepted magma, to better understand shallow melt bodies.

Regional W-phase inversion for rapid earthquake characterisation as a first step of tsunami early warning for New Zealand

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As 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 the location and magnitude of an earthquake. A method to estimate these parameters is the W-phase inversion. Unlike simpler automated magnitude determinations routinely used to analyse earthquakes in New Zealand, the W-phase does not saturate with magnitude, making it better at quantifying Mw for the largest earthquakes (Mw6.5+). 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, the W-phase earthquake characterisation is implemented in the tsunami early warning procedure of New Zealand. Commonly used at tele-seismic distances, using the W-phase on a regional scale for the Southwest Pacific brings challenges in terms of station coverage, minimum magnitude and corresponding focal mechanism and centroid times and depths we can accurately estimate and the uncertainties associated with the solutions.

A first estimate of regional W-phase outputs and associated uncertainties will be presented by looking at W-phase solutions for a catalogue of recorded Mw7+ events. We will focus on the impact of Green's functions adapted to a regional scale. Then, we will introduce the idea of representing earthquake sources with different levels of complexity to understand how the W-phase handles source complexity.

We will also present an investigation of synthetic earthquakes and waveform catalogues. With a large set of large magnitude events (Mw7+) adapted to the New Zealand and Hikurangi-Kermadec context and a full range of magnitudes, centroids and station configurations, we will refine our understanding of the limits of regional W-phase inversion.

New insights into the Mount Messenger Formation in Taranaki Basin from seismic and outcrop: Implications for environments of deposition and palaeogeography

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For more than three decades, since the seminal work of King et al. (1993) and King and Thrasher (1996), the Late Miocene-aged Mount Messenger Formation exposed along the North Taranaki coastline has been considered an archetypal example of exhumed basin floor fan strata. The predominantly sandstone, or mixed sandstone and mudstone lithology, relatively shallow dipping and presumably laterally continuous internal layering, and presence of channels matched well with what was known about the architecture of basin floor fans. Correspondingly, this interpretation permeated the literature and resulted in the offshore mapping of so-called submarine fan systems from wireline log signatures throughout large parts of Taranaki Basin resulting in paleogeographic maps (Strogen et al., 2011, 2022).

However, the interpretation of submarine fans in the Mount Messenger Formation has never been critically examined. Since that early work new concepts about deep water sedimentology have emerged, new (3D) seismic data have become available, and new seismic data analysis techniques have been developed. In this presentation, we outline newly completed research that dared to challenge the submarine fan paradigm by combining insights from seismic and well-logs with UAV-generated photogrammetric models of outcrops. In analysing seismic data situated immediately adjacent to and down-dip of the coastal outcrop, we found no objective criteria for submarine fan depositional elements based on seismic stratigraphic criteria. Rather, the mapping of seismic reflectors revealed large submarine canyon-channel systems. Submarine channel depositional elements are also observed to incise through the outcrops, but they are below seismic resolution.

In the context of the regional geology, we conclude that the lower Mount Messenger Formation accumulated as continental slope sediments cross-cut by channels rather than as basin floor fans. This study has implications for interpreting depositional environments from outcrops without adequate 3D exposure, as well as interpretations of the Miocene paleogeography of Taranaki Basin.

Complex fault traces on the northern Alpine Fault, Aotearoa New Zealand: Roles of fault interactions and structural maturity in influencing earthquake ground surface rupture patterns

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LiDAR, DEMs, field-based mapping, topographic analyses, and statistical methods are used to characterise surface rupture traces on the northern Alpine Fault (AF). Our study classifies approximately 4,500 lineaments within 2,000 km² of the north Westland AF. We use seven metrics – Principal Fault Trace (PFT) width, Distributed AF Traces (DAFT) width, fault corrugation, PFT elevation and relief, slip rate variations, PFT azimuth, and structural maturity - to categorise the northern AF into three spatial domains interacting with major faults of the Marlborough Fault System (MFS): (i) the Hope-Kelly (HK), (ii) the Inchbonnie-Springs Junction (ISJ), and (iii) the Alpine-Wairau Bend (AWB) segments.

The PFT varies from a singular trace to complex, kinematically-partitioned thrusts and dextral faults with large (>10 to >100 m) displacements. We identify zones where PFT width increases up to 500 m (HK and ISJ segments) and ~1.7 km (AWB segment), with features including step-overs, flower structures, and en echelon Riedel shears. DAFT zones include deformation structures mapped from <100 m to >4 km from the PFT.

The most complexity occurs along the AWB segment, where distinct structural morphology and kinematics are characterised by the widest distribution of DAFTs and PFTs, likely due to the segment's immaturity. Complexity along the HK and ISJ segments may arise from fault interaction zones with the MFS, potentially forming new splay faults that facilitate slip transfer. Future large AF earthquakes may involve ruptures extending up to 4 km into the hanging wall, with possible kinematics including pure normal and reverse faulting. Mapping herein has implications for understanding dynamic ground motions and rupture propagation, including antithetic MFS movements and partial ruptures segments. We develop a new approach using Monte Carlo simulations of surface rupture trace-weighted least-cost path analyses to forecast future PFTs, enhancing fault displacement hazard analyses and rupture forecasting.

Surface rupture, displacement, and river avulsion impacts during the next large Alpine Fault earthquake

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Recent large earthquakes in New Zealand (e.g. the 2010 Darfield and Mw7.8 2016 Kaikōura earthquakes) have highlighted an under-appreciated hazard related to large surface rupturing earthquakes – coseismic or fault-induced river avulsion (FIRA; McEwan et al., 2023).

The record of past earthquake multi-metre coseismic displacements is reasonably well-known from sequences of offset alluvial terraces across many West Coast rivers. But what else do they tell us? The terraces represent the part of a valley sequence whereby the river has avulsed and/or degraded and moved to another part of its valley allowing preservation of alluvial terraces and past coseismic displacements. This hints at the significant hazard posed by shifting (avulsing) rivers following the next Alpine Fault earthquake. Here we provide examples from airborne LiDAR and from paleoseismic studies to highlight past avulsions and/or alluvial degradation on the Maruia, Ahaura, Taramakau, Whataroa, Waiho, Haast, and other rivers. In many cases, there are flood control measures including stopbanks along several of these and other rivers that can be impacted by surface fault rupture and/or ground motions. These stopbanks will be susceptible to post-seismic erosion or washout that can result in a shift from the man-made controls put on the river, putting them into a state of avulsion that could overwhelm valleys that are currently underfit and host human development, e.g. roads, housing, industry. Some rivers have avulsed in recent times (Poerua, Waiho) giving us a small taste of what is possible. Thus, it is important to consider the post-seismic impact of rivers and rivers in change, and the role scientists can play in preparing councils, utilities, and the public for such multi-hazard cascade scenarios from the next Alpine Fault earthquake event.

Impact of landscape evolution on the ocean circulation and glaciation: A forward modelling of basin and landscape dynamics, northern Barents Sea, Norwegian Arctic

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Basin and landscape dynamics play a key role in oceanographic and climate evolution, such as connecting two major oceans and establishing a paleotopographic high at the onset of large-scale glaciations. The Barents Sea is an underexplored ocean gateway (also known as the Barents Seaway) connecting the Atlantic and Arctic oceans. However, unlike the Fram Strait Gateway, its formation over the past 66 Myr in the Cenozoic remains unclear. Several studies suggest that a paleo-topographic high was formed in the northern Barents Sea as early as the Miocene (c. 23 Ma), preconditioning an ice cap formation that led to the development of large-scale glaciation in the Northern Hemisphere (c. 2.7 Ma). However, the exact timing of this mountainous terrain remains uncertain. Here we used Badlands, an open-source basin and landscape forward modelling framework, to simulate the evolution of basin and landscape in the northern Barents Sea in the Cenozoic. To constrain the geometry of the oceanic basin for the sediment filling to the Nansen Basin we take advantage of GPlates. We then test different scenarios of catchment models and their associated sediment transport and accumulation in a source-to-sink context. Paleo-precipitations, sea-level fluctuations and tectonic/flexural response are used to understand the controlling parameters. The numerical results are then compared with seismic profiles and available well and core data. This study contributes to constraining the spatio-temporal pattern of the northern Barents Shelf landscape morphology, which can be applied in other formerly glaciated areas.

Improvement of small sample capability at Rafter Radiocarbon Laboratory

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Demand is accelerating for the radiocarbon measurement of small <400 µg of carbon (µg C) samples in numerous fields of research. Macrofossils such as leaves or foraminifera are ideal dating targets for the accurate chronologies required for paleo-climate, paleo-environment and paleo-hazard research, but sample size is often a limitation. The ramped pyrolysis technique has wide applications for radiocarbon measurement of multiple carbon fractions from soils and sediments, but generally produces small sample sizes. Radiocarbon measurements in atmospheric constituents such as carbon dioxide, methane, carbon monoxide and aerosols can also be sample size limited.

Previously, the graphite system at the Rafter Radiocarbon Lab at GNS Science required special treatment for samples smaller than 300 µg C leading to lower precision and risk of measurement failure for samples smaller than about 150 µg C. To improve upon this, we have developed a new graphite system, RCM10, that optimises graphitisation at smaller size ranges. RCM10 allows for 'standard' graphitisation of samples down to 200 µg C, at comparable precision to larger samples. With special treatment, we can now reliably measure samples as small as 50 µg C, albeit at lower precision than larger samples. These improvements significantly expand the lab's capabilities, increasing sample throughput and potential radiocarbon applications. For reference, our new 'standard' size limit of 200 µg C equates to about 0.5 mg of dry plant material or 1.7 mg of carbonate, and the smallest measurable size of 50 µg C equates to 0.2 mg of dry plant material or 0.4 mg of carbonate. Ramped pyrolysis measurement of sediment with 0.1% carbon content becomes feasible. Here we present the improvements to our graphitisation process and quantify the performance and reproducibility of radiocarbon measurements made with the new system.

Fossil arthropods from Zealandia reveal a complex ecological and biogeographic history

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New Zealand is known for its distinctive, overwhelmingly endemic, and idiosyncratic biota but perceptions of its terrestrial biodiversity are skewed towards the minority of species that are large and charismatic. However, the modern terrestrial fauna of New Zealand is dominated by species of endemic small arthropods including 3000 spiders (80% endemic) and 14,000 insects (90% endemic). Until 2004, their history in New Zealand was little known, based on just 7 fossil insects of pre-Quaternary age known from Zealandia. In 2024, we have more than 750 insects and 10 spiders from a dozen sites, mostly of Eocene to Miocene age, in Otago and Southland. Foulden and Hindon maars have yielded rich and diverse faunas. Foulden insects comprise 15 families and 9 orders including Blattodea (termites); Hemiptera (scale insects, bark bugs, lace bugs); Megaloptera (alderflies); Coleoptera (weevils, rove beetles); Diptera (flies, midges, craneflies, a dagger fly); Hymenoptera (ants, wasps) and Trichoptera (caddisflies). The Hindon fauna includes a primitive cicada, whiteflies, psyllids, wasps, ants and weevils and other beetles with structural colour. Twenty different taxa including planthoppers, weevils, ants and caddisflies occur in siltstone at Bannockburn. Amber from Roxburgh, Hyde, Pomahaka and Hakataramea contains 200 further invertebrates. Arthropods in amber include Pseudoscorpiones, Acari, Araneae, Collembola and insects of orders Hemiptera, Psocodea, Hymenoptera, Coleoptera, Lepidoptera and Diptera, including chironomids (non-biting midges). Many taxa are forest-dwellers with low dispersal potential such as barkbugs, scale insects in life position, and wet-wood termites. The terrestrial arthropod fossils investigated to date reveal curious extinction patterns, loss of functional groups, past higher diversity of social insects such as ants and termites, and long persistence of some groups. They provide strong fossil evidence for unravelling the complex ecologic, evolutionary and biogeographic history of New Zealand terrestrial arthropods as well as providing well-dated calibration points for molecular phylogenetic studies.

A new multi-grain size sediment transport model for rivers to help quantify landslide signals in stratigraphy

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Catastrophic sediment release in fluvial systems is largely driven by landsliding that occurs naturally in mountain belts during extreme events, such as earthquakes or storms. Sediments cascade through the river system until they are stored either permanently in alluvial fans and lakes or temporarily in terraces. The river response to such catastrophic sediment release has already been studied with numerical models using a single effective grain size. Yet, in natural systems, the grain size distribution of sediment can span several orders of magnitude and evolves during transport. The extent to which assuming a single effective grain size limits accurate forecasting of morphodynamic and sedimentological change in rivers systems during landslide-induced sediment cascades remains unknown.

We present a numerical model of multi-grain size sediment transport and storage that has the ability to capture the transport of suspended and bedload material as well as the dispersion rate and sediment sorting patterns of various grain sizes such as armouring and downstream fining. Numerical simulations reveal: i) how the grain-size specific signals propagate in a river reach over time and are preserved in the stratigraphy in response to a catastrophic sediment release, and ii) how a single effective grain size may underestimate the export time of fine sizes for wide distributions.

These preliminary results were obtained in the context of the SCALEES (Signature of sediment CAscades following Landslides triggered by Extreme Events in the Stratigraphy) project. Ultimately, the combination of empirical data with numerical simulations will allow us to predict for the first time the full signal (all grain sizes) of sediment cascades preserved in the stratigraphy in response to an extreme event at the scale of a catchment. It will also pave the way for inverting the stratigraphic record of landslide-induced sediment cascades for quantitative insights into their response amplitudes and relaxation times.

What happened here? Mapping and re-interpreting the volcanic rocks underlying Dunedin

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Dunedin City and Otago Peninsula are underlain predominantly by volcanic rocks, comprehensively mapped in the 1930s-40s (published as Benson, 1968). The underlying interpretation was of “widespread and petrographically distinctive lava-flows as horizon-marking stratigraphic units” – a shield volcano. Subsequently it has been noted that many volcanic rocks are only locally distributed and lack demonstrable lateral extent. They are in local ‘life position’ as distinct ‘volcanoes’ (e.g. Stenning, 2024), often with complex or vertical juxtaposition (e.g. domes of Price and Coombs, 1975).

Benson (1968) is still widely used as a framework for other local geological interpretations, e.g. structure, faulting, landslide potential, sedimentary and coastal processes, geotechnical and groundwater modelling.

Benson left a good data legacy of notebooks, field sheets, samples and thin sections (e.g. the first 1224 entries of the University of Otago (OU) rock collection). Many theses and publications over the last 50 years have also shed light on specific aspects of the ‘Dunedin Volcano’. Given the importance of the underlying geology we are in the process of re-interpreting the volcanic rocks of the Dunedin area in a modern geomorphic and volcanological context. We use substantial existing data, new LiDAR, new geochemical and geochronological analyses and new field work where appropriate to update the geological map.

Our emerging thinking is this is actually a diversely vented and composed volcanic complex, perhaps not as deformed or erosionally incised as previously thought. The origin of Otago Harbour and the sub-parallel volcanic ridges is an area of active debate. We aim to test whether many/any of the phonolite or ‘floodplain conglomerate’ outcrops can be credibly linked as widespread horizons. What were the emplacement geometry and mechanisms of the Port Chalmers Breccia? We present work to date, areas of interest and uncertainty, inviting discussion and insights from the community to contribute to this effort.

Investigating magmatic processes recorded in melt inclusions from a steady-state volcano, Yasur (Tanna, Vanuatu)

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Yasur, a trachy-andesitic volcano within the Yenkahe Caldera, has had persistent Strombolian activity for the last 630-850 years. As a steady-state, accessible volcano, it's a popular destination where visitors climb to the summit to observe eruptions. Constraining volatile behaviour and magmatic processes could lead to improved understanding of controls on eruption dynamics and enhanced hazard management and mitigation. Surprisingly, few petrological studies have been completed on the Yasur edifice or nearby ignimbrites from the Siwi Caldera. Existing literature implies the system (Yasur, the Siwi Ignimbrites, and the younger Yenkahe resurgent dome) are genetically related by differentiation and mingling within a larger magmatic reservoir.

Here, we present new volatile (H_2O: 0.1-0.9 wt.%, CO_2: 0-300 ppm, S: 0-330 ppm, Cl: 0-580 ppm) and major element data from recently erupted (2016, Aug/Nov 2023) naturally glassy melt inclusions (MIs) in early crystallising phases (Pl, Cpx, Ol) from proximal Yasur tephras. MI and WR major elements (K_2O, CaO, Al_2O_3, FeOt, MgO) from this study are offset from the literature Siwi ignimbrite and distal tephra trends. Al_2O_3, for example, is compatible in the Siwi sequence and incompatible in Yasur tephras. Additionally, low volatile contents suggest that degassing has occurred prior to or during MI entrapment, possibly indicating shallow crystallisation. Considering major element and volatile data in conjunction with oscillatory zoning in plagioclase, it is possible that the crystal population may be experiencing recycling in the conduit or be antecrystic in nature. These data indicate that Yasur lavas may be generated by processes separate from ignimbrite production and that the two systems are not as closely related as previously assumed. Understanding magma differentiation and volatile exsolution in the conduit and plumbing system will impact how MI data from Yasur are interpreted and may influence how we use the limited petrological data currently available.

Insights into rapidly transitioning eruptions at Ambrym volcano (Vanuatu, SW Pacific) through melt inclusions from the 1913 Hospital Tuff

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Eruption styles of mafic volcanism can fluctuate from low intensity lava flows to explosive Plinian columns, and interpretations of the driving mechanism of these changes are limited. Ambrym, a large mafic volcano in central Vanuatu, often displays variable eruption styles that impact surrounding communities. Historical eruptions can be divided into three main types: lava lake activity, intra-caldera explosive and effusive eruptions, and fissure-fed sheets and flows along the EW trending rift zone that flanks the central caldera. Of the three types, fissure eruptions pose the greatest hazard to the island's population, most of which dwell near the coast. Fissure eruptions often initiate with sub-Plinian explosions in the central caldera, transitioning to along-rift vent propagation with lava fountaining/flows, terminating in phreatomagmatic explosions at the coastal margins. Numerous tuff cones are nested at the eastern and western margins of the island, showcasing the change from effusive flows to water-driven explosive eruptions. Of the witnessed fissure eruptions observed at Ambrym, no eruption highlights this rapid transition better than the historic 1913 eruption that claimed 21 lives.

We present volatile (H_2O: 0.3-1.4 wt.%, CO_2: below detection, S: 0-1070 ppm, Cl: 210-1150 ppm) and major element analyses from melt inclusions hosted in early crystallizing phases (Ol, Pl, Cpx) from the 1913 Hospital Tuff ring. Low volatile contents suggest early degassing of the system, indicating that the explosivity resulted from interaction with water-saturated sediments. Major elements plot along typical Ambrym fractionation pathways, with the exception of K_2O, which divides into two distinct trends: high-K (basalt-trachybasalt) and medium-K (basalt-andesite). These findings suggest that there may be more than one source feeding this eruption. Investigating volatile and K_2O behaviour, coupled with trace elements, will help constrain source compositions, conditions of melt extraction/storage, and aid in confirming driving mechanisms behind shifting eruption activity at Ambrym.

Empirical validation of physics-based ground motion modelling in Wellington Basin: Insights on basin amplification

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The amplification effect of site-specific near-surface velocity structure plays a crucial role in modulating ground shaking level, and in turn, contributes to seismic risk. However, the general understanding of this effect is limited, owing to complex 3D geological structures and the influence of coseismic source dynamics on site response. In this study, we use physics-based simulations of ground motion to investigate fundamental characteristics of the regional seismic response that may not be easily analysed using regional seismic recordings.

We develop numerical models for the Wellington region, which is a seismically active area with multiple active crustal faults and the Hikurangi subduction zone beneath it. This unique geological setting requires investigating potential earthquake ruptures and their effects on ground shaking levels. Several geological and geotechnical surveys have provided valuable knowledge about high-resolution topography, shallow basin structures, and fault networks (Hill et al., 2022). In this study, we focus on simulating ground motions using local intermediate seismic sources (ML 3.8-5.1) and validating basin structure with strong motion records. Key aspects of our study include (1) establishing and validating a unified numerical workflow for modelling ground motions with strong velocity contrast, (2) examining influences of shallow basin structure on distribution of peak ground shaking (e.g. azimuthal variation), and (3) evaluation of the impacts of topography, seismic attenuation, and basin-shape effect on the ground motion levels.

By studying the ground motion of local earthquakes and the impacts of regional geology on site amplification, we combine advanced numerical simulations with regional seismological records. Based on the simulated seismic scenarios of the regional earthquakes, we aim to advance our knowledge of future ground shaking levels in the city and to provide general theoretical references to improve empirical ground motion models, and consequently, seismic hazard analysis.

Earthquake cycle models of the Hikurangi-Kermadec and Tonga-Vanuatu subduction zones

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Seismic and tsunami hazard modelling and preparedness are challenged by uncertainties in the earthquake source process. Physics-based earthquake simulators, such as RSQSim, offer a means of probing uncertainties in input parameters of seismic and tsunami hazard assessment by generating long-term catalogues of earthquake ruptures on a system of known faults. The fault initial stress state in these simulations is typically prescribed as a single uniform value, which can promote characteristic earthquake behaviours and reduce variability in modelled events. Here, we test the role of spatial heterogeneity in the distribution of the initial stresses and frictional properties on earthquake cycle simulations through case-studying the Hikurangi-Kermadec subduction interface. We explore RSQSim simulations of coseismic slip by varying the rate-and-state coefficients (a and b). Our results suggest stress heterogeneity produces more realistic and less characteristic synthetic catalogues, making them particularly well suited for hazard and risk assessment. We further find that the initial stress effects are dominated by the initial effective normal stresses, since the normal stresses evolve more slowly than the shear stresses. A heterogeneous stress model with a constant pore-fluid pressure ratio and a constant state coefficient (b) of 0.003 produces the best fit to magnitude-frequency distributions (MFD) and empirical scaling laws from global earthquakes, while the model with variable frictional properties produces the best fit to earthquake depth distribution and empirical scaling laws.

The approach of earthquake cycle modelling that we set up for the Hikurangi-Kermadec subduction interface is applied to the Tonga and Vanuatu subduction zones. Unlike the well-investigated Hikurangi-Kermadec subduction zone, the coupling distributions, the factor that largely affect the length of resulting earthquake cycles (recurrence interval), for Tonga and Vanuatu subduction interfaces are not thoroughly explored. We estimate the coupling distribution by comparing the MFDs of synthetic catalogues to the instrumental catalogue on the subsegments of the subduction interfaces.

Progress towards untangling earthquake sources in the central Hikurangi subduction zone: Holocene marine terraces between Clifton and Waimārama

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Untangling evidence for upper plate versus subduction earthquakes in the central Hikurangi subduction zone is challenging due to the number of faults and the uplift/subsidence signals changing over short spatial and temporal scales. The coast between Clifton and Waimārama is currently subsiding (0-3 mm/yr) but is characterised by one or more Holocene marine terraces indicating permanent uplift. Uplift of these terraces has traditionally been attributed to offshore faults; however these terraces are now being re-examined in the context of subduction earthquakes.

New terrace mapping using LiDAR data and field studies have confirmed a single Holocene marine terrace between Clifton and Ocean Beach (the Kidnappers terrace). The terrace appears to extend northwest as far as Haumoana, potentially constraining a pivot point between permanent uplift and subsidence further north along inner Hawke Bay. Twenty-seven new radiocarbon shell ages have filled some key data gaps (Clifton, Ocean Beach) and broadly match previous ages. The ages span 3215 to 1665 cal yr BP, suggesting coseismic uplift of the Kidnappers terrace during this time.

More detailed studies are being undertaken at Waimārama, where there is one terrace in the north, and two or three terraces in the centre and south. Nine new ages from the northern terrace span 3470 to 1336 cal yr BP, supporting previous interpretations that it is the southern part of the Kidnappers terrace. Two new ages from the oldest terrace suggest that it began as a valley infill terrace during post-glacial sea level rise but the timing of abandonment of the terraces is still being constrained. New ages from these terraces can be compared with the coseismic subsidence ages north of Napier and marine terrace ages at Aramoana to help understand the earthquake sources that drive permanent coastal deformation on the central Hikurangi subduction zone.

Impact of operational parameters on gas-water contact and water coning in underground hydrogen storage: A numerical investigation

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Hydrogen is regarded as a good energy carrier for storing surplus energy generated by renewable sources. However, due to its low energy density, it requires large volumes for storage. In this regard, depleted gas reservoirs may be a good option. However, as some depleted reservoirs have been exploited for decades, the gas-water contact can be elevated within the reservoir and this creates a risk of water coning. In this study, we analyse an existing underground gas storage (UGS) and consider the characteristics of bottom water coning in a hypothetical underground hydrogen storage (UHS) scenario. We tested the impact of different storage design parameters, such as cushion gas injection rate, cushion gas injection volume, hydrogen injection/withdrawal rate, and hydrogen injection/withdrawal volume. We found that hydrogen withdrawal rate, cushion gas volume, hydrogen injection/withdrawal volume had a significant impact on water coning, and these should be carefully considered in future project design. The impact of other parameters was limited. These findings can be used to optimise design parameters for underground hydrogen storage in depleted reservoirs to improve project efficiency without intrusion of bottom water.

A bite of evolution: Elucidating cetacean evolutionary history through their teeth

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New Zealand has a rich record of fossil cetaceans, including crown Neoceti (mysticetes and odontocetes) and stem archaeocetes. By the early Oligocene, echolocating odontocetes and filter-feeding mysticetes diversified rapidly, while modern lineages of odontocetes and mysticetes radiated by the middle and late Miocene. A key step in the evolutionary history of cetaceans was the transition from terrestrial to fully aquatic existence, with major anatomical modifications in the skull and feeding apparatus, including teeth.

Archaeocetes had elongated rostra bearing a heterodont dentition with conical anterior teeth and heavily built ornamented posterior teeth. Archaeocetes produced two sets of teeth. Archaic odontocetes were heterodont and had an increased number of teeth, which were becoming more homodont. Archaic mysticetes had teeth which later were replaced by filtering keratinised baleen. These dental morphological changes were also reflected in the organisation of dental tissues, particularly enamel. Toothed mysticetes, archaeocetes and some fossil odontocetes had complex enamel with Hunter-Schreger bands, while radial and prismless enamel were common in some fossil Platanistoidea and Delphinoidea, and in most living odontocetes. The limited food processing in living cetaceans suggest their teeth might not be subject to the same evolutionary pressures as in other mammals. This is reflected in low hardness and elastic modulus values in cetacean teeth, which in turn relate to the degree of mineralisation of enamel and dentine.

The unusual morphology of cetacean teeth, coupled with structural simplification and changes in number throughout evolution (either increased, reduced or completely absent) shows teeth are a great model system to elucidate major macroevolutionary patterns in the transition from land to water. Studies on New Zealand fossils have played a major role in piecing together pieces of this puzzle.

Dynamic rupture simulations on the Alpine Fault: Investigating the role of fault geometry on rupture size and behaviour over multiple earthquake cycles

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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. 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.

Here, we use the 3D finite element method to simulate multiple cycles of dynamic ruptures on the Alpine Fault, informed by seismological and geological observations. We embed the fault segments in a 1D velocity structure and impose heterogeneous initial tractions computed using seismologically estimated local principal stress orientations and magnitudes computed using a critically-stressed crust model. We simulate the coseismic period using dynamic rupture simulations, then account for the interseismic period by incrementing shear stress through time by adding a shear stress increment determined from the current stress state and the time since the 1717 rupture. For each simulation, we compare the modelled rupture lengths and surface slip values to geologic studies to ensure that we are producing physically-plausible simulations.

Iterative geometric, frictional 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. This implies that both fault geometry – and long-term stress patterns resulting from that geometry – are important considerations for hazard assessment on this late-interseismic fault.

Basement heterogeneity and structural influence on the Auckland Volcanic Field magma ascent inferred from gravity and magnetic anomaly modelling

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The Auckland Volcanic Field (AVF) in northern New Zealand is characterised by small-volume Quaternary volcanism that spans an area underlain by multiple basement terranes. Previous statistical analysis of vent locations suggested structural controls related to concealed faults and basement heterogeneity. We conducted gravity and magnetic modelling to test the AVF magma-structure hypothesis. We decompose the complete Bouguer gravity anomaly to model the Takapuna Gravity High (TGH) and basement depth. The Junction Magnetic Anomaly (JMA) was modelled using the total magnetic anomaly.

Joint 2.5D forward modelling of the TGH and JMA quantify the geometry of a magnetised basement terrane under the AVF, divided into the western low-density and eastern high-density parts. A non-magnetic high-density body may be present east of or enclose the magnetic high-density body under the northern part of AVF. A likely geological interpretation of the magnetic bodies is the ultramafic Dun Mountain-Maitai Terrane, with variable degrees of serpentinisation affecting its density. Meanwhile, the non-magnetic high-density body may represent metamorphosed Caples Terrane. The southward wedging of the TGH likely reflects the subsurface extent of the high-density body under the AVF, influencing its magma ascent process to focus inside the elliptical extent of AVF.

To estimate AVF basement depth variation, we model the gravity anomaly components with the overlying Takapuna Gravity High. The effects from the metasedimentary basement and below have been removed, excluding data on AVF volcanic edifices. Some AVF vents are located close to gravity gradient lineaments where basement depth changes, which may be associated with faults. This study identifies previously recognised vent-fault relationships (e.g. Mt Roskill-Te Hopua and Three Kings-Mt Smart) and new ones (e.g. Onepoto-Pupuke and Otara volcanoes). These suggest the role of these structures in channelling AVF magma at the near-surface level.

A summary and interpretation of the recent potential field and carbon dioxide gas flux data of Rangitoto volcano, Auckland Volcanic Field

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We present the results of Rangitoto's recent gravity and magnetic modelling along with new self-potential and CO_2 gas flux data. Gravity anomalies are associated with near-surface dense body and sediment thickness variations, while magnetic data are correlated with the distribution of magnetic basaltic materials associated with Rangitoto volcanism. Independent gravity and magnetic modellings reveal the existence of a near-surface dense, magnetic body under the Rangitoto scoria cone likely associated with a 600-800 m wide, 160-480 m high basaltic body. Meanwhile, a steep gravity anomaly increase at the Rangitoto-Motutapu bridge indicates the likely presence of a basement fault that may channel the Rangitoto magma at depth before being diverted by other near-surface fractures.

Altered scoria cone materials suggest that the volcano might have hosted one soon after its formation, which turned into a hidden hydrothermal system as the volcano cooled. Self-potential data shows a W-shaped anomaly with an 870 m wide, 210 mV amplitude central peak over the scoria cone, suggesting the presence of an active, hidden hydrothermal system. A simple conductive 2D heat transfer model suggests that residual heat from a cooling basalt body, previously modelled using gravity and magnetic data, may still be hot enough to drive the hydrothermal system. We also found an elevated CO_2 gas flux (max 12.2 g/m^2/day) on the scoria cone and upper 500 m of the eastern Rangitoto flank, which we interpret to come from deeper crustal levels than the near-surface basalt body since it is unlikely that this body will still degas post solidification. The CO_2 gas may rise via fractures that are not necessarily the same as the one used by Rangitoto magma.

Application of change-point detection to identify short-term slow slip events in southwest Japan using GNSS data

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Understanding the relationship between slow slip events (SSEs) and damaging earthquakes in nearby velocity-weakening portions of the plate interface is crucial for forecasting large earthquakes, thereby enhancing hazard mitigation efforts. While robust automated methods exist for detecting long-term SSEs, there is a need for similar detection methods for short-term SSEs. In the field of change-point detection, a novel method for piecewise signals has proven effective in automatically identifying change-points across various time series. This presentation explores the application of this method to detect the start and end times of short-term SSEs, regarded as change-points, in GPS data collected from 36 stations in southwest Japan. Our detection results corroborate all previously known SSEs within the analysed period and reveal additional SSEs that had not been identified in past studies. These newly identified SSEs are further validated through the co-occurrence of non-volcanic tremors, hypothesis testing, and fault estimation, confirming their inclusion in the existing SSE catalogue.

Size trends in Zealandian Mesozoic brachiopods

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After the end-Permian crisis, no brachiopods are known from most of the Zealandian Early Triassic (Nelsonian stage). In the following Malakovian, brachiopods are abundant in some nearshore beds near Ohai, along with an ammonoid fauna. A more diverse and wide-ranging fauna appears in the Etalian (Anisian). Brachiopods are generally small.

Nearly all Kaihikuan (Ladinian) marine fossils come from richly fossiliferous shellbeds in the Murihiku Terrane and the Rakaia Terrane in South Canterbury and North Otago. In these beds brachiopods are abundant and some, especially the spiriferinide. Alipunctifera reach large sizes.

In much of the Late Triassic (Oretian and Otamitan, Carnian to Norian), brachiopods are generally smaller, but larger than before the Kaihikuan. Some species, notably the characteristically Maorian *Clavigera* and *Rastelligera*, reach a large size in the Otapirian (Rhaetian).

At the end-Triassic crisis athyrids and retziids were extinguished, and spiriferinides severely restricted. Sizes in general decreased, with small to medium sized forms dominant, especially in offshore faunas. Rhynchonellides are the dominant group, with terebratulides second. Spiriferinides last for much of the Early Jurassic but are common only in the nearshore faunas of the Hokonui Hills.

Much of the Temaikan (Middle Jurassic) is non-marine to marginal marine, and brachiopods are less common. They are usually larger than in the Early Jurassic (commonly medium size). This trend continues in the Late Jurassic, although some large terebratulids are present in the middle Heterian (Oxfordian) Captain Kings Shellbed and overlying beds. Above this, brachiopods are much rarer.

Systematic work on Cretaceous brachiopods is in progress. Size trends with time are not yet clear, but most brachiopods are of small to medium size. Brachiopods are not common, but diversity is maintained, and terebratulides increase in relative abundance, in a trend that leads to their dominance in the Cenozoic.

Modelled Earth system feedbacks associated with the West Antarctic ice sheet during the last interglacial period

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The Last Interglacial (LIG, c.130-116 ka) was characterised by greenhouse gas concentrations akin to pre-industrial levels but with global mean air temperatures 1-2°C warmer and global mean sea level 6-9 metres higher than present day (Dutton et al., 2015). A substantial portion of this sea-level rise may be attributed to a diminished Antarctic ice sheet (Dutton et al., 2015; Quiquet et al., 2013), highlighting the vulnerability of the West Antarctic ice sheet (WAIS) to relatively small increases in temperature. Despite this, current modelling efforts often use modern ice sheet configurations, potentially impacting model reliability (Otto-Bleisner et al., 2020, 2021).

This study employs the intermediate-complexity UVic ESCM to simulate LIG conditions with a modified WAIS, derived from an ice sheet model simulation with LIG boundary conditions (Golledge et al., 2021). We assess the global impacts of a reduced WAIS. Using the RICE ice core and other ice core and marine sediment records, we also evaluate whether modifying WAIS in line with the ice sheet model simulation enhances model-proxy agreement.

Preliminary findings indicate that modifying the ice sheet in UVic ESCM induces warming in the Southern Ocean surface, alters the temperature and salinity structure of the Ross Sea, and affects the Atlantic meridional overturning circulation. These results underscore the significance of incorporating modified ice sheet configurations in paleoclimate modelling, potentially providing a framework for future investigations with higher-complexity models.

Regionally adaptable ground motion models for subduction seismicity in New Zealand

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The New Zealand National Seismic Hazard Model has undergone its first significant revision in 10 years, and a newly compiled high quality ground shaking motion database was built and comprises all the seismic events with Mw≥4 recorded across New Zealand since 2000. Beside this, significant improvements were also done on the evaluation of the local site parameters for stations within the national seismic network.

By exploiting this database, a new ground motion model (GMM) for subduction seismicity was developed for various intensity measures such as peak ground acceleration and 5%-damped pseudo-spectral acceleration up to 10 seconds. Beside common predictors (e.g. magnitude, depth, distances, Vs30), additional parameters were added to quantify the distinct attenuation patterns of the seismic waves observed along and behind the Havre Trough/Taupō Rift for the Hikurangi subduction zone. We observed different trends in the residuals in these regions based on the hypocentral-depth location on the slab and three distinct attenuation coefficients were added for each region in accordance with the observed 3D attenuation. This delineation with depth of the ground motion disappears after 1 second while the effect of the attenuation is still present but reduced at longer periods.

The new GMM has a robust performance compared to regional observations and the forecast capabilities of the different parameters are consistent with the ones computed using the global subduction GMM. The model is recommended for application to interface and in-slab earthquakes with Mw ranging from 4 to 7.8, and rupture distance less than 500 km.

From Taupō-nui-a-Tia to Te Moana-nui-a-Kiwa: Transforming how we monitor our volcanoes below the water

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The field of underwater volcanology is a rapidly developing field, influenced largely by booming developments in engineering, autonomous robotics, gas sampling, and in-situ geochemical analyses. We are a small group of volcanologists working to bring the newest in portable subaqueous technologies to Aotearoa New Zealand and the wider pacific.

New Zealand is in a unique position hosting a variety of underwater volcanoes on and near its shores. From coastal islands to caldera lakes with a relative ease of access, to several deep- sea volcanoes, Aotearoa New Zealand is a perfect testbed for scientists to develop transformational methods for subaqueous volcano monitoring. With industry-leading underwater robotics engineers, and internationally renowned water-quality and hazard monitoring centres as collaborators, we are looking to characterise our remote and underwater volcanoes for the first time.

Here we showcase the tools of our portable volcanic laboratory through case studies from two years of research in both salt and freshwater environments. This includes collaborative endeavours with Boxfish Robotics®, for the customisation of a portable Remote Operated Vehicle (ROV), and Te Toki Voyaging Trust to work on board traditional waka, as well as the use a Pro Oceanus Non-Dispersive Infrared (NDIR) CO_2 sensor and development of our own aquatic technologies. Vital to this work is collaboration with Māori and Pacific peoples to build connection with mātauranga surrounding, and access to, these volcanoes.

This poster will reference the achievements and technical developments of this project so far, including 18 months of PhD studentship, various engineering projects, and ongoing research development in the wider research group. To learn more about the results of the author's project visit their oral presentation, submitted separately.

The volcanic lakes of Te Ahi Tupua (Central Taupō Volcanic Zone, Aotearoa New Zealand)

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Te Ahi Tupua is a region of the Taupō Volcanic Zone (TVZ) that is dominated by geothermal activity across a multitude of volcanic calderas. Monitoring of these volcanic systems is conducted through routine environmental and hydrological initiatives conducted by local and regional councils, iwi trusts, and crown and private entities, but are largely restricted to subaerially exposed sources. Our goal is to make new geochemical measurements to provide baselines for future subaqueous volcano monitoring. Throughout this research, collaboration and co-design has been necessary to develop a scientifically and culturally appropriate plan that provides relevant data and supports Te Ao Māori.

Here we present detailed measurements of the water column at several locations at Te Roto-Whaiti-i-kite-ai-a-Ihenga-i-Ariki-ai-a-Kahumatamomoe, over the period of September 2023 to June 2024. Over this period, we observed the formation and the break-up of the thermocline through performing pCO_2, pH, and temperature measurements at multiple depths and locations. These data showed increases in CO_2 concentration, acidity, and temperature differential peaking in April 2024. Over the same period, we carried out surface flux measurements, including the first ever CH_4 flux measurements on a volcanic lake, as well as CO_2, which show that lake stratification controls seasonal atmospheric emission.

Here we present preliminary calculations of CO_2 accumulation throughout the lake at its peak, which is then transported by lake currents, and emitted through full lake mixing in Autumn, possibly explaining the spatial offset between lake surface fluxes and the known source of the heat in previous studies. Ultimately these data will provide baseline measurements for future volcanic monitoring and ongoing environmental education.

This research is funded by MBIE's 'Endeavour - Smart Ideas'.

The oldest New Zealand sea lion

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Seal fossils from New Zealand are currently limited to just a handful of Plio-Pleistocene sites across Canterbury, South Taranaki, and the north-eastern North Island. Despite their prevalence today, eared seals (otariids) are particularly rare, with a single skull of the extinct Middle Pleistocene sea lion *Neophoca palatina* being the only find of note. Here, we present a new fossil from the Whanganui Basin that belongs to the same lineage as extant New Zealand sea lions (*Phocarctos* sp.). Provisional dating based on stratigraphic context (lower Kai Iwi Group) and associated benthic foraminifera suggests an age of c.1 Ma. The new fossil is by far the oldest representative of *Phocarctos* and may suggest more rapid colonisation of New Zealand by otariids than previously thought.

Monitoring volcanic degassing at Ruapehu

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Gas monitoring of New Zealand volcanoes (including Whakaari White Island and Ruapehu) has relied heavily on measuring SO_2 emission rates by using ultraviolet-sensing correlation spectrometer (COSPEC). The first-ever measurements of SO_2 emissions at Ruapehu were made during the 1995-1996 eruptions and varied between 300 and 15,800 t/d. Since 2004, more frequent measurements (~once per month) have been made and the SO_2 emission rates observed were significantly lower (from 0 to 397 t/d in the period March 2004 to July 2024), consistent with quiescent degassing of the volcano and the presence of a crater lake. SO_2 emission rates abruptly increased to 446 t/d on 29 October 2007, a month after the September eruption and to 708 t/d on 13 May 2008.

In June 2022, GeoNet with the collaboration of the Network for Observation of Volcanic and Atmospheric Change (NOVAC) community installed four scanning mini-Differential Optical Absorption Spectrometers (DOAS) around Ruapehu volcano. These instruments collect data every 5 mins during daylight and offer the first semi-continuous SO_2 emission data from Ruapehu. The SO_2 emission rate data were compared to the COSPEC measurements from gas flights and the data and have been found to be in the same order of magnitude. This higher frequency data provides unprecedented information on the short-term SO_2 emission rate changes related to the gas released from the vents at the bottom of Ruapehu crater lake. Gas emissions observed at Ruapehu have ranged from 0 to 930 t/d since the full deployment of the DOAS network (May 2022 to August 2024). This dataset provides unprecedented insight into volcanic processes and in the assessment of volcanic activity, during eruption and unrest periods, especially alongside other complementary datasets. As an example, detailed SO_2 emission rate observations showed positive correlations with heating and cooling cycles at Ruapehu crater lake.

Evolution of the Leader River in response to a landslide dam triggered by the Mw7.8 2016 Kaikōura earthquake

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The North Canterbury and Marlborough regions of Aotearoa New Zealand were severely impacted by almost 30,000 landslides triggered during the 2016 Kaikōura Earthquake. Of these landslides approximately 200 caused river damming. In the study area, rupture of the Humps and Leader faults (and associated ground motions) initiated at least 42 coseismic landslides, the largest of these being the Leader landslide with a head-scarp 400 m wide and 200 m high, located at the junction of the two faults. This landslide generated a deposit approximately 600,000 m^2 which covered 960 m of active riverbed length, dammed the proximal Leader River and produced Lake Rebekah.

In the eight years since the earthquake, the landslide dam has not been completely breached by the river and Lake Rebekah remains. LiDAR, satellite aerial imagery and drone surveys from 2001 to 2024 present a unique opportunity to chart the evolution of the active riverbed pre- and post-earthquake for up to 2 km downstream of Lake Rebekah. Key timelines for riverbed change events were also constrained through communications with the landowners at Woodchester Station, where the landslide is located. Despite the stability of Lake Rebekah, these data show that the position and morphology of the Leader River has changed significantly to accommodate the landslide, with the formation of two knickpoint waterfalls up to 15 m high, three water bodies (two current, one past), and diversion of the river around the landslide toe. Evolution of the river is characterised by long periods of stasis (e.g. months to years) punctuated by rapid changes in riverbed morphology (hours to weeks) associated with incision and aggradation. Here we present the history of river evolution and consider factors impacting riverbed morphology changes. These factors include rain-storm events, partial lake outburst flooding, spatial changes in Pliocene-Miocene siltstone bed induration and farmer intervention to stabilise landslide dam material.

Overcoming the challenges in marine pollen records to create long records of past vegetation and climate

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In Aotearoa New Zealand, where continuous records of vegetation and climate change beyond the recent glacial-interglacial cycle are scarce, marine sedimentary records offer a unique opportunity to explore climate dynamics over longer timescales. However, when utilising pollen in these records for vegetation reconstructions, we need to consider the impact that differing pollen transport mechanisms could have in biasing a pollen record. We present a new record of past vegetation from the Hikurangi margin from the International Ocean Discovery Program (IODP) deep marine sediment core, U1520D. This 500 m long record covers the Pleistocene and presents an opportunity to investigate vegetation and climate dynamics over the Mid-Pleistocene Transition (a climate transition between 1.2 and 0.8 Ma). Through tephrochronology, foraminiferal analysis, stable isotopes, CT scanning, XRF data, and grain-size analysis, we examine the relationship between turbidite sediment facies and pollen assemblages in IODP-U1520D. We compare our new record to other long records from offshore the east coast of Aotearoa to tease out the taphonomic biases that occur in marine pollen records as a result of transport processes. Understanding and accounting for these pollen biases allows us to utilise marine sediment cores to their full potential and create long records of past terrestrial vegetation and climate. Our study sheds light on the complexities of reconstructing past climate and vegetation from offshore sediment cores, highlighting the importance of considering pollen transport mechanisms when interpreting marine vegetation records.

A national probabilistic coseismic displacement model for Aotearoa New Zealand

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In tectonically active regions such as Aotearoa New Zealand, coseismic displacements are a significant contribution to vertical land motions. In the context of coastal hazards, coseismic uplift has the potential to significantly mitigate the effects of relative sea-level rise, whereas coseismic subsidence may increase the risk for regions previously considered safe. To forecast coseismic vertical land motions in the next 100 years, we developed a Probabilistic Coseismic Displacement Hazard Model (PCDHM) for Aotearoa New Zealand, utilising both the New Zealand National Seismic Hazard Model (NZ NSHM 2022) and the RSQSim earthquake simulator.

Probabilities of displacement exceedances are calculated from 10^5 rupture scenarios utilising the fault geometries, rate models and epistemic uncertainties of NZ NSHM 2022 for both crustal and subduction interface earthquake sources. Additionally, the use of physics-based synthetic earthquake catalogues that incorporate complex multi-fault events allows for displacement contributions to be calculated which include combined crustal-subduction rupture events. This approach allows the individual hazard contribution due to uplift, subsidence, and total absolute vertical land motions to be estimated.

Initial results from the Wellington region indicate a 10% chance of ≥0.25 m of vertical land motion from crustal fault sources in the next hundred years, and a 10% chance of ≥1 m from earthquakes on the Hikurangi subduction interface. While the use of the PCDHM to quantify the likelihood of significant coseismic displacements is a focus of ongoing research, this type of approach may have utility in coastal land use and infrastructure planning.

Geology of Karioi Volcano - 1:25,000 map

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Karioi Maunga is a Pleistocene age stratovolcano (2.58-2.39 Ma) near Whāingaroa Harbour on the west coast of North Island. The mountain is notable as one of several sites on Earth where arc and intraplate basalts erupted together from the same volcanic system. This new map distinguishes the deposits of the Karioi Volcanic Formation from adjacent basalts of the intraplate Okete Volcanic Formation (2.6-2.25 Ma) and underlying Mesozoic- to Miocene-age bedrock. The map area consists of forested mountain terrain, sheer coastlines, harbours, dunes, wetlands and rolling farmland with limited rock exposure. Geologic mapping utilised ground surveys, LiDAR, aeromagnetic data and water well logs to identify and interpret geological structures, including buried volcanic intrusions, lava fields, tuff rings, maar and landslide scarps. Geological units on the outcrop-poor upper mountain were correlated using petrology, major element geochemistry and geochronology (unpublished K/Ar and new $^{40}Ar/^{39}Ar$). The map distinguishes five stratigraphic members of Karioi Volcano comprising 21 edifice and ring plain units, and another 20 units of Okete Volcanic Formation erupted from ≥50 separate vents. Most of the Okete vents are aligned along N and NE trending segments, 5-15 km in length, which coincide with known (or previously inferred) fault fractures in the underlying bedrock. The post-volcanic cover sequence includes clay-weathered rhyolitic tephra and titanomagnetite dune sands which obscure the Karioi piedmont. Two cross sections illustrate the inferred cross-cutting relationships between the volcanic strata, bedrock, and normal faults. The geology is superimposed with historical cultural information, including pā, papakāinga and place names from mātauranga-ā-Tainui. The map and its accompanying text are contained within 'Geology of Karioi Volcano, Aotearoa New Zealand' (published by the Geoscience Society of New Zealand).

The skirmish between arc and intraplate magma below Karioi – a stratigraphic perspective

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This talk summarises the stratigraphy of Mt Karioi and nearby Okete vents as proposed on the 1:25,000 'Geology of Karioi Volcano map' (see related poster). Karioi (756 m) sits at the northwest tip of the Alexandra Volcanic Group, a chain of Plio-Pleistocene basaltic volcanoes stretching 65 km across the western North Island. The eruption of arc and intraplate basalts in close spatio-temporal association is a defining feature of the group and is most obvious at Karioi, where the (intraplate) Okete and Karioi volcanic formations are essentially contiguous within the massif of the stratovolcano. New argon-geochronology indicates that the Karioi edifice formed over ~190 kyr (2.58-2.39 Ma) and was bookended by monogenetic eruptions from >50 surrounding Okete vents (2.6-2.25 Ma). Construction of the Karioi stratovolcano was characterised by: (1) early phreatomagmatic intraplate volcanism, (2) intercalated eruptions of arc and intraplate basalt forming a low-angle cone, and (3) development of a high-angle stratovolcano with ~8 vents that produced basaltic to andesitic lavas, dykes, tephra and ring plain debris of variable arc, intraplate or transitional composition. This relatively complete edifice stratigraphy provides spatio-temporal constraints on the evolution of the Karioi magmatic system, including the competing influences of arc and intraplate magma throughout the 190 kyr lifespan of the stratovolcano, as well as the post-Karioi revival of monogenetic intraplate volcanism. The stratigraphic/magmatic relationship identified between the Karioi and Okete volcanics may be a useful reference for other central volcanoes within monogenetic fields, such as the Miocene Dunedin Volcano and the late Holocene Rangitoto of Auckland Volcanic Field.

Research-informed management of the Fiordland Marine Area

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In 2005, the Fiordland Marine Area Te Moana o Atawhenua was afforded special protection and a groundbreaking collaborative and integrated management regime was established. Some nineteen years later, the Fiordland Marine Guardians continue to advise central and local government on risks to the area and potential mitigations. The management model is well established and tested, yet the pressures the area now faces are more diverse and complex. This presentation will discuss the range of issues that the Guardians and management agencies are focused on, explain the critical role of science in informing management recommendations, and discuss needs and opportunities for future scientific research in this precious part of Aotearoa.

The effect of hydrothermal alteration on the geomechanical behaviour of Whakaari volcanic rocks

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Understanding the geomechanical behaviour and failure modes of volcanic lithologies is integral to monitoring the evolution of volcanic systems. Whakaari (White Island) contains a dynamically active hydrothermal system and is currently New Zealand's most active volcano. This hydrothermal system is responsible for the fatal December 2019 eruption and continues to have eruptive episodes. However, even though Whakaari poses a volcanic hazard, there is minimal data on its static elastic properties. Previous geomechanical work on Whakaari had limited analysis on the effect of alteration, which has only been studied using elastic wave data. Here, we study the geomechanical behaviour of variably hydrothermally-altered andesitic lava, tuff, and breccia rock samples cored from blocks ejected from Whakaari's conduit.

As part of multi-stage triaxial tests using a Hoek cell, the axial and radial strain of these samples were measured in response to axial stress under confining pressures. The confining pressures (2, 5, 10 and 20 MPa) were chosen to simulate conditions in the 1 km deep conduit. Initial results indicate that alteration decreases the strength of Whakaari lavas but increases the strength of Whakaari tuffs. This is evidenced by the peak differential strength/strain hardening onset and static moduli when the samples are brought to failure at 20 MPa confining pressure. At this same confining pressure, the Young's modulus (E) of fresh-to-slightly altered lava (49 GPa) is higher than moderately altered lava (28 GPa), while the E of moderately altered tuff (8-9 GPa) is lower than highly altered tuff (14 GPa). This static moduli trend is concurrent with that of dynamic moduli from sister samples. At failure, lavas exhibited shear deformation, whereas tuffs underwent shear-hardening that is interpreted as pore collapse/compaction. This fundamental work is critical to numerically modelling deformation and fracture/rupture/eruption dynamics, which aims to mitigate future hazards such as eruptions and flank instability.

Characterisation of the 2022-23 unrest episode at Taupō volcano

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Taupō volcano is a frequently active rhyolitic caldera volcano in the central North Island of Aotearoa New Zealand 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. In 2022-23, Taupō volcano underwent a period of unrest with elevated levels of earthquakes and ground deformation, including a M5.7 earthquake that caused a tsunami within Lake Taupō. This elevated activity resulted in the Volcanic Alert Level for Taupō being raised to Level 1 for the first time. Here, we present results from a detailed characterisation of the activity beneath Taupō throughout the year-long unrest episode including a catalogue of earthquake locations, relative relocations, magnitudes and focal mechanism. We focus particularly on the detail in the catalogue that reveal the processes, state and structure of the modern magma reservoir beneath Taupō and builds our ability to interpret future unrest and possible eruption at the volcano.

Drivers of seasonal seismicity in the central Southern Alps, New Zealand

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The central Southern Alps Kā Tiritiri o te Moana is an active orogen with high deformation rates near the Alpine Fault, abundant shallow microseismicity, heavy precipitation, rapid erosion and significant glacier mass loss. These conditions offer a unique opportunity to examine the interaction between seismogenesis and surface atmospheric processes. Understanding the conditions and mechanisms that produce earthquakes is of high scientific relevance with direct societal implications for natural hazards and risk assessment.

We constructed a new decade-long high-quality microseismicity catalogue (11,687 events with local magnitudes between ML -1.81 and 3.42) for the central Southern Alps using matched-filter earthquake detection techniques and seismic data from the Southern Alps Microearthquake Borehole Array (SAMBA) seismic network. The spatial density and long duration of the SAMBA dataset allow us to analyse how microseismicity evolves with time.

Our results indicate a seasonal pattern in earthquake occurrence in the central Southern Alps, with a notable correlation between large, mostly summer, rainfall events and shallow-depth earthquakes (~1-4 km hypocentral depths) beneath the Murchison Glacier. We hypothesise that changes in the water table levels and variations in pore fluid pressure trigger these earthquakes. These events could also be potentially linked to major gravitational collapse processes taking place on the southeastern side of the Murchison Valley.

We plan to further explore this interplay between seismic activity and surface atmospheric processes at Murchison Glacier and other localities around Aoraki Mount Cook using additional climate data, geodetic data and modelling.

The South Island Seismology at the Speed of Light Experiment (SISSLE): Distributed acoustic sensing across and along the Alpine Fault, South Westland, New Zealand

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Distributed acoustic sensing (DAS) is positioned to revolutionise observational seismology by providing dense spatial sampling and temporal resolution. DAS repurposes long sections (1-10s of kilometres) of fibre optic cable into thousands of individual sensors at metre spacing and uses light to measure the ground motion as seismic waves pass through the fibre. The South Island Seismology at the Speed of Light (SISSLE) experiment involved the acquisition of DAS data from two dark telecommunication fibres along the highway near Haast, South Westland, New Zealand, that run perpendicular across the Alpine Fault and sub-parallel to the Alpine Fault and Tasman Sea coastline. The DAS acquisition is supplemented by a deployment of 24 nodal seismometers within 1 km of the surface trace of Alpine Fault. We introduce the experimental setup, share initial processing steps and preliminary observations from the DAS array deployed in two phases for nearly 5 months between late-February and mid-May 2023 and again in October-November 2023.

Maximising geoscience for societal benefit through evaluation of impact

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There is a growing demand and need for science to be societally relevant and for researchers to be able to clearly demonstrate the value of research that is funded by taxpayer dollars. Furthermore, funding agencies are also increasingly looking for projects that demonstrate impact. In the academic sector, research impact is often measured and compared using publication metrics for example the number of publications, citations, and journal impact factors. This definition of impact does not account for scientific benefits beyond the academic sector. However, scientific outputs can feed into the societal pillars through a number of sectors including education, government and commercial.

For geosciences, demonstration of impact into these sectors is often binary in terms of counting deliverables and activities communicating scientific developments back to defined stakeholders; for example, delivery of stakeholder workshops or public talks. While these activities are important and can lead to useful outcomes, there is limited understanding of how impactful these activities are and guidance on how best we can report impact as researchers.

Here we outline our initial impact evaluation framework and discuss how it can be used to both benchmark project outputs and to track progress. This framework was based on reviewing, tailoring, and adapting existing evaluation approaches used to measure scientific impact globally. We examined existing evaluation approaches and metrics used for science research projects as well as the value of more qualitative approaches of measuring impact.

The Raranga Whāriki Papa Moana/Beneath the Waves Endeavour programme (2021-2026) aims to deliver geohazard outcomes across multiple sectors including education, government and commercial. This draft framework will be tested and refined through our product development cycle.

Waikato Region Hikurangi subduction zone consequence planning

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The Hikurangi subduction zone (HSZ) is one of the Waikato region's largest seismic risks and preparing for this event is crucial to support community resilience and preparedness. Waikato Regional Council and the Waikato Civil Defence Emergency Management Group are undertaking a consequence planning exercise supported by a detailed risk assessment to understand the risks from both ground shaking and seismically triggered land instability across the four environments. This will help to inform planning at the territorial authority and regional level to address the impacts on reduction, readiness, response and recovery in response to a HSZ event in the Waikato.

To understand the likely impact of a HSZ earthquake on the built, social, natural and economic environments, a risk assessment is required and has been broken down into three key phases including:

1. Phase one: Exposure assessment.
2. Phase two: Detailed element and area-specific risk assessment.
3. Phase three: Extend methodology to other seismic sources in the Waikato region.

While the HSZ is a significant seismic risk for the Waikato region, other local faults like the Kerepehi, Te Puninga, Wairoa, and Hamilton Basin faults also pose substantial risks, potentially causing more intense shaking in northern territorial authorities. Understanding these local sources is crucial for comprehensive seismic event planning and preparedness, enhancing the region's overall resilience.

Alongside preparing for the next big one, an important role of local government is leading and supporting the reduction of natural hazard risk in our communities. Waikato Regional Council has recently developed a regional liquefaction and landslide susceptibility dataset that is being utilised to support the land use planning decisions through District Plans, adaptation planning, subdivision and consenting applications and general community education.

Interactive tools for the communication of the temporal and spatial distribution of disaster literature in British Columbia, Canada

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In an era of increasing disaster impact, having an in-depth understanding of the state of disaster research in a defined administrative area is of interest to academics and other disaster professionals alike. Such understandings can assist in place-based risk reduction solutions, or in the recognition and filling of research gaps. However, there often exists silos of knowledge between different academic fields and disaster sectors, resulting in uncertainty surrounding what disaster research has been undertaken. While literature reviews are helpful, they regularly remain behind paywalls and may not be presented in ways that are of most use to non-academic disaster professionals. Driven by this issue, we sought to create interactive tools that can communicate the state of disaster and resilience literature within the province of British Columbia, Canada. The tools are a product of a systematic scoping review where we screened 4403 records, before analysing 343 documents based upon inclusion criteria. From this analysis we created two interactive tools to allow for improved communication of what the existing literature base is. First, we created an online, interactive map of the province, which allows users to select different regional districts, or broader areas, to see what research has been undertaken there. Users can then see existing references, along with the natural hazard or broader disaster topic (e.g. community vulnerability) that was focused upon. Visually, the map also shows the most published-upon hazard type in different areas of the province. Secondly, we created an interactive timeline based upon documents that focused upon a certain disaster or hazard event, allowing users to scroll through or select time periods to see which events have been researched. These user-friendly tools have been designed with disaster management practitioners and government organisations in mind, providing a simple way to see where and when disaster research has been focused.

Determining the best core location to develop long lacustrine paleoseismic records

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Lacustrine paleoseismology allows for detailed and continuous records of seismic activity over Holocene timescales. However, the length of these records is often limited by traditional sediment coring techniques, particularly in mountain environments characterised by high sediment yields. This is because, due to the ponded nature of earthquake deposit geometries, cores from the depocentre frequently contain thick deposits which restrict the timeframe that can be captured by a specific core length. Locating cores away from the depocentre can produce much longer but potentially incomplete shaking records due to poor understanding of how earthquake deposits manifest throughout lake basins. We hypothesise that the optimal trade-off between record length and completeness can be achieved by coring depocentral margins. Lake Rotoroa, Nelson Lakes, has experienced three earthquakes in the historic record with seismic intensities exceeding MMI VII: the 1848 Marlborough, 1929 Murchison, and 1968 Inangahua earthquakes. This study uses a transect of 6-metre sediment cores to track the evolution of earthquake-related event deposits throughout the lake basin. High-resolution ^{210}Pb and ^{14}C dating was used to calibrate the historic earthquake record with sediment deposition across the basin. A combination of non-destructive core scanning techniques, grain size and carbon/nitrogen analyses were used to characterise the deposits related to earthquake shaking. We found that sites that sit just above (~10 m) the depocentral basin are ideal locations for recovering cores that optimise both record length and completeness, while sites further up the distal slope do not reliably record all events. Targeting similar morpho-bathymetric locations in other fault-proximal lakes could generate paleoseismic records around 7000 years long, a dataset that can contribute towards understanding of fault behaviour and the likelihood of a rupture cascade following future high magnitude ruptures of major faults such as the Alpine Fault.

The New Zealand Active Faults Database: Recent updates and future plans

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The New Zealand Active Faults Database (NZAFD) contains several datasets of onshore active faults, but until recently, only one dataset (NZAFD-AF250) has been publicly available on the GNS Science webmap https://data.gns.cri.nz/af/. The NZAFD-250 is at a regional (1:250,000) scale and is consistent with QMAP active fault data but is not appropriate for site-specific studies. Higher-resolution (<1:10,000 scale) datasets have been developed for parts of New Zealand over recent years using LiDAR data and are available on regional and local council webmaps (e.g. Hawke's Bay, Horizons, Taupō). Some of these active fault datasets on council webmaps are being served directly from a GNS Science Web Map Service (WMS), others are from static datasets supplied through commissioned studies.

Some major updates have recently been made to the GIS infrastructure used for sharing active fault information and the WMS is now publicly accessible via the GNS Science webmap. New higher-resolution datasets have also been added to the WMS. The data now include high-resolution traces (NZAFD-HighRes), Fault Avoidance Zones and Fault Awareness Areas, which can be viewed when zoomed in to an appropriate scale. Users can also download the reports that describe the high-resolution mapping to obtain more information. Other improvements include the NZAFD-AF250 now being downloadable in near real-time, rather than the timestamped updates that were published on an approximately annual basis. Councils are being encouraged to source their active fault data from the GNS Science WMS, to improve consistency in the data, visualisation and terminologies.

Future plans for the WMS and webmap include adding more high-resolution data and adding a download function for these datasets. Additional priorities include adding other scale datasets (e.g. New Zealand Community Fault Model, New Zealand Paleoseismic Site Database) and investigating the potential to host geotechnical consultancy reports.

Understanding geophysical properties of fluids for monitoring a CCS project at the Kapuni field

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Accurate estimation of a fluid's physical properties under varying conditions of temperature, pressure, and composition is vital for understanding flow behaviour in pipelines, wells, and in a reservoir's pore space; as well as for predicting the geophysical responses of fluid-filled rocks.

Fluid physical properties have traditionally been derived using empirical relationships based on laboratory measurements or by thermodynamic Equation of State (EoS) models. However, properties such as fluid density and speed of sound can vary by as much as ±25% between different estimation methods. These variations can impose unacceptable uncertainties on project design parameters.

A particular challenge with laboratory measurements and EoS models is the behaviour of fluids, such as CO_2, at conditions around phase boundaries. In the potential Kapuni Carbon Capture and Storage (CCS) project, surface process conditions, injection well conditions, and subsurface conditions are all such that CO_2 may exist as a gas, liquid, dense-phase liquid, and supercritical fluid within these environments.

In order to establish a set of preferred base-case properties for CO_2 and in-situ fluids, with robust uncertainty ranges, for the Kapuni CCS project we have compared and contrasted four empirical methods and four EoS methods (some in up to three different implementations). We have established ranges of applicability of the different methods in terms of pressures, temperatures, compositions, and required output geophysical properties. We have also established preferred fluid geophysical properties for pure CO_2, brine, CO_2-brine mixtures, and CO_2-hydrocarbon gas mixtures relevant for the Kapuni CCS project. In an advancement over conventional geophysical practice, we have applied EoS-derived properties for seismic modelling to better-understand the likely monitoring responses from the displacement of in-situ fluids by injected CO_2 and CO_2 mixtures.

This presentation will cover our analysis of the principal applicable empirical relationships and EoS models for CCS projects, its conclusions, and its implications for the Kapuni CCS project.

A comprehensive atlas of Late Miocene to Early Pliocene diatoms from the Pacific Sector of the Southern Ocean

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The planet's strongest current system, the ACC, is connected to three major ocean basins, and responds strongly to global climate variability. It is fundamental in producing new water masses by inducing upwelling, thus directly affecting the Meridional Overturning Circulation (MOC). The current is recognised as a key player in regulating climate due to its control on atmospheric CO_2 concentrations and Southern Hemisphere temperatures. There is a dearth of Cenozoic paleoceanographic data in the Pacific sector of the Southern Ocean. For the first time, three continuous cores were collected during IODP Expedition 383 from the Pacific sector of the Southern Ocean.

A comprehensive atlas of Late Miocene to Early Pliocene diatoms has been generated using common taxa to identify diatom species within the Southern Ocean. Diatom assemblages provide an important proxy for past environmental reconstructions. Individual species are extremely sensitive to changes in climate, resulting from a combination of long-term variations in atmospheric CO_2 and orbital forcing. Currently, diatom stratigraphy in the Southern Ocean 8-4 Mya is riddled with large uncertainties due to a lack of continuous records.

The purpose of this project is to provide a compilation of information to greatly assist in a project of which the record will be delved deeper into over the next several years. Diatom first and last appearances in the Pacific sector will be redefined to improve biostratigraphic datums and will be linked to the geomagnetic polarity record using Constrained Optimisation (CONOP). The recalibrated data will be used to generate an anticipated chronostratigraphy of key geologic and climatic events in the Southern Ocean during the Neogene, also offering a crucial perspective of the evolution of the ACC with a well-dated reference section. Such high-resolution results can be used to better inform models of future climate change and facilitate a new generation of research.

Waitaki Whitestone UNESCO Global Geopark

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In 2023, the Waitaki Whitestone Geopark became the first UNESCO accredited Global Geopark in New Zealand (WWUGGp) and the only one in Australasia.

The UNESCO Global Geopark designation – established in 2015, is one of three UNESCO site designations, with World Heritage Sites and Biosphere Reserves being the other two. There are currently 213 UNESCO Geoparks across 48 countries, with additional Geoparks achieving UNESCO accreditation each year.

Geoparks are about the land, the people, and its stories, being described as "single unified geographical areas where sites and landscapes of international significance are managed with a holistic concept of protection, education and sustainable development" (UNESCO (2016), UNESCO Global Geoparks Celebrating Earth Heritage, Sustaining local Communities, p3).

The WWUGGp covers an area of 7,200 square kilometres. It is renowned for its diverse and spectacular features including Te Kaihīnaki Moeraki Boulders, glacial valleys, braided rivers and limestone cliffs, as well as wildlife, ancient marine fossils, Māori rock art, rich cultural narratives, agricultural heritage, and Oamaru's 19th century Victorian architecture.

UNESCO Geoparks provide educational experiences such as programmes, field trips, research collaborations, exhibits and focused activities. Additionally, they enable a range of geotourism based opportunities including unique experiences that foster local pride and support regional sustainable development.

Geotourism is described as a unique holistic offering where the geology and landscapes of an area are linked to the local ecosystems and cultural aspects. It is through geotourism that local residents and visitors alike can gain insight into past and present interrelationships between the land, ecosystems and people, and through understanding what has gone before, more fully consider and appreciate future relationships between people and their environment.

Geology and origins of Te Riu-a-Māui Zealandia

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One of the outputs of a James Cook Research Fellowship is a short overview paper of the tectonics and geology of Te Riu-a-Māui Zealandia. This presentation shows some of the new graphics and content that have been assembled for the paper.

Zealandia is a c. 95% submerged, 5M km^2 southern hemisphere continent that surrounds New Zealand and New Caledonia. Zealandia is cut by the 45-0 Ma Pacific-Australia plate boundary. Like all continents, Zealandia has a diverse Phanerozoic igneous, metamorphic and sedimentary rock record. The rocks can be divided into pre-Late Cretaceous (>c. 105 Ma) basement and Late Cretaceous to Holocene (<c. 105 Ma) cover. Linear belts of Cambrian to Late Cretaceous (c. 500-105 Ma) batholiths and terranes formed by episodic subduction-accretion processes along the south polar edge of Gondwana. At about 105 Ma the tectonic regime changed. Long-lived subduction was replaced by a regime of Late Cretaceous (105-80 Ma) extensional tectonics and magmatism distributed across much of Zealandia. From c. 80 Ma oceanic crust progressively unzipped Zealandia from Gondwana with final separation of Zealandia from Australia taking place at 60 Ma. Late Cretaceous to Holocene sedimentary cover strata are present in 30 sedimentary basins across Zealandia.

In New Caledonia and the North Island, ophiolitic allochthons were emplaced in response to initiation of west-dipping subduction; eastward trench rollback stranded 40-20 Ma and 15-5 Ma remnant volcanic arcs. Non-subduction-related Cenozoic volcanism in Zealandia includes the 30-5 Ma Lord Howe Seamount Chain and diffuse, low volume, mainly alkaline intraplate lavas.

Decoding the deep: Automated signal classification in OBS data – the RUMBLE project

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The 'Rumble' project at GNS Science aims to classify signals captured by Ocean Bottom Seismometers (OBS), with a focus on identifying underwater mass wasting events, such as submarine landslides and turbidity flows. While leveraging data from the 2014-2015 Hikurangi Ocean Bottom Investigation of Tremor and Slow Slip (HOBITSS) experiment, the project's primary goal is broader signal classification rather than concentrating on slow-slip events (SSEs) as previously intended by HOBITSS.

Rumble utilises a deep learning framework that processes OBS time series data by extracting features, stored in HDF5 files, which are then used to train an Autoencoder model. This model classifies various signals, including those related to submarine mass wasting, seismic events, and marine life. We use this data science approach due to the vast amount of data available. Human identification and classification of all signals recorded over 1.5 years would not be feasible. An API supports data retrieval, while a Grafana-based dashboard allows for quick exploration of features, classification probabilities, and original signals. The project also converts OBS signals into the audible range to explore diverse acoustic and seismic phenomena.

This presentation will discuss the development of the Rumble project's tools, emphasising their application to submarine mass wasting events and other underwater phenomena, informed by data from the HOBITSS experiment. The findings contribute to understanding seismic, submarine landslides and tsunami hazard and give a deeper insight into the wealth of signals recorded in underwater deployments.

Constraining tsunamigenic earthquake sources: Integrating array seismological methods with the W-phase solution for improved far-field tsunami warning

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Tsunami early warning systems are dependent on seismic data and ocean height observations. The Southwest Pacific subduction zones lack a dense offshore network of DART (Deep-ocean Assessment and Reporting of Tsunamis) buoys and limited proximal seismic stations making it necessary to use seismic data at greater distances to quickly constrain the tsunami source. This study, which is part of the R-CET (Rapid Characterization of Earthquakes and Tsunami) project led by GNS Science aims to improve near real-time seismological analysis of regional tsunamigenic earthquakes posing a tsunami hazard for Southwest Pacific countries.

Traditionally, seismic-based tsunami warning methods have relied on earthquake point-source locations, which are too simplistic for large (Mw>7.5) tsunamigenic earthquakes. Recent efforts have attempted to relate the W-phase solution to the rupture area using magnitude-to-fault-dimension scaling relations. However, these relations cannot precisely distinguish the compactness of the rupture (e.g. 2011 Tohoku and 2004 Sumatra earthquakes). To overcome this challenge, a seismological array-based tsunami warning procedure is performed to provide direct spatio-temporal observations of the rupture area for a tsunamigenic source. Two different array processing techniques, the standard FK and MUSIC (Multiple Signal Classification) analysis, were applied to seismic recordings from a recent tsunamigenic earthquake (Mw7.7) in the Vanuatu region, the Loyalty Islands, on 19 May 2023. The results were validated against the post-processing estimates of the finite fault solution for this event reported by the USGS. The utility of this analysis in tsunami forecasts was also compared by threat maps generated from the array source and initial response maps used in real-time response on the day. A comparison was also made with the actual tsunami observations by DART and coastal gauges. The analysis demonstrates the potential to improve initial tsunami forecasts for hazard management before the onset of tsunami waves at deep ocean tsunamimeters through array-based tsunami warning.

Testing the PLUM earthquake early warning algorithm for Aotearoa New Zealand

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Earthquake early warning (EEW) systems are valuable for minimising the impact of seismic events on communities and infrastructure. Therefore, this research evaluates a potential EEW algorithm called PLUM (Propagation of Local Undamped Motion) for a national EEW system for New Zealand.

To evaluate the PLUM algorithm's performance and usability in the New Zealand context, it is necessary to test it using a range of earthquakes. We used a 220,000-year-long physics-based synthetic earthquake catalogue of New Zealand and generated synthetic seismograms using a ground motion simulator. The algorithm was tested for the Canterbury and Wellington regions in terms of alert correctness and timeliness, the effect of different warning radii, and the effect of some sensor failures.

The PLUM algorithm works well in highly populated areas of Canterbury, but not as effectively in some southern parts of Wellington, due to the lack of stations in Cook Strait to provide warnings for earthquakes centred south of Wellington. However, it does not perform well in rural areas of either region because the sensor density is too low.

For the densely populated areas of Canterbury, PLUM could provide Correct Timely Alerts (warning time >0 sec) for more than 90% of the expected shakings in a 100-year interval. Sparsely populated regions with a low density of sensors received fewer Correct Timely Alerts. The most populated areas of Wellington could also receive more than 70% Correct Timely Alerts. The results suggested an appropriate choice of PLUM warning radius for New Zealand would be more than the original 30 km radius designed for the Japan context. The study also demonstrates the robustness of the algorithm under simulated sensor or communication breakdowns, particularly in regions with high sensor density.

Magnetic monitoring of particulate matter on leaves in Ōtepoti Dunedin: Participatory science with preschool and primary students

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Why are some rocks, soils and leaves more magnetic than others? This question was posed to a cohort of Playcentre, community kindergarten, kōhanga reo and primary school students in the 2-5 and 8-13 age groups as part of the Rocks for Tots participatory geoscience project. Leaves became the focus, particularly their capacity to trap airborne ferromagnetic particulates below 10µm in size (PM_{10}) that are associated with vehicle pollution. This is the first time these methods have been applied in New Zealand.

We used environmental magnetic measurements of a variety of vegetation types to examine levels of ferromagnetic PM_{10} around school neighbourhoods in the volcanic setting of Ōtepoti Dunedin. Leaf magnetic susceptibility and saturation remanence ($SIRM_{1T}$) values are positively correlated; however, SIRM1T is the better proxy for PM_{10} accumulation as it is unaffected by the leaves' diamagnetic contribution.

Roadside mean $SIRM_{1T}$ (n=51) is 2.8 times higher than the green space control sample mean (n=29). While lithogenic particulates sourced from the Dunedin Volcanic Group likely elevate the control mean, high $SIRM_{1T}$ values (>$8x10^{-5}$ A/m) are associated with road intersections, school drop-off areas, playing fields and bus stops, suggesting that leaf magnetism is enhanced by vehicle pollution. This link is supported by preliminary scanning electron microscopy and energy dispersive X-ray spectroscopy, which found Fe (+ Co, V, Ti) particles on the leaf surfaces.

Students were involved in sample collection, paleomagnetism laboratory tours, a data analysis hui, and disseminating the results to the community. Furthermore, data is shared through an open-source platform. By including young students in multiple steps of this environmental geology study, we hope to foster environmental citizenship and a clear pathway between scientific research and environmental action, i.e. encouragement of active transportation to school, support for electrification of public transport and stewardship of neighbourhood vegetation as a pollution trap.

Assessing Holocene secular variation and relative paleointensity from Tamatea Dusky Sound and Rakituma Preservation Inlet, Te Rua-o-te-moko Fiordland: Implications for paleomagnetism in carbon sink basins

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Fiordland marine sediments are one of the most efficient carbon sequestering environments on the planet, with thick sequences of carbon-rich sediments filling small basins within the fjords. Holocene secular variation (SV) and relative paleointensity (RPI) are potentially efficient, non-destructive, correlation and dating tools for cores from these basins. Here we present SV and RPI records from two cores and evaluate their fidelity recording Earth's magnetic field.

Piston cores 12PL027-003-P1 and 12PL027-016-P1 were obtained from 169 m water depth south of Girlie's Island, Dusky Sound, and 105 m water depth near Kisbee Bay, Preservation Inlet, Fiordland, respectively. Paleomagnetic direction and intensity was determined at a 1 cm interval down-core on two u-channels, 003-P1A (1.5 m long) and 016-P1A (1.37 m), using the 2G Enterprises superconducting rock magnetometer at Otago. U-channels were demagnetised (alternating field) and Principal Component Analysis identified the characteristic remanent magnetisation (ChRM).

The top 15 cm of 003-P1A and top 45 cm of 016-P1 do not represent ChRM; however, the remaining 135 cm length of 003-P1A is a good recorder of Earth's magnetic field, with a mean inclination of -65.2° (MAD3 2.6°). For 016-P1, mean inclination is -62.1° (MAD3 1.9°) before fidelity decreases again at 126 cm downcore. The expected inclination for the site latitudes is ~-64°.

Environmental magnetic analyses identified changes in magnetic mineralogy, grain-size, and concentration that can be used to appraise suitability for, and normalise, environmental contributions to intensity in sediment records; we use whole-core magnetic susceptibility (κ), anhysteretic susceptibility (κARM), median destructive field and the magnetic grain-size parameter (κARM/κ). Coherence between the normalisers and the RPI signal is assessed using spectral analysis.

Did the most recent surface-rupturing earthquake on the Alpine Fault occur in 1717 AD?

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The Alpine Fault can produce great earthquakes and documenting the timing of its most recent event (MRE) is crucial for seismic hazard assessment. To date, the majority of publications favour an MRE on the Alpine Fault at ~1717 AD. Here we collate radiocarbon and tree-ring count ages of surface-fault rupture, terrace and beach ridge aggradation, mass-wasting deposits in lakes, and tree disturbance. We find evidence for a major event along the southern and central sections of the Alpine Fault in the early 19th century. In addition, historical records describe intense ground shaking and landslide formation along the coast of Fiordland and south Westland between 1820 and 1830 AD. To account for the available data, we propose that the most recent earthquake(s) on the Alpine Fault occurred in the early 1800s, approximately 100 years later than the great 1717 AD earthquake. We cannot determine if the observed landscape and vegetation disturbances were due to a single great earthquake (>M8) or multiple large earthquakes (M7-8). In either case, if our interpretation is correct, the elapsed time since the last Alpine Fault earthquake (~200 yrs) is less than the mean interevent time of ~250-300 yrs and the resulting conditional probability of a rupture in the next 50 years will be significantly less than the 75% that is currently accepted.

Structural controls on the geometries and displacements of Kaikōura earthquake fault ruptures

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The 2016 Kaikōura earthquake ruptured a complex system of more than 20 faults in the northeastern South Island. These faults display a wide range of orientations, lengths, slip type, displacements and slip rates. In this presentation we draw together information from the literature for fault-trace maps, displacement measurements, uplift and bedrock geology to examine what controls the geometries and displacements of the faults that ruptured in the Kaikōura earthquake. The geometries of these faults reflects the complexity of the underlying geology, with the earthquake utilising a range of pre-existing zones of weakness including basement bedding/structures, Cretaceous normal faults, Miocene reverse faults and Cenozoic strata bedding. The resulting fault network is highly connected with thrust faulting providing key linkages at depth. High slip gradients approaching fault tips are consistent with the faults being length limited by stress interactions between faults. Slip transfer between faults and kinematic coherence across the fault system is ubiquitous. The sense of slip on these faults is generally consistent with their orientation and the ~120° regional principal horizontal shortening direction. Our observations help explain the observed rupture patterns including the apparent gap in surface faulting, the absence of slip on the Hope Fault and the role of subduction splay thrusting on the Kaikōura earthquake fault ruptures.

Near-bed sediment and organic carbon transport in Kaikōura Canyon and Hikurangi Channel

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Kaikōura Canyon and Hikurangi Channel are key pathways for laterally transporting sediment and organic carbon from near-shore environments to the deep-ocean on the eastern continental margin of Aotearoa New Zealand. The near-instantaneous offshore deposition of sedimentary materials in response to the Mw7.8 2016 Kaikōura earthquake has been well-documented. However, these events operate on centennial timescales while the importance of sediment transport over shorter timescales is poorly constrained, especially in deep-water environments.

To explore sediment transport under prevailing oceanographic conditions, three benthic landers and three near-bed sediment trap moorings, with associated oceanographic instrumentation (current meters, turbidity, temperature-salinity), were deployed for one year (2022-23) in lower Kaikōura Canyon and along Hikurangi Channel at sites ~300 km and ~700 km northeast from Kaikōura.

Preliminary data on near-bed sediment fluxes show that highest fluxes were observed close to the seabed (lander traps, 2 m above seafloor) and in Kaikōura Canyon. Total mass fluxes ranged from 0.2-2 $g/m^2/d$ in the moored sediment traps (15 m above seafloor) deployed in the Hikurangi Channel, with 2-2.5 times this amount observed close to the seabed. Mass fluxes in lower Kaikōura Canyon were up to an order of magnitude higher than in Hikurangi Channel, ranging from 3-23 $g/m^2/d$ over the annual cycle. Seasonality in sediment fluxes was apparent in the channel, with winter lows and spring-summer and autumn peaks, while fluxes in the canyon were substantially more variable with little seasonality. Particulate organic carbon and nitrogen fluxes were also measured to provide indications of the relative contributions from marine versus terrestrial components based on C:N molar ratios. These observations are the first in the New Zealand region to be made using long-term deployed benthic landers and highlight the significance of near-bed sediment transport on weekly to monthly timescales outside of the catastrophic depositional events that occur on centennial-scales.

Tsunami hazard from afar: Implications for Aotearoa New Zealand

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Tsunamis pose a major threat to coastal communities, both near and far from their earthquake sources. In Aotearoa New Zealand, where most of the population lives near the coast, the risk is heightened due to its location within the tectonically active Pacific. While efforts have largely focused on local tsunami hazards, understanding the impact from regional and distant sources is crucial for quantifying the total tsunami hazard posed to Aotearoa. Our study offers a comprehensive analysis of the coastal tsunami hazard posed by regional and distant earthquake sources across the circum-Pacific. By integrating them into recent local-source studies, we offer a holistic assessment of the tsunami hazard facing Aotearoa New Zealand.

We developed a workflow utilising an established earthquake generator in New Zealand, RSQSim, using slip deficit observations and rate-and-state friction laws, to generate a wide range of synthetic earthquakes on high-resolution, Pacific-wide, subduction zone geometries. For each source, we use elastic half-space equations to calculate the seafloor displacements and simulate the tsunami wave propagation to the New Zealand coast. From these simulations, we can deduce wave amplitudes and timings, assessing the tsunami hazard over various return periods.

We found that distant sources (e.g. South America) can produce a significant land threat with coastal amplitudes greater than 5 m. We have also compared the return periods of local and distant sources to understand how hazard disaggregates between the two. These insights will help enhance community preparedness and stakeholder mitigation strategies, ensuring readiness for future tsunami events.

This work, conducted under the ‘Resilience to Nature’s Challenges’ programme, uses a next-generation approach combining observations, physics-based modelling, and probabilistic hazard methods to assess the coastal tsunami hazard to Aotearoa, which lays the groundwork for a consistent physics-based national model and the potential to include additional tsunami source mechanism in future.

Preservation trajectory of the 2016 Kaikōura coseismic turbidite and implications for turbidite paleoseismology

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Paleo-earthquake records generated from submarine turbidites have been used to produce arguably the longest and most complete records of subduction zone earthquakes around the globe. Demonstrating widespread and synchronous emplacement of turbidites is critical for inferring an earthquake trigger mechanism, routinely achieved by correlating the presence of event beds and their sedimentary structures between adjacent distributary systems along a margin. As such, understanding the preservation potential of coseismic turbidites and their diagnostic characteristics is critical for robust paleoearthquake reconstructions. Yet, time-series observations of post-depositional modification of turbidites are rare.

One of the most measured earthquakes in history, the Mw7.8 2016 Kaikōura earthquake, triggered turbidity currents in ten adjacent canyons along a 200 km length of the southern Hikurangi margin, New Zealand, providing an opportunity to explore the evolution of a fresh event deposit on the lower continental slope (2300-2400 m) and bathyal basin (2800 m). Through 5 years of successive resampling at key sites, we detail the preservation trajectory for the Kaikōura earthquake event bed and facies-defining grain-size bands, vertical grading motifs, physical and biogenic sedimentary structures, observed macrofaunal assemblages, and related facies associations. This novel integrated assessment constrains post-depositional changes and provision to speculate on factors driving preservation. We show that 9-15 cm thick turbidites from different distributary canyons show significant loss of physical sedimentary structures within 5 years of deposition. Thinly laminated silt-rich mud and layering are significantly bioturbated within 5 years, and diagnostically important grain size pulses and grading through planar to convolute silt and fine sand laminations are sometimes destroyed. Despite the magnitude and spatial extent of coseismic turbidites following the 2016 Kaikōura earthquake, repeat coring at key sites suggests that defining sedimentary characteristics of the turbidite are rapidly being lost.

On the origin of tremolite in New Zealand nephrite (including pounamu)

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Nephrite is a metamorphic rock composed almost entirely of tremolite with a distinctive texture of intergrown fibres valued for its toughness and appearance. Globally, it is the most abundant of the two kinds of jade (the other being jadeitite) and has two very different geological associations: serpentinite and dolomite. In New Zealand, nephrite is notable as the predominant variety of pounamu.

We have assessed the origin of tremolite in South Island nephrite in light of previously published geologic and geochemical data in combination with newly calculated fluid-mineral equilibria. In-situ occurrences are in serpentinite adjacent to tectonic contacts with (meta)sedimentary rock (greywacke, argillite, quartz-mica schist) in the Dun Mountain Ophiolite Belt and Otago and Alpine schists. Major and trace elements indicate tremolite replaced serpentine by addition of Ca and Si. Rb-Sr isotopes indicate that Sr and by inference Ca were derived from adjacent (meta)sedimentary rocks during metamorphism. Fluid-mineral equilibria demonstrate that aqueous fluid equilibrated with typical quartz-mica schist could drive replacement of serpentine by tremolite under greenschist facies conditions. Although mass balance estimates have significant uncertainties, complete replacement of serpentine by tremolite most likely required water to rock ratios of >300 to supply sufficient dissolved Ca and Si. Such quantities indicate fluid flow was the principal mechanism of mass transport and preclude internally generated fluid over-pressure during reaction contrary to previous interpretations.

The chronology of the 15 January 2022 Hunga eruption revealed through eye-witness descriptions, tephra and tsunami deposition

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We present an overview of the chronology of the climactic Hunga volcanic eruption of 15 January 2022. This 11-hour event occurred on the 27th and final day of the 2021-22 eruption episode. It is described in seven distinct stages. Pumice raft samples arriving to the shore of Tongatapu on 5-6 January (Stage 0) are associated with eruptions from 30 December 2021 to 2 January 2022, part of sporadic Surtseyan eruptions between 19 December 2021 and 14 January 2022. Shortly before 04:00 UTC on 15 January 2022 the climactic eruption began. Firstly a ~15-20-minute period of lapilli fall occurred (~04:40-05:00 UTC), recorded in phone videos on Tongatapu and Eua (65-115 km from the volcano). The 0.5-5 cm low-density particles formed a clean, sparse layer (approx. 1-2 particles/10 cm^2) and float-equivalent pumice of the same size and composition washed on to the Tongatapu shores in the following days. Next, coarse-medium ash fell (Stage 2), as the island went into darkness. This is covered by a continuous fining-upwards ash sequence. On the western Tongatapu coast, Stage 1 fall is covered by a tsunami deposit (~04:45), Stage 2 fall lies below the ~05:00 tsunami deposit, and Stage 3 lies below the largest tsunami deposit of ~05:45. Stages 4, 5 and 6 are gradually fining upwards (~1 cm each) above the largest tsunami. A final stage fall is represented by a thin layer of fine ash above a tsunami deposit of ~09:00-09:30 UTC. Initial deposits are pumice dominated, becoming finer, denser and less sorted over time. The dispersion axis for the fall was weakly directed towards the ESE. Particle size, shape and density characteristics suggest that apart from the initial 20 minutes, the primary fragmentation mechanism was magma-water interaction.

Geometries and slip rates of recently discovered active faults in Taranaki

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Fault scarps generated by the displacement of the ground surface provide empirical data on the timing and magnitude of pre-historic earthquakes for seismic and tsunami hazard assessment. We use high-resolution LiDAR and multibeam bathymetry datasets to map new and existing active fault scarps across the Taranaki Region and reveal the extent of crustal extension. Mapped active fault traces at the ground surface are confirmed using abundant seismic reflection lines. Over 200 recently discovered individual normal fault scarps have been identified, with many of these faults located in a 25-30 km wide NE-SW zone that intersects, and is largely buried by, Taranaki Mounga. New active-fault scarps have also been identified near Hawera, Waverley and northwest of New Plymouth immediately offshore. Individual faults have vertical slip rates of 0.01 to 0.5 mm/yr, accommodate ~1 mm/yr of regional extension and are estimated to be capable of producing surface-rupturing earthquakes up to Mw6-6.5 (multi-fault earthquakes could be larger). The locations and dip directions of the highest slip-rate faults change systematically across and along the fault system, respectively. Further work is required to understand if the new faults modify the seismic hazard for key infrastructure and urban areas in the Taranaki Region.

How accurate are benthic foraminifera as a proxy for estimating coseismic subsidence?

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Foraminifera are widely utilised for determining paleoseismic vertical land movement (VLM) in marginal marine settings. Here we compare VLM from benthic foraminifera and InSAR to determine whether the geological record can be used to measure subsidence in the Avon Heathcote Estuary during the 2010-2012 Canterbury earthquake sequence. Ten short push cores were collected across the contemporary intertidal profile, to sample both present day and pre-earthquake sequence sediments. GPS Trimble locations were recorded along the topographic profile of the sample locations. The top 1-2 cm and bottom 9-10 cm of the cores were live stained, sieved and foraminifera floated using heavy liquid separation prior to microscope analysis. Each sample was picked, and foraminifera identified and counted to determine the 'fossil record' of tidal elevation. Surface and core samples were compared to determine if a change in tidal elevation, as determined from benthic foraminifera, can be measured between pre-subsidence and post-subsidence.

Preliminary results show a change in the fossil record between top and bottom core samples. A notable difference in species diversity and frequency is recorded. The top 1-2 cm of the cores record species diversity and composition which varies with increasing distance towards the tidal zone. However, core-bottom samples 1-4 show very little to no foraminifera in a part of the site that was previously a grassed supra-tidal area. Bottom samples 4-10 show similar trends to the top core 1-6 samples. Changes in core sample species diversity and frequency show a change in environment between 1-2 cm and 9-10 cm. Benthic foraminifera record 2010-2012 coseismic subsidence in the estuary and support the use of this technique for pre-historic subsidence events in the geological record.

Redefining geoscience through Photovoice

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Photovoice, an arts-based qualitative method within community based participatory research, empowers participants to communicate issues of personal concern by taking, reflecting on, and disseminating photographs. Within the geosciences, photovoice can act as a useful tool for best understanding the factors that impact student engagement and retention. Photovoice was used to assess the impacts of GeoCaFES (Communities and Future Earth Sciences), a ten-week geoscience research program for undergraduate students held at Michigan State University. The GeoCaFES project team hypothesised that Photovoice would reveal aspects of participants' geoscience identities that could not be adequately captured using other research methods.

Undergraduate students participating in GeoCaFES and their faculty and graduate student mentors, collectively termed 'research partners', were trained in the Photovoice method and given three research questions to consider: What is a geoscientist? Where do you belong in the geosciences? What can be done to make the geosciences more inclusive? Research partners each generated two or more photos per week of the program. During the final week of the program, research partners discussed the photos they had taken, reached a consensus on a subset of photographs that best reflected experiences in GeoCaFES and geosciences, and held an exhibition to share their chosen photographs to the public

The results of this study indicate that the demographic and intellectual diversity of the geoscience community, positive mentoring experiences, and opportunities to connect with nature all serve to strengthen research partners' identities as geoscientists and to encourage their persistence within the discipline. Additional themes highlighted within the study, including research partners' concerns about academic burnout and their uncertainty regarding their career paths, suggest avenues for improvement in order to increase student retention in the geosciences.

Experimentally investigating the geochemical reactivity of volcanic ash: Implications for the environment and human health

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Ashfall is the most prevalent volcanic hazard, inducing potentially severe natural, social and economic impacts. However, volcanic ash is enigmatic. Complex feedback loops entangle the unique geochemical, physical, dispersal and magnitude properties. A barrier to geochemical ash characterisation is the requirement for fresh ash, where samples are collected immediately post-eruption to inform immediate geochemical impacts. However, anionic volatile species (F, Cl and S) within volcanic ash are leached upon contact with water, inhibiting a view of the original geochemical composition and the downstream impacts. However, leachable species may be embedded within the highly vesicular historic ash and be extractable via other means. The concentrations of elements analysed on these ground historic deposits could be proxies for the fresh ash compositions.

Here, we present preliminary investigations of possible extraction methods by grinding historic ash to reveal fresh faces. If successful, these methods would widen the tephra available for analysis and allow the inclusion of historic ash in future prediction analysis. We discuss initial similarities and differences between historic and ground samples from three samples from the Taupō Volcanic Zone (Tarawera, Kaharoa and Taupō eruptions). We present micro-CT analysis, which unpacks morphological characteristics, with the chemical characteristics of major and minor elements understood through EPMA and solution-ICPMS analysis. We show possible applications of this method with an Auckland Volcanic Field case study, where, if successful, we can enhance ashfall mitigation strategies for the largest city in Aotearoa.

Investigating conditions for phreatic volcanic eruptions with comparison to Whakaari volcano, New Zealand

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Phreatic or gas-driven eruptions are one of the most common types of volcanic eruption in New Zealand. Reliable precursors are often hidden or absent, leading to unanticipated eruptions that have caused fatalities in New Zealand and overseas. Forecasting efforts can therefore benefit from holistic, model-driven approaches that investigate a system's evolution and physical state prior to phreatic eruptions, particularly when combined with multiple types of monitoring data. Our approach is built on two key components: forward models that investigate potential pre-eruptive conditions, and an inversion technique that can find which conditions best fit observed monitoring data. Using this workflow, we have developed heat and fluid flow models and coupled them with degassing and deformation data.

Firstly, we investigated rates of heat and fluid flow from magma to the surface in 2D using CSMP++ software. We then used Waiwera software to explore near-surface permeability and heat flow conditions associated with pressure build-up in 3D. These models show that reduced permeability within a volcanic edifice, likely due to hydrothermal mineralisation, is a key factor for overpressure that could lead to a phreatic eruption.

Our next step is to combine two established open-source numerical packages, Waiwera and Pylith, to calculate variations in deformation, gas flux, and temperature at the surface in response to changes in hydrologic conditions and the amount of magma-derived fluids being introduced at depth. We then use the Ensemble Kalman Filter (EnKF) to jointly invert geodetic and surface degassing observations from Whakaari volcano, using an evolving Monte Carlo suite to investigate how changes in the system's structure, pressure, and stress state may have contributed to the occurrence of previous phreatic eruptions. This process will provide insights into volcano-hydrothermal systems prior to phreatic eruptions and has potential as a real-time monitoring tool to aid holistic interpretation of monitoring data.

Digital technologies coupled with practical and field experiences can enhance the ability of geology students to practise 3D spatial skills

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Spatial thinking and navigation skills are crucial for success in geosciences, where the ability to visualise in three dimensions is fundamental to understanding our changing planet and its processes. Evidence from the existing literature suggests that these skills are declining in the general populace but, crucially, that they can be improved with practice. In the core areas of structural geology and field mapping, geologists are traditionally trained to 'see' relationships between surface landforms and underground structures, using schematic diagrams, 2D maps and cross-sections, and field excursions to build experience. However, such methods are time intensive, exposure is generally limited to contact time, feedback is often delayed, and providing a comprehensive visualisation of tectonic and geological landscapes is difficult.

To address these challenges and provide more opportunity to practise spatial skills, we incorporated visualisation technology and digital objects into geoscience education to complement real-world experiences. Google Earth and Seequent 3D modelling tools (Leapfrog and Visible Geology) have been integrated as part of core teaching methods across five University of Canterbury geology courses. These technologies are used by students to reinforce what they learn during contact hours, are easily accessible, give immediate feedback, and allow interactive 3D visualisation of fundamental structural concepts in the early learning stages. Additionally, virtual exploration of real-world field areas can enhance in-person field mapping courses, where these technologies provide new perspectives that are notably missing in the field at ground level, particularly the subsurface and wider landscape views.

In-person practical activities and fieldwork remain essential for tactile skills, real-scale contextual understanding, and fostering a deep connection with the subject. Thoughtful integration of digital and traditional methods can create a more engaging and accessible learning environment, while maintaining essential hands-on experiences and providing additional opportunity to practise the core skills of spatial thinking and navigation.

Earthquake scenario development from physics-based simulators: Progress and problematisation

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There is growing interest in the potential applications of physics-based earthquake simulators, particularly RSQsim, in Aotearoa New Zealand, both as a tool for interrogating earthquake processes and for developing earthquake hazard scenarios. Such simulators combine 3D representations of fault network geometry with simplified stress transfer to generate catalogues of synthetic earthquakes. The appeal of these simulators lies in their ability to generate catalogues of synthetic earthquakes much longer than the observational record which can also be used as inputs into downstream models, such as ground motions, landslides, tsunami and economic risk. We present the latest developments in building and refining such models for Aotearoa New Zealand, including a new catalogue for the whole country and more local models assessing regional constraints on stress transfer between faults. We also consider two important questions raised by using simulators to underpin earthquake scenarios:

1. How can we make scenarios based on synthetic earthquakes or synthetic earthquake sequences both comprehensible for downstream audiences and responsive to queries about possible variations (e.g. about the potential for slightly different earthquake sequences or impacts)?
2. What constitutes appropriate testing and evaluation for physics-based earthquake simulators, particularly when the outputs may underpin life-safety decisions?

We outline some preliminary thoughts on these questions with the aim of opening a discussion within the wider Aotearoa hazard and risk community.

Recurrence patterns of shallow Hikurangi slow slip events change along the strike of the margin and after the Mw7.8 2016 Kaikōura earthquake

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Frequent slow slip events (SSEs) occur along the shallow (<15 km depth) Hikurangi margin, which marks the subduction of the Pacific plate beneath the Australian plate in the North Island of New Zealand. In this work, we investigate the occurrence patterns of shallow Hikurangi SSEs using statistical modelling. For that purpose, we first construct a catalogue of these SSEs using the method developed by Ducellier et al. (2022), which uses wavelet analysis to identify SSEs in GPS time series. We complement the method with manual picking of GPS time series to determine the start and end times of SSEs at each GPS station. Using this approach we identify 93 SSEs along the shallow Hikurangi margin between 2006 and 2024. To assess the recurrence patterns of SSEs in the catalogue, we fit a renewal process using Bayesian inference to obtain the posterior distribution of the parameters. These posterior estimates are then used to infer SSEs' inter-arrival time and periodicity. Our results show that SSE inter-arrival time distribution varies along the margin, less frequent SSEs occur in the southern part of the margin (offshore Cape Turnagain) and more frequent events occur in the northern part (offshore Tolaga Bay and Gisborne areas). The periodicity of SSEs also changes along strike. SSEs in the northern and southern parts of the margin occur more regularly than those at the central part of the margin. We also compare the recurrence patterns of SSEs before and after the 2016 Mw7.8 Kaikōura earthquake. Our findings show that the occurrence of SSEs is more periodic after the earthquake, while inter-arrival times do not show a significant change. Our results highlight the patterns of SSE behaviour along the Hikurangi margin and their sensitivity to external stress perturbations.

Seismicity and swarms of the northern North Island, New Zealand, 2012-2024

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The northern North Island of New Zealand (northwest of the Taupō Volcanic Zone, 400+ km behind the Hikurangi Margin) experiences regular seismicity and is home to both the enigmatic Auckland Volcanic Field and actively widening Hauraki Rift. We have deployed a machine-learning based phase picker to locate ~3000 events over the last 14.5 years, the majority of which are clustered and presumably associated with swarm events, mining blasts, and roadworks. In total ~16 clusters (radius <20 km) have been located containing 70 or more events, including three probable mine sites. The three largest include the off-shore Whangārei swarm of 2020 (275 events, largest event MLr4.1), the Te Aroha swarm which began in earnest in 2022 and may have ended in late 2023 (530 events, largest event MLr5.0 x2), and the Whitianga swarm which was primarily active in 2022 (395 events, largest MLr3.4). The Te Aroha and Whāngarei swarms likely correlate to activity associated with the Hauraki Rift, but no notable activity is proximal to the Auckland Volcanic Field. In addition to the Whitianga swarm offshore and east of the Coromandel Peninsula, three other distinct clusters (~120 events each) are present further offshore to the northeast. The Auckland-Hauraki Node Array (X5, 2023-2025, 55 BD3C 5s nodes & five Trillium Compact 120s sensors) was fortunately present for 70+ events of the Te Aroha sequence in winter 2023 and the broadband sensors from this network remain deployed until winter 2025.

New Zealand's multi-taxon deep-time cold-climate legacy, Zealandia's Late Cretaceous cryosphere, and the Plenus Cold Event's evolutionary bottleneck

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Terrestrial environmental conditions that prevailed when Zealandia rifted from the Gondwana margin at c.83 Ma are difficult to characterise because non-marine sediments of appropriate age are rare or absent. Inferences about the Late Cretaceous terrestrial environment can potentially shed light on the selective pressures that influenced the evolution of New Zealand's terrestrial biota after biotic links with Gondwana were severed and the fauna became marooned on a near-polar archipelago.

Late Cretaceous New Zealand lay at high southern paleolatitudes and was extensively ice-covered during the Plenus Cold Event (c.94 Ma). The extent of Late Cretaceous continental glaciation is indicated by the ~10^6 km^2 Waipounamu erosion surface which is here interpreted to represent a subglacial floor. Presence of bouldery glacial lake outburst flood deposits in the non-marine Momotu Supergroup and the apparent absence of glacimarine facies suggest ice sheets did not extend to sea level. The Late Cretaceous terrestrial fauna would have been confined to a narrow, sparsely vegetated, ice-free coastal zone and would have endured months of winter darkness. Fierce katabatic winds and periglacial aridity would have enforced stringent habitat restrictions well beyond the proglacial environment. Zealandia's Late Cretaceous cryosphere would have existed for the ≥~200 ka duration of the Plenus Cold Event and, as ice sheets probably outlasted the cold event, may have persisted longer.

Extant or recently extinct evolutionary derivatives of the Late Cretaceous biota include *Sphenodon*, *Apteryx*, moa (Dinornithiformes), *Xenicus* (Acanthisittidae), wētā (Rhaphidophoridae, Henicidae), *Ooperipatellus* (Peripatopsidae), and *Celatoblatta* (Blattidae). All these unrelated taxa display cold-adapted physiologies coupled with an ability to exploit dark habitats. This multi-taxon cryophily is a deep-time climate legacy reflecting selective pressure exerted on precursor forms during passage through a hitherto-unrecognised Late Cretaceous evolutionary bottleneck. Cryophily and low-light adaptation were inherited from ancestral forms that survived the cold, dark, nival conditions that prevailed in Zealandia's Late Cretaceous near-polar cryosphere.

The National Tsunami Hazard Model – 2021 update and example applications

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Accurately assessing tsunami hazard is essential for efficiently mitigating the risks they pose. The National Tsunami Hazard Model (NTHM) is a statistical model of tsunami hazard that applies a synthetic catalogue approach and uses numerically modelled tsunami scenarios to calibrate semi-empirical equations to estimate peak tsunami heights at the coast for different return periods. The model includes a systematic approach to the modelling of uncertainties that allows for hazard metrics to be generated at specified levels of confidence. The NTHM estimates the combined hazard posed by earthquake-generated tsunamis at all ranges – local, regional and distant. This latest update to the NTHM keeps the underlying method used in the previous 2013 version but updates the earthquake recurrence parameters and tsunami propagation models that underpin the model. In particular, the modelling of tsunamis caused by earthquakes on local crustal faults close to New Zealand has been significantly improved. De-aggregation of the model can be used to identify which tsunami sources contribute most to the hazard at a particular location and return period. Inundation modelling of scenarios from the de-aggregation has been used to assess onshore tsunami hazard and risk as well as to define evacuation zones, and examples from recent studies will be presented.

Celebrating collaboration: Multibeam mapping an extensive mosaic of South Taranaki's sub-tidal rocky reefs through community and scientific outreach

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Without collaboration, mapping offshore reefs can be like 'searching for needles in a haystack'. This presentation introduces the nationally recognised community science initiative, 'Project Reef South Taranaki' and how they came to be involved in a 250 km seafloor survey conducted by NIWA in 2020. We will also look at why the informally named 'Project Reef' (11 km offshore of Pātea, 23 m depth) was included in the multibeam survey.

The topographies of rocky reefs encountered during the 2020 multibeam survey will be shared – including long narrow rock ridges, some extending for kilometres, smaller scattered patch reefs and knolls and a larger raised reef complex. Fault-lines were evident for several of the reefs.

Footage from a 2021 'ground-truthing' of a small subset of those reefs will be shown, revealing a series of complex seafloor geomorphologies, often with many changes over short spatial differences.

Finally, there will be consideration of how multibeam sonar data providing landscape variables such as seafloor slope, aspect, and roughness, at fine scales (tens of metres) can be matched to video segments, and how combined, these ecological and geophysical data-sets could be analysed to answer a range of fundamental questions about South Taranaki's subtidal reefs.

The presentation will include findings from NIWA client report 'Offshore subtidal rocky reef habitats on Pātea Bank, South Taranaki', prepared for the Taranaki Regional Council, September 2022 of which 'Project Reef South Taranaki' is a contributor.

Rediscovering the past: Unveiling the geological legacy of the Albert Park Volcano, Auckland City

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Albert Park Volcano, a significant but misleadingly named geological feature within the Auckland central business district (CBD), is one of the older volcanoes in the Auckland Volcanic Field, estimated to be approximately 145,000 years old. The original form of the volcano, particularly its scoria cone, was destroyed in the mid-1800s during Auckland's rapid development. Today, the Metropolis apartments and Victoria Street carpark cover the inferred main eruptive centre, which likely had multiple eruptive phases. Historical basalt lava flows extend down what is now Queen Street (altering the course of the original Waihorotiu Stream and damming a portion) with a second flow across lower Shortland Street to Fort Street. A post-volcanic stream channel developed west of the original, with basalt gravel erosion deposits extending as far downstream as Britomart Station (evidenced from City Rail Link (CRL) ground investigations). This channel has been 'discovered' several times during linear infrastructure investigations (Auckland Rapid Transit in the 1970s, Britomart Station development in the early 2000s, as well as CRL investigations).

The volcanic deposits from the volcano have presented both challenges and opportunities for urban development in central Auckland. Challenges for both vertical and horizontal infrastructure include variable foundation conditions, differences in ground compressibility and the relocation of Waihorotiu Stream, later known as the 'Ligar Canal'. Conversely, opportunities have arisen including quarrying materials derived from the volcanic deposits and strong near-surface founding materials.

This paper employs a variety of research methods, including analysis of privately held subsurface records, public records, the New Zealand Geotechnical Database, and field walkovers, to uncover information about this obscured geological feature. We present this information to aid readers in understanding the geological history of a portion of the Auckland CBD and how people have responded to these geological influences over time.

Structure and mechanics of the McMurdo Ice Shelf: News from the K062 field camp

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Ice shelves are buttresses that limit the velocity of the ice streams and outlet glaciers that move ice from the Antarctic continent onto the ocean. Understanding the mechanical state of ice shelves is crucial to assessment of their vulnerability to thinning and potential breakup driven by interaction with warmer ocean waters.

Ice shelves are not a uniform mass of isotropic ice. Remote sensing shows strips of ice that correspond to different feeder glaciers, with sutures zones juxtaposing these. The structure and composition of suture zones is not well constrained, but it is clear that they play a critical role in arresting ice shelf rift structures. The inherited ice structure is capped by ice formed from snow that has fallen onto the ice shelf and has marine ice accreted at the base. Useful models of ice shelf mechanics need to incorporate ice shelf heterogeneity and use realistic physical property data for the characteristic ice types.

We will attempt to broadcast this talk directly from a field camp on the McMurdo ice shelf, about 20 km from Scott Base. Our 2024-2025 field programme involves three phases:

1. Geophysical surveys to define the structure of the ice shelf.
2. Drilling hot water holes to ~120 m and collecting televiewer and resistivity data to give more detail on vertical structural and physical property variations.
3. Drilling and bailing hot water holes and then using mechanical corers to collect ice samples to measure physical properties.

At the time of the GSNZ conference we will be towards the end of phase 1 and hopefully will have some results from radar, transient electromagnetic soundings and hammer-plate seismics. In addition, we may have televiewer and resistivity data from test holes. Hopefully our presentation will allow the audience to get close up to Antarctic fieldwork.

100 years of spore-pollen biostratigraphy in New Zealand: Progress and possibilities

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The first New Zealand results in this newly established field appeared in 1924 when Gunnar Erdtman studied pollen and spores extracted from Chatham Island and Otago peats, but a more substantial account of late glacial and Holocene postglacial vegetation history was published in 1936 when Auckland botanist Lucy Cranwell collaborated with another Swedish palynologist Lennart von Post to produce pollen diagrams from six southern South Island peat bog cores. These showed three distinct intervals: a late glacial grassland period with severe climate, a podocarp forest period with warm, wet climate, and a final *Nothofagus* forest-grassland period with cooler climate extending to the present day. With refinement of detail, accompanied by precise dating from radiocarbon, tephrochronology, and recognition of Polynesian and European influences, the general character of Cranwell & von Post's results has been confirmed in regional studies by a great many authors.

Some of these vegetation and climate history studies have extended further back into the Pleistocene, but pre-Quaternary research with a greater focus on biostratigraphic dating for geological mapping and resource exploration has been mainly carried out at the New Zealand Geological Survey and GNS Science, with some overseas contributions. Palynofloras have been reported from all geological periods back to the late Permian; the older palynofloras understandably show considerable similarities with those of then-adjacent Eastern Australia, but there was increasing divergence after the Jurassic.

Notable gaps in providing a well-developed biostratigraphic zonation occur in the Late Jurassic to mid-Cretaceous (upper Kawhia to Raukumara Series), and late Miocene-Pliocene (Taranaki and lower Wanganui Series), intervals of interest for tectonic, vegetation, and climate history. Both intervals can be partly covered by study of known sections, using parallel dating from marine organisms, and remain challenges for the future.

A sub-Quaternary geological map, Te Waipounamu South Island and Rakiura Stewart Island

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Conventional geological maps depict the shallowest significant geological units and typically indicate rock or sediment associations based on composition, emplacement process and age. Aotearoa New Zealand's Quaternary units are generally poorly consolidated sediments or volcanic rock/tephra that cover about a third of the land area based on the national 1:250,000 geological map. As the dominant substrate to urban areas, infrastructure and agriculture, Quaternary units are very important but they also mask and complicate understanding of older geology. A sub-Quaternary geological map has been compiled for northern, western and southern parts of Te Waipounamu South Island and Rakiura Stewart Island, mostly by interpolating and extrapolating older rocks depicted on the national 1:250,000 geological map under Quaternary units, lakes and immediately offshore. The interpolation/extrapolation has been guided and augmented by stratigraphic and other geological principles, structural geology, borehole logs and aeromagnetic and other geophysical interpretation.

Knowledge of the rock units that Quaternary deposits mask is important for applications such as natural resource exploration/extraction and deep-time geological understanding. The sub-Quaternary geological map is being utilised for the Pluton Map project that is characterising Te Waipounamu South Island and Rakiura Stewart Island plutons in terms of geochemical and other physical properties and attributes. The sub-Quaternary geological map, with Pluton Map-led changes, is also part of a future upgrade of the 1:250,000 Geological Map of New Zealand digital dataset. Other anticipated uses for the sub-Quaternary geological map include the potential for locating buried hard rock aggregate resources, better understanding of groundwater resources in rock and for exploration for metals, low enthalpy geothermal heat and natural hydrogen.

Exploring seismicity and structure at the Alpine Fault using distributed acoustic sensing

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The South Island Seismology at the Speed of Light Experiment (SISSLE) is a distributed acoustic sensing (DAS) seismic study of the Alpine Fault around Haast, New Zealand. This study, which was conducted over 120 days in 2023, utilised a 30 km section of unused telecommunication optical fibre that follows the Haast River and crosses the Alpine Fault. Using a combination of ray tracing and wavefield modelling we demonstrate that: 1) earthquakes within 50 km of the fibre can be successfully relocated using DAS-based measurements and that 2) delayed arrival times for these relocated earthquakes may inform on sediment-filled depressions along the Haast Valley. Optical fibre is widely deployed for telecommunication in New Zealand; these results illustrate the potential of DAS for both monitoring geohazards and identifying near-surface structures at the Alpine Fault, and around New Zealand.

24/7 monitoring and rapid response to tsunamigenic events in Aotearoa

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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 tsunami, earthquakes, volcanoes, and landslides. Evaluating tsunami threat is a high priority, not only due to the significant risk posed to coastal regions with the potential of onshore wave arrivals in less than an hour, but also due to the ambiguous nature of determining tsunami threat with the limitations of assessing large offshore earthquakes using New Zealand's seismic network distribution. Monitoring has evolved substantially, particularly with the addition of the New Zealand DART (Deep-ocean Assessment and Reporting of Tsunamis) network in 2020.

The DART network, comprising 12 strategically placed buoys in the Southwest Pacific, is used in conjunction with the Tsunami Gauge Network, consisting of 17 tide gauges positioned around New Zealand coastlines, Raoul and Wharekauri Chatham Islands. This combined network facilitates the immediate detection of local, regional and distant source events, enabling rapid tsunami assessment and advice. Additionally, it provides rapid information when tsunami generation is uncertain after large earthquakes or other potential trigger events.

The NGMC has responded to several tsunamigenic events including those generated by earthquake and volcanic activity, notably the March 2021 East Cape and Kermadec Island earthquakes and the January 2022 Hunga Tonga-Hunga Ha'apai volcano tsunami. It has also responded to numerous non-event-based auto-triggers which offer valuable insight into the evolution of our monitoring and operational procedures.

We will discuss the process of monitoring and analysing data during response, from initial assessment, utilising a database of pre-calculated scenarios in TOAST (Gempa's Tsunami Observation and Simulation Terminal), through to escalation of the Tsunami Experts Panel (TEP) with more detailed analysis of real time observations. This process typically occurs within the first hour of an event, underlining the NGMC's purpose to rapidly assess risk to Aotearoa and enabling quick dissemination of essential information.

Ancient mitogenomes and morphometrics reveal a new species of extinct large insular shelduck from Rēkohu Chatham Islands

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Rēkohu Chatham Islands, 800 km east of mainland New Zealand, exhibit high levels of species endemism. The islands supported a rich anatid fauna comprising at least eight species at the time of east Polynesian settlement in the 13th Century CE. Here we describe a new extinct duck from late Quaternary subfossil bone deposits on the Chatham Islands. Phylogenetic analysis of complete mitogenomes and geometric morphometric analyses confirm the Rēkohu shelduck was the sister taxon to the paradise shelduck from mainland New Zealand. The ancestors of the Rēkohu shelduck colonised the Chatham Islands around 390,000 years ago during the Middle Pleistocene and rapidly evolved to be more terrestrial and flight-reduced with short, robust wing bones, and long leg bones. The presence of Rēkohu shelduck bones in early Moriori midden deposits suggests its extinction was due to over-hunting, environmental modification, and predation from kiore Pacific rat prior to the European and Māori settlement of the islands in the 19th Century. This new discovery is put in the wider context of the biogeographic origins of birds in the New Zealand region, which is increasingly cosmopolitan – a hypothesis first proposed by Sir Charles Fleming, the grandfather of New Zealand paleontology.

Measuring a volcano's breath: Young volcanic plume emissions reveal elevated magmatic degassing amidst a long heating cycle of a hyper-acidic volcanic crater lake (Mt Ruapehu)

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Te Wai ā-moe (Mt Ruapehu crater lake) sits on top of Mt Ruapehu's magmatic system, whose complex interaction with exsolving magmatic and hydrothermal fluids has generated unheralded, gas-driven catastrophic eruptions over the last 80 years, and has led to an increase of its alert level twice over the last four years. Even though Te Wai ā-moe has a predominantly closed-vent appearance, in-situ geochemical monitoring of its lake and plume compositions have revealed vitality during the 3-12 month-long lake heating cycles that includes distinct upwelling plumes and elevated degassing. Here we describe detailed volcanic gas and aerosol measurements with in-situ sampling instruments (multiGAS, filter packs, cascade impactors) conducted at the lake outlet on 5 April 2023, in collaboration with Ngati Rangi and GNS Science. While observations on the day showed little-to-no visible clues of volcanic emanations at the lake surface, volcanic gas measurements revealed the presence of a sustained, but invisible, volcanic plume with strongly elevated and fluctuating magmatic gas concentrations with negligible hydrothermal overprint over two distinct phases: an initial 90-minute degassing phase with homogeneous plume compositions (avg CO_2/Stot = 4.5) that included halogen degassing, followed by the onset of a 2h-long phase of fluctuating heterogenous plume compositions (avg CO_2/Stot = 3.9) including secondary volcanic aerosol formation. Both phases show exceptional overlap with gas compositions measured in the aftermath of previous phreatic eruptions providing crucial insights into potential geochemical processes occurring at depth going unnoticed thus far during this exceptionally long lake heating cycle. This study therefore provides the first comprehensive update on Te Wai ā-moe's plume compositions in over ten years, highlighting the advantages of combined deployments of modern, high-resolution in-situ gas and aerosol measuring instrumentation for monitoring future volcanic unrest.

Winners and losers in the New Zealand flora since the Miocene: The effects of changing climate on vegetation in southern Zealandia

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Starting in the Miocene, southern Zealandia's climate changed as a result of global cooling, northward migration of cold Antarctic Ocean and air masses, and uplift of the Southern Alps. Such a dynamic physiographic environment makes southern Zealandia a model system for understanding the effects of changing climates on vegetation composition. Alpine and cooler lowland habitats started to emerge in the late Miocene, together with expansion of non-forest ecosystem lineages, especially herbs and small-leaved woody shrubs. Miocene arrivals like Plantaginaceae and Asteraceae joined already established Ericaceae and Rubiaceae to become diverse and widespread in Zealandia. Nothofagaceae forests are abundant today from lowland to subalpine levels; however, in the Miocene these forest trees had larger leaves and were more diverse, with some forests ecologically similar to deciduous forests in central Chile, and others to those in upland New Caledonia. While many conifers persisted through the Miocene, and some genera diversified, at the genus level, overall diversity decreased with the local extinction of *Araucaria*, *Microcachrys*, *Retrophyllum* and large-leaved *Podocarpus*. Furthermore, reduced seasonality, as much as cooling, may have led to homogenisation of lowland forests, leading to a loss of diversity in taxa adapted to more open vegetation and potentially fire, such as Proteaceae, Fabaceae, and Casuarinaceae. Instead, cool-growing humid and aseasonal lowland rainforest favoured a lush and diverse understory, especially ferns. Finally, in certain well-studied groups such as Lauraceae, significant species-level diversity loss is also evident. Overall, the fossil record indicates that antecedents of much of the modern New Zealand biota and ecosystems emerged in response to drastic changes in physiography and climate during and since the Miocene.

Magnetic fabric analysis of laboratory deposited sediments to investigate paleo Antarctic Bottom Water velocity

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Antarctic Bottom Water (AABW) is generated around the Antarctic margin and is a vital part of the global thermohaline circulation system. Numerical models indicate that AABW production is at risk because of fresh water input from ice melt and warming due to anthropogenic climate change. With limited oceanographic observations of natural AABW variability in the Southern Ocean, paleoceanographic reconstructions from sedimentary archives can shed light on the range of current variability. The 'Sortable Silt' fraction of ocean sediment (10-63 µm) is one method used to infer paleo-current intensity; however application of this method is time-consuming, the proxy is yet to be calibrated, requires adjustment for fine ice-rafted debris, and is unsuitable for low current speeds of the AABW.

Magnetic fabric (AMS – anisotropy of magnetic susceptibility) analyses offer an alternative way to reconstruct ancient current velocity. AMS measures the degree of mineral alignment in sediments, which reflects the water current velocity. Despite advancements in analytical techniques and applications, fundamental laboratory experimental magnetic fabric research has not been conducted since the 1970's and a calibration for AMS to current velocity is still to be developed.

In this study, we will attempt to use laboratory flume experiments to develop a calibration of the AMS paleo-current proxy, which we will then apply to drill core sediments around Antarctica, to provide insight into deep ocean current dynamics such as the AABW. Here we present results from preliminary laboratory experiments, and paleomagnetic and AMS data from ODP drill sites 1095, 1096 and 1101.

Landon Series biostratigraphy - developments over the last few decades and Ewan Fordyce's role in shaping our understanding of Zealandia's Oligocene Epoch

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The Oligocene is a globally significant time of change in the world's oceans, marking the onset of a cooling world. Microfossils have been a challenge to utilise as biostratigraphic makers across the Oligocene due to the dearth of clear and widespread bioevents available.

Oligocene outcrops in the Waitaki region were the focus of Professor Ewan Fordyce's four decades of paleontological fieldwork, as the rocks yielded copious globally rare and significant early baleen whales and dolphin fossils. Biochronostratigraphic controls have been a critical component of interpreting the fossil marine mammals' complex adaptive radiations and extinction patterns during their rise to dominance in the seas. Fordyce worked closely with, and mentored other, key microfossil, vertebrate and invertebrate experts to keep the focus on exploring and understanding the paleontology and stratigraphy in the Waitaki region. This made it possible to tease out cetacean evolutionary history at higher resolution, and also kept biostratigraphy an active scientific tool in the region. An overview of Ewan Fordyce's relationship to, and mentorship of, key biostratigraphic research is presented here.

Assessing the biostratigraphy of the Oligocene for the upcoming revision of the New Zealand Geological Timescale, Fordyce has been both a supporting actor and at other times a bellwether for interpreting the ages of Canterbury Basin stratigraphy, which are critical rocks for defining and understanding the Oligocene epoch in Zealandia.

A stratotype section and point for the base Duntroonian is proposed for the lower strata at the site of the Hakataramea Limestone Quarry, South Canterbury.

Modern sedimentary spatial redox variations in New Zealand's fjords

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Fjords, including Fiordland, New Zealand have been identified as major marginal marine 'hotspots' for carbon burial of organic matter. Research suggests that the concentration of bottom water dissolved oxygen (DO) impacts organic matter oxidation therefore influencing carbon burial within fjords sediment basins. Yet, the impact of bottom water DO concentrations for the long-term storage of organic matter has been poorly constrained. Freshwater discharge, tides and wind forced water column mixing and fjord topography all impact fjord circulation which in turn with the addition of primary productivity control bottom water DO concentrations.

Metal-based reduction oxidation (redox) sedimentary proxies provide a method of understanding the bottom water DO variations and can be used to reconstruct past DO conditions. The principle behind most metal-based redox proxies is under oxic conditions metals are dissolved in the water column while under anoxic and euxinic conditions metals are reduced into insoluble forms and are deposited within the sediment, capturing the water column DO concentration during sedimentation. Metal-based redox proxies have commonly been applied to marine environments which undergo redox condition variations yet have rarely been applied to fjord systems.

Fiordland provides the ideal location due to high rates of terrestrial organic matter inflow and minimal anthropogenic release of metals. Using quadrupole inductively coupled plasma mass spectrometry of 71 surface sediments from the basins and sub-basins of Milford, Bradshaw, Doubtful, Dusky and Long sounds, from a range of redox conditions, a suite of metal-based proxies have been evaluated to see if they correctly identify modern redox conditions and quantify subtle and large-scale redox variations within Fiordland. Proxies which have been identified to reliably show modern sedimentary redox variations include Cd/Mo - Co x Mn(%), UEF, MoEF, MoEF/UEF, U/Th and V/Cr. Therefore, these proxies could be applied to downcores to reconstruct past climate-driven redox conditions.

The University of Otago Geology Museum fossil database

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The fossil collections held in the University of Otago, Department of Geology (vertebrates, invertebrates and plants) are among the most important collections in New Zealand and are of international significance. The fossil collections are being digitised, using the taxonomic database software package Specify. The searchable database is already accessible online to anyone and has a user-friendly search interface.

Specify produces a searchable record of each collection, including the following information on each specimen; description, preservation, taxonomy, locality, age, stratigraphy, publication citations, collectors, preparations and storage.

All published and catalogued vertebrate materials in the vertebrate collection are now in the database including 1412 specimens with 478 images, and pdfs attached to 215 specimens (as of 23 August 2024). The invertebrate collection has 2512 specimens in the database with 750 images, and pdfs attached to 673 of the specimens. The plant collection has 554 specimens in the database with 140 images attached to specimens. More images are being added; ideally each specimen has at least one image or illustration.

By early 2025 the database will have more than 6,000 specimens entered. Papers listing all holotype specimens held in each collection are published (vertebrates) or in preparation (invertebrates and plants). However, as the collections hold 60,000 specimens, there is still a lot of work to be done.

Exercise Rū Whenua: Building an Alpine Fault earthquake scenario for a national-scale emergency management exercise

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Emergency management exercises are critical for readiness and response planning, allowing local and national agencies to practise crisis response and identify gaps and issues. The identified lessons can be integrated into plans and procedures that improve our ability to respond to and recover from emergencies. Essential to these exercises are detailed and realistic scenarios based on up-to-date scientific understanding that focus on the likely impacts triggered.

In 2024, the National Emergency Management Agency (NEMA) facilitated a national-level exercise (Exercise Rū Whenua) to test Aotearoa New Zealand's arrangements for responding to and recovering from a major earthquake with inter-regional impacts requiring a nationally coordinated multi-agency response. The exercise was structured over three days; Day 1 was a real-time event representing an earthquake in the early morning during midweek in June. Day 2 considered how the impacts from such an event might vary at different times of the day and year, with a particular interest in identifying the 'worst case scenario'.

To develop the scenario, an interdisciplinary team of scientists and emergency managers were convened to identify existing knowledge and gaps in our understanding. This presentation will outline and reflect on the processes undertaken to develop a plausible disaster scenario for an emergency management exercise. Importantly, it required a strongly interdisciplinary approach, combining natural hazard and risk modelling with engineering and social science to develop detailed estimates of the human and environmental impacts. It also acted as a catalyst to rapidly undertake novel modelling of human impacts, in terms of population exposure and household disruption. Combining existing information with bespoke models and often expert judgement necessitated clear descriptions of scientists' 'level of confidence' in the outputs produced. The lessons gained in developing the Exercise Rū Whenua scenario may serve as important guidance for future exercises, irrespective of the chosen scenario or hazard.

Five years of tsunami monitoring with the New Zealand DART network: Detections, issues & perspectives

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In December 2019, New Zealand started to deploy what became in December 2021 the fully operational Deep-ocean Assessment and Reporting of Tsunamis (DART) network of the Southwest Pacific region. This critical contribution to tsunami monitoring in the Pacific Ocean came in addition to the Australian and US DART system already active in the region. Composed of 12 permanent bottom pressure recorders (BPR) deployed between ~2,000 m and more than 5,000 m deep at the Hikurangi-Kermadec-Tonga subduction zone, and offshore New Caledonia and Vanuatu, the network was designed to detect any tsunamis triggered within 30 minutes of propagation time of a sensor. So far, it allows us to record more quickly medium-size tsunamis, for instance like those generated by the Mw7.7 10 February 2021 Matthew Island earthquake, the triplet earthquakes of 5 March 2021 in the Hikurangi-Kermadec subduction zone and the 15 January 2022 Hunga Tonga-Hunga Ha'apai volcanic eruption. The 4G DART systems' high sensitivity even enabled them to record the very small tsunami coming from the South Sandwich Islands (southern Atlantic Ocean), in August 2021. Most of the automatic detections were due to the earthquake shaking preceding the tsunami waves. However, some automatic detections have also occurred without an earthquake or a known source like a volcano, specifically on DART NZA, located off Cook Strait. The related signals recorded by the BPR look very different from the tsunami waveform. In this presentation, we will discuss the effectiveness of the network during the 5 years of activity using examples of recorded signals and discuss the unexplained automatic triggers. We will also discuss the limitations of the DART system itself, and those involved by the predefined maintenance voyages. Finally, we will show different perspectives on the use of the network, for monitoring tsunami, but also for fundamental research.

A sand balance model of the lower Rangitata River

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Excess fine sediment can alter fluvial form, ecosystem health and groundwater recharge, and altered hydrologic regimes due to changing water use or climate can alter the fine sediment balance. The dynamic nature of braided rivers make small scale surveys unusable, but recent advances in large scale LiDAR surveys enable census-level maps of fluvial substrate that resolve fine sediment cover. High-resolution topographic data can drive hydrodynamic models simulating sediment transport potential and short periods of river change. However, long-term bed evolution over decadal timescales remains elusive and expensive, especially in large braided rivers.

In this paper, we leverage new high-resolution maps of braided river facies to parameterise a simple sediment transport model, CASCADE, to interrogate the sand balance in the lower Rangitata River, New Zealand. Simulations are constrained using repeat LiDAR-derived substrate surveys. Previous applications of CASCADE represent channel morphology and sediment cover in a width averaged 1D framework. While this generalisation may be appropriate for simpler single thread channels, representing sediment transport in morphologically complex braided rivers requires an alternative approach. Here we use distribution functions parameterised using spatially explicit hypsometry and steady-state 2D hydrodynamic simulations to capture the complexity of flow and transport processes in a large braided river.

The 1D CASCADE simulations are used to examine process responses at multiple temporal scales: the postglacial incision, the period of recorded flows, and the single event scale. Deficits or increases in sediment supply result in changes in the elevation profile as well as substrate composition. Preliminary results show the balance between large-event deposition and medium event reworking is the key to matching the observed depositional mosaic in the Rangitata River, and the impacts of flood harvesting are estimated in terms of deposited sand.

An integrated 3D ‘interseismic’ GNSS velocity field, updated strain-rate maps, and geodetic slip-deficit-rate models for Aotearoa New Zealand, plus some questions

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For use in the evolving New Zealand National Seismic Hazard Model, the Te Ao Hurihuri Our Changing Coast programme, and future geodetic and solid-earth research, we assemble an integrated 3D ‘interseismic’ velocity field for Aotearoa New Zealand by combining 18 GNSS velocity fields from 15 sources (as of time of writing). We manually inspect each GNSS dataset and filter out velocities that have short occupation times, appear heavily affected by transient deformation, or are otherwise evident outliers. The integrated velocity field (thanks to the studies that go into it) provides improved (and 3D) coverage of surface motion in many parts of New Zealand, in particular Auckland/Northland and Otago/Southland. Strain rate models estimated from the integrated velocity field have lower strain rates in these regions than previous models. GNSS stations in these slow-deforming parts of New Zealand, and elsewhere in the southwest Pacific, are observed to be subsiding at 1-1.5 mm/yr. Some (possibly most) of this motion can be attributed to global solid-earth elastic deformation in response to ongoing ice loss. There is uncertainty about whether any of the subsidence signal arises from drift of the centre of mass of the Earth system (what GNSS satellites orbit around) relative to the centre of mass of the solid earth, and whether such a drift would need to be corrected in preparing vertical land motion (VLM) models. In light of these uncertainties and the variety of possible downstream needs, we prepare three alternate versions of our velocity field, in which we either remove the regional median vertical rate from each ingoing dataset, remove half of that median rate, or leave the velocities as they are. Finally, we use the new strain rate models to make new estimates of slip deficit accumulation rate on faults in the New Zealand Community Fault Model and the Hikurangi and Puysegur subduction zones.

Resourcing the future: Changing the concept of ore

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From Agricola's time to today, ore has been defined as a naturally occurring solid material from which a metal or valuable mineral can be profitably extracted. As this country refocuses attention on economic and critical minerals, with dual aims of geopolitical resilience and regional prosperity, it's worth revisiting the concept of ore.

The New Zealand Government's proposed minerals strategy to 2040, and the recently released GNS Science report on the mineral potential of New Zealand, highlight opportunities and challenges of reinvigorating a relatively quiet (with some notable exceptions) sector.

The rationale is clear: on a per capita basis, demand for metals and minerals is increasing despite increases in recycling. Agriculture, infrastructure and the transition to a low-emissions future require extraction, and it comes at a cost.

New Zealand's fast-track legislation aims to reduce costs by addressing the issue of timing for consents, but, globally, there are deeply embedded and long-standing challenges for the sector in delivering a stable supply of materials. Examples include lead times from discovery to production, vulnerability of suppliers in small markets (currently many critical metal sectors), and market volatility due to geopolitics. But other factors are equally important: job security and satisfaction, environmental performance of current operations together with legacy issues, and public perception.

So, right when the industry has its greatest opportunity because of the energy transition, it is also facing its greatest challenge. In New Zealand, that manifests as a serious pipeline issue and a determined anti-mining sentiment.

In our view, the prevailing concept of ore is part of the problem. We argue that ore is better defined as a material from which a metal or mineral can be extracted to create value. This definition opens entirely new conversations that can only be good for society, the energy transition, geoscience, and the minerals sector.

Discovering ‘The Secrets of Rocks’ and lessons from other outreach projects in Chile

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Understanding geological processes is crucial to build resilient communities, especially in tectonically active regions such as the Chilean Andes or Aotearoa. However, it is frequent that the population outside of the scientific world is not necessarily familiar with these topics, leaving a knowledge gap that must be covered.

To bridge that gap, we designed and built an interactive and educational geological exhibition at the Pan de Azúcar National Park in Chile. The park was an ideal place for this project because it is a protected area home to a unique and fragile endemic biodiversity, has rich landscapes and a privileged display of rocks that tell a 300-million-year story of the formation of the Andes. The exhibit was designed to teach key geological processes using simple language, in both guided and self-guided tours, and features two main areas: an outdoor geological trail and an indoor interactive space with a lab where visitors can explore the properties of rocks, minerals, and fossils.

This project was funded through a grant of the Chilean Ministry of Science, Technology, Knowledge, and Innovation (CIENCIA PÚBLICA-1201219), with collaboration from public, private, academic, and local institutions. Much of the geological content was derived from university-level field mapping courses. The exhibition has enriched the region’s tourism, educated park rangers, tour guides, and the local community on the earth sciences, giving value to the geological heritage of the region. Similar projects across the country have also succeeded by creating permanent or itinerant exhibit spaces and developing resources like books and geology guides. We suggest that implementing such models in other areas could effectively drive geological education and knowledge transfer in Chile and beyond, and should have early and active involvement from educators, local communities, scientists and other stakeholders.

Magma flow in feeder dikes: Chaotic or organised?

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Basaltic fissure eruptions are locally fed by dikes that have propagated predominantly laterally from a magmatic source. This is interpreted from seismic and geodetic data from modern fissure eruptions as well as paleomagnetic studies and analysis of magma flow patterns in exposed feeder dike systems. Here we describe the vesicle and crystal distribution and orientations in one of the dikes from a feeder system in the Hopi Buttes Volcanic Field, Arizona. We examined seven sites on sub horizontal planar surfaces along four of the en échelon segments that make up the ~1 km long dike. Dike widths range between 20-40 cm and have textural banding given by phenocryst and vesicle size, abundance, and vesicle elongation. Banding patterns vary along-strike and can be either symmetrical or asymmetrical across dike width. Generally we observe the following patterns: (1) a centre band that concentrates abundant coarse (>10 mm) clinopyroxene megacrysts and very small (millimetric) equant vesicles, (2) paired or non-paired 3-5 cm thick parallel bands of elongated vesicles that display imbrication, and (3) an outer band with low vesicle and phenocryst abundance. The patterns of vesicle elongation suggest that flow was complex and likely chaotic, changing over short distances to either the north-west or south-east. These changing flow patterns could represent local sites of flow focusing within the dike. Further characterization of these changes is required and could be compared with analysis of flow directions obtained from analogue experiments within an artificial fissure.

Carbon dioxide removal potential of New Zealand river catchments under enhanced rock weathering applications

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Enhanced rock weathering (EW) has been proposed as a globally viable method for large-scale carbon dioxide removal (CDR), particularly in pasture and croplands. Co-benefits of this method include enhancement of soil fertility, and it also acts to reduce soil acidity (a lime substitute). However, there remains significant uncertainty associated with both upstream and downstream losses of carbon associated with EW. The effectiveness of silicate mineral dissolution in capturing CO_2 is in part regulated by the degree and time scale of subsequent carbonate formation. New Zealand's intensive agricultural economy provides potential to capitalise on this method.

Here, we determine the carbon transport potential (CTP) of New Zealand's river catchments using a suite of silicate rock types (dunite, basalt and granite) and calcite. Using dunite as the EW soil amendment, we estimate a transport potential that exceeds New Zealand's annual gross emission of ~78 Mt $CO_2 yr^{-1}$, suggesting that CO_2 capture with EW at the national scale is unlikely to be influenced by carbonate formation during oceanward transport. This is the first comprehensive assessment of the upstream losses associated with deployment of EW in New Zealand. Overall, our results suggest that EW remains a viable negative emission technology for New Zealand and warrants further investigation of natural in-field rates of CO_2 capture.

GeoNet operational earthquake monitoring system improved information and modernisation targets

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GNS Science's GeoNet programme comprises a network of geophysical instruments, automated software applications and skilled staff to detect, analyse and respond to natural hazards in New Zealand. GeoNet's 24/7 hazards monitoring efforts have been facilitated by an automated earthquake monitoring system since 2001, and completed by the manned National Geohazards Monitoring Centre since 2018.

Operating an earthquake monitoring system and a data centre has challenges. Modern earthquake source information needs to be delivered consistently, and continuously, in a timely fashion. It must adapt to advances in operational science, technology and networking and comply with budget or capacity. Eventually, the system is faced with dramatic changes, events, and surging operational limitations.

The earthquake monitoring system and its environment has already evolved and a significant overhaul is planned to adapt seamlessly to allow for better performance, longevity, products and content and to incorporate advanced techniques.

Here, we present short-, medium- and long-term targets to modify operational system architecture, configuration and design of the earthquake monitoring system. Short-term, we plan to revisit the system architecture design to better streamline hardware, configuration, and software lifecycle to allow for better performance, longevity, products and content and to incorporate advanced techniques while keeping the core of the original rapid, resilient design. More analysis capabilities will be introduced to enhance the source information such as adopting a revised New Zealand local magnitude. A medium-term goal is to architect the operational system to develop specialised earthquake monitoring instances, initially with a rapid and review focused process to address performances in aftershock sequences or major crisis response. This gives an opportunity to set operational region-specific instances for identified hazards, or event investigations (volcanic activity, plate boundaries). Benefitting from this re-architecture, the longer-term target is to efficiently embed new and complementary techniques (e.g. artificial intelligence, moment tensor) and instrumentations (GNSS, DAS) into the GeoNet earthquake monitoring system environment and product.

Seismicity and moment tensors from a dense deployment spanning slow slip events near Pōrongahau, central Hikurangi margin

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To understand the relation between slow slip events (SSEs) and microseismicity at a locking transition boundary along the Hikurangi subduction zone, we deployed a temporary seismograph network of onshore broadband seismic stations and ocean bottom seismometers and pressure gauges. The resulting PULSE (Physical processes UnderLying Slow Earthquakes) network recorded two SSEs; one shallow offshore SSE in early 2021 near Pōrongahau and a deeper onshore SSE from 2022-2023 beneath the Manawatu region. We used deep learning (EQTransformer and GaMMA) methods and a nonlinear location programme (NonLinLoc) to locate over 38,000 earthquakes between July 2020 and April 2023. Our catalogue represents ~8 times as many earthquakes as the permanent (GeoNet) network reported during the same time interval. The preliminary magnitude of completeness for onshore events is ~M1.3.

The offshore seismicity rate increased at the initiation of the 2021 SSE, manifest as a cluster of earthquakes just offshore Pōrongahau during the SSE, with no other clusters there at any other time in the catalogue. During the SSE, seismicity extends towards the locked zone of the subduction zone, an area which does not exhibit seismicity outside of the SSE, possibly indicating a loading of the locked zone by slow slip to the north.

To help identify active structures, we used broadband waveforms to determine moment tensors (using the ISOLA program) for 16 earthquakes (Mw3.3 to 5.4). Preliminary results yield mechanisms similar to the GeoNet moment tensors for earthquakes M>4.0. Most of these earthquakes were in the subducting slab or just above the plate interface, and are consistent with regional stress field estimates. Ongoing work will investigate temporal changes in faulting style through the SSE cycle.

Evaluating the physical and mechanical properties of pounamu through ultrasonic P-wave velocity measurements and nanoindentation

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Pounamu holds deep cultural significance for Māori and was used historically in tools, weapons, jewellery, and talismans. While its beauty, toughness, and fracture resistance are well-known, systematic quantitative data on its properties are lacking. Provisional analyses of five pounamu (nephrite jade) samples are reported using SEM-EDS for mineralogical analysis, nanoindentation for hardness and reduced modulus evaluation, and ultrasonic P-wave velocity measurements to assess P-wave modulus and material integrity. The samples predominantly consist of the tremolite-actinolite amphibole series. P-wave velocities were measured at 1 atm and 1 MHz in three orthogonal directions using a pulse generator and oscilloscope with piezoelectric transducers. The data revealed varying degrees of anisotropy. Sample P94450 exhibited the most significant anisotropy, with a P-wave velocity anisotropy coefficient of 0.21 and velocity variability of 4736-7280 m/s while samples P94452 and P94455 showed moderate anisotropy (coefficients of 0.09 and 0.08) and velocities of 4134-4981 m/s and 5581-6622 m/s, respectively. Samples P94453 and P94458 displayed minimal anisotropy, with coefficients of 0.01 and 0.02, velocities of 6500-6697 m/s and 6981-7307 m/s.

Nanoindentation using a Bruker TI Premier nanoindentor (Berkovich tip, 8000 µN maximum load) revealed differing mechanical properties across samples. Sample P94450 showed reduced modulus values of 110-127 GPa and hardness of 7.3-10.4 GPa. Sample P94452 had the lowest values of measured properties, with reduced modulus of 64-89 GPa and hardness of 1.9-4.3 GPa. In contrast, samples P94453 and P94458, with minimal anisotropy and the highest P-wave velocities, exhibited the highest reduced modulus (117-127 and 113-129 GPa), and hardness (6.3-7.9 and 7.2-8.8 GPa). A strong correlation was observed between nano-scale mechanical properties and the bulk elastic behaviour of pounamu. Combining nanoindentation and ultrasonic P-wave velocity measurements offers a non-destructive approach to usefully evaluate pounamu's mechanical characteristics. This is a promising start to answer the question: why is pounamu tough?

Multi-proxy provenance analysis of the Pleistocene-Recent Giant Foresets Formation, Taranaki Basin, Aotearoa New Zealand

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Tsunamis produced by submarine landslides pose a significant risk to coastal populations, built environments, and national infrastructure. Recent mapping of seismic reflection datasets has revealed a series of giant (i.e. >1000 km^3) submarine landslides that have occurred repeatedly over the last ~5 Myr in the Giant Foresets Formation (GFF) of the deepwater Taranaki Basin. The GFF records rapid progradation of the continental margin with high rates of sediment supply hypothesised to have been associated with compressional orogenesis across the Australian-Pacific plate boundary. Although the correlation between submarine landsliding and mountain belt exhumation suggests a potential causal linkage, understanding of sediment sources to the GFF has been hampered by a lack of samples beyond petroleum well cuttings.

We present a provenance analysis of sediment core and dredge samples collected from the eastern Tasman Sea and from potential source regions. Preliminary petrographic analysis of sand from Late Pleistocene-Holocene sediment cores shows that quartz is the dominant constituent (43-52%) followed by subequal abundances of feldspar and dominantly metamorphic lithic grains. Similar results were obtained from beach and dune sediment from Farewell Spit, a proxy for sediment delivered from the western South Island northward via the Westland Current. Both Farewell Spit and the core samples are dominated by metamorphic heavy minerals with common epidote-clinozoisite, hornblende, actinolite, garnet and titanite and minor apatite, pumpellyite, zircon, tourmaline and rutile. Magmatic minerals, including clyno and ortho-pyroxenes, oxy-hornblende and fragments of volcanic glass and pumice are also present in core samples. In contrast, two dredge samples believed to have recovered material from a Pleistocene submarine landslide megablock are dominantly vesicular volcanic glass, suggesting a North Island provenance. These preliminary results confirm long-distance transport (>400 km) of South Island detritus into the deep-water Taranaki Basin but also highlight locally important contributions from volcanic centres of the North Island.

Cracks and thermal flow: Thermo-structural analysis at Maunga Kakaramea, Waiotapu Geothermal Field

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Faults and fractures in geothermal fields can alternate between permeable conduits and impermeable barriers, acting as valves controlling fluid flow. These structures modulate reservoir pressure changes, stimulate seal break-up, flashing, gas expansion, and, ultimately, may lead to hydrothermal eruptions. Changes in pore-fluid pressure and the local stress field can govern faulting and transient structural permeability. Since σ2 is co-axial with the preferred fluid-flow direction, in strike-slip regimes, this direction favours vertical tension-crack formation, enhancing vertical permeability. Therefore, in extensional settings, a shift to a strike-slip regime can optimise the decompression of hydrothermal fluids and their connection to the surface.

In this study, we present new structural-geology and thermal surveys conducted at Maunga Kakaramea, Waiotapu Geothermal Field, New Zealand, to better constrain surface heat-flow distribution within the context of the district-scale Ngapouri Normal Fault. Our findings reveal a strong correlation between subsidiary oblique-slip fault segments and associated vertical fracture networks, lining up with regions of high heat flow. In contrast, colder domains are restricted to local compressional features or less-strained rocks. We also characterise hydrothermal eruptions and other surface hydrothermal features along the Ngapouri Fault. Steam-heated conjugate NW- to E-W oriented fracture network interplay with the dominant NE to ENE oriented Ngapouri Fault zone, contributing to the overall surface heat-flow pattern. Results indicate that subsidiary oblique-slip faulting is 10-35° clockwise relative to the district-scale Ngapouri Fault trace, encompassing most high heat-flux zones, steaming grounds and active hydrothermal alteration cells. These findings provide valuable insights into the permeable structures of the geothermal field and serve as a baseline for further studies. Future work, particularly involving CO_2 flux measurements and shallow resistivity surveys, could help identify areas prone to instability, ground-collapse, and eruptions.

Heritage at Waiotapu is valued by Ngati Tahu - Ngati Whaoa Runanga and is classified as a 'Protected Geothermal System' by the Waikato Council.

Better shape up! The impact of irregular shape in numerical modelling of volcanic bombs

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Volcanic ballistic projectiles (VBPs) are a frequently fatal hazard within 5 km of active volcanic vents. The trajectory of a VBP is approximately parabolic and controlled mainly by gravity and air resistance (or drag). Discrepancies are sometimes observed when using numerical models to reproduce impact locations of bombs (semi-solid to molten VBPs), especially large, rotating bombs, which often have complex shapes. There has been little study on the shapes and resulting drag behaviour of bombs, and this knowledge gap may contribute to these discrepancies between models and mapped VBP impact fields.

We identified bomb shapes in high-speed videos of Strombolian explosions at Stromboli volcano, Italy, and developed a framework for classification of both regular and irregular bomb shapes into three categories: rounded, bilobate, and elongate. Using 3D-printed models of our bomb shape end-members, we here examine how drag differs between bombs via a wind tunnel analogue experiment. We apply these results to tracked bomb trajectories to better understand the effect of assumptions about bomb shape on calculated bomb trajectories.

We find that generally the drag coefficients (CD) of individual shapes within the same shape class fall within a narrow range and change similarly to one another as each shape is rotated. Measured CD of rounded shapes is lowest, differs no more than 37.5% from that of a control sphere, and changes little with angle of rotation. Measured CD of bilobate and elongate shapes is generally higher and is affected strongly by angle of rotation. We compare the effect of drag coefficient variation based on a time-normalised 'difference factor' measured between actual point-tracked trajectories and calculated theoretical trajectories using three scenarios: a 'no-drag' parabolic scenario, a 'sphere' scenario, and a scenario using our experimental drag coefficients. These results can better inform expectations of the drag behaviour of bombs in existing models.

Generation of synthetic ground displacements for training deep learning models: A New Zealand perspective

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During recent years there has been growing interest in the use of deep learning methods in various geophysical applications, especially in processing and interpreting data. Being a data-driven approach, deep learning requires lots of high-quality pre-processed datasets for effective training, but real-world geophysical measurements very often have various issues: data scarcity, too few examples of a signal of interest, low-quality labelling, etc. All these problems can lead to suboptimal training outcomes and hinder model performance. One promising solution to these challenges is the generation of synthetic data, which can provide massive quantities of high-quality training datasets.

In this work, we explore the techniques of generating synthetic ground displacements, focusing on the unique geological conditions of New Zealand. Also, we discuss the methodologies employed to create artificial datasets that mimic the statistical properties and patterns of real-world data, ensuring they are suitable for effective training. Our findings highlight the benefits and challenges of using synthetic data, including the ability to generate diverse training scenarios and capture the nuances of real-world data. By sharing our experiences, we aim to contribute to the broader adoption of synthetic data suitable for machine learning in various geoscience applications.

Migrating GNSS data processing to the cloud-based environment: Experiences, lessons learned and improvements

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To support the monitoring of natural hazards, and geological phenomena, GeoNet operates a network of GNSS (Global Navigation Satellite System) continuously operating reference stations. Raw data from the remote GNSS stations are routinely collected, processed, and distributed to end users. Included in this is the generation of displacement time series, used to capture how much the GNSS stations move in response to geological processes. Researchers and interested members of the public use these outputs to capture ground deformation after significant earthquakes, during volcanic unrest, or to detect slow slip events in the Hikurangi subduction zone.

Since 2016, GeoNet has been migrating its archive, processes, and systems to a cloud-based environment but, until July 2024, the GNSS processing software was still operating on-premises at the GNS Science Lower Hutt Campus. To process GNSS data and generate the displacement time series, the GeoNet programme uses an open-source scientific software called GAMIT/GLOBK (developed by MIT). Migrating the routine processing to the cloud-based environment was not a straightforward task, despite the legacy system running as a containerised service, we needed to rewrite all the code wrapping configuration in a way that was compatible with the cloud-based infrastructure.

The GNSS data analysis is a computationally intensive process, so one of the challenges we faced was to build a system that could sustain a heavy workload while being optimised in terms of cost and performance. By combining the expertise of geodesists, software developers, and system engineers, we have been able to architect a system that can work effectively in a cloud-based environment and highly improve its performance and scalability. For example, 20 years' worth of New Zealand GNSS data took about 30 weeks (about 7 months) to be processed in the legacy system, while the new cloud-based solution can process the same data in just 4 weeks.

The sedimentology, stratigraphy and geochemistry of the Waipara Greensand

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The Waipara Greensand in the mid-Waipara River section in Broomfield, North Canterbury is the source of many significant mid-late Paleocene vertebrate fossils, including the earliest examples from the order Sphenisciformes (penguins) in the world. While lipid biomarker and other geochemical studies have been undertaken in the Waipara Greensand (Hollis et al., 2014), the focus of these studies was on the Waipawa organofacies, in the top ~10 m of the formation. Additionally, this study was undertaken on sediments relating to one exposure in the Waipara River known as Site 3. However, many important specimens were retrieved from sediments found at a different outcrop downstream of Site 3, known as Site 2. Linking Site 2 stratigraphically with Site 3 is necessary to understand the environments resulting in the preservation and evolution of fossils in the mid-late Paleocene.

Using proxies from pXRF and biomarker data (including GDGT's, hopanes, n-alkanes, TOC and δC13), as well as field sedimentary descriptions and petrography, we describe changes in palaeoenvironment through the mid-late Paleocene in the mid-Waipara Section at Site 2. Secular changes in sea surface temperatures, terrestrial sediment and organic inputs, and glauconite maturity are traced through the section. An age profile will be established using dinocyst zones. The results of this study will be compared to previous studies to link Site 2 and Site 3 stratigraphically. These changes in environment can then potentially be used to understand the preservation of the fossils found in the Waipara Greensand and to infer potential drivers of evolution in early marine birds.

Pathways to preparedness: Which components of natural hazard public education initiatives get people to take preparedness actions?

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What are the drivers of disaster preparedness in Aotearoa New Zealand, from a public education viewpoint?

Several excellent national public education preparedness initiatives already exist, which have focused on the communication of key messages to promote preparedness actions. While these previous communication efforts have usually followed best-practice, evaluations show levels of public preparedness have not increased beyond 25-50% in at least 20-years. It is apparent then that public education via current communication strategies may have a limited impact, and that other interventions or tweaks may be needed to stimulate further preparedness.

Initiated in August 2024, this project is looking beyond traditional methods of communication of risk and preparedness information to identify key components of public education initiatives that encourage people to change their behaviour. By identifying the components that lead people to take more impactful actions to prepare for and respond to natural hazards, we aim to enable organisations and individuals to make national, regional, and local communication and public education programmes more effective.

Hot and cold storage within a long-lived crystal mush beneath the Dunedin Volcano

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Magma reservoirs are domains of partially or wholly molten rock with varying proportions of three constituent phases: crystals ± melt ± fluid (exsolved volatiles). Magma storage conditions within these reservoirs form a spectrum from the traditional paradigm of melt-dominated 'chambers' kept above solidus temperatures (i.e. hot storage) to the more recent concept of crystal-dominated 'mush' falling towards solidus temperatures (i.e. cold storage).

Newly identified zircon-bearing rhyolites, central to the Dunedin Volcano (South Island, New Zealand), enable the first U-Pb zircon dating (LA-ICP-MS) for the alkaline polygenetic intraplate volcano. An age discordance between older $^{40}Ar/^{39}Ar$ feldspar (13.70 ± 0.04 Ma) and younger U-Pb zircon (13.20 ± 0.11 Ma) dates, together with curious intra-crystal morphologies, textures, and chemistry indicate a dichotomy of both hot and cold storage – via discrete pockets of fractionated (rhyolitic) interstitial melt within a crystalline mush framework of trachytic bulk composition. Crystal fractionation of a dry, felsic melt with subsequent rapid cooling to near- (potentially sub-) solidus temperatures, later rejuvenated prior to eruption, resulted in: 1) an eruptible portion of the melt, facilitating late-stage zircon crystallisation and hypersolvus crystallisation of intermediate K-feldspar (anorthoclase-sanidine) zones, that remobilised and incorporated 2) an extractable portion of the mush, necessary for retention of radiogenic $^{40}Ar^*$ and subsolvus crystallisation of Na- (albite) and K-rich (orthoclase) zones, with negligible exsolution features.

The suite of evolved silica-saturated (trachyte and rhyolite) rocks exposed at Portobello record the development of a long-lived crystal mush system, punctuated by three major eruptive episodes over ~1.2 Myr (14.20-13.01 Ma). The deposits likely represent a main eruptive centre dominant during the first half of volcanic activity at the composite Dunedin Volcano. The magma reservoir storage dynamics and processes presented here are in parallel with those typically described only for large silicic caldera systems capable of super-eruptions.

A series of magma recharge and mixing events at Mt Charles, Otago Peninsula: Reconstructing the Dunedin Volcano

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The growth of polygenetic composite volcanoes and volcanic complexes can be difficult to decipher; shifting vent systems mean any given stratigraphic sequence may have originated from various sources, with complicated overlapping relationships. Through high-resolution field mapping and remote sensing, with petrography and (mineral and whole-rock) geochemistry, a new geological map and evolutionary model has been developed for the Mt Charles area, at the periphery of the long-lived Miocene alkaline intraplate Dunedin Volcano (South Island, New Zealand).

Twenty-six units (nineteen lavas and/or intrusives, and seven pyroclastic deposits) are identified, defining six lithostratigraphic groups and four lithosomes (i.e. eruptive centres). The Mt Charles and Papanui Cone edifices were built upon prior intermediate to evolved (trachyandesite to trachyte) pyroclastic density current deposits and lavas from two distal vents. The main basaltic shield-forming stage of the Mt Charles vent produced multiple lavas and lapilli tuffs to tuff breccias representing effusive and explosive activity, subsequently capped by effusive intermediate (trachybasalt to trachyandesite) lavas. A shift from earlier silica-saturated to later silica-undersaturated eruptive products (mirroring large-scale geochemical trends across the wider Dunedin Volcano) is marked by eruption of localised basanitic lavas and tuff breccias at the Papanui Cone vent, revealing an interplay of rapidly ascending primitive magmas with the shallow evolved plumbing system. The final stages of activity are preserved only as basaltic trachyandesite and phonolite outliers and dykes.

The strata record an intricate open-system governed by fractional crystallisation, magma recharge and mixing. The progressive low-, mid-, to high-penetration of pre-existing crustal reservoirs by incoming magma batches tracks the development of the plumbing system beneath the volcano, with potential implications for a systematic north-westward migration of activity within the maturing volcanic system. Reconstructing individual eruptive centres within a larger composite structure allows reinterpretation of the volcanic landform focused on Dunedin – i.e. 'Dunedin Volcanic Complex'.

Unravelling the story of Kuwae, Vanuatu, in stratigraphy, bathymetry and geochemistry

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The shallow submarine caldera at Kuwae, Vanuatu, experienced a major caldera-forming eruption – the Tombuk event – in the mid-15th century. This event has often been discussed as one of the three largest eruptions of the last 1000 years, with global climate implications and a connection to a major bipolar sulphur deposition event in 1458 CE. Here, we present the results of the first comprehensive study combining new local evidence in volcano-stratigraphy, bathymetry, and geochemistry from Kuwae caldera. Pyroclastic successions were mapped on the islands surrounding the submarine Kuwae caldera, identifying deposits originating from plume fallout, plume collapses, caldera collapse, and tsunamis. These deposits are used to characterise major plume phases and retell the eruption story from onset to climactic and waning stages.

The newly collected high-resolution bathymetry data was obtained using a side-mounted multibeam. This first full coverage dataset of the Kuwae caldera reveals two morphologically distinctive caldera portions, reflecting complex caldera generation mechanisms. The bathymetry data is used to identify whether the Kuwae caldera collapsed during one single, major event – the Tombuk eruption – or whether its complex morphology is better explained as a composite caldera structure.

Geochemical data was obtained from samples with known volcano-stratigraphic positions collected on the islands surrounding Kuwae. It reveals several distinct magma compositions that especially correlated with the major, most explosive phases. Matrix glass and melt inclusion compositions are used to provide estimates of the total sulphur budget released during the Tombuk eruption. The combination of geological, bathymetric, and geochemical data is crucial for our understanding of the impacts caused by the Tombuk event and provides clear indications for whether Kuwae should remain a strong source candidate for the 1450s climate signal. Geophysical constraints on the seafloor geology of KIS3 drill site oceanward of the Kamb Ice Stream grounding line, Ross Ice Shelf, Antarctica.

Reconstructing the deglacial thinning history at Byrd Glacier, East Antarctica using cosmogenic surface exposure dating

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How do marine-based ice sheets respond to global climate change? Antarctic ice sheet response to climate warming is the biggest source of uncertainty in forecasts of future global sea-level change. Examining the past response of ice sheets to natural climate change can help to resolve this uncertainty, as the temporal extent of modern observations (~four decades) is incomparable to the timescales of ice sheet response (centuries to millennia).

As indicated by marine and terrestrial evidence, the former ice sheet occupying the Ross Embayment was most recently at a maximum extent during the Last Glacial Maximum (~20 ka BP, LGM). Neither the timing nor configuration of this grounded ice sheet and its destabilisation as a marine-based ice sheet are fully understood. Mismatch between data- and model-derived estimates of deglaciation further complicates current understanding of how the ice sheet has previously responded to climatic forcing. Reconstructions of the ice sheet thickness differ by 200-800 m and there are few terrestrial records to test these models.

Ice-free margins of current outlet glaciers flowing into the Ross Ice Shelf contain useful records of post-LGM retreat that can help to address these issues. Here, I present a new cosmogenic surface exposure chronology of glacial erratics from Mt. Tadpole, a nunatak adjacent to Byrd Glacier, which is a major, fast-flowing outlet of the East Antarctic Ice Sheet. Our new constraints of deglacial changes to Byrd Glacier better inform the past extent, timing, and rate of retreat of marine-based ice in the Ross Sea through the last period of sustained global warming on Earth. These insights aid in the validation of numerical models used to predict future ice sheet and sea level response to present-day climate change.

"Ka mua, ka muri – Walking backwards into the future."

Breaking the ice on frozen narratives: Decolonising Antarctic research

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Pervasive settler-colonial narratives about Antarctica are frozen in time. These narratives tend to ignore the value of social and cultural contexts in Antarctic research, and cause harm to the research field and wider society by underserving Māori and marginalising mātauranga Māori. Across many other fields, researchers are shifting towards engaging meaningfully with diverse ways of knowing and practices that have been founded on generations of resilient and relational knowledge. In Aotearoa, all scientists should commit to elevating mātauranga Māori as a primary knowledge system. There is real value in weaving multiple knowledge systems to resolve complex challenges across the geosciences. Mātauranga Māori is, after all, science in its own right (Hikuroa, 2017; or a philosophy of science, as in Stewart, 2022). Considering the strong connections Māori hold with Antarctica and the Southern Ocean, diversifying our approaches may benefit Māori and strengthen collaborative research endeavours. Sharing power through partnerships in this field requires that we first dismantle the barriers impeding Māori participation in Antarctic research and leadership. To this end, the following questions must be addressed; what barriers prevent Māori from engaging equitably in Antarctic research, and how do our current systems underserve Māori? Then, how can non-Māori help to dismantle these barriers and flip harmful settler-colonial narratives? This work draws heavily on the ideas of Hird et al. (2023) to advise techniques for shift specific to geoscientists and Antarctic researchers in Aotearoa. The findings stem from a literature review conducted by a Pākehā researcher and are informed by the views of a Māori academic. We aim to convince geoscientists of the increased value afforded to the field should it be inclusive of Indigenous knowledge systems. We explore how non-Māori researchers can help to enact decolonisation in Antarctic research to re-centre essential Indigenous narratives.

Monitoring ice dynamics with low-cost GNSS positioning in Antarctica

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Field observations of glacier dynamics are often acquired with costly 'survey-grade' GNSS (global navigation satellite systems) positioning devices, priced at thousands of New Zealand dollars. The high cost poses a barrier to the widespread deployment of GNSS networks, especially in remote polar environments where power consumption and logistical challenges further complicate their installation. Low-cost, open-source, mass-market GNSS chip devices present a promising alternative, offering comparable precision at a fraction of the cost (a few hundred New Zealand dollars).

This study examines the reliability and positioning performance of two networks of low-cost u-blox GNSS devices installed at contrasting field sites in the Ross Sea region of Antarctica: Priestley Glacier (November 2022) and the northern McMurdo Ice Shelf (January 2024). We also conduct experiments comparing the precision of the low-cost u-blox systems to co-located survey-grade Trimble systems under both stationary (on land) and kinematic (on flowing ice) conditions. Multi-GNSS, dual-frequency observations are post-processed using the open-source software RTKLIB. At both field sites, the low-cost and survey-grade systems yielded almost identical error magnitudes when observing horizontal and vertical ice motion. The low-cost u-blox system is capable of centimetre-level (RMSE <2 cm) horizontal precision over medium baseline (20-30 km) kinematic-positioning scenarios. Our work emphasises that competitive and reliable low-cost GNSS systems are readily available and we encourage the application of these systems for cost effective glacier and ice-shelf monitoring.

Micronutrient-driven regulation of the Southern Ocean's carbon sink: Reconstructions for the last glacial-interglacial cycle

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The Southern Ocean is one of the world's largest carbon sinks, sequestering ~40% of anthropogenic atmospheric CO_2 each year. The Southern Ocean's ability to sequester carbon largely depends on the efficiency of the ocean's 'biological pump', in which marine primary producers convert atmospheric CO_2 to organic carbon for longer term storage in the deep ocean. This process is limited by the restricted 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 the Southern Ocean. We are applying a suite of novel micronutrient isotope tracers, based on the iron, zinc and cadmium stable isotope systems, to fossil-plankton extracted from a north-south transect of marine sediment cores collected from just south of New Zealand to offshore Antarctica. These sediments record a time-series of rapidly changing climate across the global warming and cooling transitions of the past 140 thousand years. They also capture the 'Last Interglacial', a warmer analogue of today's interglacial climate. We are currently acquiring surface ocean calibrations and 'last glacial-interglacial cycle' reconstructions of Southern Ocean micronutrient regime using (i) coccolithophore-rich carbonate records for the mid-latitude Southern Ocean and (ii) siliceous diatom records for the high-latitude Southern Ocean and offshore Antarctica. We are also integrating micronutrient regulation of the biological pump into a sophisticated Earth System Climate Model that uniquely captures ocean biogeochemistry. Our approach, combining observations and modelling, will directly quantify the influence of trace-metal micronutrients on the efficiency of Southern Ocean carbon removal during major climate reorganisations, and provide important boundary conditions for improving future-climate projections.

Late Quaternary activity of the Pisa Fault, Otago

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Over the past eight years the Otago Earthquake Science Group has studied a total of 10 active or potentially active faults in Otago, in a concerted effort to populate national active fault and earthquake source databases. The new data have also allowed long term space-and-time patterns of earthquake occurrence to be deciphered across the region. Most of the studies have involved trenching methods, but some have been restricted to mapping and dating of displaced surfaces when trenching was impractical. A case in point is the Pisa Fault, located at the base of the 1900 m Pisa Range. The scarp is well expressed in just one area along the fault, where it displaces two of five fluvioglacial terrace surfaces (T2 and T3) by about 8 m and 11 m, respectively. The terraces have been sampled and dated by cosmogenic 10Be and optically-stimulated luminescence methods, enabling the long-term slip rate and elapsed time since last event to be estimated. The terrace ages are: 16.2 ± 3.7 kyrs (T1); 45.6 ± 6.4 kyrs (T2); 62.0 ± 8.8 ka (T3); and 125.3 ± 37.1 kyrs (T4). The last displacement on the Pisa Fault is therefore constrained as pre T1 and post T2, and slip rates are in the range of 0.2-0.35 mm/yr. While these slip rates imply a recurrence interval in the 5,000-17,000 year range, the absence of events at least since the formation of T1 implies aperiodic earthquake behaviour on the Pisa Fault.

Pliocene fossil faunas and paleoenvironments of the Manukau Lowlands, South Auckland

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The Opoitian-Waipipian (5.3-3.0 Ma) molluscan faunas of the Kaawa and Ōtāhuhu formations, South Auckland, offer a rare opportunity to reconstruct Pliocene depositional paleoenvironments and paleoecology in northern New Zealand, where such fossil faunas are otherwise scarce. Historical sampling at Kaawa Creek and Ōtāhuhu Brewery uncovered diverse nearshore faunas, including numerous 'warm-water' taxa linked to Recent Australian and Indo-Pacific groups. However, the lack of extensive surface exposures has constrained our understanding of the broader faunal and paleoenvironmental context.

The recent construction of a wastewater tunnel beneath Māngere, South Auckland, provided a major opportunity to sample and study these Pliocene fossil faunas from a new locality, expanding our understanding of the regional paleoecology. Ongoing work has identified >266 taxa in shell-rich spoil excavated from the subsurface, including taxa previously recorded from Kaawa and Ōtāhuhu, as well as new species. While systematic in-situ sampling from the shellbed was not feasible, the assemblage – inferred to have accumulated in a current-swept subtidal channel – reflects a mixture of paleoenvironmental provenances. These paleoenvironments include various shallow marine habitats, such as rocky shores, intertidal to shallow subtidal soft sediment flats, and semi- to fully-exposed subtidal sandy substrates.

Decalcified molluscan mould faunas preserved in shore platform exposures along southeastern Manukau Harbour provide further insights into these potential paleoenvironmental sources and offer a chance to study Pliocene faunas in-situ at the outcrop. These faunas, which include many taxa also found at Māngere, represent low energy, sheltered to semi-sheltered intertidal paleoenvironments, such as lower estuarine settings and seagrass habitats. The latter is particularly notable due to its rarity in New Zealand's fossil record. Studying these sedimentary paleoenvironments and their faunas will enhance our limited understanding of molluscan paleobiogeography and nearshore marine ecosystem structure in northern New Zealand during the Pliocene, a period globally recognised as a key analogue for future climate change.

Unexpected alongslope and downslope interactions of the Taranaki submarine slope; Late Pleistocene-Holocene

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The Late Pleistocene-Holocene evolution of onshore Taranaki has been marked by exceptional changes to the landscape through rapid volcanic edifice building, frequent eruptions and collapse, supplying a multitude of sediment choked rivers to dynamic coasts. These dramatic changes are all superimposed upon glacial-interglacial cycles and ongoing tectonic activity of the Hikurangi subduction margin and Alpine Fault.

While onshore records preserve a rich history of dynamic change, our understanding of offshore processes is limited, with an assumption of infrequent across-shelf and downslope processes, and phlegmatic regional currents, thought to be largely incapable of transporting significant quantities of sediment. Here we present our first findings from a downslope transect of three gravity cores, collected in 2022, that span upper, mid, and base of slope positions. Foraminiferal biostratigraphic dating suggests that the cores preserve a record of sedimentation extending back ~110 kyrs with average sedimentation rates of ~17.3 cm/kyr that, in places, doubled during the last glacial maximum. A facies scheme, combining photograph, CT imagery and density, with granulometry data, suggests a mixed depositional history dominated by regional scale, persistent, oceanic bottom currents that have resulted in the slow, gradual deposition of contourites. These deposits are punctuated by downslope turbidity currents sourced from catastrophic slope collapse in the upper canyons. Several beds also display depositional characteristics of mixed turbidite-contourite deposits where turbidites are reworked by bottom currents.

These preliminary results build off a recent high-resolution multibeam bathymetry dataset collected concurrently with the sediment cores, revealing a surprisingly dynamic seascape where regional oceanic currents and rare downslope gravity currents are impacting active canyons, submarine landslides, pockmarks, and the remnants of giant underwater landslide megablocks.

Characterising microseismicity on the Alpine Fault with distributed acoustic sensing

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The Alpine Fault is a major continental transform fault that is late in its well-documented seismic cycle of M7-8 earthquakes, making it a critical area for research prior to the next large earthquake. This research aims to leverage distributed acoustic sensing (DAS) technology to detect, locate, and characterise small on-fault earthquakes in the southern section of the fault, near Haast. DAS is an emerging technology that repurposes fibre-optic telecommunications cables, enabling dense recordings of the seismic wavefield and allowing signals often missed by traditional seismic networks to be detected and analysed.

Using approximately 4.5 months of DAS data collected across the Alpine Fault near Haast from the South Island Seismology at the Speed of Light Experiment (SISSLE; Miller et al., 2023, DOI: 10.7914/bfp8-xv25), and integrating high-performance computing and AI techniques, such as PhaseNet-DAS, we aim to identify small (magnitude <3.5) earthquakes and determine their focal mechanisms to high precision. PhaseNet DAS has been demonstrated to accurately pick phase arrival times in DAS data, significantly enhancing our capacity to detect and analyse small earthquakes. Applying this algorithm to the SISSLE dataset will allow us to characterise the seismic behaviour of the fault with unprecedented precision and improve the understanding of the fault's subsurface structure. The very large effective number of sensors (~7250) is expected to provide strong constraints on the focal mechanisms of even small earthquakes occurring nearby, and to provide new insight into faulting processes on and adjacent to the Alpine Fault.

Epithermal Au Ag Cu mineralisation of the bonanza Rek Rinti vein system, Woyla gold copper district, Pidie, Aceh, Indonesia

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The Woyla gold district is located on the western part of the West Sunda Magmatic arc, known to host world-class copper gold silver mineralisation. This study examines the characteristics of the NNE-SSW trending epithermal quartz veins including mineral paragenesis, ore forming mechanism to resource potential. The paragenetic of Rek Rinti vein is classified into four stages: Stage 1 – fluidise quartz-carbonate veinlets; Stage 2 – quartz Mn carbonate breccia; Stage 3 – massive quartz; Stage 4 – colloform crustiform to cockade quartz-carbonate. Stage 1 is the pre-gold deposition, featuring greyish quartz + anhedral pyrite. Stage 2 consists of dark greyish quartz + chalcopyrite and arsenopyrite replacing early pyrite. Stage 3 is the early gold deposition associated with massive white quartz + chalcedony + sphalerite with minor pyrite. Stage 4 introduces copper sulphide such as covellite embracing the previous chalcopyrite remnant and native gold occurring with ginguro. Low to intermediate sulphidation overprint is indicated by near neutral pH of chlorite-illite-smectite gangue with oxidised, advanced sulfidation state from sphalerite, chalcopyrite-pyrite to covellite. Sphalerite composition ranges from 26.70 to 14.35 mol% FeS in Stage 3 and 10.25 to 4.40 mol% FeS in Stage 4. Hydrothermal solution derived from causative subvolcanic intrusion probably forms the first and the second stage of Rek Rinti vein. The third to fourth stage involves boiling processes that lead to the deposition of quartz-carbonate veins. A back arc pull apart basin related to the Sumatra fault possibly provided the pathway of Woyla rio-dacite to basalt bimodal volcanism. Metals are trapped due to repeated boiling-cooling mechanisms related to silica saturation and rapid temperature changes. Recent DDH intercepting ore shot hence returning fire assay results of 81 g/t Au and 734 g/t Ag, with grab sampling yielding spectacular results of 131 g/t Au, 1.508 g/t Ag, 4.84% Zn, 0.8% Pb and Cu.

The Tūeke 35 (Tsunami Care Bags) initiative in Tairāwhiti/Waiāriki kura kaupapa Māori/schools

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Aotearoa New Zealand is exposed to numerous potentially damaging impacts from various hazard events. The east coast of the North Island, one of the most active seismic regions in New Zealand, faces significant earthquake and tsunami risk. Given the variety of hazards the regions face, how risks are managed within schools needs to be considered. This research aims to understand the challenges and opportunities for enhancing earthquake and tsunami preparedness and response in Te Tairāwhiti/Waiāriki kura kaupapa Māori/schools. One of the projects was the development of care bags, named Tūeke. These were inspired by a drawstring bag used on cowboy saddles, reflecting the region's farming horsemanship culture. In September 2023, students aged 5-17 participated in this initiative, with both Te Reo Māori and English as mediums of instruction. In March 2024, students collated the top 20 suggested resources and packed them into 90 litre plastic containers to be stored at hapū/community evacuation centres. Resources included board games, playing cards, colouring pencils, colouring books, toys, drink bottles, and torches. Itemised lists were created for future reconciliation, enhancing local ownership of the items. This poster will illustrate the project and outline next steps.

GeoNet sensor network development 2023-25

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After many years of user consultation and collaborative design, the largest enhancement of the GeoNet sensor network since 2012 began in 2023. Network expansion includes new capabilities across 33 locations, including:

- 17-19 seismometers,
- 18-20 accelerometers,
- 16-17 GNSS sites,
- 2 tsunami gauges,
- 5 geochemistry sites, and
- 1 camera site.

Additionally, enhancements include:

- new boreholes for weak motion seismic sensors,
- weak and strong motion seismic sensor upgrades, and
- the adoption of the USGS station SNZO into the critical GeoNet National Seismograph Network.

Treasury funding is, however, set to decrease and there is uncertainty about the 'if and how much' of alternative funding. Hence, GeoNet must look at a range of options for how to maintain and develop its sensor network.

As a pertinent case study, we present the current work on the Tāmaki Makaurau Auckland borehole seismometer network, which is approaching end-of-life and whose like-for-like replacement sits outside GeoNet's current funding envelope.

A new diving Pliocene *Ardenna* shearwater (Aves: Procellariidae) from New Zealand

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We report a new species of shearwater, *Ardenna buchananbrowni* sp. nov., from the Pliocene of New Zealand. It is both the smallest and oldest known diving member of the genus, demonstrating that this now abundant form of shearwater has had a long presence in southern oceans. *Ardenna buchananbrowni* is among the few extinct shearwaters described from the Southern Hemisphere and adds to an increasingly diverse seabird assemblage in the Pliocene of the region.

Characteristics of earthquake slip

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The source inversions using seismic recordings and geodetic measurements have helped image rupture models for recent earthquakes. We explore the characteristics of the slip distribution, based on a set of rupture models. The source scaling relations show that rupture length grows more rapidly, with increasing earthquake magnitude, than rupture width. However, the large-slip asperity area is better correlated with rupture width than rupture length. This corroborates a physical limitation on the size of asperity. We incorporate this finding into a stochastic model for slip distribution for multi-fault ruptures. The model involves an independent scaling of average slip for each participating fault, and generation of the slip distribution using a spatial random field model based on the von Karman autocorrelation function and slip-frequency distribution given by a truncated exponential distribution. The slip distributions have spatial correlation lengths controlled by rupture widths, apart from being coherent across the participating faults.

Fossil footprints from the rohe of Ngāti Whātua o Kaipara are educational assets

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Fossil trackways offer a precious glimpse into the past and provide rare insight into the behaviour of ancient animals. Two sets of fossil footprints have recently appeared on blocks eroded from the sea cliffs along Kaipara South Head in the Auckland Region and are the focus of a research partnership principally led by Ngāti Whātua o Kaipara and Auckland Museum. An Early-Middle Pleistocene age (1 ± 0.5 Ma) and a high-tidal, sandy beach setting are inferred for the trackways. The trackmakers produced tridactyl and unwebbed footprints approximately 200 mm long and 180 mm wide and were likely a species within Dinornithiformes. The recovered fossil footprints are preserved in a dedicated collections space within the rohe (territory) of Ngāti Whātua o Kaipara where they contribute to the education of local school children under the guidance of kaiako (teachers) and other kaiarahi (leaders) from the area. Digital replicas of the footprints will become publicly accessible as part of the formally published description. The ongoing partnership between Ngāti Whātua o Kaipara and Auckland Museum with respect to the fossil trackways is a leading case study for the ethical collection and storage of fossils, and stands in accordance with the recently updated Code of Ethics for the Geoscience Society of New Zealand. Through this partnership the trace fossils are able to inspire korero (conversations) around changing environments and biodiversity among the future kaitiaki (guardians), while also providing opportunities for international engagement through further study.

Communicating science to the public: Why you should, how you can

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Is science communication a significant part of the work of researchers, or is it a 'nice to have' add-on that is only offered on an occasional ad-hoc basis?

What is the value of sharing science information with the public, and why does it seem so hard? There are several major barriers facing individual students or scientists who would like to share their science knowledge. In this presentation I will discuss these and suggest ways to overcome them to reap the personal and professional benefits of establishing a science communication practice that builds over time.

Cyclic erosion and infill of the Waitaki Canyon, offshore Otago

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The Waitaki Canyon is a major geomorphic feature of the continental shelf and slope offshore from the Waitaki River. The present canyon is sinuous, with several S-bends. The canyon incises about 20 km landward into the continental shelf, is up to 1 km deep and generally less than 5 km wide. The canyon and the subsurface strata beneath it are imaged in the Endurance 3D seismic reflection data volume. The survey shows the canyon to be composed of distinct subsections, and the subsurface to have numerous older filled canyons. The lower portion of the canyon is a deeply incised, sinuous steep-walled chasm, and seafloor dips of the canyon walls in this section can be up to 45 degrees. The upper portion of the present canyon is a region of current significant erosion and downcutting, but canyon wall slopes are less. This erosion is removing the infill of prior canyons occupying the same location.

Several episodes of Waitaki Canyon filling and erosion over the last 3.5 Ma can be documented in the Endurance 3D seismic reflection volume. In that time, the continental shelf has prograded seaward by tens of kilometres. The shelf has aggraded by about 300 m and the basin floor by about 500 m. The floor of the canyon has also aggraded, although the gradient of the thalweg has remained stable at less than 1 degree, except in areas of active erosional downcutting. Canyon sinuosity has increased with time, with previous canyons oriented more directly down the continental slope.

The Quaternary history of the Waitaki Canyon is repeated cycles of erosion and infilling. These cycles may be of the order of 1 My and may at times completely infill the canyon. The canyon then reactivates and the infilled material is eroded, increasing sinuosity in the process.

Past, present, and future earthquakes on the Alpine Fault: What lies beneath and what lies ahead?

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The Alpine Fault stands out amongst continental faults capable of generating great (magnitude 8+) earthquakes in several regards. Painstaking paleoseismological research has yielded one of the most spatially and temporally extensive paleoearthquake records worldwide. This record indicates that the Alpine Fault regularly produces large earthquakes on timescales of less than 300 years. Although the times between one earthquake and the next are remarkably consistent, their inferred sizes vary depending on which of three sections of the fault rupture at once. More than 300 years have passed since the last major earthquake, and the Alpine Fault is thus late in the typical period between successive earthquakes. The likelihood of a magnitude 7+ earthquake occurring in the coming 50 years is ~75%; the odds of that earthquake exceeding magnitude 8 are ~80%. The Alpine Fault is also unusually hot, at least along its central section where the Southern Alps are experiencing the most rapid uplift and where long-term slip rates are the highest. Along-strike variations in the thermal regime affect the distribution of present-day low-magnitude seismicity and deformation processes; these temperature variations are likely to influence patterns of slip in future large earthquakes.

We review progress in understanding the Alpine Fault's late-interseismic state made during seismological experiments conducted in the decade since the second phase of the Deep Fault Drilling Project (DFDP-2). We address the insights afforded by novel observational and analytical techniques such as distributed acoustic sensing, virtual earthquakes, and artificial intelligence-based earthquake detection; the logistical challenges of field deployments spanning large distances in remote terrain; and lessons and opportunities for source-to-hazard research.

We also outline steps the geoscience community could take now to record invaluable data ahead of and during the next Alpine Fault earthquake, thus advancing global understanding of rupture phenomena.

What is the relationship between green hydrogen, carbon sequestration, (ultra)mafics, and fault creep?

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When moderate temperature (200-250°C) alkaline aqueous fluids, with catalysing Al or dissolved CO_2, interact with ultramafic and some mafic rocks, they can both generate hydrogen, and sequester carbon (as carbonate) (Kein & McCollom, 2013, http://dx.doi.org/10.1016/j.epsl.2013.08.017; McCollom et al., 2010, https://doi.org/10.1016/j.gca.2020.05.016). The specific controls on these reactions in natural environments are complex and significant research is required to determine how to control them. However, inevitably the reactions will proceed most rapidly in fine-grained rock. Rather than generating such fine-grained material by inducing fracturing, we could exploit natural fault zones, where there has already been significant tectonic grain size reduction. These zones also modify inherent permeability of rock masses in mountainous regions, and in some regions are already recognised as zones where fluids heated by circulation through deeper crust are known to rise to the surface (cf. Sutherland et al., 2017, https://doi.org/10.1038/nature22355; Carbajal-Martínez et al., 2024, https://doi.org/10.1029/2023GC011145; Diamond et al., 2018, https://doi.org/10.1130/G45394.1). However, this sort of 'stimulation' will not only modify the chemical, but also the mechanical properties of these existing fault zones, which has various implications in tectonically active regions.

We will present microstructural and microchemical observations of gouges from an active strand of the San Andreas Fault, sampled during the SAFOD drilling project, that suggest that the same reactions that generate hydrogen and sequester carbon, play an important role in generating the clay mineral tri-octahedral smectite (saponite) when they occur in a mixture of ultramafic and metasedimentary rock. This clay mineral has very low frictional strength, thus when present may stimulate fault creep (Carpenter et al., 2015; https://doi.org/10.1002/2015JB011963). Superficially this may seem to reduce the seismic hazard presented by such zones, but there is also some likelihood that creep stimulates seismic rupture in such heterogeneous materials (Lavier et al., 2021; https://doi.org/10.1029/2020JB020325), thus caution is advisable.

Integrating real and virtual field experiences for geoscience education

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During the Covid-19 crisis, a plethora of digital teaching tools were developed (e.g. JSG Special Issue Virtual & Digital Structural Geology, https://www.sciencedirect.com/special-issue/10XGPDNVDCF; Solid Earth/Geoscience Education Special Issue Virtual Geoscience Education Resources, https://gc.copernicus.org/articles/special_issue431_1145.html). However, on return to classroom teaching, these tools have largely been neglected in favour of traditional methods, or allocated to an alternative assessment in case of illness or disability.

However, these tools have significant value to students who are already (extremely) familiar with virtual environments and may even entice these students to engage with the real world. Our goal is to develop exercises that employ both traditional and virtual components in an integrated didactic concept, illustrating how these methods provide complementary information and engaging students in novel ways.

In one of these excursions, our students visit a quarry of jointed sandstone representing a potential geothermal reservoir rock. They carry out traditional line-scan characterization of the joints as permeability pathways in the field. Subsequently, in the classroom, they visit the same outcrop in the 'Outcrop Viewer', developed using the 'Unreal' game engine. The students also employ an online tool 'PlaneSightOnline' to make supplementary measurements of the orientations of structures that they were unable to access in the field analysis. The most ambitious didactic focus of the exercise is to guide the students to develop their own understanding of the concept of 'orientation bias' and how it is accommodated with a Terzaghi correction.

One particularly valuable aspect of our approach is that there are a range of potential steps in the classroom analysis, which is valuable for the students who are not immediately engaged with online 'geo-gaming'. Challenges include optimising the performance of the software to run without gaming-focussed hardware while ensuring that photogrammetric models sufficiently resolve key features, and that the control scheme remains intuitive.

Where does the carbon go? Reconciling atmospheric observations, surface observations, and lateral transport of carbon in Fiordland

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Atmospheric observations and modelling of carbon dioxide over New Zealand have demonstrated that the apparent net sink due to terrestrial biospheric exchange is much larger than previously thought. Regions of indigenous forest, particularly Fiordland, appear to be responsible for much of this carbon uptake. The magnitude of this apparent sink is inconsistent with our understanding of terrestrial carbon exchange processes for old growth forests and lateral transport of carbon through rivers and landslides can potentially explain this inconsistency. We will present an overview of the Fiordland carbon system, and the pathways through which carbon can be absorbed, transported, sequestered and returned to the atmosphere. We demonstrate that while lateral carbon fluxes are poorly constrained, literature estimates and new research suggest that these fluxes are likely to be of sufficient magnitude to reconcile the top-down atmospheric observations and bottom-up understanding of fluxes. We will point to the areas of research needed to better constrain the carbon fluxes and carbon sequestration rates in the various components of the Fiordland system.

Exploring and quantifying factors controlling landslide deposit surface roughness using coseismic landslides from the Mw7.8 2016 Kaikōura earthquake

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The initial occurrence of a landslide produces well-defined morphological features (e.g. scarps, ridges, cracks, hummocks) that smooth out with time due to erosion and soil transport processes. Observations of landslide morphology have long been used as a tool to assign landslides qualitative age estimates. More recent studies have calculated landslide deposit surface roughness from high-resolution LiDAR derivatives to more accurately estimate landslide ages using empirical age-roughness models. Despite their practicality in quantitatively estimating landslide ages at a regional scale, uncertainty in age roughness modelling due to natural variability in initial landslide roughness remains poorly understood. In addition to age, landslide surface roughness may reflect differences in lithology, slope steepness, slope direction, failure style, and climate. To explore and quantify the relative importance of each of these factors on initial landslide roughness, we use signal processing techniques (continuous wavelet transform with a Richter wavelet) to calculate and compare the roughness of more than 500 medium to large coseismic landslides from the Mw7.8 2016 Kaikōura earthquake. We conduct statistical analyses of roughness values for landslides within four major groups including: 1) lithology (greywacke, other sedimentary rocks), 2) slope direction (North, South, East, West), 3) slope steepness (0-15, 15-30, 30-45, 45-60, 60-75), and 4) failure style (rock/earth slide, rock/debris flow, rock falls). We expect our findings to improve the accuracy and applicability of a proposed Wairarapa age-roughness model and reduce uncertainty in age predictions. Improving the accuracy of age-roughness modelling will better predict landslide timing across large regions and may better highlight temporal patterns related to specific known landslide triggers (e.g. earthquakes, large storms).

Assessing carbon storage capacities in Fiordland fjords: Insights from high-resolution seismic imaging

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Fjords are globally recognised as significant carbon burial sites due to their ability to trap and preserve organic carbon, playing a significant role in the global carbon cycle. Fiordland, located along the southwest margin of New Zealand's South Island, is characterised by high westerly wind-driven precipitation rates (6-8 m/yr), high relief, and native forests, with earthquake-triggered landslides, and low salinity riverine freshwater input to the fjord basin, which serve as natural carbon traps.

Our research aims to provide the first comprehensive high-resolution seismic overview of Fiordland's fjords, focusing on understanding the variations in sill depth, basin geometry, and key morphological features. By analysing these aspects, we seek to quantify not only the maximum basin storage but also other key geomorphological statistics, such as length, width, and sinuosity, and assess the spatial variability of sedimentary deposits. This includes investigating how morphological features, such as entrance sills, flooded deltas, terraced basins and basin floor debris impact sedimentary deposits in Fiordland.

We conducted multiple seismic surveys using a 75-m-long, 24-channel Geometrics MicroEel hydrophone streamer and a Ferranti or Applied Acoustics Boomer seismic source, enabling high-resolution imaging. These surveys are complemented by geomorphometric analysis of multibeam bathymetry data from LINZ and NIWA, providing critical insights into the geometry and sedimentary processes of the fjords. These insights are essential for estimating basin capacities and understanding the fjords' roles in carbon preservation. This study enhances our understanding of Fiordland's fjords as critical components of the global carbon cycle and highlights their complex evolution since the Last Glacial Maximum. By establishing a baseline for carbon storage, it also underscores the importance of deglaciation, reforestation, and Holocene depositional processes in shaping current sedimentary architecture. This foundation is crucial for future paleoenvironmental studies, including deep drilling and sediment sampling.

Ensuring invaluable scientific observations are obtained pre- and during the next Alpine Fault earthquake

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Do you worry about the Alpine Fault being late in its seismic cycle? We know the conditional likelihood of a large Alpine Fault earthquake in the coming 50 years is about 75%. What pre-rupture observations might we regret not having when the next earthquake occurs? Join us at our poster to comment, add ideas, develop a new collaboration, or highlight the essential observations we should be making now along the Alpine Fault. Our aim is to discuss what and how Aotearoa's geosciences community can do now to ensure invaluable scientific observations are obtained pre- and during the next Alpine Fault earthquake. We welcome input from (but not limited to) seismology, geodesy, paleoseismology, structural geology, landscape evolution, interdisciplinary studies and linking science with end-users' needs.

Cenozoic fossil wood records of extinct and extant angiosperm tree lineages from southern Zealandia

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Forests have been present on Zealandia since it was a wedge on the side of Gondwana, and are represented by fossil palynomorphs, leaves, seeds, and wood in every time period since the Jurassic. These fossils preserve a history of diversification and extinction of forest tree taxa resulting from climatic change. We discuss four new records of well-preserved Cenozoic angiosperm wood from southern Zealandia. Bortonian Waihao Greensand at Boulder Hill near Dunedin yielded calcified fossil wood which closely resembles Leguminosae subfamily Caesalpinioideae, likely representing an extinct genus. The legume family is large, with almost 20,000 extant species, and had a major diversification event during the Eocene. Though there are more than 300 records of fossil leguminous wood globally, this the first record of fossil legume wood from Australasia. Calcified material was also collected from Miocene volcanic tuffs at Karitāne Peninsula. This material consisted of a 30 cm long branch with distinctive wood anatomy similar to that of modern Violaceae (*Melicytus*). Several sites of Miocene-Pliocene age from Canterbury and Otago have yielded trunks of silicified wood with features resembling Myrtaceae (*Eucalyptus*). The abundance and distribution of these samples raises the possibility of forests with a prominent *Eucalyptus* element covering part of the eastern South Island during the Late Cenozoic. Though extinct in New Zealand, *Eucalyptus* is a diverse genus that has more than 800 extant species in Australia, Papua New Guinea, and Indonesia. Finally, a sample from Adams Island in the sub-Antarctic Auckland Islands, interbedded with volcanics of Late-Oligocene – Miocene age, was identified as Araliaceae (*Araliaceoxylon*). The Araliaceae are one of the few families extant on the islands that have a tree growth form. Together these samples provide new evidence for distinctive elements of the fossil flora of New Zealand, and contribute to understanding our modern flora within a regional context.

Predicted margin stratigraphy and hydrogen storage potential using landscape evolution models

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The transition to net-zero emissions by 2050 and the urgency of decarbonisation necessitate innovative energy solutions, with green hydrogen playing a crucial role due to its potential for large-scale, long-term energy storage and the reduction of fossil fuel dependence. Hydrogen storage is typically cyclic, involving seasonal storage and withdrawal to meet energy demands. Moreover, due to its low density, approximately four times less than natural gas, hydrogen requires a larger storage volume, making geological storage the optimal solution for hydrogen storage. Underground geological formations can be utilised to store various types of gases and fluids, such as reducing greenhouse gas emissions through carbon dioxide storage or storing excess renewable energy in the form of hydrogen for long-term energy needs.

Using an open-source landscape evolution model, called Badlands, to forward predict stratigraphy, this study investigates sediment distribution patterns during the Cenozoic, with an emphasis on the transition from greenhouse to icehouse climate conditions. During icehouse climates, the presence of ice sheets makes sea levels highly sensitive to climatic changes driven by orbital variations (Milankovitch cycles), resulting in rapid fluctuations. These sea level changes are predicted to facilitate the formation of successive sequences of multiple sedimentary seals through repeated transgressions and regressions, potentially reducing hydrogen migration given the high mobility of the gas. In contrast, greenhouse climates, characterised by the absence of continental ice sheets, lead to relatively stable sea levels with more gradual changes. In this study, we model a generic case of landscape evolution in a passive margin context over a period of 66 million years. Understanding the patterns and the sequence of these processes is crucial to improving predictive capabilities and evaluation methods for potential geological hydrogen storage sites, typically in saline aquifers or other stratigraphic reservoirs, thereby supporting the broader goal of achieving net-zero emissions by 2050.

Cataloguing and promoting the use of paper records in the National Earthquake Information Database

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New Zealand has a long-storied history in early observational and instrumental seismology and GNS Science acts as the principal custodian of these unique records of New Zealand seismicity. Preservation of these records is critical because researchers need to utilise all available information for understanding long cycle geological events. This is particularly true in a place like New Zealand with a relatively short history of human occupation. Research into historic New Zealand seismicity requires a well-managed, curated, and published collection of records so recently GNS Science has embarked on efforts to catalogue all these records, digitise documents, and has improved the completeness of published metadata and made inventory information of the collections available online to enhance their usability and discoverability.

In the late 1860s, a network of human observers known as the 'Reporter Network' was established. When a member experienced an earthquake, they posted an A5-sized survey form to the Meteorological Department, founded in 1868. In addition, GNS Science holds collated letters, newspaper cuttings and other first-hand, primary observations of earthquake intensity. The first instrumental recording in New Zealand began with a Milne seismograph installed in Wellington in 1900, and the network gradually expanded to span all of mainland New Zealand. These original paper seismograms, recorded from 1900 to 2005, extend to the Pacific Islands and Antarctica and consist of over 1,000,000 individual records, all stored and accessible through GNS Science.

We will highlight how researchers at DEVORA (DEtermining VOlcanic Risk in Auckland) have been using paper seismograms to understand baseline seismicity in Auckland and discuss a project the National Earthquake Information Database has funded to compile historical felt reports used between 1868 and 2010. Overall, we are aiming to assist the understanding of the usefulness and limitations of the macroseismic data available for historic earthquakes in New Zealand.

5 Minute Volcano - designing educational games about geological disaster risks with and for New Zealand classrooms

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Volcanic phenomena are commonplace in the landscape of Aotearoa New Zealand. Children, a vulnerable group in natural disasters, require knowledge about volcanoes and related risks, and games can be an engaging way to educate them. This contribution illustrates the design process of the game, 5 Minute Volcano, with and for formal educational settings in Aotearoa New Zealand. It encourages collaborative learning and play within classrooms and identifies key volcanic hazards using local and cultural imagery, such as animals and Taniwha (supernatural beings) to represent characters and hazards.

Using observations, interviews and user studies, the full version of the game has been completed. These methods have also focused the research aims, looking into how games can be used within formal educational environments and how they can encourage collaborative play, learning and communication skills.

To further this, the addition of a teacher guide has been drafted, tested and adapted to suit teachers in New Zealand. This guide is used alongside the game to assist teachers align the game with their teaching plan, to help children achieve science learning goals, and to address the curriculum needs of the students and teachers. A student workbook is used to record the children's learning and to engage them in science, as well as understanding whanaungatanga (learning to understand each other) through play. Results from teacher interviews suggest these workbooks could help to guide discussions, collaboration, and communication within and outside the classroom. Both can be used for research purposes to evaluate how the game and accompanying materials are used and experienced.

This work highlights the importance of games as collaborative learning tools, in addition to their importance in the development of children's skills and growth. The ongoing goals of collaborative learning and play will help instruct future design principles using digital collaborative mini games.

Estimating marine ice thickness beneath the Amery Ice Shelf from airborne radio-echo sounding

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Ice shelves affect the long-term stability of ice sheets due to their supporting effect on the mass balance of the ice sheets. Marine ice that forms at the base of ice shelves is a significant source of mass gain that affects the dynamics of the ice shelf. We apply the principle of hydrostatic equilibrium to provide a new estimate of the marine ice distribution beneath the Amery Ice Shelf (AIS) in East Antarctica using surface elevation and the meteoric ice thickness obtained from radio-echo sounding (RES) data during the Chinese National Antarctic Research Expedition (CHINARE) between 2015 and 2019. Our new estimates reveal two longitudinal marine ice bands beneath the northwest area of the AIS, spatially consistent with studies conducted 20 years ago, but thinner than marine ice observed in earlier borehole measurements. In addition, a marine ice layer exceeding 30 m in thickness is found beneath the central part of the ice shelf. We speculate that shallow topography beneath the southeastern part of the AIS hinders intrusions of warm water, leading to the accumulation of marine ice at the central AIS. Our results represent the first mapping of marine ice beneath the AIS in nearly 20 years, and will provide important data for numerical models to quantify ice-ocean interaction and material transport in the ice shelf system.

The International Bathymetric Chart of the Southern Ocean (IBCSO) – Version 2

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The Southern Ocean surrounding Antarctica is a key region to a range of climatic and oceanographic processes of global importance. This includes anthropogenic CO_2 and atmospheric heat uptake influencing the global climate and the formation of cold, dense bottom waters, crucial for the global thermohaline circulation. Interactions of the Southern Ocean with Antarctic glaciers and ice shelves are the main drivers of present, past, and future ice sheet mass balance. Furthermore, the Southern Ocean is a high-productivity area with high biodiversity. Despite its remoteness and harsh conditions, with extensive sea-ice cover and year-round severe weather, human activities, including research, fisheries, and tourism, are increasing. Quality spatial seabed information, such as maps and grids, are crucial for understanding the Southern Ocean's role in global climate, supporting sustainable human activities, and enabling effective conservation and management.

Since 2013, the International Bathymetric Chart of the Southern Ocean (IBCSO) has represented the most comprehensive bathymetry compilation for the Southern Ocean south of 60°S. Recently, the IBCSO Project has combined its efforts with the Nippon Foundation/GEBCO Seabed 2030 Project, supporting the goal of mapping the world's oceans by 2030. New datasets initiated a second version of IBCSO (IBCSO v2). This version extends to 50°S (covering approximately 2.4 times the area of the seafloor of the previous version), including the gateways of the Antarctic Circumpolar Current (ACC), the most significant ocean current on Earth, and the Antarctic Circumpolar frontal systems. Due to increased (multibeam) data coverage, IBCSO v2 significantly improves the overall representation of the Southern Ocean seafloor and resolves many submarine landforms in so far unseen detail. This makes IBCSO v2 the most authoritative seafloor map of the area south of 50°S.

We sincerely thank all agencies, institutions, and individuals who contributed to data collection and compilation.

Hidden patterns: Spatio-temporal evolution of Chatham Rise pockmarks

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Seafloor depressions, often known as pockmarks, are common features found in various geological and oceanographic settings on the seabed. Pockmarks range in size from tens of metres to several kilometres and can appear isolated, clustered, or aligned in strings, with shapes varying from simple, almost circular, to complex irregular forms. While often associated with fluid or gas release at the seafloor, the formation mechanisms, including gas/fluid composition, timing, and physical processes, remain ambiguous in many cases. The Chatham Rise, located offshore of New Zealand's South Island, hosts over 45,000 pockmarks, which appear to be bathymetrically controlled. Proposed formation mechanisms include gas hydrate dissociation, dewatering, and, more recently, episodic geological CO_2 releases during glacial terminations. In 2020, a high-resolution survey using parametric sub-bottom profiler (SBP) data was conducted over a pockmark field on the Chatham Rise. We generated pseudo-3D cubes from an extensive grid of densely spaced profiles (~25 m apart) using a newly developed, open-source processing workflow. Analysis of seafloor and buried pockmarks extending up to 100 m below the surface reveals a range of pockmarks sizes from ~50 to several hundred metres. These pockmarks occur as isolated, stacked, or nested features. Several erosive horizons appear to be temporally linked to pockmark formation. We propose different physical processes for pockmark formation, such as fluid release at the seafloor and bottom current erosion. Linking these processes to spatial and temporal patterns of recurring pockmarks, we compiled a conceptual model of spatial-temporal pockmark development in our study area.

Operational template-matching for rapid aftershock analysis and source characterisation

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The early aftershock period following an earthquake can provide robust information on the mainshock source and on the time-varying hazard during the aftershock sequence. However, early aftershock catalogues are often highly incomplete due to elevated rates of aftershocks and high background seismic amplitudes. Aftershock hypocentral location accuracy, and hence source information, is also often compromised by inclusion of incorrect picks on closely spaced phase arrivals and a backlog of manual inspection by geohazard analysts during high-rate sequences.

Template-matching methods, based on cross-correlation of known earthquake waveform with continuous data, have been shown to significantly improve the completeness of aftershock catalogues and can improve pick accuracy in an automated way. Until recently, applying template-matching methods in real-time was not tractable. As part of the Rapid Characterisation of Earthquakes and Tsunami (RCET) programme, we have developed robust and efficient near real-time, open-source, template-matching workflows and tools (RT-EQcorrscan), including improved location and magnitude calculation processes.

Here, we outline the development, testing and application of our methods and the capability of RT-EQcorrscan and associated workflows to enhance aftershock catalogues, source characterisation and event response. We provide examples of these methods as applied to simulated real-time scenarios of recent M6+ sequences across Aotearoa New Zealand, including the Eketahuna, Cook Strait and Kaikōura earthquakes. Our results show that the distribution of robustly detected and located aftershocks can be used to estimate fault length, scaled magnitude and source fault geometry (strike, dip) within a few minutes of a trigger event, depending on source complexity and background seismicity rates (available templates). These outputs provide a valuable response tool for use alongside other source characterisation methods (e.g. FinDer) as inputs for shaking estimates and in key stakeholder messaging.

Detecting mass movements in alpine regions using infrasound

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Surficial mass movements in alpine regions, including snow avalanches, rockfall, and ice collapse, pose a hazard to people and infrastructure. During the 2022/2023 Northern Hemisphere winter, 30 people died from avalanches in the United States and 104 people died in Europe. In New Zealand, there have been 742 reported avalanche incidents between 1999 and 2018, including 27 fatalities. The highway to Milford Sound and the access road to Mt Hutt ski-field frequently face closures due to the threat of rock fall and avalanches, while, in the United States, the economic loss when Interstate-70 through Colorado closes due to avalanche impacts is estimated at NZD 1.6 million per hour. It is hard to detect and characterise mass movements in alpine environments. Challenges include adverse weather conditions, reduced daylight hours during the winter, steep topography, and the broad geographic regions where mass movements can occur.

Geophysical monitoring using seismic and infrasound (low frequency sound waves in the atmosphere) has proven to be effective for monitoring mass movements. In particular, infrasound waves are minimally attenuated in the atmosphere and are useful for monitoring large regions, such as whole valleys, whereas camera observations are limited to a single direction.

Here, we present results from a field campaign in the Hooker Valley of Aoraki Mount Cook National Park, where we made infrasound and camera observations. During the field campaign, the cameras recorded seven avalanches; only one of these was recorded by the infrasound system. However, the infrasound system recorded 33 other events from all around the valley, potentially related to a range of mass movements including avalanche activity, rock fall, ice collapse, and glacier calving. This illustrates how infrasound and visual observations are complementary tools for monitoring mass movements.

Fibre optic sensing of earthquakes at Ruapehu

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Distributed acoustic sensing (DAS) is a rapidly developing technology that enables standard fibre optic cables to be converted into hundreds of seismometers. An interrogator unit sends a laser pulse along the fibre, which is reflected by imperfections in the cable. The properties of the backscattered light relate to strain along the fibre, enabling DAS to measure seismic waves in the solid Earth at unprecedented spatial and temporal resolution.

Here, we present results for a field campaign in March and April 2023 where we made DAS observations along a two-kilometre-long existing fibre optic cable on the northern flank of Ruapehu (connecting the West Ridge Café to GeoNet seismometer MAVZ). We sample at a spatial resolution of ~6 m, which turned the fibre optic cable into approximately 300 closely spaced seismometers, which provides exceptional spatial resolution compared to the four broadband seismometers that GeoNet maintains on Ruapehu and provides opportunities to visualise the spatial distribution of the seismic wavefield.

This is the first time that DAS has been used to record seismic data on an active volcano in New Zealand. The DAS observations are compared to the GeoNet earthquake catalogue and data from the nearby seismic stations. Despite the cable lying on the ground with heterogeneous coupling to the Earth, the DAS system can detect regional earthquakes and local low frequency volcanic events. We have ongoing work to develop an automatic detection algorithm to identify interesting signals in the DAS data that are not observed by the seismometers.

Measuring the impacts of ship anchoring

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Routine vessel anchoring impacts the seabed with direct and indirect implications for the health of the shallow marine environment. Even still, anchoring practices remain largely unmeasured, undocumented, and most importantly, unregulated. Remarkably, anchoring is absent from any national and international policies designed to reduce human impacts on the marine environment.

Our pioneering field experiments measured the real-time impacts of anchoring in a multi-vessel campaign. We used two vessels: RV Ikatere, used for data collection before, during and after the anchoring event; and RV Tangaroa, which was at anchor for 24 hours in Wellington Harbour anchorage. In March 2024, fieldwork started by surveying and seafloor sediment sampling in the anchorage area before anchoring, as well as in a control site nearby. Then, RV Tangaroa was put on anchor and equipped with a range of sensors measuring the immediate impacts in the water column. Simultaneously, RV Ikatere was also recording and sampling the anchoring impacts in the adjacent area. Finally, after the anchoring event, the study region was resurveyed again to gain comparative datasets. For the entire duration of the fieldwork campaign (3 days), moorings were deployed near the experiment area to measure variations in ambient environmental conditions. The datasets collected during this field campaign will delineate a complete environmental signature during anchoring practices, including physical, chemical, biological, ecological changes. Collectively they will help constrain the spatial extent and severity of anchoring impacts and provide real-time observations and longer-term impacts of anchoring. This campaign aims to measure the real-time impacts of commonplace vessel anchoring practices. To achieve more sustainable and lower-impact shipping corridors, the hidden costs of ship anchoring must be incorporated into future global trade strategies and environmental management. Our new approaches are timely and will have global relevance and could be presented to the Marine Environmental Protection Committee at the International Maritime Organization.

Exploration of a time-dependent forecast for tsunami in New Zealand

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New Zealand's 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 New Zealand. 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 to develop rules that bridge the numerical forecast with an end-user early warning product. These rules must be developed 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.

New insights from hydrothermal spring monitoring on Taranaki Volcano, New Zealand

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Taranaki volcano has an estimated 50% chance of erupting over the next 50 years. Here we present geochemical data from 20 mineral springs in the vicinity of Taranaki volcano. Our research aim is to monitor changes that may precede renewed volcanism, after previous work showed that mineral springs had reacted with magmatic fluids at depth. Kōkōwai (ferrihydrite) springs emerge in at least seven localities around the maunga (mountain), falling on northeast-southwest lineaments, subparallel with regional fault patterns. Cold springs degas carbon dioxide (CO_2), nitrogen (N_2), methane (CH_4), hydrogen sulphide (H_2S), and minor amounts of various hydrocarbons as they emerge at the surface, with highest concentrations reaching 5500, 100, and 2.5 ppm of CO_2, CH_4, and H_2S, respectively. Gases have equilibrated with air-saturated water, which is consistent with transport through the porous volcanic cone. Ages of the waters issuing from these springs range from 8 to 44 years, based on tritium dating, with older waters emerging on the ring plain (~ 190 years). The stable isotopic compositions show that all mineral springs originate from the summit of the volcano, regardless of location. Helium isotopic signatures range from 4.0 to 5.9 Ra, demonstrating a strong mantle contribution. The $\delta^{13}C$ of the dissolved inorganic carbon ranges from -11 to -3.5‰ vs. PDVB, and when combined with the CO_2 / ^3He overlaps considerably with gases from TVZ volcanoes and hydrothermal areas. Ring plain springs range from 12-31°C and show a history of travertine precipitation over the last 2000-3000 years. These springs have elevated levels of SO_4 and Cl relative to the kōkōwai springs, and we have observed a constant temperature, but a gradual increase in SO_4 and Cl, between 2020 and 2024. This recent change in chemical composition is notable, with the 2020 values nearly identical to those sampled 40 years ago.

The secrets of sequestration: Assessing the modern carbon stocks in Tamatea Dusky Sound

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The current global interest in reducing carbon emissions has prompted a rapid increase in studies aimed at understanding the carbon cycle, and in particular potential pathways toward increased burial of CO^2. Fjords have been recognised as extremely efficient marine carbon sinks, due in part to the strong link between land and oceans. This link facilitates a pathway for large quantities of terrestrially derived material to be transported into over-deepened basins where favourable conditions can lead to high rates of sequestration.

The fjords of Te Rua-o-te-moko, southwest New Zealand could be described as an idealised setting to sequester carbon. The combination of high relief, thin soil cover, dense native forest, high annual precipitation (6-8 m), and earthquake-driven landslides fuel a continual cycle of organic carbon production and sequestration over decadal to centennial timescales. Fiordland's national park status, remoteness, and the relatively recent arrival of humans to the South Island (~800 years ago) provide a unique opportunity to examine fjord carbon cycling under natural conditions.

The distribution of sedimentary carbon in Fiordland marine environments is not well constrained which has limited our ability to assess the carbon stocks of this nationally significant sink. This presentation summarises the recent efforts to map the extent of sedimentary carbon environments of the New Zealand fjords, with a focus on Tamatea Dusky Sound. We highlight the heterogeneity of sedimentary environments and the impacts on effective carbon burial. Our work provides a snapshot of the modern carbon stocks, as well as a shallow dive into the sediments of the late Holocene via short multicores. These findings are crucial for assessing the current state of carbon burial, identifying potential vulnerabilities, and establishing a baseline for historical comparison, which will inform policies aimed at preserving this vital carbon sink.

Seismic imaging of the Auckland crust towards understanding the origins of the Auckland Volcanic Field

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The city of Auckland, New Zealand, sits atop an active volcanic field. This Auckland Volcanic Field (AVF) is monogenetic and intraplate, but what drives the AVF is unknown. An international team of geoscientists has recently started an interdisciplinary study of the AVF.

This year, the national network of seismometers in the region has been augmented with a temporary array of land- and ocean-bottom seismometers to image the AVF from surface to deep in the mantle. The resulting 3D image of the AVF – together with the existing information on the geology and geochemistry – will then be used to drive geodynamic modelling. This modelling aims to find out what causes the upwelling of mantle material that results in the Auckland Volcanic Field. In particular, we are interested in whether the upwelling is driven by local structure on the lithosphere/asthenosphere boundary, and what – if any – is the influence of subduction more than 200 km southeast of Auckland.

Still at the start of this large project, in this presentation we will present our efforts thus far, with an emphasis on new seismic tomography of the AVF crust with earthquakes and noise.

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 heterogeneous nature of the New Zealand seismograph network, can mean earthquakes are mislocated or not detected at all. In contrast, regional research-focused catalogues offer a much more in-depth view of seismicity but require additional manual input and data which are not realistically available for a nationwide catalogue. We have developed and applied a cutting-edge automated workflow to generate a research-grade earthquake catalogue for Aotearoa New Zealand which balances the best of national and regional earthquake catalogues. This workflow expands and improves the current catalogue, enabling further research into New Zealand's seismotectonic setting and a better understanding of present-day seismic hazard. We apply uniform identification, classification and location methods 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 seismic phases of earthquakes already listed in the GeoNet catalogue, ensuring each event has as many picks available as possible. We then use the Eberhart-Phillips et al. (2022) NZWide 2.3 3D Velocity Model with NonLinLoc to produce accurate locations and robust uncertainties. This has been completed for a large portion of the existing catalogue with relative relocations also set to be computed. We present the results of this initial updated catalogue, and use notable seismic activity to illustrate how this enhanced catalogue can help us better visualise and understand seismicity in New Zealand. We also present the results of the initial testing phases of the catalogue, methodology development and classification of uncertainties. Finally, we explore future developments to the catalogue, expanding it to include earthquakes not currently detected by GeoNet.

Deep and clustered microseismicity at the peripheral edge of southern New Zealand's plate boundary: Results from the Southland Otago Seismic Array (SOSA)

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Our understanding of crustal deformation in the Southland region of Aotearoa New Zealand is limited due to the low strain rates and sparse coverage by the permanent GeoNet network. To address this knowledge gap, we deployed 19 short period seismometers between October 2022 and October 2023 through the Southland Otago Seismic Array (SOSA), which, supplemented by the GeoNet network and an ongoing Fiordland array (Fiord22), provided a station spacing of ~30 km across a 150 km wide region extending from the Catlins to Fiordland. We detected 85 events in and around Southland during the SOSA deployment, which represents a significant improvement on the 13 events recorded by GeoNet over the same period. These events are not uniformly distributed, with a step decrease in seismicity east of Fiordland. We also identified three areas of elevated seismicity: around Mossburn, the western Southland Plains, and northwestern Catlins. These areas all correspond to spatial clusters identified in previous Southland catalogues. This indicates that they are persistent regions of elevated crustal stresses. Previous seismic arrays to the north in Otago indicate that seismicity there is limited to depths <15 km. By contrast, focal depths in Southland extend continuously from the surface to ~35 km depth. Using 1D lithospheric strength profiles, we suggest that the embrittlement of Southland's mid-lower crust corresponds to the region's mafic terranes that were accreted onto the Gondwana margin during the Mesozoic. Cumulatively, the preliminary results from SOSA indicate that seismicity in Southland is (1) spatial-temporally clustered and (2) strongly influenced by pre-existing geologic structures; features which are frequently observed in low strain rate regions around the world.

Mixed glass compositions in the c. 230 AD Taupō Tephra: Multiple magma types or particle recycling from earlier deposits?

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The c. 230 AD Taupō Tephra is a widespread marker bed in terrestrial, lacustrine and marine deposits around the North Island. The eruption comprised six phases, generating a characteristic and distinctive suite of fall deposits and ignimbrite. In proximal deposits, crystal-poor juvenile pumices from all fall and ignimbrite units display a very narrow chemical compositional range throughout the eruption sequence. These compositions are distinct from older eruption units, including the 25.5 ka Oruanui supereruption, in having lower SiO_2 (73.5-75 wt%), with restricted mineralogy and crystal zonation also suggesting a hotter and less evolved magma source. Distal tephra deposits, however, variably contain glass shards that span a wider range of compositions, from ~74-79 wt% SiO_2, with a distinct cluster at 78 ± 0.7 wt% SiO_2. Here we investigate the relative content and origins of higher-SiO_2 glasses in the Taupō Tephra from different depositional settings and geographic locations around the North Island. We infer that the published Taupō Tephra glass field contains a significant proportion of glass shards recycled from earlier eruptions and, in particular, the 25.5 ka Oruanui supereruption that was sourced from a broad vent region within which lie the 230 AD Taupō vent sites. Oruanui composition glass shards are typically found only in the fine ash component and become more common in the final and most explosive phases, including co-ignimbrite fall deposits. The recycling of glass shards was facilitated by the fine-grained nature of the phreatomagmatic Oruanui eruption deposits and their kilometre-scale intracaldera thicknesses, coupled with the outstandingly explosive nature of the 230 AD Taupō eruption. The mixed modal compositions found in documented locations (including Antarctica) thus represent a unique double fingerprint for this event and highlight that caution must be taken when interpreting compositional fields and magmatic processes from distal fine-grained tephra deposits.

Potential new turtle species from the Neogene of North Canterbury, New Zealand

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New Zealand has a well-documented history of reptiles, including notable Mesozoic taxa such as plesiosaurs and mosasaurs, as well as a diverse array of Cenozoic squamates, amphibians, and the evolutionary relict, the tuatara (*Sphenodon punctatus*). Turtles (Reptilia, Testudines), however, are relatively rare compared to other marine animals in the New Zealand fossil record despite being described from every epoch since the Cretaceous. Most fossil turtles that are reported from New Zealand were found as isolated postcranial elements. In January 2023 an ex-situ, calcareous muddy siltstone concretion approximately 25 cm in diameter with a small section of bone visible was collected from Motunau Beach in North Canterbury. The concretion was mechanically prepared using pneumatic tools and chemically prepared using dilute acid. Upon preparation, the fossil was revealed to be a cranium from a potentially new species of turtle. The generally triangular shape of the skull in dorsal view, large forward-facing orbits, and beak-like upper jaw, are similarities the new discovery shares with extant sea turtles. A comparative analysis of the cranium with those of extant sea turtles is underway to identify morphological similarities. This specimen represents one of the largest known fossil turtles found in New Zealand with an estimated length of 1 metre, the carapace length being between 75 and 80 cm. This record will extend the range of Neogene sea turtles further southwest and potentially give new insights into the phylogeny of extant sea turtles (Cheloniidae). The presence of sea turtles at Motunau during this time period indicates ocean temperatures were higher than those observed today.

Reassessing tsunami risks: High-resolution mapping of submarine landslides in Pegasus Canyon, Aotearoa New Zealand

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Submarine landslides, which involve the rapid displacement of sediment, rock, and other materials across underwater slopes, are a significant geohazard beneath the ocean's surface. These events can trigger tsunamis, posing a considerable threat to coastal communities and infrastructure. Around Aotearoa New Zealand, submarine landslide scars are prevalent along many canyons, including Kaikōura and Pegasus Canyons, where varying sizes of scars are observable in bathymetric data.

In 2020, we used an Autonomous Underwater Vehicle (AUV) equipped with high-resolution bathymetry and sub-bottom profiling systems to map a landslide in Pegasus Canyon. Contrary to earlier beliefs that this landslide was a recent event, our data revealed it to be much older, covered by a substantial sediment drape. Accurately estimating the tsunami risk from such submarine landslides hinges on the precise calculation of the displaced material volume. Previous studies have shown that errors in landslide volume estimation can be up to 18% using subsurface (seismic) datasets, but the errors associated with volume estimates from landslides mapped in multibeam data are not well understood. We demonstrate that previously used lower-resolution data would have significantly underestimated this volume. Our new high-resolution multibeam and sub-bottom datasets show how crucial data resolution is for accurate volume assessments and, consequently, for evaluating the tsunami risk posed by underwater landslides. Furthermore, integrating sub-bottom data to map sediment layers enhances the accuracy of these calculations. Given that over 3,000 underwater landslides have been identified in the waters around Aotearoa, the potential tsunami risk may be considerably higher than previously estimated.

Unlocking the secrets of ancient predation: A study of fossil drill holes and crustacean damage in invertebrates from a rocky shore ecosystem, Cosy Dell, Southland

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Drill holes and crustacean damage on fossils provide a unique window into ancient ecological interactions, revealing predatory behaviours and defence mechanisms of past geological eras. These holes, typically found on the shells of marine organisms such as molluscs and brachiopods, are primarily attributed to the activity of drilling predators such as gastropods. Crustacean damage is often recognised from distinct crushing marks on the shells of molluscs and other marine organisms. Fossil drill holes and crustacean damage are relatively uncommon in New Zealand mainly due to challenging preservation conditions. Here we report a diverse invertebrate fauna from the Late Oligocene Chatton Formation at Cosy Dell, Southland, with more than 350 species of molluscs (approximately 90 bivalves and 250 gastropods) that boasts numerous examples of fossil drill holes and crustacean damage. Drill holes are seen in over 80 species of mostly aragonitic molluscs, including 60 species of gastropods, 15 species of bivalves and scaphopods. Most drill holes are attributed to the gastropod family Naticidae, with Muricidae being a minor driller. About 110 specimens of the small irregular echinoid, *Fibularia*, have been examined, and 18 show subcircular to circular drill holes, which are interpreted as evidence for molluscan predation. Twenty-four gastropods of various sizes from hand specimen scale (8 cm length) such as *Amplicolpus healyi* to tiny specimens (3 mm in length) such as *Spirocolpus tophinus* and one scaphopod specimen show crustacean damage of different types, and crabs are assumed to be the most likely predator. Our results demonstrate complex but fascinating predator-prey relationships within the invertebrate fauna at Cosy Dell. The Cosy Dell invertebrate fauna displays a diversity of fossil drill holes and crustacean damage which expands our understanding of changes in marine biodiversity, ecological pressures and paleoenvironmental conditions in the New Zealand Cenozoic fossil record.

A Late Oligocene chiton fauna (Polyplacophora) from a rocky shore ecosystem, Cosy Dell, Southland, New Zealand

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Chiton (Class Polyplacophora) fossils are rare globally, mostly because they are restricted to hard habitats such as rocky shores that are taphonomically under-represented in the geological record. New Zealand is rich in Cenozoic marine molluscan fossils, but chitons are uncommon. The earliest New Zealand records of fossil chiton species are all from the Late Oligocene (Duntroonian) Chatton Formation in Southland. They include *Callochiton chattonensis* (Ashby, 1929), *Acanthochitona* (*Notoplax*) *ashbyi* (Laws, 1932) and *Rhyssoplax allanthomsoni* (Mestayer, 1929). However, little work has been carried out on fossil chiton faunas in New Zealand in the past 90 years. Here we describe the chiton fauna from the remarkable rocky shore ecosystem preserved in the Chatton Formation at Cosy Dell, Southland. This diverse fauna comprises seven families and seven genera, including *Callochiton* cf. *chattonensis*, *Acanthochitona* cf. *ashbyi*, *Ischnochiton* sp., *Leptochiton* cf. *inquinatus*, *Lorica* sp., *Plaxiphora* sp., and *Rhyssoplax* sp. The Cosy Dell locality has the highest recorded fossil chiton diversity and the best preservation of chiton material in New Zealand, due to rapid burial and minimal transportation of the disarticulated chiton valves. All genera described in the fossil assemblage are associated with extant taxa still living in modern New Zealand near shore environments. The New Zealand stratigraphic range of four genera (*Ischnochiton*, *Plaxiphora*, *Lorica* and *Leptochiton*) is extended back to the Duntroonian (Late Oligocene). All chiton species present at Cosy Dell probably lived in the lower intertidal zone, under boulders or in rock crevices, grazing algae. This paleoecological information reflects the very shallow rocky-shore paleoenvironment preserved at Cosy Dell which includes nine species of intertidal and subtidal barnacles and numerous other shallow-water, herbivorous grazers such as *Haliotis*.