「早坂犀牛」之名字使用論析

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生物分類學上的「名字」可概分學名與俗名，前者基於國際上制定的生物命名法規，後者則廣見於任何與自然實體存在各種關係的文化體系。由博物館對名字使用的觀察出發，學名常擔任學者之間的溝通橋樑，以及典藏管理上對物件進行管理、詮釋時的重要參考；俗名則於面向大眾的展示、教育場合扮演關鍵角色，更強調與在地語言相契合的程度。故整體來說，學名、俗名定義與使用上的穩定性，對博物館業務推展至關重要。本研究透過在國立臺灣博物館館史上有著特殊地位的「早坂犀牛」，說明學名歷史沿革以及學名與中文俗名之間的對應關係，可能衍生何種複雜情境。1942年，早坂一郎教授發表產自桃園的犀牛化石。1984年，大塚裕之和林朝棨教授將其併同產自臺南的犀牛化石發表作*Rhinoceros sinensis hayasakai*。在中文語境下，被稱為早坂中國犀、中國犀牛早坂亞種、早坂犀牛或臺灣犀牛。然而由於缺乏證據支持產自桃園、臺南的犀牛化石確為同一物種，*R. s. hayasakai*欲定義的分類群從一開始就有其複雜性，連帶使上列中文名也變得不穩定。近期研究將產自桃園的犀牛化石歸入新屬，正式更名為*Nesorhinus hayasakai*，並建議中文名可使用「早坂島犀」。此發展下，產自臺南的犀牛標本應採用何學名、俗名最為妥當？本研究透過分類學期刊以及國際動物命名法規的梳理，來釐清目前早坂犀牛化石的分類現況及該使用的中文名稱，並藉此為開端討論臺灣古生物中文命名未來的原則建立。

中文關鍵詞：左鎮動物群、菜寮溪、奇蹄目、化石

Synthesis of Plant Macrofossils and Remains in Taiwan: Implications for Paleovegetation Reconstruction

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Plant macrofossils and remains in Taiwan have been documented since the Japanese colonial period, yet formal morphological descriptions of specimens were scarce until 1968. Despite extensive collecting efforts, related publications remain sporadic and often face issues such as incomplete data. Compared to the more widely studied spore and pollen (sporollens) data, research on vascular plant macrofossil/remain records is still in its infancy, which limits the comprehensive reconstruction of paleovegetation.

This paper presents the most extensive review to date of vascular plant macrofossil and remain records in Taiwan, by examining records, publications, and research reports from different periods, and systematically reviewing and assessing each document and specimen in the past. A checklist of 118 records, encompassing 40 families, 68 genera, and 9 undetermined taxa, is compiled to facilitate future studies in related fields. Furthermore, we integrate macrofossil and remain records, and compare them with the palynological records from different geological periods. These analyses help explore the connections between fossil flora and extant vegetation, as well as the taphonomic challenges faced by the specimens. The result provides a crucial foundation for advancing paleobotanical studies in Taiwan, aiding the reconstruction of the island's past flora and paleoenvironment.

Keywords:Paleoenvironment , Paleovegetation, Plant macrofossil, Plant remain

以岩屑進行鏡煤素反射率量測流程初探

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因成本的考量，岩屑(Cuttings)通常是探勘鑽井會全井採集的樣本。岩屑為鑽頭在下鑽過程中擊碎的岩層碎片，會隨循環泥漿被攜回地表後再經清洗、過濾取得。理想上在排除泥漿回流造成的時間差後，岩屑可反映當下鑽遇岩層的岩性，但因為井壁崩移或泥漿添加物(如重晶石、木屑與稻殼等)等因素，實際上我們取得的岩屑常會是多個岩層碎片與添加物的混合。有機質/油母質鏡煤素反射率常被應用於資源探勘、古熱流與構造活動研究等工作中，此項技術的使用已長達近100年，是一個可靠的有機質/油母質成熟度指標，特別是在油氣探勘方面，鏡煤素反射率最常被用來當作判斷目標區的生油岩是否已達到成熟並開始產生大量油氣的依據。然而，因岩屑常混有人為添加的有機質(即木屑、稻穀等)，這些添加物會造成反射率量測上的偏差，故在對岩屑進行分析時，如何解析出可信賴的數據便是一個重要的議題。過去對於岩屑鏡煤素反射率的推估係先假設添加的有機質皆為低反射率，在量測完一個樣本的反射率數據群後，會將反射率最低的群體去除後再計算平均值，並以此作為該樣本的鏡煤素反射率，但前述方式有可能因為假設錯誤而得到偏差的數值。本研究利用台灣中油股份有限公司於臺灣西南部5口鑽井的岩屑樣本，分別對各鑽井不同深度樣本(共19個樣本)的結構鏡煤素與均質鏡煤素進行反射率量測，並將前述結果與相同鑽井的岩芯樣本數據進行比較，以了解是否可藉由油母質的型態，來區別並排除添加有機質的干擾。結果發現，不同鑽井與深度樣本的結構鏡煤素反射率具有相似的分佈區間，多集中在0.28%~0.41%(R_o)區間；而均質鏡煤素的反射率分佈區間較廣，且平均的反射率值有隨深度增加的趨勢。此外，在與相近深度的岩芯樣本數據比較後，發現當岩芯樣本的反射率≧0.60%(R_o)時，對應深度的均質鏡煤素反射率則與其非常相近。綜合上述，在進行岩屑的鏡煤素反射率分析時，當樣本反射率≧0.60%(R_o)時，可僅量測均質鏡煤素的反射率，以獲得可信賴的鏡煤素反射率值。

中文關鍵詞：岩屑、鏡煤素反射率、油母質成熟度、油母質型態鑑定

Towards a Low-Pollution Future: Lessons from Leaded Gasoline for the Global Energy Transition

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Since the last gallon of leaded gasoline sold in Algeria in July 2021, the world has concluded a 100-year-long era spreading a toxic pollutant to the atmosphere. Leaded gasoline, as an emerging fuel in the history, a source of lead pollution, had once spread like an 'aeolian chemical virus' and 'infected' more than 50% of children around the world, resulting in one of the world's worst health issues from chemical exposure. Therefore, the end of leaded gasoline era is often regarded as a magnificent achievement of pollution management. Now standing at the end of the leaded gasoline era and the start of global energy transition, we review the rise and fall of environmental lead level from geochemical records including ice cores, sediments and corals. By combining geochemical records and heath data, we reflect on where we are and what we learn from it in terms of environment, public health and humanity. The lead in gasoline will not be the last one of its kind that the world faces. Lessons from the leaded-gasoline world can help us in dealing with future fuels that may be associated with other pollutions in the environment.

Keywords:lead pollution, fuel, geochemical records, energy transition

Intraslab stress heterogeneity and continental lithospheric mantle rheology revealed by the earthquake doublet in Northern Manila subduction zone

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The impact of lithospheric rheology and subduction dynamics on intraslab stress regimes and earthquake source characteristics, as well as the reason for the scarcity of continental mantle earthquakes, are debated topics. We investigate the 2006 Pingtung offshore earthquake doublet (Mw 6.9) at the northern Manila subduction zone, where thinned continental lithosphere is subducting, to explore these topics. The earthquake doublet is characterized by its mantle depth (~30-55 km) and its complex source process, which is varied in different studies due to poorly-constrained fault geometry. To better constrain the source process without predefined fault geometry, we applied a potency density tensor inversion method on teleseismic waveform data to construct source models for the 2006 doublet. We found that the first event exhibits predominantly normal faulting with nearly simultaneous minor reverse faulting at a deeper depth, while the second event is characterized by strike-slip faulting at an even greater depth. These diverse focal mechanisms reveal fragmental mantle faulting and stress heterogeneity within the slab. To explain the observed stress states, we conducted geodynamic models constrained by subduction zone morphology, seismic azimuth anisotropy, and seismic background seismicity distributions. We found that the necessary conditions to reproduce the observations are a strong mantle and a weak upper crust for the subducting slab. The occurrence of earthquakes in the subducting continental lithosphere mantle is facilitated by the enhanced differential stress induced by bending. Conversely, the global scarcity of continental mantle earthquakes may be due to the absence of sufficient differential stress in most continental lithospheres.

Keywords:rheology of continental lithosphere, 2006 Pingtung offshore earthquake doublet , intraslab earthquakes, mantle earthquakes, Northern Manila subduction zone

Lithological and structural controls on surface deformation in the mudstone-rich fold-and-thrust belt of southwestern Taiwan: A perspective from numerical experiments

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Understanding the spatiotemporal characteristics of surface deformation and its underlying mechanisms is crucial for accurate earthquake hazard assessment. While elastic dislocation models traditionally explain interseismic deformation as the accumulation of elastic strain along faults, recent studies suggest that additional rheological properties and geological factors, such as the distribution of rock masses, may play an important role in controlling surface deformation. In this study, we investigate the mechanisms driving anomalously rapid surface deformation in southwestern Taiwan's fold-and-thrust belt. Given the presence of aseismic slip, its correlation with mudstone exposures, and findings that suggest interseismic and co-seismic deformation cannot be fully explained by crustal or seismogenic faults alone, mud diapirism—a lithologically controlled viscous deformation process—has been proposed as a potential mechanism. However, the influence of fault geometry and variation in mechanical properties remains unexplored. To address this, we conduct numerical simulations, focusing on a profile that includes the Lungchuan fault system and the Gutingkeng Formation. Our model integrates key structural features and also accounts for the varying mechanical properties of lithological and structural unit configurations. Model results, compared with geodetic observations, suggest that the anomalously high deformation rate in southwestern Taiwan is primarily controlled by lower fault friction, with active backthrusting significantly shaping surface deformation patterns. By exploring various mechanical and geometrical configurations and their corresponding contributions to surface deformation, this research provides new insights into the governing mechanisms of surface deformation. The findings may serve as a valuable reference for refining interpretations of future geodetic observations and improving earthquake hazard assessments.

Keywords:numerical simulation, fold-and-thrust belt, mud tectonics, Gutingkeng Formation, surface deformation

Preliminary study on the mineralogy and geochemistry of ferromanganese crust from the Gagua Ridge

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Marine ferromanganese (Fe-Mn) oxides occur as nodules or crusts on the seafloor surface. They are rich in cobalt, nickel, copper, lead, zinc, rare earth elements (REEs), and platinum group elements (PGEs), giving them high economic value. For decades, these deposits have been important targets for exploration and research. Scattered occurrences of Fe-Mn oxides have also been reported along the Gagua Ridge, located off southeastern Taiwan. In this study, crustal Fe-Mn oxides were collected from the Gagua Ridge's northeastern flank using dredge during the *R/V New Ocean Researcher I* NOR1-0038A cruise in 2022. Additionally, igneous rock samples with oxide coatings were collected during the *R/V Hakuho Maru* KH-23-10 cruise in 2023. Mineralogical and geochemical analyses were conducted to preliminarily investigate the genesis, age, and economic potential of the Fe-Mn crusts along the Gagua Ridge.

The crustal Fe-Mn oxides were retrieved from near the summit of the northeastern flank of the Gagua Ridge. The samples are several centimeters thick, with a porous and loose upper surface and a dense lower portion overlain by a thin Fe-Mn oxide layer. From top to bottom, the crust can be divided into three layers:

1. The first layer consists of spheroidal aggregates of Fe-Mn oxides interconnected to form columnar structures with abundant porosity between the columns.
2. The second layer is composed of dense, massive Fe-Mn oxides.
3. The third layer mainly consists of white carbonate.

X-ray diffraction (XRD) analyses show that the mineral compositions and relative abundances of the first and second layers are similar. In addition to vernadite (δ-MnO_2), the Fe-Mn oxides contain detrital minerals such as quartz, feldspar, and muscovite, as well as zeolite derived from the alteration of mafic igneous rocks, and minor calcite from biogenic sources. The third layer is primarily composed of calcite, followed by zeolite, indicating that the crust gradually precipitated on a hard substrate composed of calcite and altered igneous rocks. Igneous rocks ranging from felsic to mafic compositions collected nearby exhibit secondary minerals such as zeolite, prehnite, chlorite, and pumpellyite. These minerals occur as vein fillings, amygdaloidal infills, or replacements of primary mafic minerals, indicating widespread low-temperature alteration. This observation supports the inference that the Fe-Mn crusts formed atop altered igneous rock substrates.

Geochemical analyses indicate that the samples are hydrogenetic Fe-Mn crusts, formed directly by precipitation from ambient seawater. Based on empirical formulas derived from cobalt, iron, and manganese contents, the estimated precipitation rates range from 3.95 to 5.85 mm per million years (mm/Myr). Considering the sample thickness, the initial precipitation period is estimated to have begun approximately 1.95–2.23 million years ago. Since Fe-Mn crusts require stable bottom currents and redox conditions for deposition, these findings suggest that the Gagua Ridge has maintained relatively stable environmental conditions conducive to Fe-Mn crust formation at least two million years following the low-temperature alteration of its igneous rocks. The concentrations of REEs, cobalt, nickel, copper, lead, and zinc in the samples are comparable to those found in other seafloor Fe-Mn oxide resource potential areas, indicating that this region warrants further systematic exploration.

Keywords:ferromanganese crust, rare earth elements, hydrogenetic, Gagua Ridge

應用分布式光纖感測技術於鐵路路基成像

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近年來，分布式光纖聲學感測(Distributed Acoustic Sensing, DAS)技術在工程應用、石油勘探、地質碳封存監測與地震學研究等領域備受關注，相較於傳統受波器，DAS 具備高密度的空間取樣能力，不僅能獲取高解析度數據，且能適應複雜的感測環境，使其在鐵道應用分析方面展現出極大的潛力。

本研究採用一條 283 公尺長的光纖纜線，直接布設於鋼軌上，記錄列車行駛時段4 小時期間所產生的振動訊號。透過震波干涉技術提取沿路基傳播的表面波訊號，並應用多頻道表面波分析法(MASW)反演路基材料的剪力波速度構造。研究結果顯示，僅基於 4 小時的環境振動數據，仍能獲取足夠的表面波資訊，而列車行經時所產生的振動為主要的表面波來源。此外，反演所得的速度影像顯示，地下 10 至16公尺深處的低速區與鄰近標準貫入試驗(SPT)中的低 N 值區域高度相關，驗證反演影像的正確性。

本研究證實，DAS 可有效量測列車震動訊號並解析地層特性，展現其作為非破壞性檢測技術的可行性與準確性，DAS 的大範圍分布特性及被動式震源提取技術，亦使其成為長期監測路基材料強度的可靠工具，無論是在路基掏空監測或背景地質調查方面，皆展現高度應用價值。

中文關鍵詞：分布式光纖聲學感測、多頻道表面波分析、震波干涉技術、鐵路路基

颱風對被動式多頻道表面波的增益效應：以臺灣西部沿海為例

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環境噪聲已成為強大的地下成像工具，透過自然產生的噪聲與人為噪聲，環境噪聲干涉法可從記錄的噪聲中提取兩個受波器之間的格林函數，進而分析表面波的傳播特性並推導地下的剪力波速度構造。然而，環境噪聲的頻譜特性決定了地下成像的解析能力，因此不同噪聲來源的影響需進一步探討。本研究聚焦於颱風經過所引發的地震噪聲特性，並評估其對多頻道表面波探勘(MASW)方法的影響。

本研究利用臺中濱海地區一條 1000 公尺長的線性分布式光纖感測陣列(DAS)，該陣列的感測節點間距為 1 公尺，理論上可解析的波長範圍為 2 至 1000 公尺，適合作為研究颱風對環境噪聲影響的觀測工具。我們分析了颱風凱米(GAEMEI)經過臺灣的 14 天資料，並以小時與天為單位，透過環境噪聲干涉法重建表面波訊號並提取頻散曲線。結果顯示，在颱風最接近臺灣的兩天內，2 Hz 以下的低頻能量明顯增強，該頻段的增益在非颱風時期未曾觀測到，顯示颱風帶來額外的低頻能量。此外，比對外海的浪高與波向數據，結果顯示，僅當波向與感測陣列方向平行時，才會出現建設性干涉效應，且表面波的訊噪比與浪高呈現高度相關，證實這些低頻能量訊號的來源為海浪之間或與近岸的撞擊所引發的震動，其能量增益可達非颱風時期的 4 倍。

本研究證實，颱風引發的海浪撞擊可作為有效的地下探勘訊號來源，並在 2 Hz 以下的頻率範圍內顯著增益，提升低頻訊號的可靠度增強近地表地質探勘的能力。本研究結果為利用颱風事件增強被動式噪聲成像提供了新的應用方向，並拓展了DAS 技術在近地表地球物理探勘中的潛在應用。

中文關鍵詞：颱風、震波干涉技術、多頻道表面波分析

大屯火山群熔岩流災害之數值模擬研究

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大屯火山群熔岩流災害之數值模擬研究

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摘要

大屯火山群位於台灣北部，地質研究顯示其仍具火山活動潛勢，可能對周邊地區構成威脅。本研究使用Matlab中的VolcFlow數值模擬軟體，針對磺嘴山與大屯山兩個噴發口，探討不同火山爆發指數（VEI）與岩漿黏滯度條件下的熔岩流行為。透過設定在四種不同VEI下，換算的噴發速率（50、100、200、2000 m^3/s）與五種黏滯度(50000、100000、500000、1000000、5000000 Pa·S)，共進行20組模擬，分析熔岩流動速率、影響範圍及地形影響。

結果顯示，較低黏滯度的熔岩流動速率較快，影響範圍更廣，而高黏滯度熔岩則流動緩慢且易於堆積。此外，地形對熔岩流向有顯著控制作用，陡坡區（如磺嘴山東側）加速熔岩流動，而平坦區（如大屯山北側）則形成熔岩湖或堆積區。根據熔岩抵達時間，可將影響區域劃分為高風險、中風險及低風險區。

本研究為對大屯火山群進行熔岩流數值模擬，結果可應用於火山災害防範與應變計畫。未來可進一步擴展模擬範圍至七星山與大油坑，並引入更精細的物理參數，以提高模擬精準度。本研究不僅填補了大屯火山群熔岩流災害評估的研究空缺，也為台灣火山防災規劃提供了重要的科學依據。

中文關鍵詞：大屯火山群、熔岩流、數值模擬、VolcFlow、火山災害

A Stochastic Dynamic Model of Earthquake Rupture: Exploring Self-Similarity and the Fisher-Shannon Characterization in Frictional Failure Processes

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Earthquake ruptures are generally considered to occur in extremely heterogeneous stress environments and involve the instability of frictional sliding. Their complex and nonlinear nature remains at the core of many key issues in modern seismology. Given the scale invariance summarized from previous studies across rock shear experiments and field earthquake observations, we regard earthquake rupture as a stochastic process, establish a stochastic dynamic equation governing this process, and quantify the disorder of the system based on information theory.

Starting from a one-dimensional slider model that analogizes rupture as frictional failure, we employ the Langevin approach to simplify the momentum transfer at the rupture front as a Markov process. We use the trajectories of representative Brownian particles in velocity space to describe the fluctuation of the momentum of shear slip at the front where the rupture sweeps by. By decomposing the forces acting on the representative Brownian particle into deterministic (classical) and stochastic (thermodynamic) components, the mechanical problems in multi-body systems become practically solvable.

We generate a large number of sample paths based on the proposed Langevin equation and solve the corresponding Fokker-Planck equation analytically. The results show that the analytical solutions of the ensemble statistical distribution coincide with the empirical laws of earthquake slip distribution, and the analysis of sample paths reveals a universal energy (moment)-duration scaling law that aligns with regional and global earthquake statistics under a wide range of parameter conditions.

The results of informational analysis indicate that the Fisher-Shannon characterization of sample paths can effectively distinguish different background frictional dissipation mechanisms and help explain the structure and lubrication state of sliding surfaces in rock friction. In summary, our study proposes a stochastic dynamic model that offers a new descriptive framework and insights into the frictional dissipation processes in earthquake faulting, demonstrating the potential application of informational analysis in studying the behavior of rock shearing in seismogenic environments.

Keywords:self-similarity, stochastic process, Shannon Entropy, Fisher Information Measure, slip-distribution

Taiwan Rock Guy: 用短片當作開啟認識台灣地質的一把鑰匙 // Taiwan Rock Guy: Using Short Form Content to Promote Taiwan's Geology

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*"**第一次看到著麼有生命力的石頭故事** (This is the first time I've ever seen such a lively story about a rock)", "**我以為在看好笑短片，結果知識偷偷溜進來了** (I thought I was watching a funny video, but it turns out I secretly learned something)", "**很有趣的解釋，以後看岩石都有不一樣的感覺了** (Interesting explanation, after this I'll look at all rocks differently)"* are a few of the many comments left under James (Jimmy) Kelloway's videos on Instagram, TikTok, and YouTube. Jimmy Kelloway is better known by his internet alias: *Taiwan Rock Guy*. Jimmy, a master's graduate in environmental education from National Dong Hwa University, promotes Taiwan's unique geology and general earth science education through short-form videos as *Taiwan Rock Guy*. After publishing his first video in October 2024, in half a year, *Taiwan Rock Guy* has garnered a hundred thousand followers, and millions of views on content focused entirely on the geology of Taiwan. *Taiwan Rock Guy* videos are published both in Mandarin and English, which led to the growth of an international fanbase. According to data provided by Instagram and Youtube, only 60% of *Taiwan Rock Guy* followers are actually from Taiwan. *Taiwan Rock Guy*'s purpose is not only to promote Taiwan's geology but also to foster a greater global appreciation and understanding of geoscience. This presentation will explore the process and challenges of taking complex, multi-faceted geologic concepts and breaking them down into minute-long educational videos. This presentation will also discuss the future of *Taiwan Rock Guy* and the steps needed to be taken for turning viewers' 'interest' in geosciences to geoconservation efforts.

Keywords:Environmental Education, Social Media, Geoconservation

Widespread Thick Turbidites in the Kuril Trench: Possible Evidence of a Mw~9 Earthquake in the 13th Century?

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The intense ground shaking and induced tsunami of the 2011 Mw 9.0 Tohoku-oki earthquake devastated northeast Japan. The onshore tsunami deposits indicate that earthquakes of similar magnitudes have recurred along the Japan subduction zones over the past several thousand years, which may occur again. Investigating the affected regions and impacts of paleo-earthquakes is essential to enhance disaster preparedness. Five meter-scale turbidites were identified across a sequential piston core along the seafloor of the southern Kuril Trench. These thick turbidites obtain comparable geochemical signals and magnetic intensity but are distinct from other thin turbidites, suggesting their correlations and shared sediment source areas. Paleomagnetism-based chronostratigraphy estimates the emplacement ages at 675–755 BP, aligning with the estimated timeframe of the 13th-century giant earthquake. The increased mud fraction and waning flow energy with distance from Kushiro Canyon are inferred from the decreased normal grading level and absent parallel laminations at the base of turbidites. Combining with the SW-NE paleo-flow direction indicated by the magnetic fabric alignment, the turbidity current was expected to enter the trench near the Kushiro Canyon and travel along the trench floor for at least 100-150 km with a total volume of >1.7 km3. The extensive thick turbidites are the first documented massive submarine landslides, likely triggered by a giant earthquake in the Kuril Trench area, providing valuable insights into the hazard assessments and highlighting the non-negligible risks from landslide-induced tsunami and turbidity currents.

Keywords:paleo-seismology, submarine landslides, earthquake-induced hazard, core correlations, turbidites

Tectonic Deformation and Backthrust Fault Development Along the Chelungpu Fault: Insights from PSInSAR Analysis

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Taiwan is located in a highly active orogenic belt, where numerous active faults have developed along the foreland, resulting in multiple significant earthquakes throughout history. Among these, the Chelungpu Fault ruptured during the devastating 1999 Chi-Chi earthquake (Mw 7.7), causing severe damage and casualties, making its activity a key focus of geophysical research. To investigate surface deformation along the Chelungpu Fault and surrounding areas, we applied Persistent Scatterer Interferometric Synthetic Aperture Radar (PSInSAR) to analyze Sentinel-1 satellite imagery from 2018 to 2021. The results indicate no significant movement along the main fault during this period; however, noticeable deformation and velocity variations were observed in the Hsinshe and Ailiao regions, suggesting active tectonic processes. By integrating PSInSAR velocity fields, topographic analysis, field observations, and forward modeling using an elastic dislocation model, we infer that the Hsinshe Lineament and Ailiao Fault likely represent backthrust faults associated with the Chelungpu Fault system. Their activity appears to be driven by stress transfer resulting from the locking of the shallow leading edge of the fault, with continuous compressional forces from orogenic processes causing eastward movement and vertical uplift. These findings underscore the effectiveness of PSInSAR for high-resolution surface deformation monitoring and offer new insights into the development of backthrust faults within the fold-and-thrust belt of Taiwan.

Keywords:PSInSAR, Hsinshe Lineament, Ailiao Fault, backthrust, forward modeling

臺灣西南海域枋寮海底峽谷之濁流沉積物紀錄及可能沉積機制

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枋寮海底峽谷被認為海底地質災害高潛勢區，峽谷頭部海床構造不穩定，海底山崩、碎屑流與濁流沉積可從地層剖面觀察到。2006年屏東地震事件中，推測5處海底電纜斷裂點可能是獨立海底塊體運動造成的，其中2處斷裂點位處枋寮海底峽谷區域。本研究於勵進研究船LGD-T56航次挑選鄰近於2006年屏東地震中海底電纜最先發生斷纜位置，以同站位多次採樣方式（東經120°36'； 北緯22°12'），共探取兩活塞與一重力岩心紀錄。不同於岩心OR1-983-GCC（東經120°34.90'； 北緯22°12.21'，水深245公尺）採集自混亂狀堆積層，LGD-T56-C-PC則探取自枋寮海底峽谷東側谷壁海床，該站位於OR1-983-GCC之東南方，水深204公尺。相較於枋寮海底峽谷西側站位，東側三岩心紀錄之岩心沉積物組成主要以黏土與粉砂為主，均可發現明顯之侵蝕面與紋層，其中LGD-T56-D-PC與LGD-T56-E-GC全岩心均可發現紋層沉積物的存在，約略公釐至公分等級，LGD-T56-C-PC紋層的出現則以第二節35～50公分處（即75-90公分處）較為明顯。三岩心近乎為同採樣點，但岩心特徵略有不同，初步排除岩心採樣作業所造成之因。濁流沉積僅在活塞岩心LGD-T56-C-PC於311.5-320.5公分處觀察到，該粗顆粒濁流層長達約10公分，但此現象並未在其他岩心中紀錄到。透過顯微鏡觀察，沉積物中植物碎屑、貝殼碎片與白雲母應是來自於台灣陸地或鄰近陸棚。LGD-T56-E-GC重力岩心頂部5公分處一浮游有孔蟲富集層存在，且LGD-T56-C-PC與LGD-T56-D-PC分別於第二節48公分處（即88公分處）與第三節22.5公分處（即205.5公分處）亦發現底棲有孔蟲*Ammonia* spp.、*Bolivina* spp.。而LGD-T56-C-PC於第三節90～93公分處（即274-277公分處）發現一長4公分、寬1.5公分的木頭碎片。推測此時應有較大傳輸動力始能攜帶木頭碎片於此處沉積。然而，現階段缺乏年代控制，對於上述沉積事件之瞭解有限。未來將挑選沉積物中浮游有孔蟲層位與木頭碎片進行碳十四定年，以瞭解枋寮海底峽谷這一海底地質災害高潛勢區東側地質事件的可能成因。

中文關鍵詞：枋寮海底峽谷、勵進研究船、海洋岩心、濁流沉積、海底地質災害

混魚龍屬（Ichthyosauria: Mixosauridae）的發聲方式與生長模式 Acoustic communication in, and ontogenetic stage of Mixosaurus sp. (Ichthyosauria: Mixosauridae)

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中生代的海生爬行動物稱霸古海洋生態系約一億五千萬年。其中，魚龍類（Ichthyosauria）在身體形態及生理構造上對水域環境展現出高度的演化適應。魚龍類生存於中生代，其形態在演化過程中逐漸發生改變，由早期細長的軀幹與較短小的四肢，至後期流線型的軀幹與鰭狀四肢，並與現生齒鯨呈現趨同演化。親緣關係顯示，魚龍類與鱷類、龜鱉類及有鱗類相近，而其生活型態則與現生鯨豚類相似，因此鯨豚類常作為魚龍類研究中的比較類群。上述現生類群皆具有發聲能力，且被證實能夠使用聲音進行多樣化的溝通。然而，目前針對魚龍類，甚至是所有海生爬行動物的發聲構造及其能力的研究仍有限。在演化史上，混魚龍除保有早期魚龍類的特徵，也同時出現晚期的衍徵，被視為魚龍類中的過渡類群，在生態學與演化學上均具有重要研究價值，因此選擇混魚龍作為本次研究對象。

本研究利用一件藏於國立自然科學博物館、來自中國貴州的混魚龍化石標本（NMNS004728-F003962），透過電腦斷層掃描及骨組織學分析，進行其喉部構造觀察與生長歷史判讀。雖並未於喉部附近發現軟骨保存的證據，但因標本保存完整，可清楚觀察到舌骨。舌骨在現生鱷類、龜鱉類及有鱗類的發聲機制中扮演重要角色，與附近之軟骨共同協助聲門的開合，以控制氣流，故推測其具備與上述類群相似的發聲能力。此外，骨組織學分析結果顯示該個體為一亞成體，其股骨的密質骨中可清楚觀察到有三條生長停滯線（lines of arrested growth），推測此個體死亡時年齡至少為三歲。肱骨則出現皮質骨增厚之現象，呈現適應深水生活的特徵。

對比其他魚龍類標本後，本研究所探究之混魚龍與其他魚龍類物種擁有相似的舌骨形態，然而，多數動物的發聲仍需仰賴軟骨與肌肉的協同作用。因此，未來研究將著重於探詢喉部附近軟骨保存之證據，同時搭配生長階段判定，將有助於進一步了解其使用聲音的形式，並為中生代海洋生態系的聲學研究提供初步的研究線索。

中文關鍵詞：聲學、骨組織、海生爬行動物、中生代、舌骨

恆春西台地泥貫入體特徵

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恆春西台地地層微向東傾，以往研究推測在西側海域有一向東傾斜的逆衝斷層(西海岸斷層)，因斷層抬升造成恆春西台地地層東傾。陳松春(2017)分析恆春西台地附近海域之反射震測和精密水深資料，辨識出3處泥貫入體(HC1~HC3)，HC1及HC2位於恆春西台地南側海域，而HC3則位於緊鄰台地西側海域，應是HC3泥貫入體抬升造成恆春西台地西側上拱，致使地層微向東傾，並未發現有相關斷層構造，認為前人所推測之西海岸斷層可能不存在，或是緊鄰近岸區，未在震測調查範圍內。換言之，現今影響恆春西台地發育的主要活動構造為泥貫入體構造，另位於屏東海生館旁的龜山應是泥貫入體(陳松春，2017)，也發現恆春斷層有延伸進入海域，在海床有明顯線形構造，且地層被嚴重擾動，顯示該斷層應還在活動中，在南灣海域也發現因泥貫入體抬升造成的正斷層(南灣斷層)，由於南灣斷層在海床上有明顯的線形、錯動珊瑚礁海床及發現有大量逸氣現象，顯示南灣海域之泥貫入體還在持續活動中。謝凱旋及王士偉(2024)從恆春西台地鑽井岩心微體化石生物地層研究，發現馬鞍山層缺失(更新世石灰岩之下即為中新世晚期地層)，及中新世晚期岩層夾雜於更新世早期岩層內，推測可能是在更新世早期岩層堆積之後，其下之中新世晚期沉積物受泥貫入體上擠侵入所致。從目前先期各項調查成果都顯示恆春西台地應受到泥貫入體抬升影響，在野外泥貫入體地質調查，發現位於核三廠西側之台電南部展示館、龜山西測之海生館行政區(研究二館、行政中心)，以及海生館展覽館(珊瑚王國館、世界水域館、廣場等)的建築物及地磚都有明顯抬升破裂情形，顯示恆春西台地泥貫入體仍有持續抬升。另從和海生館行政人員洽談了解，海生館常有地下管線斷裂情形，是否因抬升差異所造成的，後續將持續了解。雖然核三廠將於2025年除役，但泥貫入體可能受到斷層活動或地震影響而快速抬升，建議核三廠仍需考量泥貫入體地質安全。

中文關鍵詞：泥貫入體、恆春西台地、恆春斷層 、南灣斷層

Spatial variation on subsurface geochemical characteristics in the southern flank of Mienhua Submarine Volcano, South Okinawa Trough

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The Mienhua Submarine Volcano (MHV), located at the southernmost Okinawa Trough, exhibited vital hydrothermal activities in its southeastern flank with acoustic flares observed, even active vents, so far, the Devil Chimney, Witch Mound, and Casper Chimney, discovered by ROV. Sediment cores collected this area were classified into three groups according to their geochemical characteristics. The 1st group of sediment cores, collected from the region characterized by acoustically stratified masses, showed stable pattern of pore-fluid Mg^{2+} concentration at different depths, indicating no influence of hydrothermal fluid. The 2nd group displayed obviously downward decrease of Mg^{2+} (low to 29.1 mM) and increase of Li^{+} (up to 2.27 mM) in pore fluid, implying an influence of hydrothermal fluid associated with high-temperature (>350 ˚C) rock/sediment-fluid interaction. The slightly low pH (5.76～6.66) with downward increase of pore-fluid DIC (up to 59.5 mM) and its heavy isotopic compositions ($\delta^{13}C_{DIC}$= +2.5~+7.0 ‰) further inferred an *in-situ* liquid CO_2-impregnated sedimentary circumstance. The pore-fluid chemistry of 3rd-group sediment cores, which collected within 100~120 m of the Devil Chimney, also revealed significant anomalies, like apparently low Mg^{2+} (low to 21.1 mM), high Cl^{-} (up to 676.3 mM) and Li^{+} (up to 2.05 mM), indicating the influence of high-temperature brine-rich fluid related to phase separation. But the sedimentary carbon chemistry, such as DIC and TA weren't as elevated as in sediments impregnated with liquid CO_2, with lower pH (low to 5.54). It is suspected to be exposed to acid-sulfate hydrothermal fluid. Additionally, oily smell, oil impregnation, and increased TOC content were observed, pointing to the occurrence of hydrothermal petroleum generation in that core area. In summary, this study highlights small-scale diversity of geochemistry in a submarine sediment-hosted hydrothermal system.

Keywords:Submarine sediment-hosted hydrothermal system, Mienhua Submarine Volcano, Devil Chimney, South Okinawa Trough, Phase Separation

On the Accuracy of Traveltime Measurements in Noise Interferometry: A New Approach Using Higher-Order Cross-Correlation within a Plane Wave Framework

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Under a diffusive wavefield, the retrieval of impulse responses from spatiotemporal correlations among a set of receivers has been validated through acoustic experiments and theoretical approaches, including normal mode and ray-based analyses. A homogeneous source distribution is a common prerequisite in these derivations. However, a critical aspect of ray-based derivations is the implicit high-frequency approximation, which plays a central role in establishing the link between the time domain cross-correlation function (TDCF) and the Time domain Green's function (TDGF), whereas such an assumption is not required in mode-based derivations. Although the use of seismic ambient noise for probing Earth structures has become a well-established technique over the past two decades, the specifics of errors in traveltime measurements have received relatively little attention. In this study, we demonstrate that systematic errors may arise in noise studies due to the common use of a symmetric TGCF in dispersion measurements. Furthermore, under a two-dimensional far-field scenario, the TDCF resembles the TDGF only when the noise sources are confined to one side alone the station pair direction, rather than being homogeneously distributed. In this study, we propose an approach to evaluated travel time from an arbitrary distribution of far-field noise sources, and apply this method to real data. Besides, a long interstation distance is no longer a necessary condition, as the TDCF is not treated as a TDGF of far-field surfaces wave in this study. As a result, phase velocities can be determined more accurately at lower frequencies, enabling improved resolution of deeper Earth structures using ambient noise data.

Keywords:dispersion, Time Domain Green's Function, noise interferometry

Deep-Sea Turbidites of the Huatung Basin and SW Ryukyu Trench

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The Huatung Basin, located between Japan and Taiwan, is a key area for studying regional sediment transport processes from Taiwan mountain belt to Ryukyu Trench. During the KH23-10 cruise (2023.12.13–12.24), two piston cores and one set of multi-cores were retrieved. The core PC01 was retrieved from the northern flank of the Hualien Canyon, south of the accretionary wedge (23°12.4750'N, 122°35.1059'E, water depth: 5,381 m). This core provides insights into the characteristics of thick deep-sea turbidites and sediment sources in the northern Huatung Basin. The core PC02 was collected from a small basin on the western flank of the Gagua Ridge, distant from the main submarine canyons in the Huatung Basin (22°22.456'N, 122°43.012'E, water depth: 4,997 m).

For PC01, a total of 648 cm of piston core and a 26.5 cm pilot core (PL01) were obtained. Sediments below 359.5 cm showed evidence of flow-in. The lithology of PC01 comprised thick, massive sand to very fine sand, while PL01 displayed massive fine to very fine sand. For PC02, a total of 812.5 cm of piston core was recovered, with sediments below 465.8 cm showing flow-in. The lithology of PC02 consisted of homogeneous clayey silt interbedded with very fine sand roughly in 3-5 cm thick. MC01, collected at the same site as PC02, exhibited a lithology similar to that of PC02. Core splitting, X-Ray CT scans, Multi-Sensor Core Logger (MSCL), X-ray fluorescence core scanning (ITRAX), and sampling were conducted at the Kochi Core Center, Japan. Based on the X-ray fluorescence core scans, the Ca/Fe and Zr/Rb ratios show trends similar to those observed in cores from the Ryukyu Trench. Magnetic Property Measurement System (MPMS) analyses of sediments from PC01 and PC02 reveal magnetic signatures indicative of pyrrhotite, suggesting that Taiwan-sourced sediments are transported not only through submarine canyons but also dispersed into the deeper Huatung Basin.

These preliminary findings offer valuable insights into the sedimentary processes and transport dynamics within the Huatung Basin, contributing to a better understanding of its role in regional sediment dispersal systems.

Keywords:Turbidites, Sediment Transport, Pyrrhotite, Huatung Basin, Ryukyu Trench

利用微地動之方向性共振特徵分析臺灣西南部泥岩區之變形模式

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位於臺灣西南部泥岩區的中寮隧道，以近乎垂直方向穿越呈東北－西南走向的斷層邊界（fault-bounded）區域，其西側為車瓜林斷層，東側則為旗山斷層。根據高密度GNSS與精密水準測量結果顯示，此寬度約數百公尺之斷層邊界區域在整體西北-東南向的構造聚合環境中，垂直抬升量約為20-80 mm/yr，且有50 mm/yr向西北西方向（即垂直斷層方向）的水平運動，呈現高度變形模式。為解析於此高度變形環境中，斷層邊界泥岩區的變形模式，本研究於垂直斷層走向設置三條測線進行量測，利用微地動單站頻譜比（microtremor horizontal-to-vertical spectral ratio）及時頻極化分析（time-frequency polarization）方法分析其地動反應特徵。每條測線皆包含20個測站，每個測站均配備一套DATA-CUBE^{3}記錄器及HG-6速度感震器，測線長度均小於1000公尺。微地動單站頻譜比剖面顯示，受車瓜林與旗山斷層的影響，地下構造呈現明顯的不連續性，並具高傾角特徵，與區域內已知之高角度地層構造特性相符。此外，頻譜比結果顯示，兩斷層間的地層缺乏明顯之速度分層，推測位於斷層帶內，地層受到強烈的斷層活動（如擠壓與錯動），進而形成高度破碎的地質結構。此觀點與Eikonal層析成像所揭示的兩斷層間存在低速異常相一致，共同印證了斷層活動對泥岩區地層的顯著影響。再者，極化分析結果指出，靠近斷層位置的微地動極化方向呈現與斷層走向（東北-西南）呈高角度或近乎正交的特性；相對地，兩斷層間區域的極化方向則主要與斷層走向平行，此特徵與斷層低速帶內的「斷層陷波」（fault-trapped waves）特性相吻合。

中文關鍵詞：微地動單站頻譜比、時頻極化分析、西南部泥岩區

地質保育：地質科學與社會參與的橋樑

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地質保育的議題近年在國際上逐漸盛行，國內也因《地質法》裡的地質遺跡、《文化資產保存法》中的地質公園與自然紀念物、礦區的文化資產保存等增加了許多實務與研究的案例。對於地質遺跡的價值評估、經營管理及社區參與的推動，除了地質科學的基礎之外，還存在不同面向的課題。本研究透過和平島地質公園、黃金博物館、利吉惡地地質公園、東部海岸富岡地質公園、八仙洞自然紀念物等案例，分析不同法規的執行規範、主管部門的業務考量、以及地方居民的反饋意見，來了解身為地質專業人員如何在地質保育的推動中所須扮演的角色。

由本研究歸納之結果，地質保育的推動不僅需要地質科學的內涵，更需要理解不同權益關係人的需求，透過對法規的充分理解、業務單位需求的溝通、與社區民眾的多方交流，才能創造出更多展現地質科學價值的機會，也讓地質保育的工作得以順利推展。

中文關鍵詞：地質保育、地質公園、地質科學、社會參與

Petrogenesis of mafic granulite xenoliths in southern Vietnam and its implication to the lower crust of Indochina

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A petrographic and geochemical study was carried out on a suite of mafic granulite xenoliths from the Xuan Loc volcanic field, southern Vietnam. The volcanic field, composed of an estimated volume of ~500 km^3 basaltic magmas erupted in the Late Cenozoic, is known to contain peridotite and pyroxenite xenoliths entrained from the lithospheric mantle, as well as crustal fragment such as granulite. The granulite xenoliths consist of clinopyroxene (Mg#=63-68), orthopyroxene (Mg#=63-65), plagioclase (An_{52-53}) and accessory apatite and Fe-Ti oxides, exhibiting equigranular and granoblastic textures. They have SiO_2 ranging from 48 to 55 wt.% and MgO from 4 to 8 wt.%. The REE patterns of the xenoliths are gently right-dipping (e.g., La/Yb = 2.8 to 4.5) with a positive Eu anomaly, while the extended trace element patterns of the them are characterized by a positive Sr anomaly, and negative anomalies of Nb, Ta, Zr, Hf and Ti. Thermobarometric estimates suggest equilibration at 835–905°C and 10–13 kbar, corresponding to depths of approximately 33–40km. Symplectic intergrowth is variably developed around orthopyroxene grains with a mineral paragenesis of olivine, clinopyroxene, feldspar, and Fe-Ti oxides. The symplectites are interpreted to have formed by decompression recrystallization during transport by the ascending basaltic magma, possibly with melt-rock interaction. Preliminary data and observations indicate that the granulite xenoliths were likely developed from meta-igneous protoliths of cumulate or residue origin that might have formed during Late Cretaceous arc-related magmatism associated with Paleo-Pacific subduction. This work provides direct evidence for the presence of mafic lower crust in the Indochina Block, and should be considered in geophysical models of crustal architecture.

Keywords:Xenolith, Granulite, Continental crust, Xuan Loc volcanic field, Indochina block

Evidence of Significant Destratification of the Subantarctic Pacific During the Past 3.3-2.4 Million Years

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In recent years, Earth's climate system has been profoundly affected by rising atmospheric CO_2 from industrial activities. Elevated CO_2 levels not only drive temperature changes via the greenhouse effect but also alter the global carbon cycle. Understanding how Earth responds to CO_2 fluctuations is crucial for assessing climate system dynamics and carbon cycle regulation.

The Southern Ocean (SO), a major atmospheric CO_2 sink, regulates the global carbon cycle through ocean ventilation. We examine sediment from the central South Pacific (IODP U1541) during the warm-to-cold Plio-Pleistocene transition (3.3-2.4 Ma), using planktonic foraminiferal assemblages and geochemical proxies. Key planktonic foraminiferal groups include *Neogloboquadrina pachyderma* (cold-water indicator), *Globoconella* spp. (thermocline indicators, *G. puncticulata* and *G. inflata*), and *Globigerina bulloides* (nutrient-enrichment indicator). Faunal results indicate the northward migration of the SO frontal system, marked by increased *N. pachyderma* abundance and decreased thermocline dwellers, suggesting the occurrence of destratification. Variations in Mg/Ca ratios and stable isotopes reveal a climate system increasingly governed by glacial-interglacial cycles after the intensification of Northern Hemisphere Glaciation (iNHG).

Our findings suggest that before iNHG, the study site resembled modern subtropical conditions but shifted to the Subantarctic Zone afterward, aligning with present-day patterns. The frontal system migration, enhanced deep-water upwelling, and strengthened cold-water sinking likely increased CO_2 storage efficiency as the climate cooled from the mid-Pliocene to the early Pleistocene.

Keywords:iNHG, Southern Ocean, destratification

The preliminary report of diatom assemblages from a 50 m core sample at Paitan Lake, Luzon Island, Philippines

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Lake Paitan, a volcanic lake in central Luzon Island, Philippines, remained a deep lake for over 50 ka before becoming a shallow pond or dry land around 5 ka. In March 2024, a new 50 m sediment core was collected for paleoenvironmental reconstruction. This preliminary study analyzes 52 samples from the core. Although radiometric dating is not yet available, a previous 27 m core suggests an average sedimentation rate of 1 m per 1,000 years (Nakanishi et al., 2017), implying that the base of the 50 m core may date back to ~50 ka.

Diatom analysis reveals environmental and climatic changes over the past 50 ka. The upper 5 m contains sparse diatom assemblages, except at 1.2–1.5 m and 5.0 m, indicating two humid phases around 1.2–1.5 ka and ~5 ka. Between 5–6 m, benthic diatom *Gomphonema lingulatum* dominates, suggesting a shallow lake around 6 ka. From 7–30 m, planktonic diatoms are prevalent, with *Aulacoseira* Types 1–3 successively dominating, and *Stephanodiscus dubius* appearing prominently at 25.0 m and 29.0 m. These layers are tentatively correlated with key paleoclimate events: Younger Dryas (13.0 m), Heinrich Event 1 (17.0 m), Last Glacial Maximum (19.0–21.0 m), Heinrich Event 2 (25.0 m), and Heinrich Event 3 (29.0 m).

Below 30 m, *Aulacoseira* Type 1 was dominant, but benthic and semi-planktonic taxa became to be dominated at depths of 31.0 m, 36.0–37.0 m, 40.0 m, 44.0–45.0 m, and 47.0–50.0 m. These intervals may correspond to cooling events between 30–50 ka, as inferred from the GRIP and NGRIP ice cores.

Keywords:Lake Paitan, Lake Drilling Core, Diatom Assemblages, Paleo-environmental Changes

High-precision measurements of the triple oxygen isotope compositions of phosphate in bioapatite for reconstructing body temperature of extinct marine vertebrates

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The body temperature of extinct vertebrates can be highly useful to clarify ecology and evolution of vertebrates. The $^{18}O/^{16}O$ ratios (the $\delta^{18}O$ values) of phosphate in bioapatite — the main component of bone and tooth of vertebrates — have been used to estimate body temperature, because phosphate in bioapatite attains a temperature-dependent oxygen isotope equilibrium with body water in the presence of the enzyme pyrophosphatase. The body water of multicellular organisms, however, consists of both ambient H_2O ingested as foods/water and metabolic H_2O, of which the oxygen atoms are derived from inhaled atmospheric O_2. Thus, it was difficult to constrain the $\delta^{18}O$ values of body water without evaluating the contribution of metabolic H_2O to body water.

In this study, we analyzed the triple oxygen isotope compositions [$\Delta'^{17}O = \ln(\delta^{17}O+1) - 0.528 \times \ln(\delta^{18}O+1)$] of phosphate in bioapatite as an additional tracer to detect the contribution of metabolic H_2O to the body water of extant and extinct marine vertebrates. Because atmospheric O_2 has an extremely lower $\Delta'^{17}O$ value (-443×10^{-6}) than seawater (-5×10^{-6}), the $\Delta'^{17}O$ value of phosphate in bioapatite should be lower than those of phosphate under the isotope equilibrium with seawater if the contribution of metabolic H_2O to body water is significant.

We found that the $\Delta'^{17}O$ values of phosphate in bioapatite of extant fish and extinct marine reptiles were close to those of phosphate under the isotope equilibrium with the modern seawater, implying the negligible contribution of metabolic H_2O to their body water. In our presentation, we will discuss the estimated body temperature of extinct marine reptiles and explore a potential use of $\Delta'^{17}O$ as a proxy for the physiological evolution of vertebrates.

Keywords:Triple oxygen isotope composition, Phosphate, Bioapatite, Ecophysiology, Paleoenvironment

礦區的地質保育與社群參與：以礦山環境資源盤點計畫為例

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地質保育的目標除保護重要地質遺跡、亦期望促進地方永續發展，因此促進地質遺跡周邊之社群參與是不可忽略的議題。本報告以筆者於黃金博物館執行的「礦山環境資源盤點計畫」為例，分享透過地質保育概念保存九份—金瓜石—水湳洞（水金九）地區金銅礦業文化資產的工作架構、促進社群參與的策略、最後彙整與討論現階段成果。

本計畫緣起於兩個脈絡：(一)黃金博物館近年建立「水金九礦山學」地方知識學系統，欲在此架構下彙整金銅礦產業發展、歷史變遷、人文動態等研究資源；筆者再於礦山學中納入地球系統服務概念，強調礦山的地質、生態、文化研究皆屬礦山學的內涵，並嘗試帶領地方社群參與資源盤點工作，長期目標為培育地方社群成為具專業能力的地方研究者。(二)黃金博物館近年提報「九份金瓜石水湳洞地質公園」指定，欲從保護礦業地質遺跡出發，進行金銅礦業文化資產保存與活化，並促進地方社群參與，以達地方永續發展目標；筆者亦嘗試加強與學術界的連結，期待促進學界以水金九作為研究對象，創造水金九研究的永續性。

「礦山環境資源盤點計畫」以九份、金瓜石、水湳洞為計畫執行區域，盤點目標囊括地質、生態、及文化領域，並期望彙整既有研究資源與創造新的研究題材。計畫執行所需經費與人力、以及地方社群的持續參與是計畫得以延續的最大關鍵。

中文關鍵詞：地質保育、社群參與、地質公園、礦區、永續性

Changes in the Tsushima Warm Current Systems in the Japan Sea Throughout the Holocene

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The Japan Sea, connected to neighboring seas through four shallow straits (Tsushima, Tsugaru, Soya, and Mamiya), is characterized by limited water exchange confined to surface waters, resulting in the formation of distinctive Japan Sea Proper Water. The Tsushima Warm Current (TWC), which originates from the East China Sea, serves as the main current system transporting heat and nutrients in this semi-enclosed basin. The Holocene period (last 11,700 years) experienced three distinct climate phases: the Early Holocene warming (11,700-8,200 BP), Mid-Holocene maximum warmth (8,200-4,200 BP), and Late Holocene cooling (4,200 BP-present). The Arctic Oscillation (AO), a prominent climate pattern affecting the Northern Hemisphere, influences winter climate patterns and potentially affects Japan Sea oceanography and TWC dynamics.

Previous research has shown strong correlations between radiolarian species distribution and water mass properties, particularly nutrients and sea surface temperature (SST). Our study aims to reconstruct TWC evolution throughout the Holocene and examine possible links with AO phases. We analyzed radiolarian assemblages from seven sediment cores collected along a south-north transect in the Japan Sea. These cores were obtained by the Geological Survey of Japan (Exp. DGC6; GH93-82; GH95-1202; GH96-1217; GH772-P103; GH872-308) and JAMSTEC (Exp. KR15-10). By reconstructing paleo-SSTs based on radiolarian assemblages and comparing them with TWC-related species fluxes and nutrient-indicator species, we evaluate TWC variability during different Holocene climate phases and AO conditions.

Keywords:Japan Sea, Holocene, Tsushima Current, Winter Monsoon, Radiolaria

首幅台灣渺子成像術密度影像－桃園石門水庫（24°49’27.5"N, 121°17’9.8"E）

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本研究以桃園石門水庫地區地理位置（24°49’27.5"N, 121°17’9.8"E）為調查基地，運用渺子探測術完成了台灣首幅精細的密度剖面影像。渺子探測術利用了自然界宇宙射線中的渺子（muon）穿透物質後所產生之衰減行為，結合精確定位與數據重建技術，進行穿透對象之密度計算工作。本研究成功地製作出一幅涵蓋水平方向約60公尺、深度約10公尺的地層密度剖面圖，剖面走向為北92度東。透過渺子穿透後所測得之通量與理論模擬資料的比對分析，本研究明確區分出桃園石門水庫地區南港層中可能之砂岩段與頁岩段的密度差異。分析結果顯示，砂岩為主的地層密度約為2.5869 g/cm^3，而頁岩為主的地層密度則約為1.9284 g/cm^3，地層走向約為北52度東。根據密度變化與地層走向的計算，推估頁岩段厚度約為12.66公尺（沿密度剖面之視厚度約19.74公尺）。這項成果不僅證實了渺子成像技術在地質岩層密度掃描上的高解析能力，也展示其在野外地質調查與工程地質應用上的潛力與價值。本研究為台灣首次將渺子成像術應用於實地地層構造之量測，所建立的技術流程與成果影像，對後續地質調查技術發展具有開創性意義，亦可作為未來應用於水庫壩體、隧道或山區構造等工程地質調查之參考。

中文關鍵詞：渺子成像術、密度、南港層、桃園石門水庫阿姆坪

近期台灣海嘯沈積物的調查成果

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近年來，地質學界成功地發現了台灣的海嘯沈積物，使得現有的海嘯目錄更為詳實、涵蓋的期程大大提前。此前，基於文字歷史的目錄僅限於過去四個世紀，不僅海嘯數目稀少，敘述常語焉不詳、真偽難辨。

調查台灣海嘯沈積物的動機中，一者是近來印太地區的災難性海嘯都發生於隱沒帶，與台灣周遭的地體環境相同；另者，就是為了回應隨之而起的公眾關切——於何時何地，海嘯會再次侵襲台灣。截至目前，調查進展大致分為二個階段，主要成果有：階段（一）起始略早於2010年，跨國團隊於基隆、東海岸與蘭嶼的首發。階段（二）自2013年以來，本國為主的團隊於北海岸、東海岸與澎湖的發見。累積的主要貢獻有三項：（1）間接支持二次疑似海嘯的歷史紀錄——在澎湖與北海岸的沈積物年代相當於1661年台南安平地震與1694年康熙台北湖地震。（2）擴充了海嘯目錄的數目與年代——二千四百年來北海岸有七起海嘯堆積事件，七千年來東海岸有十起堆積事件，一千七百年來澎湖諸島有四起堆積事件。（3）揭露海嘯曾經引起的作用——溢淹高程與海侵距離，不亞於也常常遠超過當地的颱風暴潮，以目前人為開發與居住分佈來看，再發生海嘯的災損將會輕易創下新的紀錄。

在台灣當前密集的人為開發下，海嘯沈積物的保存與調查都非常不易；潮濕炎熱多颱風的氣候與活躍的新期構造活動也會加速物理與化學風化，使得辨識工作遭遇更多挑戰。目前的調查累積了一些寶貴的經驗：低開發的緩傾海階值得多多留意；地球化學與物理探測儀器的應用正方興未艾，應多加嘗試與利用。在當下，台灣的海嘯沈積物調查仍應延續，因為還有許多海岸仍未踏查；已知的海嘯沈積物也需再調查，以全面描繪其分布與精確掌握其年代，目前許多海嘯事件尚屬於管窺蠡測的階段；亟需建立基於地質證據——海嘯沈積物制約的災害機率分析，這將有助規劃減災與避災的政策與設施，例如地質敏感區與疏散撤離計劃。

中文關鍵詞：海嘯沈積物、目錄更新、再現間隔、溢淹規模、未來方向

新型Yardbird-BB OBS感震器平衡機構的效能評估

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寬頻帶海底地震儀（Yardbird-BB OBS）的佈放方式 為自由落體沉降至海床。然而，與陸地地震站不同，海底感震器無法透過人工調整水平，因此若發生傾斜，將導致額外的電力消耗，並影響震波訊號的記錄品質。為確保震波資料的準確性，感震器必須能自動調整至水平狀態。

原本的 Yardbird-BB OBS Seismic Sensor（TC-120s）採用安裝於 **7 吋玻璃球** 內的 **輪型自走式指向平衡裝置**，具備 **360 度角度調整能力**。然而，該機構在每次執行平衡動作時，會使 TC-120s **旋轉一圈**，導致水平方位的指向與調整前不同，進而需要在地震資料分析時重新校正。此外，玻璃球封裝易受水密問題影響，可能導致漏水並損壞內部元件。

為解決上述問題，**台灣海洋科技研究中心（TORI）** 設計了一款 **封裝於鈦合金艙體內的新型感震器平衡機構(Gimbal system)**。其優勢包括：

360 度精準調整水平傾角，使感震器達到幾乎 **0 度**，確保三軸感震器獲取高品質的地震數據。

僅具 X、Y 軸兩自由度，無需重複校正感震器的方位角。

鈦合金艙體封裝更穩定，降低封裝過程的複雜度與漏水風險。

然而，該新型平衡機構的效能仍需透過多種測試與海域數據分析來驗證。本研究設計了一系列校驗方法，包括：

機械結構共振頻率測試，評估其收錄的地震信號不會被結構的共振頻率所汙染。

機構重複精度測試，確認調整精度與一致性。

深海實測驗證，於 **基隆外海 1400m 海床** 佈放該裝置，並與前一代兩種不同底座的感震器平衡機構進行對比測試。

透過分析收錄的數據，包括 **海床地表震動的功率譜密度** (Power Spectral Density, PSD) 及 **遠震資料比對**，本研究評估新型平衡機構的效能，驗證其在實際海域環境下的應用價值。

中文關鍵詞：寬頻帶海底地震儀（Yardbird-BB OBS）、共振頻率、機構重複精度、功率譜密度（Power Spectral Density, PSD）

大屯火山群火山地形之定量化探討

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大屯火山群（Tatun Volcano Group, TVG）位於台北盆地北方，範圍約250平方公里，主要由大屯山、竹子山、七星山、磺嘴山與丁火朽山五個亞群組成。該區地質以熔岩、火山碎屑岩、火山集塊岩及火山泥流堆積物為主，區域內有金山斷層與崁腳斷層兩條斷層構造，火山活動集中於兩條斷層之間。由於現有鑽探與地球化學資料有限，本研究透過火山地形分析，重新界定火山熔岩流的範圍，估算總噴發體積，並針對各火山亞群探討其熔岩流體積、火山爆發指數（Volcanic Explosivity Index, VEI）、熔岩流規模（magnitude）與火山泥流體積。研究方法採用ArcGIS Pro軟體，基於解析度為6x6公尺的數值地形模型（DTM）進行體積計算，並設置台灣大地座標系統（TWD1997）。計算過程中，以噴發區面積中值對應的等高線作為基準，減少過去研究中因忽略地形造成體積高估或低估所產生的誤差。

研究結果顯示，五個火山亞群中各類火山噴發體積多數小於0.05立方公里。其中大屯山、七星山、磺嘴山、丁火朽山亞群以熔岩流為主，竹子山亞群則有大量火山泥流堆積，主要分布於北側。熔岩流規模與火山爆發指數方面，大屯山、七星山、磺嘴山、竹子山亞群的熔岩流規模主要介於2至4，僅少部分介於1至2及4至5之間（約相當於VEI=1至3），其中大屯山亞群曾出現一次達到規模4.6（相當於VEI=4）的熔岩流，竹子山亞群曾出現一次達到規模4.5（相當於VEI=4）的熔岩流，丁火朽山亞群的熔岩流規模2.6至3.1（相當於VEI=2）。熔岩流的數量與體積以大屯山亞群最高。相較於先前研究認為大屯火山群的熔岩流VEI多介於3至4，本研究發現其主要介於1至3，並確認兩條熔岩流達到VEI=4。此外，本研究估算的火山泥流總體積顯著低於過去研究，反映出更精確的計算結果。透過高解析度數值地形模型與火山地形分析，重新繪製了大屯火山群的熔岩流與火山泥流分布界線，為未來火山活動監測與風險評估提供了重要基礎。

中文關鍵詞：大屯火山群、熔岩流、火山泥流、火山爆發指數、規模

大屯火山群火山地形之定量化探討

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中文關鍵詞：大屯火山群、熔岩流、火山泥流、火山爆發指數、規模

利用經驗格林函數法探討2025大埔地震之強地動特性

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2025年1月21日於嘉義大埔鄉發生芮氏規模6.4的有感地震(簡稱2025大埔地震)，此次主震與餘震的發震深度約在地下8 ~ 17公里間，主要發生於基底滑脫面附近或是以下的位置，且無明確的地表破裂證據。在鄰近震源的TSMIP與P-Alert測站紀錄到0.4 ~ 1 g的地動加速度值，主要分佈於震源西南測的位置，而這呼應了震央西南方向的臺南楠西、玉井與嘉義曾文水庫等區域傳出之災情，包括多處房屋、道路與橋樑破損。為瞭解2025大埔地震的地動特性與提供未來地震災害潛勢頻估資訊，本研究使用經驗格林函數法(Empirical Green's Function method, EGF)來建立2025大埔地震的破裂模型，並輔以使用單站頻譜比法(Horizontal-to-Vertical Spectral Ratio, HVSR)與時頻分析，來估算受強震而產生的土壤非線性程度，以確保經驗格林函數計算時不受場址非線性效應的影響。研究結果顯示，近震源區域的部分測站出現輕微的土讓非線性反應，而多數測站的強地動紀錄皆能透過EGF法線性模擬來合理解釋，2025大埔地震向南破裂釋放能量，與PGA的分佈一致。另外時頻分析結果顯示，鄰近震源的測站在水平分量紀錄中，在2 ~ 5 Hz呈現較大的能量，和這HVSR分析一致，而該頻段易對於相對低矮樓房造成影響，也解釋了此次災害所造成建物破壞型態。

中文關鍵詞：Rupture directivity 、Strong motion generation area、Site response

伯格曼規則與艾倫規則於竊蛋龍類恐龍的適用性The validity of Bergmann's rule and Allen's rule in Oviraptorosauria

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生態地理規則(ecogeographic rule)泛指一系列用於解釋生物的形態特徵與其地理分布的變異呈現高度相關性的規則，其中伯格曼規則(Bergmann's rule)與艾倫規則(Allen's rule)指出：相對於低緯度或低海拔，生存在高緯度或高海拔的恆溫動物之體型增大與副肢縮小的趨勢。相較於現生鳥類及哺乳類，上述兩規則在古生物領域中鮮少被討論。竊蛋龍類為一類在白堊紀時廣泛分布於北半球的獸腳類恐龍，加上其與現生鳥類接近的親緣關係和同為恆溫動物的特性，相當適合作為探討上述兩規則應用於古生物時的研究對象。本研究透過文獻中35件竊蛋龍類標本，分別以股骨長度（代表體型大小）及相對前後肢長，結合古緯度進行相關性分析，以探討竊蛋龍類是否符合伯格曼規則與艾倫規則。結果顯示股骨長及相對前後肢長皆與古緯度無顯著相關性，即竊蛋龍類不符合伯格曼規則和艾倫規則。此結果反映環境溫度並非影響竊蛋龍類體型與附肢大小的主要因子，而可能受到生殖策略、競爭、捕食行為及移動效率等多重因素的共同塑形。此外，晚白堊世的全球暖化事件造成高緯度及低緯度地區之間的溫度差異縮小，此現象亦可能進一步降低竊蛋龍類的體型和副肢大小在分布緯度變化上的顯著性。然而，化石標本的稀缺及分布的不連續嚴重影響了統計結果的代表性，因此目前尚無法完全排除竊蛋龍類符合上述兩規則的可能性，仍需等待未來更多標本的發掘，以更深入探討竊蛋龍類的形態演化與地理分布的相關性等生物地理學上的相關議題。

中文關鍵詞：生物地理學、生態地理學規則、統合分析、非鳥恐龍、體溫調節

Ambient-noise tomography of northern Ryukyu constrained by OBS data and the development of the Okinawa Trough

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The northeastern margin of the Eurasian Plate, the overriding plate of the subducting Philippine Sea Plate, is currently breaking apart from the continent, creating the non-volcanic Ryukyu Arc (RA) and the Okinawa Trough (OT) backarc basin. We present an ambient noise tomography for isotropic and anisotropic shear-wave velocities for the northern Ryukyu rift using data recorded by an ocean-bottom seismometer array. The isotropic model shows high velocity in the crust of the backarc and arc compared with the forearc. Azimuthal anisotropy exhibits arc-subparallel fast shear-wave polarization direction in the mid crust and arc-normal fast direction in the lower crust. We interpret this as a result of vertical shearing of the OT mid-crust imposed by the arc-subparallel, right-lateral boundary motion of the RA and the horizontal shearing imposed by the mantle-wedge corner flow induced by subduction, respectively. We also developed a dynamic model to explain how the arc and the back-arc basin have developed to its current asymmetrical convex shape. The key to shape the Ryukyu rift system lies in the degree of subduction-interface coupling. Summarized from previous reports, we apply a high interface coupling at the western edge of the rift system, dropping to low toward east and progressively increasing toward Japan. We examine the success of modeling based on the curvature and the retreat rate of the RA. This model is consistent with the presence of along-arc shearing inferred from the ambient-noise tomography.

Keywords:Okinawa Trough, OBS, ambient noise

以P波衰減特性與Vp/Vs比值在時空上變化探討2022年關山-池上地震序列

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本研究利用P波頻散衰減的特性探討地震前Qp值的殘差(dQp)異常與地震發生的關聯性，並依據孕震帶周圍dQp異常，推估2022關山-池上地震序列潛在的孕震帶區域。本研究選用2022年1月至12月期間垂直分量的直達P波第一完整波形(first-cycle)訊號，以多重濾波法(Multiple Filter Technique)分析後得到群速度延遲時間-頻率譜，再根據線性彈性鬆弛模型理論(Continuous relaxation model)與基因演算法(GA, Genetic algorithm method)，反演出最佳頻散衰減因子(Qp)，其中為了提升訊號的解析度與訊噪比，本研究採用牛頓多項式插值法(Newton polynomial interpolation method)與高斯濾波(Gauss filter method)將地震波形訊號進行重採樣，增加訊號點數以提高頻率域解析分辨程度。研究結果顯示EDH站、STY站、ELD站在震前4-7個月，dQp值有明顯先上升後下降的趨勢，其餘在CHKH站、EYUL站、TTN站亦有看到微幅的異常趨勢。dQp值上升反應該區域受到應力作用，使介質更加緻密且裂隙閉合，導致震波衰減變小；dQp值的下降反應應力持續累積使介質變得破碎與流體流入，導致震波衰減變大。為驗證dQp變化趨勢的可靠性，本研究亦以地震事件的累積速率為依據，將資料依時間分段並計算其Vp/Vs比值。以 2021年6月至12月的平均Vp/Vs為基準，結果顯示在震前6-8個月之Vp/Vs比值降低至1.625，震前1-5個月之Vp/Vs比值上升至1.762，震前1個月之Vp/Vs比值下降至1.675。此一變化趨勢顯示，dQp值上升的時段與Vp/Vs比值下降的時段吻合，dQp值下降的時間段亦與Vp/Vs比值最高值的時段吻合。整體而言，本研究顯示P 波頻散衰減特性與Vp/Vs比值變化可共同反映震前應力狀態與介質變化，並具備作為地震預警潛在指標的應用潛力。

中文關鍵詞：2022關山-池上地震序列、P波頻散衰減、Q值、震前異常現象、Vp/Vs

Lithological and geochemical evidence for the linkages between OAE1a and Ontong Java volcanic events at Deep Sea Drilling Program Site167

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The Ontong Java Nui (OJN) is the largest volcano on Earth and is believed to have triggered significant environmental disturbances during the Early Cretaceous, including global warming, a decline in heavily calcified plankton, and Oceanic Anoxic Event (OAE) 1a (~120 Ma). However, the linkage between these events is still actively debated due to uncertainties in the formation age of OJN. An effective approach for verifying their causal connections is to identify volcanic signals within sequences documenting environmental perturbations. Previous studies indicated that mid-Pacific sedimentary records (e.g., Deep Sea Drilling Program Sites 167 and 463) contain volcanic ash layers that may have originated from OJN. By directly comparing the timing of volcanic ash deposition with horizons that record environmental disturbances, their precise temporal linkages can be established.

In this study, we present detailed Pb and Os-C isotopic data from volcanic ash layers within the sedimentary sequences recovered at Site 167 (Magellan Rise), once located near OJN. Our Os and C isotopic data confirm that the volcanic ash layers were deposited during the early Aptian OAE1a. Furthermore, the Pb isotopic composition of the volcanic ash is identical to that of OJN basalts, strongly suggesting that the ash originated from OJN eruptions. By integrating Os, C, and Pb isotopic data, we propose that a short-term and explosive volcanic eruption occurred at OJN during the earliest phase of OAE1a, which was accompanied by extensive volcanic ash and volatile emissions. This phase of volcanism is restricted to the early stage of OAE1a (~300 kyr), but likely contributed to prolonged environmental disturbances, including global warming, ocean acidification, and OAE1a.

Keywords:OAE1a, Ontong Java Plateau, Cretaceous

臺灣鄰近深源地震芮氏規模之探討

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中央氣象署地震目錄的規模為芮氏規模(Local Magnitude, M_L)，然而，相較於地震矩規模(Moment Magnitude, M_w) ，M_L有些許高估現象。前人研究有針對淺部地震重新分析，不過深部地震衰減特性與淺部地震不同，因此，本研究針對深部地震的規模進行探討。M_L由Richter在1935年提出，以測站震央距下M_L=0.0所造成之理論最大振幅($\log A_0$)以及實際觀測之最大振幅定義，並以震央距100公里$\log A_0=10^{-3}$毫米作為標準。當初Richter是採用南加州的資料，然而後續研究指出，地震波衰減會受地體構造的影響，因此有求取適用不同地區的$\log A_0$之必要性。本研究依據前人方法，將M_L定義中的規模項替換成M_w，因為在南加州地區M_L與M_w為1:1。接著將觀測的最大振幅代入式中，如此即可得$\log A_0$，最後再建立以震源距(R)為參數的$\log A_0$關係式。選用1994～2020年經重新定位深度大於35公里且M_L大於3.5的地震事件，去除明顯因定位不佳的2006年屏東序列地震，最後總計730起事件，使用了213個測站共57,684筆最大振幅紀錄。經迴歸分析後，所得結果在R=100公里的$\log A_0$值略高於前人重新計算淺部地震的值，這與深部地震的地震波行經路徑Q值(Seismic Quality Factor)較高、能量衰減較少有關。經重新計算後的M_L與M_w平均差值由原本的0.51降低至0.02，誤差為±0.22。不過部分事件重新計算後的M_L與M_w相比仍有明顯低估，這與事件位於地震網外導致定位較不精確有關。此外本研究發現誤差有區域的特性，未來將嘗試分區建立衰減關係式，以降低誤差。

中文關鍵詞：深源地震、芮氏規模、地震矩規模

Fluid pressurization in overconsolidated sediments: A seismic indicator at the shallow subduction front

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The frontal part of subduction zones, which may host trenchward rupture propagation, comprises sediments that have experienced complex tectonic stress paths leading to various consolidation states. Yet, effects of consolidation states on dynamic friction behaviors at seismic slip rates have remained largely unclear. Here we aim to unravel roles of sediment consolidation state on frictional behaviors at a seismic slip rate of 1 m/s. We deformed the clay-rich gouge samples prepared from the Nankai subduction front sediments with or without pore pressure (P_p) control performed by a low-to-high velocity rotary shear apparatus. Before high-velocity shearing, the gouge samples were subjected to normal or overconsolidation by a stepwise loading or loading-unloading path with effective normal stress (σ_N') ranging from 2 to 18 MPa. The experiments show a dynamic weakening behavior regardless of the consolidation state or fluid drainage conditions. Grain-fluid shear flow is identified by a very weak dependence of steady-state shear stress on σ_N' and grain size segregation after the experiment at lower σ_N' without Pp control according to microstructural observations. Overconsolidated gouge samples sheared with Pp control are more dilated than normal consolidated gouge samples, but exhibit rapid slip weakening behavior with their breakdown work being approximately 1/3 of those sheared without Pp control. These experimental and microstructural features suggest that fluid pressurization effects overcome dilatancy effects. Our results thus imply that earthquake rupture is readily propagated even in overconsolidated sediments due to rapid fluid pressurization at the seismic slip rate.

Keywords:Overconsolidation, High-velocity rotary shearing, Subduction zone sediments, Rupture propagation

Using Strong Earthquake to Evaluate the Application of the P-alert System in Structural Health Monitoring

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Taiwan is located at the junction of the Eurasian Plate and the Philippine Sea Plate, where earthquakes are frequent, and strong earthquakes may lead to house collapses, structural damage, and other impacts, so structural health monitoring is gradually being emphasized. However, due to the high cost of hardware facilities and experiments, it is not easy to fully promote the traditional structural health monitoring to the community. In order to solve this problem, this study adopted the P-Alert system developed by the National Taiwan University, and evaluated the feasibility of the P-Alert system for structural health monitoring (SHM) by taking the advantage of its lower cost. In a previous study, already demonstrated that P-Alert can analyze structural damage by using damage curves, but time correction using cross-correlation is required to analyze inter-story drift. In this study, the performance of P-Alert and the high-precision accelerometer Setra on inter-story drift and mode shape was further tested, and the results showed that P-Alert recognized the same results as Setra.

In addition, different types of buildings are analyzed, including P-Alert single station structures, P-Alert multiple station structures, and the Central Weather Administration (CWA) building array. The fundamental mode of the structure is calculated by deconvolution, and the inter-story drift and inter-story drift ratio angle are predicted by double integration method. In the parameter analysis of Intensity measure (IM), the peak ground acceleration (PGA) and response spectral acceleration (Sa) are used. The results showed that in P-Alert single-station structures, PGA needs to be higher than 50 gal to stably recognize the fundamental mode of the structure; in the analysis of P-Alert multiple-station structures and building array, it is found that: 1. The frequency of the fundamental mode decreases when the structure is damaged. 2. P-Alert showed a linear relationship with both PGA and Sa (T1) as measured by the building array. 3. With the same IM parameters, the longer the vibration period of the structure, the larger the inter-story drift. 4. The Variety of inter-story drift ratio angle can immediately recognize the status of structural damage.

In summary, P-Alert not only matches the results of the vibration table test with the high-precision accelerometer Setra, but also demonstrates the reliability of the strength measurements by comparing the building array of the Central Weather Administration. On the other hand, with the change of basic mode and inter-story drift ratio angle, P-Alert can expeditiously recognize the damage level of the structure, which demonstrates the potential application of its system in structural health monitoring.

Keywords:Structural Health Monitoring, Intensity measure, Deconvolution, Double integration method

2025年ML 6.4大埔地震之破裂機制探討

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大埔地震（2025年1月21日0時17分，台灣時間，M_L 6.4）震源深度15.8公里，位於西南部褶皺逆衝斷層帶的基底滑脫面（Décollement）下方，為研究台灣西部活躍構造區內的斷層交互作用，乃至於既存斷層的再活化機制的一個重要參考案例。綜合主餘震時空分布與斷層滑移模型的分析，我們認為2025年大埔地震的破裂機制符合「反向逆衝斷層連動模型」（antithetic thrust fault linkage model）。此模型顯示，該地震由兩個傾角相反的逆衝斷層構成，即向東傾的前衝斷層（forethrust）與向西傾的背衝斷層（backthrust），兩者以高角度相交，且因同步破裂導致複雜的滑移現象。強震站的速度波形資料所顯示之方向性脈衝波（directivity pulse），亦進一步支持了本研究所提之破裂模式：向東傾的斷層朝東南方破裂，而向西傾的斷層則朝向西南方破裂。值得注意的是，位於震央西南區域建築物損害較為嚴重，這與向西傾斷層的破裂方向性效應高度相關，突顯其在本次地震中的影響。研究結果揭示，共軛斷層（conjugate fault）間的交互作用可能引發規模更大、破壞力更強的地震。因此，在地震災害評估中，特別是在褶皺逆衝帶等地質複雜區域，精確識別斷層的幾何構造，並考量既存斷層再活動的影響，顯得至關重要。

中文關鍵詞：2025年大埔地震、反向逆衝斷層連動模型、方向性脈衝波

碳封存場址誘發地震安全性研究

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依據臺灣2050年淨零排放路徑及政策，需加強對於地質封存技術研發及驗證，且必須對大眾關切議題—二氧化碳超臨界流體灌注於地層中，誘發斷層地震或者裂隙再活化成為洩漏路徑，進行研發並妥善說明，以利公眾接受碳封存場址。本計畫以彰濱碳封存先導場為例，發展微型電腦斷層掃描(Micro-CT)應用於孔隙率與滲透率推估、碳封存誘發地震數值模擬/模式與碳封存微震監測技術。在第一年研究中，是將國家原子能科技研究院(國原院)自行開發之Micro-CT的空間解析度提升達10 μm；依據彰濱鑽孔岩芯更細緻的砂頁互層模型，以三維分離元素法軟體建立水力耦合模擬技術，評估二氧化碳灌注活動(灌注速率、壓力或體積)是否會影響彰化斷層與鄰近盲斷層之穩定性；完成分散式振動感測系統測試。本期第二年計畫將規劃再提升微型電腦斷層掃描之空間解析度達5 μm，並進行孔隙率與滲透率推估，完成灌注誘發地震之水力耦合數值模擬驗證，完成地表與鑽孔建立分散式振動監測系統之光纖佈署與驗證。本計畫成果可以系統化地整合碳封存誘發地震的上下游議題，提供產學界碳封存技術解決方案。

中文關鍵詞：碳封存、誘發地震、孔隙率、X光電腦斷層掃描、分散式振動感測

Distinct Characteristics of Nepheloid Layers Triggered by the 2024 Hualien Earthquake (Mw 7.4) and Super Typhoon Kong-rey

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Hualien and its offshore region experience the highest frequency of episodic events—earthquakes and typhoons—in Taiwan. In 2024, this area was struck by a M_w 7.4 earthquake and two super typhoons. To investigate the impact of these events, six consecutive cruises were conducted to monitor the occurrence and evolution of nepheloid layers triggered by the earthquake and Typhoon Kong-rey. Compared to baseline conditions, both the earthquake and typhoon led to a 7- to 12-fold increase in suspended particulate matter (SPM) load in the bathypelagic zone. While the earthquake caused an overall increase in SPM across the entire ~2 km thick deep-water column, the typhoon's impact was more localized, elevating SPM only in specific horizons. The particulate organic matter mobilized by these two events exhibited distinct characteristics, as evidenced by differences in stable carbon isotopic signatures and atomic C/N ratios. These variations in SPM distribution and composition were tentatively attributed to differing sediment mobilization mechanisms that ultimately shaped the formation of the nepheloid layers. This study presents the first comparative analysis of SPM transport induced by two distinct types of episodic events. The findings provide valuable insights into paleo-extreme event reconstructions, enhancing our understanding of sedimentary responses to seismic and meteorological disturbances.

Keywords:Nepheloid Layer, Earthquake, Typhoon

以骨組織學反映臺灣最古老鱷類化石的生長歷史與生態棲位
Bone histology insights into the growth history and niche of the oldest crocodilian fossil from Taiwan

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2006年，在臺灣澎湖西嶼的漁翁島層發現了一具鱷類化石，化石出土後，被送至國立自然科學博物館進行清修與研究。而後，這件化石被命名為潘氏澎湖鱷（*Penghusuchus pani*），並歸類為長吻鱷科（Gavialidae），其地質年代可追溯至約1500萬至1700萬年前的中新世中期，是目前臺灣與周邊地區已知最古老且最完整的脊椎動物化石。

有別於過去的研究著重在潘氏澎湖鱷的形態學與系統分類學，本研究透過骨組織學了解其生長歷史及生態棲位。將潘氏澎湖鱷的左股骨中段、右肱骨中段及第三根右肋骨近端30%處製成薄片後，利用偏光顯微鏡觀察。結果顯示，在潘氏澎湖鱷骨組織中，存在大量次級骨元、休止線與較高的骨骼重塑率，指示其死亡時已是相對年老的個體；此外，在形態特徵中，潘氏澎湖鱷頸椎的椎體椎弓縫合線完全閉合，表示已是成年個體，此結果亦與骨組織分析所得的結論相符。而將骨組織影像放至BoneProfilerR軟體中分析，所得數據再代入前人提出的生態預測模型進行計算，結果顯示潘氏澎湖鱷的生態棲位與現今多數鱷類類似，屬於兩棲類。

然而，鱷類現今已不再分布於臺灣及周邊地區，因此本研究期望透過對潘氏澎湖鱷與現生長吻鱷科進行骨組織特徵比較，以了解澎湖鱷滅絕的可能因素，進一步探討鱷類在臺灣的演化歷史，並為臺灣古生物群的演替與環境變遷提供更多證據。

中文關鍵詞：潘氏澎湖鱷 Penghusuchus pani、中新世 Miocene、漁翁島層 Yuwentao Formation、次級骨元 secondary osteon、骨骼重塑 bone remodeling

Thermo-Tectonic Evolution of the Taiwan Slate Belt: New Constraints from High-Resolution LiDAR 3D Structural Mapping

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The thermo-tectonic history of orogenic belts provides crucial insights into geodynamics and regional tectonics. It can be investigated using geothermometry, thermochronometry, and structural geology. In sparsely exposed terrains, however, limited outcrops hinder the reconstruction of large-scale structural geometry. Previous studies have shown that delineation of lineaments revealed on LiDAR-based digital elevation model (LiDAR DEM) provides a comprehensive perspective on regional structures. This study integrates LiDAR DEM 3D mapping and field mapping to investigate the structural architecture of the southwestern Central Range of Taiwan. The analysis reveals a newly mapped overturned synform, referred to as the “Siangyang Synform”. The stereo view of LiDAR DEM proves effective in identifying the orientation and regional patterns of thick competent layers, which are challenging to discern through field surveys alone. The combination of new structural architecture and published geothermometry and thermochronometry data indicates that the peak thermal event either postdates or synchronizes with syn-orogenic ductile deformation. This highlights the significance of syn-orogenic undethrusting and metamorphism of the Central Range during the late-Cenozoic arc-continent collision in Taiwan.

Keywords:Airborne LiDAR, Digital Elevation Model, Foliation patterns, Basal accretion, Taiwan orogen

坡地的知識與風險：屏東來義鄉排灣族地景實踐與災害治理交織之探討

ruljigaljigtjuku[1]、許錕安[2]、王凱倫[3]、歐伯恩[1]

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部分排灣族人自稱「kacalisian」(居住在斜坡的人)，其傳統生活、生產與文化記憶皆深植於坡地中。tjalja'avus（屏東縣來義鄉來義部落）為排灣族的重要聚落之一，族人長年於斜地上進行耕作、建居與儀式，累積大量與環境密切互動的知識系統。自莫拉克風災以來，國家以防災與治理之名，透過山坡地保育利用條例、水土保持法與國土計畫等制度，逐步擴展對斜坡空間的治理邊界，當地原住民族的土地使用受到越來越多來自國家治理體系的限制，族人原有的文化祭儀、生活空間與農業實踐將面臨更多挑戰。

本研究整合人文地理與地質學的視角，透過田野訪談、傳統地名調查與語意分析，建構來義地區坡地利用的歷史圖像與知識邏輯，並結合現場調查、遙測與光達地形分析技術，探討傳統地名與坡地災害潛勢之間的空間關聯。研究發現，許多族語地名所指涉的崩塌、陷落與禁忌區域，往往對應當代地質學所判釋的脆弱區，反映族人長期對地景中具危害風險的觀察與辨識能力。這些地名不僅是地理記憶的標記，更是傳遞原住民族災害知識與環境經驗的重要媒介。此外，部分舊社選址與傳統建築工法，也展現出族人對坡地穩定性的主動治理思維。

地質學在本研究中不僅扮演地形解讀與災害辨識的角色，也與在地知識形成有意義的對照與互補關係。雖然防救災政策與執行多由國家主導，若可配合原住民族對空間的理解與操作經驗，有助於補足全國一體的制度下對於地方尺度的空間盲區。本文呼籲，在坡地災害治理與土地規劃的未來想像中，應強化多元知識的對話，透過跨域協作建構更貼近地方且具彈性的治理模式。

中文關鍵詞：排灣族、坡地利用 、坡地災害、地名

Additional Sharks and batoids (Chondrichthyes, Elasmobranchii) from the Middle Miocene Gaj Formation, Bhavnagar Gujarat and late Miocene Baripada Beds, Odisha, India: A discussion paleobiogeography

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The recent field work conducted at the middle Miocene, Gaj Formation of Bhavnagar, Gujarat and late Miocene Baripada Beds of Odisha, India recovered additional shark and batoid remains. The fossiliferous conglomerate and greyish mudstone bed of Gaj Formation yields teeth of sharks, batoids, certain invertebrates and microfossils. The elasmobranch fauna from the study area comprises of *Carcharadon carcharias*, *Sphyrna zygaena*, *Carcharhinus perseus, Hemipristis serra*, *Rhizoprionodon* sp., *Isurus oxyrinchus*, *Isurus desori*, *Isurus pagoda*, *Myliobatis* sp., *Aetobatis* sp., etc. Elasmobranchs fauna from the late Miocene Baripada Beds comprises a total of 9 families of shark and batoids including the family: Carcharhinidae, Hemigaleidae, Alopiidae, Myliobatidae, Dasyatidae, Pristidae, Rhynchobatidae, Rajidae, Sphyrnidae were recorded from Mukurmatia and Itamundia locality. The present paper also records additional elasmobranch species namely *Carcharhinus amblyrlynehoides, Carcharhinus brevipinna, Carcharhinus perezi*, *Carcharhinus plumbeus*, *Physogelus hemmoorinsis, Physogelus latus*, *Aetobatus cappettai, Taeniurops* sp. etc. for the fisrt time from Baripada Beds. The present paper records five elasmobranch species including *Carcharhinus amblyrlynehoides, Carcharhinus brevipinna, Physogaleus hemmooriensis, Physogaleus latus* and *Aetobatus cappettai* for the first time from the Miocene deposits of Indian Subcontinent. The majority of the reported fauna shows the prevailing of tropical to sub-tropical climatic conditions. Correlation study of the Miocene elasmobranch of India and its global counterparts were done using the beta diversity (Sørensen–Dice coefficient) data. The faunal similarity index of the late Miocene elasmobranch of India is closer toward South Pacific Ocean and Indo-Pacific region suggesting the shifting of migration path from the Mediterranean region after permanently closing the Tethys Sea ways. Most of the collected species of the late Miocene sharks and batoids are also presently found today in the Indian Ocean

Keywords:Sharks, batoids, , elasmobranch,, Miocene,, paleoenvironment, , paleobiogeography, etc.

The Past Behavior of the Tatun Volcanic Group: Key to Its Future Behavior and Hazards

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The >30 volcanic centers of the Tatun Volcanic Group (TVG) pose serious yet poorly quantified hazards to Taipei and Taiwan. In pre-historic times, lahars raced toward plains now home to coastal communities, lava flows and slope collapses partially filled mountain valleys to depths of many tens of meters. Rarely, volcanic ash has blanketed neighboring urban and agricultural areas. Future events like these would severely impact the populations, industries, agriculture, and governance of northern Taiwan. Their future effects could be greatly mitigated through planning and preparedness that has been well-informed by earth science. Through coordinated geological mapping, petrology, geochemistry and geochronology, we have begun a robust program aimed at understanding the history and nature of TVG volcanoes. We are using 1) high-resolution LiDAR topography to map the TVG in unprecedented and necessary detail, 2) state-of-the-art $^{40}Ar/^{39}Ar$ geochronology to understand the dates and frequency of past events, and 3) modern petrological analyses, including diffusion chronometry, to establish the evolution of magmas in the decades to weeks prior to ancient eruptions. These data will inform modeling of future hazards, allowing for changing topography, variability in volume and eruptive style, and randomness in wind conditions. Progress in our first year will be detailed in several other talks at this meeting. These talks will focus on the characteristics and evolution of the Shamao, Songshan, and Huangzuei complexes and on thermobarometry of various lavas.

Keywords:Tatun, volcano, hazard, geomorphology, geochronology

Tracing the Storm and the Shake: Can Sediments Tell Earthquakes from Typhoons?

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For paleo-extreme event reconstruction, there is broad interest in identifying goechemical signatures that can differentiate sediment transport events triggered by earthquakes and storms. In 2024, a coordinated effort involving water-column profiling, a trap experiment, and sediment coring was conducted offshore of Hualien to investigate nepheloid layers and settled sediments associated with the Hualien Earthquake (Mw 7.4) and two super typhoons. Our findings revealed an organic geochemical distinction in the nepheloid samples: those linked to typhoons contained a higher proportion of terrestrial organic matter compared to those associated with the earthquake. This signature was retained in the settled sediments. However, two key challenges emerged. First, the geochemical signal could be averaged out at the typical 1-cm sampling resolution used in sediment cores—a limitation particularly significant for overbank levee deposits, for which our trap served as a proxy. Second, one of the typhoon-related sediment transport events showed a delayed onset, with initiation occurring at least 15 days after the storm. Such delayed responses may complicate high-resolution reconstructions. Additional geochemical parameters are currently under analysis to further assess their potential for event reconstruction.

Keywords:earthquake, typhoon, marine sediment, sediment trap

Reduced thermal conductivity of hydrous aluminous silica and calcium ferrite-type phase promote water transportation to Earth's deep mantle

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Subduction of oceanic slabs introduces chemical heterogeneities in the Earth's interior, which could further induce thermal, seismic, and geodynamical anomalies. Thermal conductivity of slab minerals crucially controls the thermal evolution and dynamics of the subducted slab and ambient mantle, while such an important transport property remains poorly constrained. Here we have precisely measured high pressure-temperature thermal conductivity of hydrous aluminous post-stishovite ($\Lambda_{Hy\text{-}Al\text{-}pSt}$) and aluminum-rich calcium ferrite-type phase (Λ_{CF}), two important minerals in the subducted basaltic crust in the lower mantle. Compared to the dry aluminous stishovite and pure stishovite, hydration substantially reduces the $\Lambda_{Hy\text{-}Al\text{-}pSt}$, resulting in ~9.7–13.3 W $m^{-1}K^{-1}$ throughout the lower mantle. Surprisingly, the Λ_{CF} remains at ~3–3.8 W $m^{-1}K^{-1}$ in the lower mantle, few-folds lower than previously assumed. Our data modelling offers better constraints on the thermal conductivity of the subducted oceanic crust from mantle transition zone to the lowermost mantle region, which is less thermally conductive than previously modelled. Our findings suggest that if the post-stishovite carries large amounts of water to the lower mantle, the poorer heat conduction through the basaltic crust reduces the slab's temperature, which not only allows the slab bringing more hydrous minerals to greater depth, but also increases slab's density and viscosity, potentially impacting the stability of heterogeneous structures at the lowermost mantle.

Keywords:post-stishovite, Al-rich calcium ferrite type phase, thermal conductivity, deep water cycle

利用光達三維數值地形模型精進西部麓山帶及雪山山脈地質區交界附近之構造幾何：以桃園地質圖幅為例

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臺灣的地質架構可概分為濱海平原、西部麓山帶、雪山山脈、中央山脈與海岸山脈等地質區。其中，西部麓山帶與雪山山脈之間長期以屈尺斷層為界，傳統上被視為「界限斷層」。然而，近年來生物地層、岩石地層、構造分析及野外調查等研究均指出，傳統界限斷層的概念在多處細節上並不適用。因此，在繪製較大比例尺的精細地質圖時，原本以單一條屈尺斷層描繪的兩地質區交界，其構造幾何有重新檢視的必要。桃園圖幅地區的地質圖中，屈尺斷層的位置與幾何仍存在爭議。然而，由於山區地形險峻、交通不便，且植被茂密導致露頭有限，僅靠傳統野外調查難以顯著提升地質圖的解析度。為克服此限制，本研究利用空載光達技術產製的高解析度數值地形模型，於GIS軟體之三維且可任意旋轉角度的環境中，重新檢視該區域的地質構造。利用光達可濾除植被的特性，提供巨視尺度下更連續的地質資訊。本研究首先判釋並描繪代表層理的線型，以掌握區域性層理面之變化，並將其轉換為三角面向量以計算層理位態；同時透過野外查核，動態修正層理線型之繪製。層理分布進一步用以界定斷層與褶皺的位置及幾何，亦能顯示地層厚度之變化。研究成果顯示，西部麓山帶與雪山山脈的交界，在東北部仍以單一條屈尺斷層為主，向西南則漸趨破碎、模糊，間夾數個向斜構造，且主要斷層錯距往北跳躍至枕頭山斷層，顯示桃園圖幅地區的兩地質區交界帶呈現更為複雜的褶皺與逆衝斷層交互作用。

中文關鍵詞：三維地質製圖、光達產製數值地形模型、界限斷層、屈尺斷層、桃園圖幅

地質法配套之地質資料蒐集填報系統建構與數位治理探析

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地質法第十七條及地質資料蒐集管理辦法明定地質調查報告之提交義務與格式標準，地質資料蒐集填報系統即建構於此法規基礎上，為國內首套以法源依據之地質資料提交彙報作業平台。系統依案件屬性區分為土地開發或非土地開發類型，分別設計對應欄位與作業流程。填報者須輸入案名、調查位置、核發或審定日期等關鍵欄位，確保資料內容與行政要求一致。資料完成上傳後，系統將寄發通知信，並產出具唯一識別碼之提交證明單，具有等同公文之效力，符合數位治理下對資料正確性與可控性之基本要求，以及提升程序透明度及行政效率。

在資料完整度檢核機制方面，由專人於後端確認上傳資料是否齊備與格式是否正確，必要時主動通知補正。此程序取代傳統紙本往返與人工查核流程，強化作業標準化，亦為後續資料納入全國地質資料庫建立品質門檻。在身分驗證與資料治理層面，導入自然人憑證與工商憑證機制，確保資料與填報者之間的不可否認性（Non-repudiation）。系統亦記錄登入與修改歷程，並支援報告批次查詢、進階搜尋與匯出功能，強化資料追溯與再利用能力。若需更正已提交資料，填報者可透過系統回溯歷次版本，避免重複提交與版本混淆，確保責任歸屬與作業一致性，體現數位治理政策之落實成效。

對涉及鑽探者，系統進一步導入專業資料驗證機制。填報者須上傳工程地質探勘資料庫（MDB格式）檔案，並由中央主管機關認證之合格人員建置與簽證。系統將比對人員姓名與證書編號，若不符即拒絕提交。此流程除防杜錯誤資料進入資料庫外，亦建構涵蓋資料產製、驗證、提交至應用的生命週期管理機制，此一「技術即規範」的設計，顯示系統不僅是地質資訊的填報與展示平台，更是法規執行、專業責任落實與標準化治理推動的關鍵數位基礎設施。

中文關鍵詞：地質資料蒐集管理辦法、資料蒐集、工程地質、數位治理

Mapping the Mud Diatreme Range in the NKUST Region Using Microtremor Techniques

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Long-term geological disasters often occur inland in active mud-diapir zones. Near-surface diatreme structures are anticipated and observed in regions with notable ground surface deformation, such as GunShuiPing (GSP) in Taiwan. Previous project findings suggest that the GSP area generally exhibits site effects of amplification at frequencies between 1 and 2 Hz and includes a deamplification feature within high deformation zones in the same frequency range, as established by microtremor H/V spectral ratios (MHVR). However, no significant differences were observed in the shear wave (Vs) structure inversion from microtremor array measurements (MAM), which are expected to reveal a similar pattern difference in the Vs structure. This inconsistency in site effects helps us identify the high-surface deformation area associated with the mud diatreme. In the current project, we extend this concept to the NKUST region located in the southwest corner of the GSP area, which is characterized by lesser observed deformation. We conducted three MAMs along with over thirty MHVR measurements. The results indicate that across a total area of approximately 700 m by 500 m, the Vs structures from the three MAMs are identical for the first and second layers. This suggests no significant difference in the surface wave features near the surface passing through the area. Conversely, the MHVR exhibits a cross-shaped deamplification in an area roughly 150 m to 200 m wide, particularly at 1.7 Hz. This differs from the site amplification seen in the 1 to 2 Hz range, aiding in the approximate mapping of the potential mud-diatreme zone.

Keywords:mud-diapir, mud-diatreme, microtremor H/V spectral ratios, microtremor array measurements, Taiwan

A New Empirical Probability Model for Surface Faulting Utilizing Width-Rupture Ratio for Crustal Earthquakes

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Models for the probability of surface rupture (PSR) aid probabilistic fault displacement hazard analyses (PFDHA). Most PSR empirical models rely on faulting magnitude and style. They require fewer assumptions about the depth of rupture in large earthquakes but ignore differences in seismogenic thickness. Thinner faults (e.g., 5 km wide) are more likely to rupture from smaller earthquakes, as seen in the 2010 Mw 5.0 Ecuador quake and the 2019 Mw 4.9 France quake. Mammarella et al. (2024) proposed a PSR model using a numerical approach that factors in seismogenic thickness and fault dip. While this model uses specific hypocenter depth distributions, it assumes that rupture depth can be derived from all magnitudes' hypocenter distributions. Our study combines empirical and numerical methods by developing an empirical model using the width-rupture ratio (WRR) instead of magnitude for logistic regression. The WRR, measuring rupture width vs. fault width, is based on crustal earthquakes from 1970 to 2023 with magnitudes above 6. This model, through WRR, integrates fault-specific seismogenic thickness and dip while maintaining empirical constraints on PSR, effectively managing both large- and small-magnitude cases for PSR evaluations.

Keywords:probability of surface rupture, probabilistic fault displacement hazard analyses, Global dataset

Classifying MiDAS Optical Fiber data

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Milun Fault Drilling and All-inclusive Sensing (MiDAS) project was carried out in 2020. As part of the project, two boreholes were drilled and instrumented with optical fibers for Distributed Acoustic Sensing (DAS), along with co-located borehole seismic arrays. The interrogator (iDAS) system features a10-meter gauge length, 4-meter spatial resolution, and a 1000 Hz sampling rate, enabling high spatial and temporal resolution for detecting subsurface motions. In addition to the conventional seismic event, which are typical of interest in the 0.1 to 20 Hz frequency range, many intriguing signal features were observed, the origins of which remain unclear. This study aims to unravel these unknown signals, potentially related to subsurface activities, by leveraging complimentary observations from the borehole seismometers. By combining DAS data with borehole seismometer recordings, we aim to identify key signal characteristics to facilitate future machine learning-based classification, ultimately enabling automated analysis of MiDAS observations.

We analyzed optical fiber data from March to September of 2023, crossing-referencing it with seismic events identified by the borehole seismometer. These events were categorized into Types A, B and C as the typical regional seismic events. And an intriguing feature as Type D, which is characterized by either a single pulse or a signal appearing only at shallow depths. Based on this classficiation, we created a dataset of labeled DAS images to train machine learning models for seismic event detection. Given the large volume of data, we also evaluate the performance of machine learning models using different image resolution to determine the optimal setup for automatic DAS-based event detection.

Keywords:Optical Fiber, Milun Fault Zone, Distributed Acoustic Sensing

Infragravity Wave Observations in the Pacific Ocean Using Multiple Ocean-Bottom-Seismometer Arrays

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Infragravity waves are long-period ocean waves that bridge the atmosphere, ocean, solid Earth and polar ice, influencing sea level measurements, coastal sediment transport, the breakup of Antarctic ice shelves and the excitation of Earth's seismic hum. We collected ocean-bottom pressure data recorded by up to 700 pressure gauges from 15 ocean-bottom seismometer arrays deployed on the Pacific seafloor and computed cross-correlation functions between each station pair to extract coherent energy of infragravity waves. Beamforming analysis was conducted to determine the incoming direction of infragravity waves and ray-tracing calculations were applied to locate their sources. Our results reveal pronounced seasonal variations in the spatial extent of infragravity wave sources. During boreal winter, coastlines of the northern and eastern Pacific Ocean are distinct sources, particularly in the northeastern segment, strongly correlating with significant wave height triggered by eastward-moving storms and with infragravity wave height predictions. By contrast, during boreal summer (i.e., austral winter), waves predominantly originate from the western coast of South America and New Zealand coasts, as those in the prediction model. A secondary hotspot is illuminated along the Antarctic coast, which we hypothesize originates from distant primary sources in the Southern Hemisphere, reflecting off the Antarctic coast. The reflected waves then propagate northward several hundred to thousands of kilometers seaward toward the Northern Hemisphere, where they are recorded by stations in the Northern Pacific Ocean. The detected infragravity wave source locations in this study support that Earth's seismic hum is triggered unevenly, with distinct seasonal patterns.

Keywords:Infragravity waves, ocean-bottom seismometer, cross-correlation function, Pacific Ocean, Earth's hum

Geochemistry of paleo-Yamuna channel sediments from NW India: Implications for variations in provenance, paleoclimate, and paleovegetation patterns in the late Quaternary

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In this work, we utilized subsurface stratigraphy and geochemistry of drill core sediments from the paleo-Yamuna channels in NW Indo-Gangetic Plain (Haryana) to establish the sediment sources, role of climate and glacial cover on the erosional distribution patterns at the sources, and the paleovegetation patterns in the Late Quaternary (since MIS 4). We determined $^{87}Sr/^{86}Sr$ and ε_{Nd} in silicates, $\delta^{18}O$ and $\delta^{13}C$ in carbonate nodules, and $\delta^{13}C$ in sediment organic matter ($\delta^{13}C_{SOM}$) from three (~48 m deep) drill cores. The $^{87}Sr/^{86}Sr$ (0.734–0.806) and ε_{Nd} (−14.0 to −21.2) down-core variabilities reveal varying proportions of sediments were derived from the Higher and Lesser Himalayan sources. Results imply reduced contribution of Higher Himalaya sediments during cold and arid periods characterized by weaker Indian summer monsoon (ISM) precipitation and increased glacial cover over the Himalaya. The $\delta^{18}O$ in carbonate nodules (−7.80‰ to −4.04‰) shows a negative covariation with the precession-controlled Northern Hemisphere summer insolation, suggesting intense ISM precipitation during late MIS5, early and late MIS3, and early MIS1. The $\delta^{13}C_{SOM}$ (−27.4‰ to −22.3‰) exhibits a C_3-dominated vegetation in the Himalayan catchment with a discernible increase in $\delta^{13}C_{SOM}$ during late MIS4 to early MIS3, late MIS3, and early MIS1 periods, marked by the intense ISM (warm and moist). The $\delta^{13}C$ in carbonate nodules (−3.63‰ to 1.56‰) could be influenced by dissolved inorganic carbon and/or atmospheric CO_2 and therefore may not be representative of paleovegetation. We conclude that both the ISM strength and glacial cover dominantly control the erosion pattern over the Himalaya.

Keywords:paleo-Yamuna Channel, Indo-Gangetic Plain, Sr, Nd, C, O isotope ratios, Himalayan erosion pattern, Indian summer monsoon

Detectability of transboundary air pollution pathway variations associated with climate change using anthropogenic aerosols

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There is an urgent need to accurately detect the effects of climate change, which causes a significant threat to human life. As climate change progresses, transboundary air pollution pathways are expected to change globally. However, observational evidence to support this remains limited. In this study, we analyzed long-term satellite observations of aerosols, using anthropogenic aerosols as traces to capture long-term changes in transboundary air pollution pathways associated with climate change. The analysis focused on the Pacific region in the downwind area of China, which is a major source of aerosol emissions. To offset the temporal changes in China's emissions, we proposed a new metric named R_{AOD}, which is defined as the normalization of Aerosol Optical Depth (AOD) data by the AOD over coastal regions of China. Our analysis revealed a clear exponential decrease in R_{AOD} values from China towards the Pacific Ocean. Furthermore, the seasonal variations in atmospheric transport fields are consistent with the slope of R_{AOD}. These findings indicate that it is possible to detect long-term changes in the atmospheric transport fields by utilizing anthropogenic aerosols as tracers. Additionally, we found the eastward transport distance of aerosols has been shortened in recent decades. This trend can be explained by a slight northward shift in transboundary air pollution pathways as climate change progresses. Based on these findings, to enhance the detectability of variations in transboundary air pollution pathways associated with climate change, we proposed the continued use of long-term satellite observations and the R_{AOD} data derived from those observations.

Keywords:Climate change, Transboundary air pollution, Long-term satellite observation

建築物分布對於土壤液化評估影響之探討

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由於臺灣西部的地質環境主要為河流作用下所形成的沖積層，以砂礫為主的地層特性易受到地震的影響而產生噴砂、下陷的土壤液化現象；然現階段土壤液化災害的分析方式主要為利用公共建設及土地開發時所進行的地質鑽探的岩心資料，透過模擬設定或實際地震事件的地震加速度，計算抗液化安全係數判別液化的潛能指數（建築耐震設計規範，2022），再透過克利金法（Kriging）將各鑽孔的土壤液化指數由點轉換為面的土壤液化潛勢分布。但隨著都市開發以及建築法規之健全，於沖積層進行建築物以及公共設施等建設時，皆需建築耐震設計規範依照進行地盤改良；為有效了解建築物存在區域對於土壤液化發生之影響，本研究嘗試透過建物稅籍資料，篩選具地下樓層之建物，同時假設各建物為一經地盤改良之岩心鑽孔位置，以最鄰近實際岩心鑽孔資料為原始資料，依各建物不同地下樓層深度進行地盤改良，以探討建築物存在對於土壤液化潛勢評估之影響。

中文關鍵詞：土壤液化、建築分布、地震災害

應用分散式光纖溫度感測技術監測森林環境中風速與太陽輻射之空間分布

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觀測森林中風速與太陽輻射剖面，對於理解森林微氣象特性與能量交換過程具有關鍵性意義。風速剖面能揭示林內氣流的分布情形、紊流混合程度以及氣體交換機制；而太陽輻射剖面則反映了能量輸入與空間分布情況，直接影響植物的光合作用與生長動態。

過去，DTS風速的估計多仰賴能量平衡法，需額外測量輸入光纖的短波、長波輻射強度來估算風速。本研究中，嘗試直接利用加熱與未加熱光纖間的溫差，透過建立其與風速之間的關係式，推估風速剖面。研究結果顯示，DTS系統估算的一分鐘平均風速與WXT風速儀所測數據之間的相關係數達0.99，顯示兩者具有極高的一致性。此外，藉由選用具有不同吸光特性的光纖包覆材質，亦可量測由太陽輻射所引起的溫度差異，進而反推太陽輻射的強度，達成太陽輻射剖面的估算。

本研究展示了光纖感測技術於森林微氣象觀測上的潛力，能夠補足傳統氣象儀器難以涵蓋的空間與時間解析度，有助於揭示更多過去未能觀測到的微氣象過程。

中文關鍵詞：分散式光纖溫度感測器、微氣象監測、風速剖面、太陽輻射

臺灣離岸風電地質與環境感知系統發展成果與未來可應用領域研究

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海域地質調查除了對於海洋資源開發、環境保護及防災減災具有重要意義外，對於發展離岸風力發電產業亦有關鍵影響。經濟部地質調查及礦業管理中心(地礦中心)持續在臺灣西部海域進行多頻道反射震測、電火花震測及底拖聲納-底質剖面、岩心採樣等海域地質調查，並將成果逐一彙整至「臺灣離岸風電地質與環境感知系統」(以下簡稱感知系統)，基於「地質是公共財」的理念，依據「經濟部地質調查及礦業管理中心離岸風電地質與環境感知系統服務平臺資料提供及使用作業要點」將調查成果提供各界調查、研究、分析、規劃之參考。

地礦中心透過海域地質調查，除了可以掌握臺灣西部海底地形、地層構造及沉積物特性等，亦透過多尺度的震測剖面，辨識海底斷層、空白帶(Blanking zone)與堅硬地層等，進而彙整地質影響因子，評估地質狀態可能對風力發電的前(選址)、中(設置)、後(營運)期造成影響的影響潛勢，提供風力發電機組評估與規劃設置之參考，友善風力發電產業環境。

除了開放調查成果資料外，感知系統透過資料視覺化技術，可視化震測剖面於空間中的位置，除了讓使用者更容易了解各震測剖面的位置與相互關係外，更有助於資料的檢核比對，提高資料的正確性與合理性。因為有了空間中的關係，可進一步將這些特徵層面位置標定後，利用徑向基函數內插(Radial Basis Function，RBF)方法，建立特徵層面的連續型模型。從原本的「線」(震測剖面)推演出「面」(層面)，進一步瞭解層面在地下的分布形貌。

震測剖面亦應用在油氣勘探中，透過震測剖面推演出的地層層面資訊，推估油氣儲集層與蓋層的可能位置。本研究透過海域震測調查成果及RBF方法，描繪地層狀態，藉由延伸與油氣探勘相同的概念，期能尋找適當的材質(地層)與足夠厚的蓋層，支援日漸受到全球對氣候變遷與減碳重視的碳封存 (Carbon Capture and Storage，CCS) 技術。感知系統除了能支援離岸風力發電產業外，在未來應用方面，可導入深度學習、類神經網路等人工智慧技術，從震測剖面資料中尋找適當的材質、足夠厚的蓋層或適當構造(背斜)等關鍵資訊，作為提供實現氣候承諾的輔助資訊，對全球環境永續貢獻助益。

中文關鍵詞：離岸風電、震測剖面、地質影響潛勢、海域地質、碳封存

Inferring Earthquake Stress Drops with Passive Acoustics in Laboratory Experiments Using Machine Learning

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Stress drop is a key parameter that influences earthquake rupture processes and ground-motion characteristics. By quantifying the difference in shear stress before and after a rupture, it offers direct insight into how energy is released during an earthquake. However, stress drop varies significantly from fault to fault and from event to event, underscoring the importance of improved measurement techniques. Previous studies have successfully adopted machine learning models in laboratory earthquake datasets to predict time to failure and shear stress. However, their experimental fault systems were predominantly unstable. Specifically, the system is unstable when the loading stiffness k' is much lower than the critical stiffness k_c', i.e., $k' \ll k_c'$. The single state variable rate-and-state friction model suggests that slow-slip behavior emerges in the special case where $k' \sim k_c'$, which has significance for slow earthquake detection and earthquake early-warning systems.

In this study, we conducted double direct shear experiments on granite faults and generated laboratory earthquakes across a range of critical stiffness ratios ($K = k'/k_c'$), from near-critical conditions ($K \sim 1$) to highly unstable ($K \ll 1$). These conditions were achieved by varying normal stress, shearing rate, and loading stiffness. Acoustic emission (AE) data were collected continuously at 2.5 MHz using an array of 12 ultrasonic piezoelectric transducers embedded in a steel block, which is in direct contact with one of the granite side blocks. Additionally, shear strain was recorded at 13 equidistant locations at 100 kHz to capture transient local strain perturbations along the 15-cm saw-cut granite fault. At near-critical conditions, we observed consecutive events with highly variable stress-drops. The datasets with diverse event characteristics better emulate natural faults without strictly repeating rupture patterns and offer a broader training set for machine learning models, enhancing robustness in stress drop estimation and potentially improving their ability to generalize across varying fault conditions.

For large earthquakes, well-established techniques—such as finite-fault inversions, back-projection, and other seismological models—can be used to estimate stress drop. However, for small earthquakes (magnitude M <= 2), these methods often become infeasible due to sparse data and low signal-to-noise ratios. To date, accurately measuring the in-situ stress drop at small fault ruptures remains a challenge, and thus these techniques are typically evaluated through numerical simulations or laboratory analogs. Leveraging the power of Transformer-based machine learning, multiple acoustic emissions signals from different channels are concatenated into multi-dimensional features and fed into a Transformer model. By treating all these signals as one "multi-feature" sequence (rather than separate inputs), the self-attention mechanism within the Transformer can learn the complex temporal correlations among them. The model can effectively capture how changes in one signal relate to another over time, enabling robust predictions of stress drop even with limited, noisy data.

Our results confirmed that Transformer-based machine learning models can effectively estimate stress drop in laboratory earthquakes using AE data. The diverse dataset produced in our experiments better captures the variability seen in natural faults, making it more promising to apply ML models trained on laboratory data to real-world seismic events.

Keywords:Stress Drop, Earthquake Rupture Processes, Laboratory Earthquakes, Direct Shear Experiments, Machine Learning

Recycling ages of oceanic crusts: implications from FOZO and HIMU type OIBs

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Timescale of mantle convection is essential to understanding Earth's material cycles. A key piece of information on the timescale is the residence time of crustal material in the mantle, commonly referred to as the "recycling age". The recycling age is usually given as the time from the formation of oceanic crust through the deepest mantle to the remelting of the crust in a mantle plume. To quantitatively understand Earth's material cycles, significant research efforts have been made to constrain the recycling age using the isotopic composition of OIB (ocean island basalts). However, definitive estimate of the recycling ages has remained elusive.

To constrain time scale of the material cycle in the Earth, the recycling ages of oceanic crust were calculated based on three assumptions: (1) source areas of FOZO (focal zone) and HIMU (high-μ) consist primarily of recycled oceanic crust and upper mantle peridotite; (2) model age of recycled oceanic crust in the OIB source is identical to its recycling age; and (3) present day MORB compositions can represent ancient oceanic crust compositions. Under these assumptions, each OIB source has two unknowns, (a) model age (recycling age) and (b) mixing ratio of recycled oceanic crust and peridotite. Recycling age and mixing ratio are thus uniquely determined with single set of OIB isotopic composition by combining two equations of Pb-Pb and Nd model ages. The obtained age distributions of HIMU hotspots were characterized by single peaks at 1.7 Ga for Pacific HIMU and 1.9 Ga for Atlantic HIMU. In contrast, age distributions of FOZO hotspots ranged from 1.0 to 2.1 Ga and included multiple peaks.

Keywords:HIMU, FOZO, Recycling, Material cycle, Mantle

Active Fault Geological Sensitive Area (F0026 Lichi Fault)

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The Lichi Fault is one of the major active faults in eastern Taiwan. Field investigations have revealed that, on the eastern bank of the Pinan River, west of Rongshan (Figure II), the Pinan Conglomerate on the western side of the Lichi Fault dips to the northwest, whereas the conglomerate on the eastern side dips to the east. These two rock masses are in fault contact rather than forming an anticline structure. The primary reason for this configuration is the presence of an approximately 10-meter-thick sandy mudstone interbedded within the conglomerate on the eastern side of the fault. This mudstone layer has experienced low-angle thrusting over the conglomerate and exhibits significant differences in stratigraphic sequence and lithological composition compared to the conglomerate on the western side (Lin et al., 2004; Lin et al., 2009).The borehole samples (Figure III) and C-14 dating, calibrated using tree-ring data, indicate that the fault was active between 10,234 and 10,120 years ago (Liming Engineering Consultants Co., 2023; Liang & Lin, 2024). Following the 2022 Guanshan–Chishang earthquake event, surface ruptures and co-seismic deformation were observed along the Lichi Fault near Hsinliang in Taitung (Liu et al., 2022). Geological outcrops and borehole data indicate that the fault separates the Lichi Formation from the Pinan Conglomerate, resulting in the eastern beds of the Pinan Conglomerate becoming nearly vertical or even overturned (Figure IV). Furthermore, the fault intersects Holocene strata (Liming Engineering Consultants Co., 2023; Liang & Lin, 2024). Due to the potential for future fault activity, which may present significant risks to human life and property and result in considerable economic losses, the Lichi Fault has been designated as a geologically sensitive area. It serves as a warning to the public, urging heightened awareness of the potential risks associated with its activity.

Keywords:Active Fault Geological Sensitive Area, Lichi Fault, 2022 Guanshan–Chishang earthquake event, Holocene strata

土場仁澤裂隙模型之更新

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宜蘭仁澤土場（JTTC）裂隙模型是以SLB公司Petrel®解釋系統Discrete Fracture Modeling模組進行。此模型是基於民國109年初步裂隙模型進行精進，本研究納入台灣中油公司在此區塊九口地熱井井下裸孔微電阻地層影像儀（Fullbore Formation MicroImager, FMI）所得之裂隙訊息，並藉由地表地質資料，建構地下三維構造模型進行協同參照建立。由於本區塊缺乏三維震測資料，建立三維裂隙模型仍缺少部分裂隙關鍵參數，因此本研究利用反覆試驗（trial and error）法進行參數測試、相關裂隙理論參數與經驗公式而得，後續相關研究與應用仍需補強與小心使用。

根據目前之JTTC地下斷層構造模型，共計有18條斷層包含66個截切關係。在Petrel®平台下進行構造模型建立（structural modeling），其步驟為：構造框架（structural framework）、斷層框架（fault framework）、模型邊界（model boundary）、模型建立（model construction）、模型精進（model refinement），以及構造格點化（structural gridding）。其中JTTC模型邊界，目前設置根據地形起伏以及目標層段深度需求，上邊界為地表，下邊界則為海平面參考面以下1.5公里；構造格點化則為正方格點（50公尺見方、垂向格點距離5公尺），格點數I-J-K方向為66×66×478。根據裂隙分類、統計與形貌之設置後，最終進行裂隙模型粗化，獲得裂隙模型於I-J-K不同方向之滲透率，其結果可應用於工程測試與後續動態模擬之用。

中文關鍵詞：地熱、裂隙模型、仁澤、土場

Regional disparities and the role of long-range transport in global wet nitrogen deposition

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Atmospheric wet nitrogen deposition ($NDep_{(wet)}$) is essential for keeping ecosystems healthy and managing nitrogen (N) cycling in different regions. However, figuring out historical patterns of $NDep_{(wet)}$ is quite difficult not only because of the lack of observation but also the involvement of complicated interactive processes. In this study, we applied the advanced machine learning model to estimate annual $NDep_{(wet)}$ across global land surfaces at a 0.5° spatial resolution for the period between 2005 to 2019. A remarkable global reduction from 2005 to 2019 was found in both regional observations and our global estimates. In 2005, the annual deposition was 61.24 teragrams (Tg), and by 2019, it had decreased to 52.31 Tg. A considerable reduction of ~14.6% shows that the efforts and policies put in place to control nitrogen level. In the Global North, including the USA, Europe, and China, emissions of NO_x and NH_3 fell by 26% and 5%, respectively, contributing to this overall reduction. Interestingly, in the Global South, nitrogen deposition also went down even though emissions were on the continuing rise. The modest decreases of 3.4% in Africa and 0.6% in India, while South America saw a slight increase of 0.8%, highlight the role of long-range atmospheric transport. The HYSPLIT (a hybrid trajectory model developed by NOAA) trajectory analysis indicated that the backward-to-forward (B/F) trajectory ratio (indicating probability of emission export) declined from 0.94 to 0.36 in Africa, and from 1.16 to 0.88 in India, which demonstrated the long-range transport of nitrogen to other regions. Besides, in most regions, approx. 18%-35% of nitrogen deposition (excluding Africa and South America) is from local sources. Our study which determined the regional disparities and the role of long-range transport in global wet nitrogen deposition, implied that region-dependent nitrogen assessment and management are required.

Keywords:Wet nitrogen deposition, Machine Learning, HYSPLIT, Global North, Global South

透地雷達與管線探測器應用於地下管線調查案例研究

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地球物理探勘利用儀器在地表進行非破壞性探測，如磁力、重力、電磁或震波測勘等方法。透地雷達探測技術在地表對地下發射一種高頻電磁波，當地下物的介電常數發生變化時，電磁波產生反射現象而被地表所接收，由累積接收的反射訊號可分析解釋地下物的形貌與材料特性等，依照探測天線頻率之高低不同，分別可應用於鋼筋、橋面板、混凝土裂縫、管線、空洞、地層層位、水中沉積物與考古等調查工作。管線探測器則利用電磁感應方法，探測交流電持續變化產生之電磁場，並藉由感測訊號強度，推測管線之位置與埋設深度。

本研究分別應用透地雷達探測與管線探測器技術，針對同一場址進行地下管線調查，以瞭解場址之地下管線分布情況。其中，透地雷達資料經過零點修正、背景移除、濾波和移位等資料處理後，得出地下雷達剖面圖，並藉由反射訊號在剖面上的形態特徵來判識管線。管線探測器則針對3條出露之管線進行主動探測，將發射器依序連接出露之金屬管線，再利用接收器以S型路徑探測，以瞭解這些出露管線之地下分布情況。

透地雷達探測成果顯示此一場址淺部普遍具有鋼筋鋪面分布，影響雷達波訊號，並於底下偵測到52條連續管線訊號。管線探測器成功探測出3條地下管線之路徑與深度，且其中2條管線能與透地雷達探測成果進行比對。後續現場進行初步開挖工程，共開挖出9條管線，其中8條管線位於透地雷達探測區域內，可與透地雷達探測成果進行比對。透地雷達與管線探測器結果能有效釐清場址內地下管線之分布情況，並協助後續開挖工程之進行，以提升開挖工作之安全性。

中文關鍵詞：透地雷達、地球物理探勘、非破壞性檢測、管線調查

Frictional Behavior of the Active Milun Fault Zone During Experimental Seismic Slip

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Over the past century, multiple destructive earthquakes in the Hualien area have triggered the Milun Fault. In 2020, the Milun fault Drilling and All-inclusive Sensing project (MiDAS) was initiated to retrieve borehole cores and analyze fault zone properties. A previous study identified the Milun Fault's principal slip zone as a foliated yellow-black gouge layer, possibly indicating strain localization. However, the frictional behavior of the active fault remains poorly understood. Here, we sheared MiDAS yellow gouge samples, mainly composed of quartz, at seismic slip velocity (1 m/s) and 10 MPa under drained and undrained conditions. Results show that under undrained conditions, the friction coefficient achieves a peak value, then dramatically decreases to a steady-state, accompanied by gouge compaction. Under drained conditions, the friction behavior is complex, including weakening and strengthening, which is similar to previous studies on quartz-rich sandstone, although the mechanisms remain unclear. After shearing, the yellow gouge changed to black only under fluid-drained conditions. Microstructural observations show the formation of a principal slip zone (PSZ) characterized by grain size reduction. In addition, synchrotron X-ray analyses reveal similar mineral assemblages in the PSZ and the surrounding materials. Our observations are similar to the natural PSZ of MiDAS core sample, suggesting the presence of coseismic fluid drainage during seismic slip. We further suggest that the formation of the foliated yellow gouge may be a consequence of multiple seismic slip events, and further experiments are required.

Keywords:Rock friction experiment, Milun fault, Seismic slip, Fluid drainage

利用PlanetScope影像所產製之多時期數值地表模型探討山崩地的變化：以玉穗溪上游為例

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臺灣是一座位於西太平洋的島嶼，獨特的氣候條件與地體架構使其擁有豐沛的降水情形與頻繁的地震活動，因而導致無數的山崩事件。為了瞭解山崩災害的時間與空間分布與變化，光學遙感探測資料常被作為山崩地區的繪製與分析之重要監測工具，除可用於評估山崩發生之數量、面積與時序之外，另可藉由影像立體對產製數值地表模型，進而估算災害山崩事件前後的體積變化與後續之搬運作用。而隨著衛星遙感技術的持續發展與創新，光學遙感資料之來源也逐漸多元化，從傳統地球觀測衛星較長間隔的監測資料，逐步往密集的立方地球觀測衛星資料發展。在這些新興的衛星遙感資料中，由行星實驗室（Planet Labs）所設計的PlanetScope即是在過去十年中甚為重要的一組立方衛星監測影像產品，該產品可提供全球尺度再訪週期為1天、空間解析度3-4公尺的地面觀測影像，對於全球尺度的山崩災害監測與分析上能提供近即時的重要監測與分析資料。

為了瞭解利用立方衛星資料進行全球尺度的山崩災害觀測與地形變化研究之潛力，本研究聚焦於臺灣南部玉穗溪地區之山崩，透過分析2019年至2021年間PlanetScope的短時期多重影像建置並比較該山崩地區的三維數值地形變化。本研究初步成果證實以PlanetScope多重影像建置的三維數值地形可應用於估計該地區的土砂體積變化，並可能協助研究者建立山崩地區地形地貌變化的時間序列。

中文關鍵詞：衛星影像、玉穗溪、山崩

利用東海陸棚沉積物重建近兩千年東亞季風與極端氣候變化

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東海陸棚閩浙泥質區因其對東亞季風及熱帶氣旋（颱風）的高度敏感性，是研究過去氣候變化的理想區域。該區沉積物主要由中國沿岸流（China Coastal Current, CCC）、閩浙沿岸流（Zhejiang-Fujian Coastal Current, ZFCC）、長江淡水（Yangtze River Diluted Water, YDW）及臺灣暖流（Taiwan Warm Current, TWC）輸送而來，這些水流攜帶的物質受氣候變化的顯著影響。本研究利用閩浙泥質區的W12-2岩心，重建過去兩千年東亞季風與極端氣候事件的變化。當東亞冬季季風（East Asian Winter Monsoon, EAWM）增強時，風力驅動的CCC將較粗粒沉積物傳至陸棚，沉積物粒徑分布因此可作為EAWM強度的指標；此外，沉積物中的元素比值亦為重要的古氣候重建依據：鋯/銣（Zr/Rb）比值反映洪水與熱帶氣旋頻率，鉀/鈦（K/Ti）比值指示EAWM強度，銣/鍶（Rb/Sr）比值則追蹤東亞夏季季風（East Asian Summer Monsoon, EASM）的變遷。本研究採用雷射粒徑分析儀測量沉積物粒徑特性，並結合可見光-近紅外反射光譜（350-2500 nm）分析礦物組成，以及手持式X光螢光光譜儀（XRF）測定元素組成。通過整合鄰近ST1與ST3岩心的定年、粒徑、礦物及元素資料（李家德，2025碩士論文），本研究將進一步探討閩浙泥質區近兩千年來極端氣候事件（如強降雨與洪水）及季風的時空變化。本研究將增進我們對東亞及西太平洋近二千年長期氣候變化的瞭解，並為現代氣候趨勢與極端事件的歷史背景提供重要參考。

中文關鍵詞：東海、極端氣候、粒徑、反射光譜、XRF

大屯火山噴泥事件初探

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大屯火山群位處台灣北部都市區近郊，其後火山活動至今仍活躍，主要表現在持續的噴氣、溫泉水湧出，顯示其淺部熱液系統具備活化潛勢。若此類熱液活動發展為大規模蒸氣噴發事件，勢將對台北盆地周邊都市區域造成衝擊，更凸顯本區監測與研究的重要性。根據前人對本區熱液蝕變帶的研究，指出安山岩與火山碎屑岩在酸性流體長期作用下，會形成典型的方矽石－明礬石－高嶺石礦物群分布，並呈現由熱液通道向外遞變的礦物分帶結構。這些結果顯示，本區熱液交代作用具空間性分布，且可由礦物組合與分布推論熱流強度與封蓋強度變化。大油坑為其中最具代表性的蒸氣加熱型酸性泉區，近年觀測到多起小規模泥噴事件及泉水之水化學異常。為釐清其泥噴機制與熱液演化，本研究整合 2022－2024 年間大油坑主口與周邊噴氣點和庚子坪(GTP)之泉水化學資料和小油坑(SYK)泥體礦物分析（XRD），探討泥噴前後離子濃度變化與其對應的熱液物理化學意義。本研究整合這些前人觀察與最新 XRD 資料，發現泥噴事件中噴出的泥體組成對應酸性硫酸鹽型(acid-sulfate)系統的特徵礦物組合，亦支持封蓋層(sealing cap)遭酸性流體交代與破壞的模式。配合水化學參數的時間序列變異驗證氣體脫氣、酸化、閃蒸與噴泥過程之間的連動性。大屯山作為都會火山，其釋壓行為若與酸性流體相關，若可透過水化學和氣體監測預先掌握，即可為未來火山監測與潛在噴泥預警建立基礎。此外，本研究亦對照日本箱根火山之蒸氣噴發案例進行對比，雖然箱根火山的蒸氣噴發研究已指出黏土礦物封蓋層（如伊利石、蒙脫石）在封存氣體壓力與控制脫氣過程中扮演關鍵角色，但本研究顯示大屯火山泥體中黏土礦物含量相對較低，反而以明礬石與矽化物為主，推測其封蓋效能可能由酸性交代後形成之明礬石蓋層所主導。此種蓋層在極酸、高硫環境下穩定，可能具有不同於傳統黏土質蓋層具有大規模蒸氣噴發的潛力。未來研究應進一步釐清明礬石蓋層與熱液交互作用機制，從而建立適用於酸性硫酸鹽型系統的蒸氣噴發模式。

中文關鍵詞：大屯火山群、噴泥事件、蒸氣噴發、蓋層、熱液換質

大屯火山噴泥事件初探

陳昇平[1]、賴昱銘[1]、林毓潔[1]、李曉芬[2]、蕭秀璟[3]、凌韻雅[3]、郭京達[1]

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大屯火山群位處台灣北部都市區近郊，其後火山活動至今仍活躍，主要表現在持續的噴氣、溫泉水湧出，顯示其淺部熱液系統具備活化潛勢。若此類熱液活動發展為大規模蒸氣噴發事件，勢將對台北盆地周邊都市區域造成衝擊，更凸顯本區監測與研究的重要性。根據前人對本區熱液蝕變帶的研究，指出安山岩與火山碎屑岩在酸性流體長期作用下，會形成典型的方矽石－明礬石－高嶺石礦物群分布，並呈現由熱液通道向外遞變的礦物分帶結構。這些結果顯示，本區熱液交代作用具空間性分布，且可由礦物組合與分布推論熱流強度與封蓋強度變化。大油坑為其中最具代表性的蒸氣加熱型酸性泉區，近年觀測到多起小規模泥噴事件及泉水之水化學異常。為釐清其泥噴機制與熱液演化，本研究整合 2022－2024 年間大油坑主口與周邊噴氣點和庚子坪(GTP)之泉水化學資料和小油坑(SYK)泥體礦物分析（XRD），探討泥噴前後離子濃度變化與其對應的熱液物理化學意義。本研究整合這些前人觀察與最新 XRD 資料，發現泥噴事件中噴出的泥體組成對應酸性硫酸鹽型(acid-sulfate)系統的特徵礦物組合，亦支持封蓋層(sealing cap)遭酸性流體交代與破壞的模式。配合水化學參數的時間序列變異驗證氣體脫氣、酸化、閃蒸與噴泥過程之間的連動性。大屯山作為都會火山，其釋壓行為若與酸性流體相關，若可透過水化學和氣體監測預先掌握，即可為未來火山監測與潛在噴泥預警建立基礎。此外，本研究亦對照日本箱根火山之蒸氣噴發案例進行對比，雖然箱根火山的蒸氣噴發研究已指出黏土礦物封蓋層（如伊利石、蒙脫石）在封存氣體壓力與控制脫氣過程中扮演關鍵角色，但本研究顯示大屯火山泥體中黏土礦物含量相對較低，反而以明礬石與矽化物為主，推測其封蓋效能可能由酸性交代後形成之明礬石蓋層所主導。此種蓋層在極酸、高硫環境下穩定，可能具有不同於傳統黏土質蓋層具有大規模蒸氣噴發的潛力。未來研究應進一步釐清明礬石蓋層與熱液交互作用機制，從而建立適用於酸性硫酸鹽型系統的蒸氣噴發模式。

中文關鍵詞：大屯火山群、噴泥事件、蒸氣噴發、蓋層、熱液換質

利用SeisComP軟體建置新一代地震測報系統—以2025大埔地震為例

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臺灣位於歐亞大陸板塊與菲律賓海板塊交界，地震活動頻繁。為精進地震定位與預警作業，中央氣象署（以下簡稱本署）近年導入開源地震監測軟體SeisComP（Seismological Communication Processor），藉其自動化資料處理流程、資料庫整合能力與多樣化資料介面，作為新一代地震測報系統建置計畫的核心平台。由於本署現行地震預警系統僅採用點震源模型進行震度預估，於大地震發生時在規模估算與高震度影響範圍存在一定物理限制。為強化震度預估能力，自2023年起本署與瑞士聯邦理工學院地震研究中心（ETHZ-SED）合作，引進建構於SeisComP平台之點震源演算法「虛擬地震學家」（Virtual Seismologist, VS）與線震源演算法「有限斷層破裂偵測法」（Finite-Fault Rupture Detector, FinDer）。2025年M_L 6.4嘉義大埔地震（後修正為臺南市楠西區）發生時，VS與FinDer 兩套演算法自地震後第7秒起即開始產出預警結果，其中 FinDer最終成功對全國13個應發布災防告警細胞廣播訊息（PWS）之縣市中的12縣市發送警報，僅澎湖縣未收到，展現其即時掌握破裂行為之能力。地震活動監測系統整合具備優異波形辨識能力的SeisBench與SeisComP進階的震相關聯與事件組合模組，於主震發生後三日內自動定位出1,119筆地震資料。相較於本署公布之90筆正式地震報告，系統定位之平均誤差約為4公里（水平）、5公里（深度），規模誤差約為0.17，展現良好準確度，惟深度估計不確定性較高，顯示速度模型設定仍有優化空間。綜合上述，本研究以大埔地震為案例，成功驗證 SeisComP 系統整合 VS 與 FinDer 後，具備快速掌握震源資訊與預測地震影響範圍之能力，有助於提升本署地震預警服務之準確性。地震監測系統方面，結合 SeisBench 深度學習模組後，雖然自動定位結果與正式地震目錄仍存在誤差，惟透過持續測試與參數優化，預期可更進一步提升系統效能，強化地震目錄建置與災後分析資料品質。

中文關鍵詞：大埔地震、SeisComP、地震預警、地震監測

碳補存試驗推動及應用技術研發計畫-我國封存場域評估

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碳捕捉、利用與封存(Carbon Capture, Utilization and Storage, CCUS)為我國淨零排放多元策略之一，經濟部現已於台中火力發電廠、鐵砧山啟動「碳捕捉封存先導示範計畫」，聚焦於技術安全性驗證與小規模封存測試。長期減碳規劃則預期碳封存技術於2040年後進入商業運轉階段，並逐步擴大碳封存量能，為無法透過再生能源、製程降低之產業碳排放，提供碳匯進行抵減，同時扮演能源產業於能源轉型過渡期間提供減碳、擴大低碳電力的關鍵角色，因此規模至少需擴大維十至百萬噸級以滿足長期減碳需求。為加速我國CCS技術推動及商業化，本研究將彙整既有地質資料、碳排放源、土地利用情形、社會民情，進行整體條件考量與細部場址評估，初步評選潛在商業規模碳封存示範場址。

據既有潛能評估研究指出，臺灣主要封存區潛能區域位於西北部至中部，考量大型排碳源分布、長期商業發展需求，潛在碳封存示範場址以鹽水層封存潛能區為主要選址範圍，其中以台西盆地、台南盆地區域具較高封存量，然而台南盆地區域於陸海域多與活動構造相鄰或重疊，具較高地質風險；台西盆地儲集系統頂部最深可達3000公尺深，考量技術難度與建置成本下，初步將潛在場址設定於台西盆地南北端，由北至南分別為桃濱、彰濱、麥寮三處。三處場址儲集層深度皆落於國內鑽精技術能力範圍內，其中彰濱潛力場址深度最深，具較高建置難度，且與其他兩處相較下有更高地質風險；麥寮潛在場址雖具備地質條件、技術可行性，然而先前曾有民眾、媒體曾對碳封存開發提出疑慮，民情不利於示範場址推動建置，桃濱場址在學界長期調查與經營下，已有局部調查成果，市政府與民眾初步持正向態度；整體考量三處場址條件，建議優先投入推動桃濱場址進行碳封存示範模場建置。

中文關鍵詞：碳封存、封存潛能區、潛在場址評估

Shear Velocity Structures Related to Arc-Continental Collision and Ancient Rift Events beneath Southern Taiwan Revealed by Rayleigh Wave Tomography

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Taiwan presents a unique geological laboratory featuring the tectonics from subduction to collision between the Eurasian plate and Philippine Sea plate. To obtain high-resolution seismic images of this transition zone, we established the Southern Array for the Lithosphere and Uplift of Taiwan Experiment (SALUTE), a passive broadband amphibious seismic network spanning southern Taiwan and adjacent southeastern offshore areas since 2021. By combining SALUTE data with existing Broadband Array in Taiwan for Seismology (BATS) stations, we extracted Rayleigh waves over periods of 10-70 seconds using ambient noise cross-correlation functions and intra-array cross-correlation analysis of teleseismic surface waves. These were inverted to produce phase velocity maps and 2D shear-wave velocity tomography profiles down to 120 km depth. Our results reveal a dramatic crustal thickening from ~25 km to ~40 km near 23°N, and a distinct lateral velocity contrast at 10–40 km depth beneath the forearc region coincidence with seismicity, likely delineating the Eurasian–Philippine Sea plate boundary. Additionally, a prominent low-velocity anomaly below 50 km beneath the subducted Eurasian slab in southwest Taiwan may reflect remnants of ancient Taiwan Strait rifting events. In contrast, a high-velocity anomaly at 70–100 km depth offshore eastern Taiwan likely corresponds to a subducted forearc fragment. The enhanced spatial resolution provided by the SALUTE dataset, combined with our integrative imaging approach, offers unprecedented insight into crustal and upper mantle structures governing the subduction–collision system in this region.

Keywords:SALUTE array, Rayleigh wave tomography, Shear velocity structures, Subduction to collision

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4C OBN Intertidal Zone Seismic Reflection Survey: A Case Study of the Guanyin Intertidal Zone

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Taoyuan tableland and adjacent offshore have been identified as a potential carbon sequestration sites due to the permeable Kueichulin and Nanchuang formations which are covered by a sealed formation, the Chinshui Shale. Previous studies conducted by CPC have provided high resolution seismic profiles of onshore and offshore regions. However, due to the limitations of the shallow water environment, the subsurface structure of intertidal zone remains unknown. In this study, we aim to establish a data processing workflow for acceleration-type four-component (4C) ocean-bottom node seismometer (OBNs), then constructs an intertidal zone seismic profile with OBNs and onshore velocity based nodal seismometers by vibroseis source. Removal of instrument response and 5Hz high pass filter has been applied to two instruments for signal consistency. The length of survey is 2,425 meters, with 25-meter spacing for both receivers and sources, 98 channels in total. The acquired data underwent key processing steps, including bandpass filtering, near-surface correction, amplitude correction, ground roll attenuation, deconvolution, and normal moveout correction. Additionally, the OBN's acoustic pressure data was combined with the vertical velocity vector through PZ summation to suppress down-going multiple reflections from the water column. As a results, the reflection signal could reach a maximum two-way travel time of 2.2 seconds. The reflections correlate well with the data from other on-offshore profiles and boreholes. No significant fault is observed in the profile. This study fills the gap in high-resolution seismic imaging of the intertidal zone, providing a critical foundation for future geological carbon storage simulations and migration pathway assessments.

Keywords:Intertidal zone, Shallow water seismic reflection survey, Ocean bottom node seismometers

Shallow Seismogenic Structures Offshore Hualien: Analysis of Seismic Stratigraphy and Seafloor Features

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The eastern offshore area of Taiwan is located in a plate convergence environment with frequent seismic activity. However, most of seismic hazard assessment only considers onshore seismogenic structures, omitting offshore faults, which may limit the accuracy of the model. Additionally, the magnitude 7.2 Hualien earthquake on April 3, 2024, further highlighted the frequent seismic activity in this region. This study aims to investigate the seismogenic structures by identifying offshore fault and their geometric characteristics from newly acquired and existing multichannel seismic profiles and multibeam bathymetry data. Based on the spatial distribution of the 0403 Hualien earthquake and its aftershocks with magnitude greater than 5, this study area is divided into three regions: the northern aftershock site-Hsincheng Ridge, the mainshock zone-offshore Lingding, and the southern low seismic activity zone. The fault systems identified offshore of Hualien mainly trend north-south, with eastward-thrusting thrust faults. A few faults exhibit the characteristics of east-dipping normal faults in the northern part of the study area, indicating the presence of different tectonic stress fields, potentially influenced by the subduction of the Philippine Sea Plate. The northern aftershock site features an east-dipping normal fault identified crossing the Hsincheng Ridge, along with multiple collapsed sliding surfaces observed in the profiles. Through integration with previous studies on active faults in Hualien, we suggest that the offshore segment of the Meilun Fault extends to both the Hualien Ridge and Hsincheng Ridge, although its position near the Hsincheng Ridge is located further west than previously proposed. In the mainshock site, a distinct eastward-thrusting reverse fault was identified, indicating a dominant compressional environment closely associated with ongoing plate collision, demonstrating active crustal deformation and a gradual thickening process. Furthermore, we suggest that the southern aftershock activity is related to the Takangkou-High thrust. In contrast, seismic interpretation in the southern low-activity zone reveals continuous, parallel facies, indicating minimal structural deformation and a low seismic activity. The fault that we first identified by new seismic data has been observed in the previous published fault systems (Hsieh et al., 2020; Shyu et al., 2020). Overall, incorporating offshore faults into seismic risk assessment models will provide a more comprehensive basis for seismic potential and geological hazard risk assessment. Future studies can further integrate other geophysical exploration methods to more fully analyze regional tectonics and seismic potential.

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Poster Student Competition

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Keywords:seismogenic structures, fault, seismic, bathymetry, offshore Hualien

變溫熱處理岩石有機物之定量定性對比分析方法建立

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在傳統石油地球化學分析中，常透過總有機碳含量及熱裂分析，以獲取岩石中有機物的總量資訊，然而，此類方法無法進一步顯示岩樣有機物在受熱過程中所生成碳氫化合物的細節。若想更細緻地評估岩樣釋出碳氫化合物的潛能，須有效區分具潛力的活性有機碳與相對較無潛力的惰性有機碳。本研究針對岩樣所釋出碳氫化合物之沸點範圍與鍵結特性，結合熱裂分析儀及熱裂解氣相層析儀的分段升溫與持溫功能，建立變溫熱處理分析方法，此方法包含：(1)定量樣品中游離性碳氫化合物(S_1)含量的石油評估方法，可直觀呈現不同成熟階段與釋出碳氫化合物之間的關聯；(2)定量裂解性碳氫化合物(S_2)含量的熱裂解評估方法，其於不同溫段釋出碳氫化合物，能對應至四種常見定義的油母質類型及其理論活化能分布；(3)定性產出碳氫化合物種類的氣相層析方法，用以探討岩樣所產碳氫化合物的組成特徵。由於變溫熱處理方法在定量及定性分析需分別使用熱裂分析儀及熱裂解氣相層析儀兩種儀器進行，因此本研究取得美國綠河(Green River)頁岩、台灣東坑層煤頁岩，以及非洲油井的湖相砂頁岩岩屑等三種不同類型樣品，以升溫速率、進樣量及持溫時間作為實驗控制條件，進行方法測試及結果比對。所建立之變溫熱處理定性與定量分析方法，能有效提升傳統有機碳分析的解析能力，增進對岩石有機物生成碳氫化合物潛力的評估。

中文關鍵詞：Pyrolysis、Petroleum Assessment Method、Pyrolysis Assessment Method、Thermal Desorption/Pyrolysis Gas Chromatography Method

Relative importance of nanoflagellate grazing and viral lysis for bacterial and Synechococcus spp. mortality in a high-latitude fjord (Adventfjorden, Svalbard) during the summer

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Viral lysis and grazing play crucial but distinct roles in microbial community dynamics and carbon cycling. Yet, their relative influence on bacterial and picophytoplankton populations, especially in Arctic fjords, remains poorly understood. To address this knowledge gap, we conducted modified dilution experiments in Adventfjorden, Svalbard, in August 2024, to quantify microbial growth, grazing pressure, and virus-induced mortality. Our results showed that the abundance of viruses ranged between 1.4 and 8.9 × 10^6 viruses mL^{-1}, with a negative correlation to salinity, explaining 54% of the variation. This suggests that freshwater inputs, such as meltwater, could contribute to higher viral concentrations in these waters. Conversely, bacterial abundance increased with salinity, suggesting different ecological drivers for these communities. *Synechococcus* spp. dominated picophytoplankton communities, ranging from 0.5 × 10^3 cells mL^{-1} to 25.6 × 10^3 cells mL^{-1}. Grazing, primarily by nanoflagellates, emerged as the dominant factor in reducing bacterial and *Synechococcus* spp. populations, accounting for 12–55% and 20–110% of their production losses, respectively. Furthermore, this study was conducted during a period in summer when meltwater discharges entered coastal waters in Arctic fjords at an extremely high rate, providing an opportunity to study microbial processes under projected future warming conditions.

Keywords:Viral lysis, Grazing, Arctic fjords, bacteria, Synechococcus spp.

以高壓鑽石砧及雷射加熱精準量測地核鐵鎳矽合金的熱傳導率

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地球內部組成物質的熱傳導特性對於理解地球的熱演化和熱能收支非常重要。我們過去已透過高壓鑽石砧(DAC)及時域熱反射技術(TDTR)得到許多地幔和地核組成物質在高溫(~1000 K) 及高壓下的熱傳導率。為了能直接獲得地球深處高溫(>2000 K) 及高壓下之熱傳導率，我們建置了雷射加熱技術結合DAC與TDTR以實現在接近核-幔邊界溫壓下的熱傳導率原位量測。我們將報告對地核可能組成成分鐵鎳矽合金所做的高溫高壓熱傳導率量測結果。

中文關鍵詞：熱傳導率、雷射加熱、高壓鑽石砧、時域熱反射

上次冰盛期以來南部海岸之高頻率沈積層序再探

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依據之前9口深達240公尺的鑽井調查，曾文溪與高屏溪最近19千年形成的岩心中，有多達14個千年尺度的堆積層序，顯示上次冰盛期結束以來的高頻率環境變遷。為了進一步確認「等時性普遍出現層序」，以探索氣候與基準面變遷因子的影響，本次調查納入8孔新鑽岩心的層序分析，一併建立高密度、小於20公尺間隔的碳十四年代－深度模式，據以展現曾文溪與高屏溪流域的縱深與走向層序對比。

新舊鑽岩心的岩相多屬於河道平原—堰洲島瀉湖—三角洲的沈積體系，以砂、泥與其互層為主，常有海相化石、植物碎屑、生物擾動與古土壤。礫石質岩相主要在高屏溪流域，屬於沖積扇體系的辮狀河外洗平原產物，散佈於最深部與最上部各數十公尺區間。堆積層序是數公尺到數十公尺厚、沈積相向上變淺的序列，顯示基準面逐漸下降；上下界限是不連續堆積的界面，並伴隨基準面突然上升的現象。在沖積扇—河道平原—洲瀉的層序中，從下到上，礫砂質水道填充物逐漸減少，瀉湖與泛濫平原泥質堆積物增加，呈現砂泥比例變小、顆粒度變細；層序界限是水道砂層的侵蝕底面，之下的泥質堆積物常夾有古土壤，代表堆積遲緩甚至間斷、再到基準面上升的現象。在三角洲的層序中，從下到上，三角洲前部分支河道與河口沙洲砂層逐漸增加，三角洲前緣遠濱相泥質堆積層減少，呈現砂泥比例變大、顆粒度變粗；層序界限是遠濱泥層的底面，以下的砂層頂面具有貝殼富集與強烈生物擾動帶，代表泥質細料堆積遲緩甚至間斷、再到基準面上升的現象。

依據層序對比剖面，曾文溪與高屏溪流域主要的堆積作用都發生在最近12千年，並有8個等時性的層序，各自對應邦德氣候變冷事件1到8（Bond event），層序界限則對應之後氣候快速變暖的轉折。在19—12千年前之間，堆積作用普遍較為緩慢，有3個等時性的層序，大致對應最老、老與新仙女木氣候變冷事件（Dryas events）。

中文關鍵詞：南部海岸、上次冰盛期、高頻率沈積層序、邦德氣候變冷事件、仙女木氣候變冷事件

索馬利蘭Nogal盆地之油氣潛能

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根據Nogal盆地之5口井下資料進行電測沉積相分析，將其電測沉積相劃分為內遠濱、濱面、潮下帶、潮間帶、三角洲及陸相河流6種，其中晚白堊紀之Yesomma(Jesomma)層及Gumburo層常見碎屑沉積物與碳酸鹽岩交互出現之現象，指示Nogal盆地之沉積體系屬於間歇性受碎屑沉積物影響之碳酸鹽岩淺海陸棚。後續依據電測沉積相變化之序列及層序對比分析結果，將Nogal盆地晚白堊紀地層劃分為8個層序，沉積環境由潮下帶－內遠濱向上變淺為三角洲－潮下帶，整體沉積環境呈現向上變淺的過程。

沉積環境對比剖面得知Nogal盆地在高水位時期地層以碳酸鹽岩為主，在低水位時期堆積來自於Nogal盆地西側之三角洲沉積物，作為主要的有機質供應來源，其中又以Yesomma層之三角洲沉積物分布範圍最廣且厚度最厚，是Nogal盆地最重要之儲集岩及陸源有機質供應來源。

由地層對比剖面觀察到Nogal盆地西側保留較多晚侏羅紀地層之現象，而Nogal盆地東側之侏羅紀地層較多遭侵蝕而缺失，推測與盆地東緣之早白堊紀地殼隆起作用有關，推論晚侏羅紀之生油岩在Nogal盆地西側外緣地區內仍有保留，且Nogal盆地西側更接近陸源有機質來源，其Gumburo層及Yesomma層之有機質含量應更為豐富，可作為自生自儲之探勘目標層，應有可觀之生油潛能。

中文關鍵詞：索馬利蘭、Nogal盆地、沉積環境、層序對比分析

鹽水坑頁岩固體瀝青可能來源

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固體瀝青（solid bitumen）為不同熱演化階段生成並殘留於地層中的固態有機物，其組成變化可反映油氣生排移聚與破壞過程。本研究固體瀝青樣品採自甲仙地區上新世鹽水坑頁岩露頭，以熱裂氣相層析串聯質譜儀（pyrolysis-gas chromatography-tandem mass spectrometer, Py-GC-MS-MS）分析其生物指標(biomarker)化合物組成，同時與鄰近區域鑽井油樣組成比較探討其可能來源。分析結果顯示固體瀝青與油樣組成均以五環類三萜烷為主，三環類萜烷相對含量較少，且C_{29}類固烷系列化合物佔優勢，指出固體瀝青與油樣均含較多陸源有機物，來源可能相近，惟油樣成熟度較高。進一步比較固體瀝青、油樣與附近區域露頭及鑽井岩樣萃取物之生物指標化合物組成，顯示與固體瀝青、油樣與漸新統及上部中新統地層均有相近特徵，存在一系列重排藿烷(rearranged hopane)化合物。因此區域油氣與固體瀝青可能來源為區域深部漸新統，或經深埋的上部中新統地層。

中文關鍵詞：固體瀝青、熱裂氣相層析串聯質譜儀、生物指標、重排藿烷

Analyzing Seismic Models and Their Application to Probabilistic Seismic Hazard Assessment: A Case Study of the Longitudinal Valley, Taiwan

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This study validates several seismic models with both long- and short-term forecasting capabilities used in applications in probabilistic seismic hazard assessment (PSHA) and evaluates their impact on hazard levels in the Longitudinal Valley, Taiwan—a region known for its high seismic activity and high-quality seismic data. The Gutenberg-Richter (G-R) law exhibits strong performance in modeling the long-term occurrence rates of small to moderate earthquakes, while the pure characteristic earthquake (PCE) model, which estimates maximum recurrence rates for individual seismogenic structures, is more effective in representing the long-term rates of large earthquakes. The seismic hazard and earthquake rates in fault systems (SHERIFS) model integrates the G-R law with structural parameters and accounts for multi-fault rupture scenarios, showing good performance in forecasting long-term seismicity rates, especially for moderate to large events. To address the limitations of long-term models in short-term and aftershock forecasting, the epidemic-type aftershock sequence (ETAS) model is incorporated to analyze short-term earthquake occurrence rates and to capture the temporal evolution of seismic hazard. The ETAS model is validated using the maximum ground shaking recorded by strong-motion stations during a short observation period. By providing near-real-time forecasts of seismic activity, the ETAS model effectively complements traditional models. Our results present seismic hazard assessments across multiple timescales and highlight the importance of integrating diverse seismic models to enhance the accuracy and reliability of PSHA. This study provides valuable insights into seismic processes and delivers essential parameters for future PSHA efforts in Taiwan.

Keywords:Probabilistic seismic hazard assessment (PSHA), Gutenberg-Richter (G-R) law, Pure characteristic earthquake (PCE) model, Seismic hazard and earthquake rates in fault systems (SHERIFS) model, Epidemic-type aftershock sequence (ETAS) model

2025年大埔地震序列之高解析重定位與震源機制探討：密集地震陣列的應用與成果

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2025年1月21日，臺灣西南部大埔地區發生芮氏規模6.4地震，震央位於嘉義縣政府東南方約38公里，處於麓山帶構造前緣。該區域屬於新生代前陸盆地系統，具有多重疊覆褶皺與逆衝斷層構造，地殼變形極為活躍。本研究於主震發生前一週在震央鄰近地區布設39台三分量短週期地震儀，震後再增設40處臨時觀測站，以提高地震定位精度並解析震源區構造特性。本研究透過AI震相挑選與震相關聯技術與三維速度重定位方法，針對整起地震序列進行高精度重新定位。結果顯示地震活動主要分布於5至20公里的淺層地殼，並呈現出三群不同的震群分布，其中主要餘震構成X型地震分布，主震震源深度亦由初步估計的9.7公里修正為15.75公里。震源機制解分析顯示，此次地震序列主要由東北－西南走向的逆斷層破裂構成，並伴隨部分走滑型破裂機制。綜合機制解與餘震空間分布結果，主震推定發生於向西傾的逆衝斷層上，隨後誘發南側另一向東傾斷層的破裂活動，顯示震源區內可能存在一對共軛斷層系統，並具明顯的應力觸發效應。整體而言，本研究展示高密度地震陣列在解析震源行為、破裂構造與潛勢斷層幾何上的關鍵角色，對於理解台灣麓山帶的構造變形模式、地震潛勢評估以及區域地殼動力學具重要參考價值。

中文關鍵詞：大埔地震、餘震序列、密集地震網

古近紀鄰近臺灣區域的岩漿活動年代為何?

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晚白堊紀的南澳運動結束後，歐亞板塊東緣轉變為被動大陸邊緣，地殼開始經歷伸張作用。這一過程除了在陸棚上發育出一系列北東走向的正斷層，並構成了半地塹盆地與地壘高區外，還促使了岩漿活動的發生。本研究旨在了解古近紀時期鄰近臺灣區域的岩漿活動年代。為此，除了進行野外地層的詳細研究外，本研究還利用各地層中碎屑鋯石的鈾鉛年代，彙整了此時期可能發生的岩漿活動事件。研究結果顯示，古近紀期間發生了三期岩漿活動事件，分別為：第一期發生於65-58百萬年前（花嶼），第二期為54-48百萬年前，第三期為40-35百萬年前。

中文關鍵詞：鈾鉛年代、岩漿活動、碎屑鋯石

銅質文物材質及其次生礦物的非破壞性檢測

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青銅器材質文物是全世界著名的古文明共有的物質文化，占有極重要的地位。具有歷史價值的銅器常是稀有且珍貴的，或者屬於文物身分的含銅金屬典藏品，如果因研究或修復的目的，要瞭解其合金化學成分與次生物種類，甚至必須辨別其真偽時，以非破壞性的儀器進行分析是必須的。傳統鑑定含銅文物方法，大多只能依器物的外表顏色與型制去判斷，靠的是經驗的累積，這對銅器物的鑑定非常有幫助，行之多年亦頗受信賴。然而，缺乏詳細科學的解釋與證據，爭辯時有。

本研究介紹作者近年進行的非破壞性含銅文物材質檢測研究案例，分別使用拉曼光譜儀及X光螢光分析儀等非破壞性儀器進行科學鑑定，以瞭解器物的材質變化、次生礦物種類及合金化學成分。本研究期望建立以非破壞性方法鑑定材質的流程，透過目視觀察及適當的科學檢測正確地鑑定材質，以提供做為文物保存維護與近用之重要參考。

在以中國古銅錢及銅鏡為例的研究中，根據非破壞性檢測結果，發現包括孔雀石、白鉛礦、赤銅礦、藍銅礦、鋅孔雀石、水白鉛礦等多種次生礦物的存在；由於含銅文物合金材質的化學成分，受限於僅可使用非破壞性儀器進行檢測，本研究亦探討應注意事項，及不同檢測數據差異所代表的意義。

中文關鍵詞：合金、拉曼光譜儀、X光螢光分析儀

The Impact of Climate Change on Sources of Marine Calcium Carbonate

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This study investigates the variability in calcium carbonate ($CaCO_3$) sources and their relationship to climate changes across glacial-interglacial (G-IG) timescales. Previous studies have demonstrated that tropical carbonate fluxes respond to G-IG (~100 kyr) and shorter-term climate oscillations; however, the mineralogical characteristics of $CaCO_3$ and their variability remain unclear.

To address these issues, we apply X-ray fluorescence and X-ray diffraction (XRD) analyses to quantify Sr/K ratios and identify $CaCO_3$ mineral phases, thereby reconstructing the shifts in $CaCO_3$ provenance. Sediment core MD05-2925 (151°E, 9.3°S, water depth 1667 m, in the southwestern Western Pacific Warm Pool) is selected due to its well-established age model and environmental data providing a foundation for exploring the causes of change. We hypothesize that $CaCO_3$ composition is influenced by complex paleoenvironmental conditions linked to climatic variability, including sea level change. By characterizing changes in $CaCO_3$ mineralogy and relating them to regional paleoceanographic records, we seek to clarify the processes controlling carbonate deposition across different climate states.

Sediment samples are wet-sieved to isolate the fine fraction (<63μm), dried, powdered, and analyzed using XRD and elemental analyzers. By integrating elemental composition data, particularly total organic carbon, with $CaCO_3$ mineralogical information, we try to assess the relationship between organic matter preservation and carbonate mineralogy.

This research offers new insights into climatic controls on $CaCO_3$ deposition and improves interpretation of sediment archives in the Western Pacific Warm Pool region.

Keywords:Calcium Carbonate ($CaCO_3$), Climate Change, Glacial-Interglacial Cycles, X-ray Diffraction, Total organic carbon

Controls of modern benthic foraminiferal assemblage distribution in the Tainan coastal area revealed through cluster and canonical correspondence analysis

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Benthic foraminifera are valuable bioindicators commonly used to reconstruct past environmental changes. Analyzing their assemblage composition and distribution, along with environmental variables, is key to understanding modern and past environmental conditions.

This study has collected seasonal benthic foraminiferal assemblages from the Qigu Lagoon and Sicao Wetlands in Tainan, Taiwan. Rose Bengal staining was applied to distinguish living from dead individuals. Foraminiferal specimens were documented using field emission scanning electron microscopy, providing a solid basis for taxonomic identification. Cluster analysis and canonical correspondence analysis (CCA) were used to ensure objective interpretation.

Abundance data show that Qigu Lagoon samples have higher foraminiferal abundance than those from Sicao Wetlands, and stained (living) individuals are more common in spring and summer. *Ammonia tepida* is the dominant species in the lagoon, whereas *Elphidium limpidum* and *E. hispidulum* prevail in the wetland environments. *Trochamina inflata* is the most abundant species at mangrove-covered site. Cluster analysis has identified three main assemblages corresponding to estuarine, lagoon, and mangrove environments. CCA results show that salinity and total organic carbon (TOC) are the primary factors influencing spatial distribution, with TOC showing strong positive correlation with the mangrove assemblage. The estuarine and lagoon assemblages, however, are dominated by highly tolerant species, indicating weaker correlations with environmental variables. Our findings provide valuable contributions to regional modern and paleoenvironmental reconstructions.

Keywords:Benthic foraminifera assemblage, Clustering analysis, Canonical correspondence analysis, Tainan coastal area

Unraveling the evolution of Sciaenidae (Perciformes): a window into Cenozoic marine diversity and paleogeography

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The Sciaenidae (croakers or drums) are a diverse fish group predominantly inhabiting estuarine and nearshore environments across tropical and subtropical regions. Modern sciaenids encompass 67 genera and 297 species, and their fossil records also displayed remarkable high diversification and are wide-spread through time: about 90 genera and 250 species, including both extinct and extant forms preserved as fossils, are documented to date. Molecular evidence positions the major diversification of Sciaenidae in tropical America during the Oligocene to early Miocene, yet fossil evidence traces their origins to the early Eocene (~54 Ma), presenting the discrepancy between fossil records and molecular data when investigating the evolution of Sciaenidae. Beyond their significance in diversity, sciaenid fossils offer valuable insights into ancient coastlines and terrestrial drainage systems. In this study, we investigated speciation and extinction rates in Sciaenidae using fossil occurrence data, focusing on regional differences during their diversification. Our results showed that Sciaenidae accumulated their diversity early in the West Atlantic, followed by the East Atlantic, East Pacific, and Indo-West Pacific regions. Notably, diversification rates peaked during the Miocene and the rate shifts were aligned with sea temperature variations. The negative correlation between diversity and diversification rates suggested a competitive interaction might have influenced speciation. Overall, sciaenid fossils not only exhibited global paleodistribution patterns but also regional turnover processes shaped by competition and climatic factors.

Keywords:Croakers, Otoliths, Diversification rates, Regional heterogeneity, Cenozoic

Spatiotemporal characteristics and focal mechanisms of tremor clusters along the mountain range of Taiwan

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Tectonic tremors occur in various geological settings worldwide, with distinct characteristics reflecting their local tectonic environments. This study analyzes five tremor clusters distributed along the mountain belt of Taiwan in the lower crust, using the 2012-2022 tremor catalog proposed by Ide and Chen (2024, GRL). Unlike subduction zone tremors, the mountain-wide tremor zones in Taiwan offer valuable insights into tremor generation in a collisional belt.

We found that the southernmost tremor cluster (Cluster 5) in the southern Central Range exhibits the highest occurrence rate (1.2 events/day, 36.6 seconds/day), while the other tremor zones further north (Clusters 1 to 4 from the northernmost tip to central Central Range) show lower rates (<0.2 events/day, <7 seconds/day). Their recurrence intervals range from 2-4 months, comparable to those observed in Mexico and Eastern Shikoku but notably shorter than Cascadia's. Strong tidal modulation is evident in all clusters, with spectral analysis of the tremor catalog revealing prominent peaks coinciding with tidal constituents O1, S1, M2, and S2. When comparing continuous tide records with tremor activities, 47%, 84.7%, 92.9%, 97.2%, and 81.7% of tremors in Clusters 1 to 5, respectively, coincide with higher-than-median water levels. The weaker tidal correlation in Cluster 1 may reflect different physical environments and/or tectonic settings, which we explore through moment tensor inversion.

To better understand the similarities and differences in deformation mechanisms, we determined focal mechanisms for all five tremor clusters by applying moment tensor inversion in the very low-frequency band (0.02-0.05 Hz) and employing broadband seismograms stacked relative to the hypocentral time of the tremors (Ide et al., 2015, GRL). Results reveal different deformation patterns between clusters. Cluster 5 exhibits a well-defined low-angle thrust mechanism with N-S striking, different from the E-W striking observed in Clusters 1-4, although the latter are less constrained due to fewer events. However, all five clusters reveal nearly horizontal P-axes and higher-angle T-axes, indicating a reverse-faulting regime under horizontal compression. The depth-dependent stress orientation is observed at the tremor zones. At shallow depths less than 20 km, the Cluster 1 area has experienced extensional deformation due to the combined effect of crustal thinning and Okinawa Trough extension, while Clusters 2-5 have experienced compressional stress consistent with the plate convergence direction. At deeper levels between 30 to 50 km, the Cluster 1 area exhibits N-S striking, while Clusters 2-5 show predominantly E-W striking, resulting from compression following the continuous sinking of the Eurasian and Philippine Sea Plates driven by collision and subduction processes. The observed stress orientation from mountain-wide tremors suggests a layered deformation pattern, supporting the anisotropy study by Huang et al. (2015, Science). Our observations indicate that orogenic processes may play a more important role in upper crustal deformation, whereas plate convergence and subduction contribute more significantly to deformation in the lower crust.

Keywords:tectonic tremors, focal mechanisms, tidal modulation, moment tensor inversion, Taiwan mountain belt

應用深度學習於岩層岩芯影像裂隙辨識模型之建置

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裂隙特徵為評估地層力學性質與水力行為之重要依據，對於地質調查與工程設計具有關鍵價值。傳統裂隙辨識方式仰賴地質師以觀察岩芯樣本並進行紀錄，然而此方法耗時且人力成本高。隨著電腦運算能力的提升與大數據技術的發展，深度學習因其高效能與強大學習能力，在各領域應用迅速增加。因此，本研究擬應用深度學習中的 U-Net 影像辨識技術，蒐集臺灣山區多岩類之裂隙岩體影像資料進行訓練，建構具高泛化能力之岩芯裂隙影像辨識模型，期能提升岩層中裂隙特徵之辨識效率與準確性，作為地層力學、水文地質分析與工程應用之基礎。

本研究蒐集臺灣山區鑽孔岩芯影像，尺寸為每米一張，作為建構模型之資料集。所採集之影像涵蓋砂岩、頁岩、泥岩、板岩、片岩與安山岩等，具高度岩性多樣性。多樣化的影像資料可協助模型學習並辨識各種岩性下的裂隙特徵，有助於提升模型在不同地質環境中的適用性與預測準確性，對增進模型泛化能力具關鍵意義。

本研究分別建置沉積岩類、變質岩類與混合岩類三類影像辨識模型。各模型皆使用 300 張影像，依 7：3 比例劃分為訓練集與驗證集，主要用於模型訓練與參數更新。測試集則從未納入訓練集與驗證集的影像中，另行選取 30 張岩芯影像進行辨識，並從中隨機抽取 15 張進行三次重抽樣測試。因這部分資料未參與模型訓練與驗證，辨識結果可較客觀呈現模型的效能及泛化能力。

研究結果顯示，三種影像辨識模型於測試集上的平均交併比（MIoU）約介於 0.6 至 0.7 之間，其中沉積岩類模型表現相對較佳， MIoU 可達 0.7 以上。即使在具有複雜背景、解壓裂縫及破碎構造的影像中，模型整體仍能維持穩定辨識表現，顯示 U-Net 架構於裂隙辨識任務中具應用潛力。 然而，在辨識細微裂隙或裂隙邊緣模糊區域方面，模型表現仍有不足，與人工標註結果存在些微偏差。此外，研究也發現模型在處理部分影像時會受到雜訊影響，如曝光過強或陰影干擾等因素，影響辨識效能，後續仍需透過資料強化與模型優化進行改善。

中文關鍵詞：裂隙、深度學習、岩芯影像

Holocene Reef Dynamics and Optimizing Large-Area Ecological Surveys: Insights from Coral Terraces in Lanyu, Taiwan

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Holocene coral reef terraces offer insights into past biodiversity and ecological dynamics under changing sea levels. Using 3D photogrammetry, we surveyed two terraces (400m² each) at Lover's Cave, Lanyu, Taiwan. Six coral growth forms—branching, massive, encrusting, tabular, foliose, and tube-like—are identified across nine families. Coral coverage, family/genus composition, colony size, and Simpson's Diversity Index (D) are assessed. The upper terrace, formed during the MidHolocene sea-level highstand (~5300 years ago), showed high diversity (D = 0.81), coral coverage (53%), and patchy structure (Im = 1.46), dominated by encrusting and massive corals (*Acroporidae*, *Merulinidae*). A large *Porites* colony (1.53m²) indicates long-term growth. In contrast, the lower terrace, formed during sea-level fall, had slightly lower diversity (D = 0.67) but higher coral coverage (58%), dominated by fast-growing *Isopora palifera*. Increased wave energy likely favored encrusting forms, illustrating reef adjustments to environmental change.

To optimize ecological survey efficiency, we tested random quadrat sampling strategies. Sets of 10, 20, 30, and 40 quadrats (1×1m²) are randomly selected with up to 10 repetitions. Coral group accumulation curves, Bray-Curtis dissimilarity, mean square error (MSE), and Pearson correlation assessed sampling efficiency. 30 quadrats captured all coral groups and plateau after five repetitions. Dissimilarity and MSE approached 0 by the 10th repetition, while 40 quadrats showed redundancy. We recommend 30 quadrats for accurate and efficient ecological surveys. These findings highlight long-term reef resilience and inform future monitoring strategies.

Keywords:Holocene sea level change, photogrammetry, paleo-coral reef niche evolution, random quadrat selection, ecological surveys

Stalagmite-based Paleo-hydroclimate Variability of the Eastern Mediterranean over the past 46 ka

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Here we present stable oxygen and carbon isotope records of three stalagmites collected from Börtlüce Cave, western Türkiye, which provide valuable insights into paleo-hydroclimate variability in the Eastern Mediterranean over the past 46 thousand years (ka). These isotope records capture significant climatic shifts, including major transitions linked to Greenland Stadial/Interstadial, the Bølling-Allerød warming, the Younger Dryas cooling, and the Holocene Climatic Optimum, since the last glacial. The records also document some of the abrupt Holocene climate events, such as the 8.2 ka and 4.2 ka events, which had substantial regional climatic and environmental impacts on societies. New Börtlüce Cave isotope records exhibit similarities with multiple climate-sensitive proxy records from the Eastern Mediterranean region. This consistency suggests that the cave's speleothems effectively record regional past hydroclimate changes driven by variations in atmospheric circulations, such as latitudinal shifts in the westerlies. The findings contribute to a better understanding of the spatial and temporal climate variability in this climatically sensitive region and provide a valuable new dataset for evaluating the Eastern Mediterranean hydroclimate's response to global and regional forcing mechanisms over the late Quaternary.

Keywords:Paleo-hydroclimate, Stalagmite, Stable Isotope, Eastern Mediterranean, Late Quaternary

A New Palynological Record of the Last Millennium from a Sediment Core in Lake Marmara, Western Türkiye

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A 1,100-year palynological record from a 146-cm sediment core collected in Lake Marmara, western Türkiye, provides information on vegetation changes linked to climate variability and human activity. The palynological data indicate that herbaceous and steppe plants—including *Artemisia*, Poaceae, Amaranthaceae, Cyperaceae, Asteraceae Chichorioideae, and Asteraceae Asteroideae—were more abundant during the Medieval Warm Period (ca. 1100–700 cal yr BP). In contrast, Mediterranean/temperate forests, primarily dominated by deciduous *Quercus* and *Olea europaea*, expanded significantly with the onset of the Little Ice Age (ca. 500–100 cal yr BP). Cultivated trees, mainly *Olea europaea*, first appeared around 1,080 cal yr BP and continued to increase, reaching their maximum between 250 and 30 cal yr BP. This trend suggests that agricultural activities may have played a significant role in shaping the landscape, potentially driving anthropogenic changes rather than climate alone.

The palynological record shows both similarities and discrepancies with regional proxy records. These differences can be attributed primarily to human influence, as supported by anthropogenic indicators in the pollen record. Additionally, variations in temporal resolution and proxy sensitivity to climatic changes contribute to the observed inconsistencies among records. However, there is a link between the vegetation trends and the phase of the North Atlantic Oscillation over the last millennium. These findings contribute to a better understanding of past environmental changes in the Eastern Mediterranean.

Keywords:Paleoclimate, Paleovegetation, Little Ice Age, Medieval Warm Period

利用剪力波分離分析裂隙系統特徵:以苗栗泰安地熱場址為例

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地熱能作為再生能源，具備成為基載電力的潛力，對於臺灣實現2050年碳淨零目標至關重要。為有效評估地熱發電潛能，掌握熱流通道的分佈，有助於降低鑽探風險與成本。因此，本研究將著重在探討地下裂隙系統的走向與分佈。

研究區域位於苗栗泰安地熱場域，其坐落於西部麓山帶內麓山帶，受造山運動影響形成褶皺與逆衝斷層系統。此研究將透過剪力波分離分析，探討可能的地下裂隙系統。

本研究使用的資料來自2024年5月20日至6月25日期間，在泰安地區布設的62台三分量短周期地震儀所記錄的地震波形數據，並利用自動剪力波分離分析軟體（SWSPy），得出S快波極化方向與快慢波到時差。其中，快波的極化方向反映裂隙的主要走向，而快慢波之間的到時差則可用以推估裂隙的長度。根據目前測站數據進行統計與空間分布分析，預期結果將瞭解地下裂隙的空間分布與走向，建立泰安地熱區域構造與裂隙系統模型。

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中文關鍵詞：地熱、剪力波分離、非均向性、裂隙系統、地質構造

岩石喚起的地方記憶：臺東市富岡社區的「在地創生」

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地質公園是近年來全球盛行的保育手段，透過由下而上的社區參與機制以及促進地方永續發展的目標來促進地質遺跡的保育。臺東縣東部海岸富岡地質公園以小野柳遊憩區內的富岡砂岩及海蝕地景聞名，現行的解說素材多強調特殊地質地形的成因，因此使社區民眾與遊客對地質環境的理解，僅限於園區內的範圍，難以與社區營造做深入的連結。本計畫為推展富岡社區地方創生工作，將地質公園以Pásková et al.（2021）提出的ABC概念（abiotic-biotic-cultural concept）進行資源盤點，並以Soja（1996）的「第三空間（Thirdspace）」概念尋找地質環境與社區生活空間的連結。

富岡砂岩的深海濁流岩與海岸地形景觀是富岡地質公園最重要的地質遺跡，而位在社區內的「臺東港開港紀念碑」正立於富岡砂岩的露頭之上，地質環境也連結了富岡社區原住民的傳統領域（加路蘭部落 karoroan：洗頭髮的地方，利吉混同層泥岩；石山部落 kakawasan：祖靈出現的地方，利吉混同層天然氣）、富岡漁港的建設（富岡砂岩）、大陳義胞的社區（海階）以及地質公園的發展故事。利用大地故事（Geo-story）敘事，試圖翻轉地質公園在地質、生態、人文上的片段解說，讓社區民眾與遊客能從地球歷史的脈絡，理解到特殊地質環境與自然、文化遺產之間的關聯，符合UNESCO世界地質公園所倡議的精神，也創造出新的認同與價值。

中文關鍵詞：地質公園、富岡砂岩、地方創生

應用主成分分析於臺灣連續磁力量測數據：地磁場的主要變化模式與影響因子

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地磁場變化受地球內部核心及太陽風等多種因素的影響，包含來自電離層及磁層共同效應、潮汐效應、海水導電度差異、火山活動、磁暴事件或其他地球外部效應影響，雖大多皆屬極小尺度之變化，但對於理解地磁變化之物理意義仍具有重要影響力，故連續性之監測將有利於獲取相關資訊，以利深入探究。中央氣象署於全臺設置12座連續三分量磁力測站，本研究使用主成分分析（Principal Component Analysis, PCA）處理測站獲取之連續性時間序列資料，嘗試自長時間段數據中提取有意義之資訊，解析地磁場變化之主要模式及其物理機制。

本研究首先探討傳統頻譜分析（Spectral Analysis）之優劣，發現其因單純針對訊號頻率，難以有效區分有效訊號與雜訊，因而改用主成分分析以同時考量時間與空間的變化。藉此地磁場變化可被分解為多個獨立的主成分，每個主成分可能對應於特定的地球物理現象，例如日變化（Sq variation）、電離層效應或地質構造之影響。此外，分析各測站對不同主成分之貢獻程度，能獲取地磁變化之空間分布特徵。另外將進一步探討主成分隨時間變化的模式，並嘗試找出與潮汐、磁暴及地震等活動之潛在關聯性。成果將有助於提升對地磁變化之理解，透過主成分分析，能更精細解析地磁場的多種變異機制，可為地震前兆監測建立新的數據分析框架，並為將來地球物理探測與研究提供更深入的見解。

中文關鍵詞：地磁變化、主成分分析、區域性地磁異常

大屯火山群蒸氣噴發火山灰的井下及地表石英鍶同位素分析比對：驗證A2C模擬之風場結果

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蒸氣噴發是大屯火山群岩漿活動後的大規模噴發活動，在現今大屯火山群表層土壤中可發現大量石英顆粒及換質岩屑，這些火山灰沉降在冷卻的溶岩流及火山碎屑岩之上(林毓潔，未發表)。

本研究使用A2C煙陣模式模擬大屯火山群潛在蒸氣噴發事件，並透過岩心紀錄與地表石英的鍶同位素比對驗證模擬結果。從七星山東側裂隙爆裂口(Site 3-1)鑽井岩心(深度3.0-3.25m)中發現的石英鍶同位素值($^{87}Sr/^{86}Sr$=0.713766)與大屯山頂土壤石英的鍶同位素值($^{87}Sr/^{86}Sr$=0.713717)高度一致，Site 3-1深度3.0-3.25m的碳14年代為1685±140年。

A2C的使用參數為：使用USGS提供的不同VEI之火山灰雲噴發高度、Tephra量及岩石質火山灰平均密度等參數，假設在大油坑發生VEI=3和4的火山爆發，火山口半徑240m(參考磺嘴山火山口)，設定每10秒紀錄一次，連續噴發5分鐘並持續追蹤5天火山灰變化，以了解火山灰在大氣中的分佈狀況。A2C模擬結果顯示，冬季時10km以下火山灰受大氣影響，會有部分風場吹西風。

由石英鍶同位素、碳14定年、A2C參數模擬結果得知，1825~1545年間的冬季，七星山東側裂隙曾發生蒸氣噴發事件，以至於我們在大屯山山頂可以同時接收到此次噴發事件的火山灰。

中文關鍵詞：大屯火山群、蒸氣噴發火山灰、石英鍶同位素、A2C煙陣模式

Illuminating Earthquake Sources with Borehole Fiber Optics: Insights from the 2022 ML6.8 Chihshang, Taiwan, Earthquake

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Recent advancements in distributed acoustic sensing (DAS) offer a transformative approach for seismological research. A DAS system has a broadband instrument response, measuring continuous strain or strain rate along fiber-optic cables, effectively functioning as a spatially dense seismic array. With its high spatial resolution, integrating DAS technology into existing seismic observation frameworks has the potential to enhance the ability to capture detailed seismic information. Despite these promising applications, DAS remains an emerging tool for seismic source analysis. In this study, we explore the utility of DAS from the Milun fault Drilling and All-inclusive Sensing (MiDAS) project for analyzing source characteristics of the 18 September 2022 M_L6.8 Chihshang, Taiwan, earthquake. Established in 2022, MiDAS integrates borehole drilling, DAS, and borehole seismometers (BHS) to facilitate unprecedented seismic observations across the Milun fault in Hualien, Taiwan. MiDAS recorded over 10 seismic events with magnitudes exceeding 6 in Taiwan, including the 2022 Chihshang earthquake sequence. Notably, the 18 September 2022 M_L6.8 Chihshang mainshock occurred within a complex fault system, where the west-dipping Central Range fault system (CRFs) meets the east-dipping Longitudinal Valley fault system (LVFs), forming a head-to-head conjugate fault system. It is a unique opportunity to assess the capabilities of DAS in resolving rupture characteristics of large earthquakes in complex tectonic environments. Our analysis utilizes the borehole fiber-optic data, along with seismic records at frequencies of 0.05-10 Hz from downhole seismometers and nearby broadband and strong-motion stations at the surface, to evaluate the relative source time function (RSTF) using the empirical Green's function (EGF) deconvolution method. Due to complications associated with later arrivals in near-field seismic recordings for large earthquakes, we focus on the initial 20 seconds of the rupture process rather than attempting to resolve the entire rupture behavior through RSTFs. A key advantage of using borehole-based system with DAS and BHS is their high signal-to-noise ratio, which enables the detection of subtle variations in rupture behavior. Additionally, borehole DAS records, logging data, and drilling core samples allow for high-resolution site response analysis and identification of rock site locations, helping to determine whether signals in RSTFs originate directly from the source. The results reveal that RSTFs exhibit a bumpy-shaped pattern of energy release with three significant energy bursts. Moreover, the spectrum of RSTFs derived from both DAS and seismometers exhibit consistent high-frequency (> 1 Hz) source characteristics. These findings highlight the potential of DAS technology to complement traditional seismic networks and capture small-scale rupture details, opening new avenues for understanding earthquake rupture process in greater detail.

Keywords:2022 ML6.8 Chihshang earthquake, Distributed acoustic sensing, Seismic source analysis

Current progress of the gouge triaxial direct-shear experiments in Taiwan

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Fluid injection during operations of deep geothermal energy alters pore pressure, which may lead to unstable slip. The physical conditions leading to fault-slip instability can be assessed using the experimentally-derived rate-and-state friction (RSF) law. To develop experimental approaches to understand fault-slip behaviors in Taiwan, we conducted confined direct-shear tests using a commercial servo-controlled rock triaxial apparatus. Water-saturated kaolinite powder was sandwiched between two stainless-steel, L-shaped platens. The samples were sheared at room temperature under constant confining (Pc) and pore pressure (Pp) of 20 and 10 MPa, respectively. After 8–12 hours of Pp equilibration, a load-point displacement rate was applied at 1 μm/s until reaching deviator stress (Sd) of 4 MPa, followed by a velocity reduction to 0.1 μm/s until achieving displacement of 1.5 mm. Velocity-step tests were then performed in magnitudes of 10-fold, ranging from 0.015 to 0.15 μm/s with target displacement of 0.3 mm during each step. A steady state coefficient of friction is reached at 0.27. The RSF parameters were calculated assuming system elastic stiffness of k = 0.02 mm^{-1}. Results showed a velocity-strengthening behavior with a-b of 0.006–0.009 and Dc of 4–40 μm. Calibration of O-ring friction leads to a better alignment of a-b, from 0.004 to 0.008, comparing to the reported a-b of 0.002–0.006 for saturated samples. We anticipate that our experimental approaches can be further applied to evaluate fault-slip instability during geothermal operations in Taiwan.

Keywords:confined direct shear experiments, velocity-step tests, rate-and-state friction law (RSF), fault-slip instability

以光流技術應用於潛在大規模崩塌地表位移初探

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光流技術(Optical flow)為透過比對連續序列圖像中像素亮度在時間域上的變化，以及空間上相鄰影像之間的相關性來找到不同幀圖像之觀測目標(像素點)的對應關係，進而以最小平方法計算出觀測目標的運動軌跡(位移場)的技術。該技術現已可見應用於電腦視覺、運動偵測、影像處理及流體力學領域，地質方面在探測冰川表面運動、無人機影像小範圍山體滑坡監測、土石流表面顆粒動態影像追跡及火山活動地表變形追蹤等已有相關文獻成果。

本研究利用2期空載光達數值地形模型（經濟部中央地質調查所(民國99-104年)、內政部(105-112年)）所產製之臺灣山區坡度圖，對於潛在大規模崩塌區域進行光流技術分析。在資料處理部分，本研究透過固定光源照射角度正規化圖層坡度灰階值，以符合光流法之物體亮度恆定假設；後以Python進行光流場的運算。

測試成果顯示在宜蘭縣南澳鄉大濁水北溪流域上游區域、南投縣仁愛鄉塔羅灣溪流域，以及花蓮縣秀林鄉奇萊山鄰近區域的崩塌地有較大的光流場量值，且因其光流場分量所指示為觀測區域的水平位移場，故可用於探測崩塌地內活動塊體運動行為；經檢視崩塌地內所量測之水平位移場方向對比崩塌地坡向一致，且為向下滑動，符合塊體活動的合理性。顯示光流技術探測大規模崩塌區域地表水平變形是可行性，並且透過比對歷史崩塌事件，提供一種相異於傳統使用互相關函數之質點影像量測技術(PIV)於地表水平位移場量測方法。值得持續發展以用於分析崩塌機制及可能成因，提供後續邊坡治理或監測規劃之參考。

中文關鍵詞：大規模崩塌、數值地形模型、光流技術、水平地表位移

臺灣丹大地區變質構造之初探與岩石組構分析

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丹大地區位於中央山脈與雪山山脈交會之構造轉換帶，是臺灣造山帶構造與變質演化研究的重要關鍵區域。該區橫跨南投與花蓮山區，地層分布以眉溪砂岩為界，東屬中央山脈地質區，主要出露盧山層、大禹嶺層、黑岩山層及大南澳片岩；以西則屬雪山山脈地質區，出露佳陽層與眉溪砂岩。區內構造變形橫跨脆性與韌性岩石變形，葉理面普遍呈北北東－南南西走向，發育多組正斷層與左移斷層，並伴隨複向與背斜構造，如丹大山複背斜等大型構造，顯示區域曾歷經強烈構造活動與岩石變形作用。

本研究透過岩石組構與構造分析，針對丹大地區主要變質地層之岩性與變質特徵進行初步歸納:佳陽層之板劈理發育良好，由石英與長石構成，仍可見沉積碎屑組構；眉溪砂岩具等粒組構與局部石英再結晶，雖偶含雲母但無明顯劈理，呈現低度綠色片岩相特徵；盧山層之石英顆粒受壓拉長、雲母強烈定向排列，劈理發育清晰連續；大禹嶺層由石英與雲母組成平板狀劈理，局部含碳質物顯示共軸伸張構造；黑岩山層中石英顯現膨突變形(bulging)，顯示變質程度較高，而雲母定向排列不明顯；大南澳片岩中石英與雲母形成明顯劈理，並可見夾皺劈理，反映高變質度與後期構造疊加。

透過本研究之岩相與構造分析，初步建立丹大圖幅主要地層之岩性與變質構造特徵，進一步深化對臺灣造山帶深部變形機制與演化過程之理解。

中文關鍵詞：岩石組構、丹大圖幅、變質構造

美國Haynesville 頁岩之衰減全反射式傅立葉紅外光譜官能基鑑定與油氣潛力評估

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Haynesville 頁岩為富含有機質的非傳統油氣儲層，相鄰井產量差異被認為與儲層特徵的異質性密切相關。有鑑於此，本研究利用衰減全反射傅立葉紅外光譜（ATR-FTIR）技術對美國Haynesville 頁岩樣品進行官能基團鑑定，將頁岩複雜的化學成分轉為特定官能基資訊，目的在於識別頁岩中有機物的化學結構與地球化學屬性，以作為評估油氣潛力的佐證。本研究分析了兩口井之 Bossier、Upper、Middle 及 Lower Haynesville 層位的岩屑與岩心樣品，透過 ATR-FTIR辨識出醇/酚 (O－H)、脂肪族(CH_3、CH_2)、芳香環 (C=C)、C=O及C－O 伸縮振動等官能基。整體分析結果顯示，頁岩樣品之脂肪族占主導成分，甲基、亞甲基豐度與油氣潛能呈正比，指示樣品具有絕佳的產油潛能。比較不同子層之官能基分布發現Bossier、Upper Haynesville 頁岩呈現較高的含氧官能基吸收波，推論可能原因是含氧碎屑泥岩沉積於高水位體系域所致; Middle 及 Lower Haynesville 頁岩則呈現較弱的芳香環及含氧官能基，顯示沉積於較還原環境，有利於有機物保存。此外，所有樣品均具有芳香族C=C伸縮振動與 C－H 外平面彎曲振動之吸收波，表示所有樣品均已達到成熟階段。值得一提的是在當CH_2 和CH_3 彎曲振動(C－H bending)吸收波呈現微拖曳狀況時，往往反映著具有較高含量之碳酸鹽岩相關，顯示以紅外光譜特徵波能反映岩層的地化特性。ATR-FTIR具快速判讀、微量、適用性廣等優勢，可獲得岩層之整體脂肪族和芳香族比例，以確認油氣潛力區段，除此之外，能與其他地球化學分析(TOC、XRF、XRD)結果交互參照，有助於為鑽井開發與勘探決策提供輔助之科學依據。

中文關鍵詞：Haynesville頁岩、衰減全反射式傅立葉紅外光譜、化學官能基、成熟度

池上地震觀測網及池上即時微震監測系統

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池上地震觀測網(the Chihshang Seismic Network, CSN)為池上斷層多維度觀測計畫(MAGIC-Chihshang (Multidimensional Active Fault Geo-Inclusive Observatory Center - Chihshang) 項目之一，透過建立即時微震監測系統，長期觀測池上斷層周圍地震活動，以期解析地震孕育與深度流體循環的關連。由於池上地區周圍40公里見方內缺乏固定短週期或寬頻地震站，對池上地區微震活動觀測解析度有限，台大及中研院團隊在2021年11月底設置五個寬頻地震站，期間陸續克服資料傳輸問題及確認測站穩定性，在2022年6月底全數改為即時傳輸，在2024年12月底新增四個寬頻地震站。在2022-09-17Mw6.5關山前震及隔日的Mw6.9池上主震發生後，利用即時傳輸的波形資料，快速偵測出39小時內，共1,223筆地震位置與餘震發展方向，發佈於網路平台，供災防單位用於救災評估及研究人員規劃後續調查工作之參考。池上主震發生後，由於餘震分別逐漸往南向鹿野及往北向玉里瑞穗移動，遠離池上寬頻地震網範圍，因此整合網外50公里內中研院地球所臺灣寬頻地震觀測網(BATS)十個即時測站資料，以獲得足夠的測站包覆，並在2023年3月開始即時微震監測系統的運作，透過email及Line自動發佈每日地震報告給予計畫相關人員參考。經系統參數測試及與氣象署地震目錄比較，池上地震觀測網的確有效提升池上地區微震偵測解析度，不僅實現近即時AI地震目錄的建立、獲得完整池上地震前震-主震-餘震序列的震源演變時空分布，目前已累積超過三年的池上地區AI地震目錄，顯示池上地震餘震序列的消退歷程，並同時收錄到池上附近數個規模五地震序列，包括2023-2024年萬榮地震序列、2025年成功地震序列等。

中文關鍵詞：池上地震觀測網、池上即時微震監測系統、池上斷層多維度觀測計畫、MAGIC-Chihshang

透過量化臺灣不同區域的海水面變化以修正海岸構造抬升量之估計

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在構造地形與地震地質的研究中，常利用被抬升的古海水面指標，瞭解沿海的構造活動與地震風險。傳統上，相關研究大多選用一條全球平均（或來自數個地點平均）的古海水面曲線作為基準，以估算海岸的構造抬升量與其速率。然而，近年來學界發現，地區性的海水面會受侵蝕與沉積造成的沉積物均衡調整作用（sediment isostatic adjustment，簡稱SIA）影響，而在空間上有不同的變化模式：即侵蝕會減輕岩石圈荷重，造成均衡抬升，導致相對海退；沉積則會增加荷重使岩石圈均衡下沉，造成相對海進。而臺灣具有全球數一數二快速的侵蝕與沉積作用，過去有關海岸構造抬升的研究卻未將此效應納入考量，將導致沿海構造抬升速率的估算失準。因此，本研究透過重建末次間冰期以來（約122 ka至今）臺灣與周圍海域的沉積物傳輸歷史，將其輸入海水面模型進行模擬，來定性且定量地瞭解SIA對於臺灣各海岸之相對海水面變化的影響，並利用模擬結果來修正各沿海的構造抬升速率。

本研究之海水面模擬結果顯示，臺灣的相對海水面變化與古海水面紀錄明顯受SIA作用的影響，而顯著地偏離全球海水面的變化趨勢，且確實具有高度的空間變異性：苗栗沿海、東北海岸及花東海岸因鄰近侵蝕速率極快的山區，而均衡抬升並相對海退；相反地，小琉球、澎湖、恆春沿海則因附近平原區與海域的快速沉積，而均衡沉降並海進。定量上，SIA在十萬年尺度上可對臺灣海岸造成高達約220公尺的均衡抬升與約70公尺的均衡沉降及相對海水面變化，為全球目前已知最大的SIA效應。透過定量化的模擬結果，本研究得以繪製各海岸考慮SIA效應後的相對海水面曲線，並藉此重新估算構造抬升量與速率。我們發現，考慮SIA效應後的構造抬升速率需要大幅度修正，例如：於花東沿海需下修約30%以上，甚至可達約90%；於小琉球則需上修超過100%，這些都將大大影響海岸之地震危害度評估與構造解釋。因此，本研究結果顯示，在臺灣乃至其他侵蝕與沉積作用活躍的造山帶，未來在瞭解海岸之構造活動或地形演育時，定量化地考慮 SIA 所致的相對海水面變化實屬必要。

中文關鍵詞：相對海水面變化、海岸抬升速率、均衡調整作用、沉積物傳輸、侵蝕與沉積速率

沉積物懸浮行為之數值研究：濃度梯度法與不連續雙黏性流模型之整合與應用

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過去研究文獻表明，劇烈海溝型地震除可能會引發海嘯外，於周圍海床上亦有異常高度混濁之現象。此外，林等人(2024)在台灣外海屏東的高位盆地研究長活塞岩芯中，發現均質岩層顯示出顆粒先粗後細的沉積特徵，並提出一種新的均質層沉積模式，用於解釋受地震影響的封閉盆地中的沉積過程，有助於理解均質層的多樣性和其由極端事件如地震觸發的機制。沉積物懸浮於地質學角度上為較小尺度且難以描述之運動過程，然對岩層沉積模型而言，卻為不可忽視之關鍵。理解沉積物之懸浮行為，有助於揭示其沉積過程，並驗證沉積模型假說。相較於數值模擬，惟目前針對海底沉積物懸浮運動之數值研究亦付之闕如。拉格朗日座標系統雖可透過顆粒動力學描述懸浮行為，然對於懸浮顆粒數目過多導致計算成本過高。因此，本研究於尤拉座標下，全新發展濃度梯度法（ Concentration Gradient Method, CGM ）來描述複雜沉積物懸浮行為，並輔以大渦模式（ LES ）更精確描述紊流條件下懸浮物之運動行為。

由於沉積物往往具有非牛頓流體之行為，因此本研究進一步結合不連續雙黏性流模型（ Discontinuous Bi-viscous Model, DBM ），以模擬海底山崩後沉積物崩塌與懸浮之過程。整體數值模式包含求解VOF方程式與Navier-Stokes方程式，並採用Two-Step Projection Method結合Solenoidal Condition，以求解多相流之動力與運動學過程。在Predictor step中，導入新發展之沉積物擴散模式及DBM模式。研究結果顯示，擴散係數增加時，海底山崩形成之濁流頭部於相同時間內到達較遠距離，且上方懸浮沉積物體積亦隨之增加。由於擴散係數影響動量總和，速度場中可觀察到濁流尾部速度提升，當擴散係數增大時，促使尾部速度前移，進而推動濁流進一步向前發展。

中文關鍵詞：濃度梯度法、不連續雙黏性流模型、VOF、海底沉積物懸浮、深海均質岩

Kaoping slope marine carbon sink variations during the past 150 kyrs

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This study aims to investigate the marine carbon sink variations on the Kaoping Slope over the past 150,000 years. Due to the lack of long-timescale paleoceanographic research materials in the waters surrounding Taiwan, this research utilizes the Mebo-23 series sediment cores drilled in the Fangyuan Canyon and the region of the Kaoping Slope in southwestern Taiwan during the Sino-German collaborative SO-266 Sonne cruise. We attempt to reconstruct the paleo-oceanographic environment and carbon sink changes over the past 150,000 years. The study area is located on the northeastern margin of the South China Sea, where marine sediments are influenced by both terrigenous and marine materials and are controlled by multiple factors such as paleoclimate change, the East Asian monsoon, and sea-level fluctuations. By analyzing the content of organic carbon, calcium carbonate, total nitrogen, total carbon, and total sulfur in the core sediments, we aim to understand the changes in these substances during different periods and their relationship with the paleo-ocean. Preliminary results show that the core samples are rich in nannofossils and planktonic foraminifera, which can serve as good materials for biostratigraphy and isotopic dating in subsequent studies. Elemental analysis reveals significant variations in the content of organic carbon and calcium carbonate in the sediments, with a carbon-nitrogen ratio ranging from 8.6 to 16.4, indicating a mixed marine and terrigenous origin of the sediments, with the proportion changing over time. The proportion of terrigenous material may have been slightly higher during the Last Interglacial period (~100 ka) compared to the Last Glacial period. The preliminary analysis of this study reveals the elemental composition characteristics and potential changes in sediment sources of the Kaoping Slope marine sediments over the 150 ka. In future research, we will further reconstruct the paleo-oceanographic record of this region over the 500 ka through more precise dating and high-resolution sample analysis, and explore the relationship between past seawater temperature and carbon sink variations. This will help predict the carbon sink changes in the waters adjacent to Taiwan under future ocean warming scenarios and evaluate potential marine carbon dioxide removal strategies.

Keywords:Kaoping slope, Paleoceanography, Marine carbon sink

A Deep Learning Framework for Peak Ground Velocity Prediction Using Multi-Station Velocity Waveforms: The Taiwan Transformer Shaking Alert Model (TT-SAM)

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This study presents a deep learning-based earthquake early warning framework—the Taiwan Transformer Shaking Alert Model (TT-SAM)—designed to predict peak ground velocity (PGV) using multi-station seismic waveforms. The model integrates a convolutional neural network (CNN) for local feature extraction and a Transformer encoder to capture spatial relationships among seismic stations.

In contrast to traditional systems focused solely on peak ground acceleration (PGA), TT-SAM incorporates low-frequency waveform components, along with engineered features such as Peak Displacement (PD) and Cumulative Absolute Velocity (CAV). These additions improve the model's sensitivity to ground motion characteristics more closely associated with structural damage.

The model was evaluated using seismic events recorded in Taiwan in 2016. It achieved a top-1 accuracy of 55.4% in intensity level classification, with 95.1% of predictions falling within ±1 intensity level—demonstrating strong robustness in moderate shaking scenarios. However, reduced accuracy was observed in high-intensity events, suggesting a potential underestimation bias.

These results underscore the potential of AI-driven, end-to-end seismic modeling, and position TT-SAM as a practical prototype for real-time, multivariate ground motion forecasting in next-generation earthquake early warning systems.

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Keywords:Seismology, Machine Learning, Deep Learning, Earthquake Early Warning, Artificial Intelligence

運用透地雷達法於陽明山大屯池滲漏之探測與修補後之監測

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大屯池位於陽明山國家公園大屯自然公園內，大屯自然公園因位居兩山之間，積水成澤成為大屯池，池水終年豐沛。然而，2023年4月，大屯池池水幾乎漏光'。根據現地地形、地勢及河流資料，推測滲漏的池水應由大屯池經過巴拉卡公路之後排入河川，故以透地雷達法進行滲漏原因調查，共施測十一條測線，以路旁護堤為起點，巴拉卡公路上坡紅線旁，施測測線L1，上坡路中施測L2測線，雙黃線施測L3測線，下坡路中施測L4測線，巴拉卡公路下坡紅線旁，施測測線L5，L1至L5每條測線長50公尺，然後垂直路面施測H1至H6，每條測線間隔10公尺。由透地雷達調查成果推論，在L各測線位置0至18.0公尺，深度1至4公尺，有較強的滲水反應，推測是本次造成池水漏光的主因。2023年6月，大屯池以皂土在規畫的滲水處進行填補裂縫整修，同時也發現在排水箱涵處(L各測線位置3至5.公尺處)也有破損，也一併整修，整修時，各測線均重複施測，各測線反映池水幾乎沿路面漏光，之後，大屯池重新蓄水，在2023年7月、8月及2025年1月各測線重複監測成果顯示，大屯池滲漏整修十分成功,無新滲漏情況發生。

中文關鍵詞：大屯池、透地雷達、滲漏

內波與山崩動力耦合作用下霞狀層的形成

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霞狀層（Nepheloid Layer）為海洋中高濃度懸浮顆粒所形成的混濁層，依其位置與成因可分為表層（SNL）、中間層（INL）與底層霞狀層（BNL）。SNL主要源自生物活動與河川輸入；INL則與內波（如內孤立波）傳播與反射有關；BNL則由底床沉積物因強水流或海底風暴而重新懸浮形成。內波於通過大陸坡或海底峽谷時，常在邊壁產生局部渦漩，進一步擾動底床，造成沉積物懸浮。另一方面，海底山崩攜帶粒徑分布廣泛之沉積物，小顆粒形成濁流、大顆粒則形成碎屑流。在濁流中，小粒徑顆粒因沉降速率低，易造成擴散懸浮效果。而本研究提出一新假說：當海底山崩與內波擾動交互作用時，可共同促成霞狀層之形成，為霞狀層成因理論提供補充觀點。

本研究使用以美國國家實驗室Los Alamos National Laboratory(LANL)開發之開源計算流體力學數值軟體Truchas為基礎Splash3D作為本次研究模擬之執行方法，Splash3D本身計算求解Navior-Stokes方程式，具有流體體積法Volume of Fluid(VOF)求解計算域之離散流速場以及離散壓力場。求解過程是透過初始條件以及邊界條件設置以布置計算域中初始之流速場以及壓力場，透過二步投影法Two-Step Projection Method求解壓力場及流速場。在計算流體之黏滯項，Splash3D結合不連續雙黏性流模型(Discontinuous Bi-viscous Model)，更精準於模擬持續受到應力作用時，流體從固化區轉至液化區之流變行為。

本研究利用三維流體數值模式分析討論泥沙在水下之運動行為，尤其在霞狀層及濁流模擬方面，使用少許經驗物理模型發展數值方法試圖描述其行為，並對於沉積物之擴散傳輸之分布有更精準、詳細的解釋，本研究目前發展出濃度梯度法(concentration gradient method, CGM)，此方法對於海底山崩分布有更準確地模擬結果，更好的描述山崩行為，在模擬中結合內波以及海底山崩之兩現象，計算出霞狀層之生成。根據模擬結果，大量的情境分析中發現，若海水中出現密度分層，則海底山崩所產生之懸浮物有機會躍動在密度交界處，出現沿等交界面之霞狀層(Nepheloid)，且隨著密度差異，混濁層有愈加明顯的趨勢，除了密度分層之探討，本研究也針對不同山崩材料密度進行分析，針對不同崩塌情境進行行為分析。

中文關鍵詞：濃度梯度法、不連續雙黏性流模型、流體體積法、霞狀層、內波

Toward Improved Probabilistic Seismic Hazard Assessments in Continental Southeast Asia

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This study assesses probabilistic seismic hazards in continental Southeast Asia by integrating a seismic model based on earthquake catalogs, an active fault database, suitable ground motion prediction equations (GMPEs), and site effects. Based on tectonic structures, fault distribution, and subduction zones, the seismicity in the study region is divided into 18 area sources and 1 deep source. Seismicity rates for each source are quantified using the truncated exponential model, the characteristic earthquake model, and/or the Seismic Hazard and Earthquake Rate in Fault Systems (SHERIFS) model. The analysis incorporates regional variations in seismic activity, including shallow crustal earthquakes, active fault events, and earthquakes occurring along the subduction interface and within the subducting slab. To describe ground motion attenuation from sources to sites, GMPEs for both crustal and subduction settings are applied. Site effects are considered via the average shear wave velocity within a depth of 30 meters (Vs30). To consider model uncertainties, a logic tree approach is used to compute seismic hazards in the forms of hazard maps, hazard curves, and disaggregation. Our results indicate a high earthquake occurrence rate along the Sagaing Fault, exposing nearby cities such as Sagaing and Mandalay to elevated seismic hazard levels. The outcomes of this assessment are intended to inform disaster prevention strategies, support the development of building code standards by relevant authorities, and guide effective disaster recovery planning and long-term seismic risk management following the 2025 M7.7 Mandalay earthquake.

Keywords:probabilistic seismic hazard assessment, continental Southeast Asia, Sagaing fault, SHERIFS

3D Upper Crustal Shear-Wave Velocity Model of Eastern Taiwan from Ambient Noise Tomography with Dense Seismic Arrays

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Eastern Taiwan is recognized as a boundary of arc-continent collision between the Eurasian Plate and the Philippine Sea Plate, resulting in complex tectonic and geological structures. These active structures frequently generate earthquakes and pose significant hazards. Therefore, developing a high-resolution and well-constrained 3D shear-wave velocity model of the upper crust is crucial for understanding the region's subsurface structural architecture. In this study,we conducted an ambient noise tomography experiment using 411 seismometers deployed in 5 dense seismic arrays along the Longitudinal Valley and the Coastal Range. The reliable Rayleigh wave phase velocity periods range from 0.6 to 14 seconds, enabling a well-resolved Vs structure from the surface to a depth of around 6 km of the crust. The Vs model reveals a prominent NNE-striking variation in Vs that follows the trend of tectonic units. Lateral and vertical velocity variations observed in the region align with known geological structures and fault zones, highlighting heterogeneous lithological compositions. Specifically, in the north, the Longitudinal Valley fault system is well imaged as a velocity contrast between Coastal Range rocks and Longitudinal Valley sediments, while in the south, the fault zone is less resolved due to the similar velocities of the Lichi Mélange rocks and basin sediments. By integrating seismic velocity data with earthquake distributions, we emphasize the role of lithological heterogeneities in controlling strain accumulation and seismic activity. The observed correlation between seismicity and velocity discontinuities around 23.5°N suggests that structural boundaries are vital in accommodating deformation and are associated with the transition from collision to subduction.

中文關鍵詞：eastern Taiwan、plate boundary、ambient noise tomography、dense seismic array、3D shear-wave velocity model

活動斷層地質敏感區基地地質調查及地質安全評估案例研析

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依據《地質法》第五條及《地質敏感區劃定、變更及廢止辦法》第二條與第五條規定，具特殊地質景觀、地質環境或可能發生地質災害之虞之地區，公告為地質敏感區。透過法規命令將活動斷層及其兩側易受活動斷層錯動或地表破裂影響範圍劃定為活動斷層地質敏感區，此類地質敏感區因關乎公共安全及土地利用，為全國各界高度關注的議題。

活動斷層地質敏感區自民國 103 年底開始公告，至 113年已逾 11 年，累計已公告 25 個。為了解活動斷層地質敏感區內相關土地開發案件後續「基地地質調查及地質安全評估(以下簡稱調查與評估)」報告內容及審查情形，本研究收集相關個案報告進行分析。

依據各技師公會提供的統計資料推算，六大技師類別中，以土木技師承接活動斷層調查與評估案件數量最多，其次為應用地質技師，再次為水土保持技師。此外，本研究亦彙整建築管理、環境影響評估、區域計畫等相關案件報告之內容、審查流程及收費情形。進一步透過分析56件位於活動斷層地質敏感區內之基地地質調查與安全評估開發個案，針對報告內容撰寫項目、技師專業職能及斷層資料應用等問題，提出深入討論與具體建議。

中文關鍵詞：活動斷層、活動斷層地質敏感區、地質敏感區基地地質調查及地質安全評估

自然律及法律觀點下的地質敏感區

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我國於2011年施行地質法後，依據該法及地質敏感區劃定變更及廢止辦法將具有特殊地質景觀、地質環境或有發生地質災害之虞之地區公告為地質敏感區，迄今已陸續完成68項地質敏感區劃定公告。地質敏感區之公告係基於法律授權，且對多數不特定人民對外發生法律效果，惟其不適用中央法規標準法第3條所定的7類法規名稱，屬於以法規形式訂定有所困難的「實質意義之法規命令」。依據法務部2012年函釋，地質敏感區劃定後的影響僅有地質法第8條有關申請土地開發前應進行基地地質調查及地質安全評估之規定，如此並未直接限制一定區域內人民之權利、利益或增加其負擔，且非針對具體事件之處理，因此性質上應歸屬為行政程序法第150條第1項規定之法規命令。

地質敏感區之定義為具有特殊地質景觀、地質環境或有發生地質災害之虞的區域，依地質敏感區分類，地質遺跡指在地球演化過程中，各種地質作用之產物；地下水補注區指地表水入滲地下地層，且為區域性之地下水流源頭地區；活動斷層地質敏感區為活動斷層及其兩側易受活動斷層錯動或地表破裂影響範圍；山崩與地滑地質敏感區為曾經發生土石崩塌或有山崩或地滑發生條件之地區，及其周圍受山崩或地滑影響範圍。以上各類定義均以自然律的地質證據為劃定依據。然而地質敏感區劃定過程中，仍參考人為地籍邊界進行編修，或界定劃定標的縣市，或人為定義影響範圍，因此自然律的地質證據之下仍有人為法律色彩作為的介入。這些議題均顯示地質敏感區在自然律及法律觀點下的差異性，並非僅須考量自然律的地質證據，相關議題值得持續廣泛探討，以使地質敏感區制度更臻完善。

中文關鍵詞：地質法、地質敏感區、實質意義之法規命令、地質證據

Enhancing Automated Earthquake Detection with Deep Learning: Application to Ocean-Bottom Seismographs Using Automated Labeling and Transfer Learning

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We aim to enhance deep learning for earthquake detection using ocean-bottom seismographs (OBS). Although we can identify P and S waves using EQTransformer and associate seismic arrivals across stations using GaMMA, EQTransformer performs poorly on OBS data due to marine noise and complex horizontal waveforms. We evaluate OBSTransformer, a transfer learning adaptation of EQTransformer specifically designed for marine environments, using our OBS dataset.

To address this limitation we used 30 Taiwan-developed Broadband OBS units deployed in the mid-Okinawa trough, we compared EQTransformer+GaMMA and OBSTransformer+GaMMA against the Japan Meteorological Agency (JMA) catalog. For February 1, 2019 (26°–32°N, 127°–132°E), JMA recorded 31 earthquakes. OBSTransformer identified 13 events (3 matching JMA) with higher precision but lower recall, while EQTransformer detected 378 events (7 matching JMA) with higher sensitivity but produced numerous false positives. EQTransformer struggles with larger earthquakes, while OBSTransformer has difficulty with smaller events.

Given the differences in design and specifications among various OBS instruments, we aim to further enhance the model's generalization capabilities by integrating automated labeling and transfer learning strategies. Automated labeling leverages seismic catalogs and multi-model consensus to reduce manual annotation efforts while improving phase pick quality. Transfer learning enables efficient adaptation to new datasets under limited data availability and computational resources. This work advances earthquake detection in marine environments, enabling more precise localization of offshore seismic events.

Keywords:Deep Learning, Seismic Phase Detection, Automatic Earthquake

Evaluation of Macroseismic Intensity, Ground Motion Characteristics and Earthquake Sequence of the 2022 Mw 5.9 Keng Tung Earthquake in Eastern Myanmar

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On July 21, 2022, a Mw 5.9 earthquake struck approximately 30 km southeast of Keng Tung Township, eastern Myanmar, at a depth of 10 km. Following this moderate earthquake, the Thai Meteorological Department (TMD) recorded over 200 aftershocks. The event resulted from left-lateral strike-slip faulting within the Shan Fault System, which has a long-term slip rate of 1–2 mm/yr. Shaking was widely felt across eastern Myanmar, southern Yunnan (China), northern Thailand, and Vietnam, with reports indicating perceptibility extending several hundred kilometers from the epicenter, including Bangkok. Significant structural damage occurred in Keng Tung Township, likely influenced by local site conditions. To assess macroseismic intensity, we applied the European Macroseismic Scale (EMS-98) to 120 locations based on social media reports. We also evaluated the suitability of intensity prediction equations (IPEs) and ground motion prediction equations (GMPEs) for the region, focusing on their applicability to this tectonic setting. Our analysis tested several IPEs and GMPEs, employing various methods to rank and identify the most suitable equations for the study area. Our findings indicate that intensity estimates from Bindi et al. (2011) for Central Asia and Szeliga et al. (2010) for the Himalayan and Indian regions align well with observed data. Additionally, ground motion parameters, particularly peak ground acceleration (PGA) and peak ground velocity (PGV), were calculated using several GMPEs and analyzed. These findings contribute to a better understanding of regional seismic hazard and support the selection of appropriate IPEs and GMPEs for future studies.

Keywords:Seismic Hazards, Macroseismic Intensity, Ground Motions, Intensity Prediction Equations, Ground Motion Prediction Equations

潛在大規模崩塌地形特徵與活動度之初探

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臺灣島多震多雨且抬升與侵蝕速率高，由光達地形判釋出為數眾多之潛在大規模崩塌，欲了解其個別潛勢高低，須以最新地形地貌資料分析後進行分級分類，才能有效管理與決定調查順序。前期研究透過崩塌地形特徵分級表(LTFGF)評估，由高至低分別為A級6處、B級96處、C級763處、D級396處(共1,261處)。據此，本研究將分級結果進行統計分析，並針對A級6處與地礦中心重點場址34處(共40處)，藉由潛在大規模崩塌活動度評分表(PLAAF)評估其破壞機制與活動度。本研究以LTFGF評分結果進行統計，如評分分布、地理區域、地層與岩性、攻擊岸與否等，其中「攻擊岸」與「非攻擊岸」分別有323處與938處，而被評為A、B級之攻擊岸與非攻擊岸案例分別為21%和3.6%；反之，D級之攻擊岸與非攻擊岸案例分別為5.9%和40.2%，故有無攻擊岸對LTFGF評分有顯著影響。

以PLAAF分析高崩塌潛勢案例之破壞機制(重力邊坡變形(GSD)、弧形滑動(RS)、平面滑動(PS)與巨厚崩積層(TC))與活動度(高、中、低)，GSD、RS、PS、TC案例數量各有13處(33%)、11處(28%)、9處(23%)、7處(18%)，高活動度案例分別為5、1、1、3處，平均分數最大為TC(50.57分)，最小為PS(39.11分)。PLAAF中關鍵不利穩定因素數量分別為36個、18個、14個、21個，平均每處有2.77個、1.64個、1.56個、3個，其中被選擇最多次的前三項因素為「蝕溝向源或兩側破壞」、「新鮮趾部崩塌」、「滑動體內破壞」。各破壞機制類型於歷史崩塌數量、裸露面積比例、滑動體應變之分布情形顯示TC通常為數量較高類型，而PS則皆為數量最低。當LTFGF中B級以上無低活動度之場址，且A級之PLAAF分數大多高於50分，故崩塌特徵明顯之案例通常亦反應較高活動度。綜上所述，崩塌地形特徵能反映潛在大規模崩塌穩定性，再由活動度評估協助篩選高潛勢區域，本研究成果可作為後續潛在大規模崩塌調查及防災優先處理之參考，並提供相關單位在資源分配與風險管理上之依據。

中文關鍵詞：潛在大規模崩塌分級分類、地形特徵、破壞機制、活動度、攻擊岸

透過反射震測法分析北桃園區域是否適合作為探封存場址

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隨著全球人口持續增長與經濟快速發展，二氧化碳排放量迅速上升，對全球氣候變遷造成了嚴重且不可逆的影響。為了減緩地球暖化及減少極端氣候事件，各國紛紛投入大量資源開發各種替代能源技術，並推動多元化的減碳策略。除了積極減少溫室氣體排放量外，如何有效回收與封存已排放的二氧化碳，也成為達成淨零碳排目標的重要手段。碳捕捉與封存（Carbon Capture and Storage, CCS）技術作為減碳計畫中的關鍵一環，雖然無法直接減少源頭排放，但能有效地將工業活動中排放出的二氧化碳從排放源捕捉下來，經過壓縮後注入深層地層中永久封存，從而降低大氣中的二氧化碳濃度，減緩溫室效應。儘管台灣已經初步識別出幾個具有潛力的封存系統，但由於台灣位處於地震活動頻繁的地區，且地質構造年輕且破碎，對於實際的封存可行性仍需更進一步的詳細評估與分析，以確保長期封存的安全性與穩定性。

本研究將運用淺層反射震測技術（Shallow Seismic Reflection Method），針對桃園北部沿海地區進行震測調查，規劃六條測線用以分析此區域的地下地層構造。淺層反射震測相較於傳統探油震測具有較高解析度，能有效描繪地下數百米至二公里以內的地層變化，適合作為封存場址初步篩選的地球物理方法。此外，本研究運用兩種不同震測資料處理技術，在資料處理上選擇對於每個步驟較為適合的軟體進行互補分析，以提高地層解釋的準確性。最終，期望本研究成果能提供北桃園地區碳封存可行性的重要地球物理依據，並作為台灣未來碳封存（CCS）計畫推動及政策制定的參考資料，助力台灣邁向永續淨零的目標。

中文關鍵詞：反射震測、碳封存、桃園沿海

北臺灣大屯火山群七星山岩漿庫行為之研究

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七星山亞群為大屯火山群中的亞群之一，其主要山體包括七星山、白雲山、燒庚寮、竹篙山、紗帽山與七股山等。依據前人研究成果，七星山之岩漿活動可區分為三期，分別產出紫蘇輝石角閃石安山岩、含角閃石兩輝石安山岩及兩輝石角閃石安山岩等不同岩性。七星山東、西兩側各發育一條包含約四個噴發破裂口之裂隙帶。陽管處於2021年執行之地質鑽探計畫中，完成東側四口鑽井，並成功取火成岩之岩心資料。本研究旨在利用上述鑽井所獲岩心中之火成岩樣本，探討七星山下方潛在岩漿庫之性質與活動機制。岩心採樣位置集中於七星山東側蒸氣噴發破裂口帶，取樣自S1及S3兩口井。其中S1井取樣深度為4.3－4.6m、9.4－9.8m及11－11.4m；S3井則取自5.7－6m與7.4－8m，共五段岩心區段。將岩心樣本製成岩石薄片進行岩象學觀察，確認其中所包含之礦物種類，將需要做礦物化學的礦物鎖定在斜長石、角閃石、輝石。製作岩石靶進行掃描式電子顯微鏡（Scanning Electron Microscope, SEM）與電子能量散射分析（Energy-Dispersive X-ray spectroscopy, EDS）來觀察礦物外型及化學組成。SEM-EDS得到的結果，再利用電子微探儀（Electron Probe Microanalyzer, EPMA）對礦物進行化學成分的定量分析。礦物化學數據藉由前人文獻中的經驗公式，針對斜輝石進行地溫計與Fe-Mg擴散速率的計算、角閃石進行地壓計的計算、斜長石觀察其An值與Mg擴散速率之間的關係，推論此岩漿在地下所停留的時間及有岩漿補充的歷程。並進行全岩主要及微量元素地球化學分析，比對前人的地化特性。七星山全岩的地球化學成分均一，鈥同位素值變化極小，顯示岩漿源區單一。藉由計算結果得知，此岩心中的礦物生長環境在地下6-12公里之間的區域，晶體開始生長時的溫度在1130℃～1180℃間。將壓力所得之深度符合Huang et al,(2021)所提出的大屯火山岩漿庫深度範圍，透過擴散速率得知岩漿在噴發之前，最久於岩漿庫停留了約5000年的時間，而在岩漿噴發的前十年間，出現了密集的3次岩漿補充事件。

中文關鍵詞：岩象學、礦物化學、全岩地球化學、岩漿補充、七星山

Assemblages analysis of planktonic foraminifera during the Pulleniatina Left Coiling Event 5 in ODP Hole 1115B, Western equatorial Pacific Ocean

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Shifts in dominant coiling direction events of *Pulleniatina* genus have been used as useful biostratigraphic control points during 3.90 – 0.86 million years ago (Ma). However, the ecological significance and environmental context of the *Pulleniatina* coiling direction change events remain poorly understood. According to previous studies, left-coiling event 5 (L5 event, ~2.15 – 1.89 Ma) is initiated by a significant reduction of absolute right-coiling (RC) abundance, leading to a coiling percentage change reaching up to 90%. We aim to clarify the ecological and environmental influences associated with left-coiling events through analysis of planktonic foraminiferal assemblages.

This study selected seventeen samples between 2.14 – 1.72 Ma from ODP Hole 1115B (9°11' S, 151°34' E, water depth 1149 m) in the Solomon Sea. Following splitting and sieving procedures, more than 500 specimens >250 μm were counted in each sample. We identified and counted all planktonic foraminiferal species, and calculated relative abundances and fluxes to assess ecological interactions during the L5 event.

Data analysis suggests that *Pulleniatina* likely did not experience strong ecological competition with the majority of planktonic foraminiferal species. However, several species (*Globorotalia tumida, Gr. truncatulinoides, Orbulina universa, G. ruber, Neogloboquadrina dutertrei*) exhibited similar flux changes to those of left-coiling *Pulleniatina*, implying a shared response to marine environment changes which may need further studies.

Keywords:ODP 1115B, left-coiling events, L5 event, Pulleniatina, planktonic foraminifera

以現地調查與地球物理的方法探討崁腳斷層在空間下的分佈

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摘　要

崁腳斷層是位於北台灣眾多逆斷層之一，其橫跨台北、新北和基隆的部分地區。由於其斷層活動在一萬年內不再有任何明顯活動的痕跡，因此不被歸類為第一類活動斷層。在與斷層活動有關的研究上往往不受重視，因此大部分的研究資料僅限與岩芯和野外露頭的紀錄。隨著地震學和相關技術的發展，越來越多利用地震學原理探討地下構造方法也隨之誕生。微地動（Microtremor）訊號分析的技術已被廣泛應用於探討地下構造，其結果的可靠性和正確性也被為人認可。其原理是利用環境或人為活動的噪聲作為訊號，通過分析這些訊號在地底下的傳播速度來構築出地下構造。經過地形、人力和經費的考量下，決定採用此方法進行研究。同時本次研究區域內多為山區，因此能將人為及其它不必要的干擾降到最低，如此一來得出的數據能更接近真實的地下構造。

本次研究的研究區域專注於崁腳斷層南端即台北市內的內湖和大屯火山群，因為在斷層兩端的地層在排序和岩性上具有高度一致性，同時加以文獻資料可以判斷出斷層在某些區域有出露或通過的痕跡。前期會先透過在兩地進行野外實地調查，嘗試尋找出斷層出露或是具有相關特徵的露頭作為設立微地動陣列的參考依據。在完成初步調查後，將通過在調查區域的岩芯資料與地表上的露頭進行連結進一步衍生出地下構造。其所得到的結果將作為後期微地動資料分析的對照，加強最終結果的可信度。

本研究利用微地動資料分析法中的陣列分析法和單站頻譜分析法來推斷出崁腳斷層在地下的具體通過的區域，並配合野外調查結果與岩芯資料作為本研究的最終成果。本研究成果或可成為針對其它非第一類活動斷層研究的重要參考。

中文關鍵詞：崁腳斷層、微地動、陣列分析、HVSR

以地表構造線型與裂隙活化趨勢探討臺中谷關地熱潛能

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因應我國2050淨零碳排政策之規劃，使國內再生能源需求量提升，因地熱能可作為基載電量其前景備受矚目。近年來彙整高精度遙測判釋與區域應力反演分析，進而繪製地熱潛能圖之技術已逐步研發並應用至我國多個案場，然而遙測圖資精度高低可能受限於成本、尺度、機密性等因素進而影響分析結果，為了協助地熱產業界瞭解對應圖資之分析成效，本研究將量化並比較不同圖資解析度之分析差異，以利國內地熱產業發展。

本研究基於前人方法，於臺中谷關地區使用高精度數值高程模型並肉眼判釋地表裂隙線型，以三角網格法進行位態計算。為評估潛在導水裂隙位態，使用震源機制應力反演結果進行裂隙不安定性、擴張趨勢與滑動趨勢分析。進一步，以野外實際導水裂隙位態反算各活化分析之閥值，繪製臺中谷關地區潛在導水裂隙空間分布圖。為比較圖資解析度對裂隙判釋結果的差異，以20米及6米解析度之數值高程模型分別套疊 6米及1米解析度之坡度圖與多向陰影圖為底圖，以線型判釋結果比對位態、數量及長度等特性並量化其差異性。此外，本研究亦篩選大於活化趨勢閥值之裂隙進行上述對比，以期釐清線型特性與導水裂隙之間的可能關聯。

本研究初步完成兩種解析度衍生圖資之地表線型判釋、區域應力反演及裂隙活化分析。線型判釋結果顯示20米圖資以西北-東南走向為主，而6米圖資則具多組走向，兩者傾角皆為高傾角。長度與數量分布顯示20米圖資之長度眾數落在300至400米區間，而6米圖資之長度眾數則多落在100至200米間，且兩者大於500米之線型數量並沒有明顯差異。應力反演結果顯示谷關地區以走向滑移斷層應力場為主，最大主應力軸為東南傾向之近水平。裂隙活化分析結果顯示西北-東南向之近鉛直為高潛能裂隙面，野外查核結果顯示導水裂隙位態大致為西北-東南方向之中至高傾角。

本研究將進一步比對不同解析度之高活化裂隙於各線型特性中所占範圍，評估地熱探勘尺度下所需最小圖資解析度，並結合其他地熱前期探勘方法，以提高我國地熱開發競爭力。

中文關鍵詞：地熱、谷關溫泉、地表線型判釋、裂隙活化分析、解析度差異

Geochemistry of Mesoproterozoic dyke swarms of the Southern and Superior provinces, Canadian Shield

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The Archean Superior Province and Proterozoic Southern Province form the cratonic cores of North America. These long-lived cratons preserve the history of distinct tectonomagmatic events. Large igneous provinces (LIPs) represent anomalous volcanic activity not driven by typical plate tectonics. Precambrian LIPs are often expressed as giant radiating dyke swarms, the eroded remnants of magmatic plumbing systems. This study examines three Mesoproterozoic dyke swarms: Sudbury (1.2 Ga), Abitibi (1.1 Ga), and Pukaskwa (part of the Keweenawan LIPs, 1.1 Ga). Thin section analyses show that these samples have low matrix content, euhedral plagioclase, euhedral to subhedral pyroxene, and some olivine. Major and trace elements reveal geochemical differences: Abitibi (SiO_2 = 43.9–47.4 wt%, Sm/Yb > 3), Sudbury (SiO_2 = 47.0–50.7 wt%, Sm/Yb ≈ 2), and Pukaskwa (SiO_2 = 48.4–53.0 wt%, Sm/Yb ≈ 1). The primitive mantle-normalized Tb/Yb ratio indicates that the Abitibi swarm (Tb/Yb_{PM} > 1.8) was derived from a garnet peridotite source, whereas the other swarms originated from a shallower spinel peridotite source. Geochemical fingerprinting (Th/Nb vs. TiO_2/Yb) suggests different mantle sources: Abitibi and Sudbury are from an OIB/OPB-like source, and Pukaskwa from a subduction-modified lithosphere (SZLM) source. These results indicate multiple Mesoproterozoic magmatic events in the Superior Province were sourced from both lithospheric and sub-lithospheric mantle.

Keywords:Mesoproterozoic, Superior craton, Large igneous province, Giant radiating dyke swarm

Local patches of negative core-mantle boundary heat flux in numerical simulations of thermo-chemical convection

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The heat flux at the Earth's core-mantle boundary (CMB) partially controls the outer core dynamics and its associated geodynamo. On the mantle side, spatial and temporal variations in this flux depend, in turn, on details of mantle convection, including the rheology of mantle rocks and the mode of mantle heating. Previous simulations of mantle dynamics showed that CMB heat flux may be locally negative, meaning that in these regions heat flows from the mantle to the core. In this study, we investigate the conditions needed to generate patches of negative CMB heat flux. For this, we perform a series of high-resolution numerical simulations of thermo-chemical convection in spherical annulus geometry using the code StagYY. The compositional initial condition consists in a thin basal layer of chemically denser material (alos referred to as primordial material), which subsequently evolves into piles of hot, primordial material, modelling the large low shear-wave velocity provinces (LLSVPs) observed on global seismic tomography maps. We focus on the influence of two key parameters that promote temperature increase within the piles of primordial material: the excess internal heating within these piles ; and the temperature-dependence of thermal conductivity. We quantify the size and amplitude of negative heat flux patches depending on these parameters. As one would expect, a larger internal heating excess and a stronger temperature dependence of thermal conductivity both favor the development of negative heat flux patches within piles of dense material. However, these parameters also alter the piles stability, such that there is no straightforward relationship between them and the size and amplitude of the negative heat flux patches. In particular, we find that the amplitude of the negative heat flux start decreasing again after some threshold value of the excess internal heating in piles. Finally, we discuss possible consequences of our findings for core dynamics and geodynamo.

Keywords:Mantle dynamics, Core-mantle boundary, Heat flux, Thermal conductivity

從光譜到熱史：紅外光譜技術在地質溫度重建中的新應用

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地質熱定年（Thermochronology）和地質溫度計在解析造山帶冷卻速率、地殼變動歷程及重建地球熱演化歷史方面，提供了關鍵的科學依據。傳統熱定年技術如核飛跡（Fission Track）與鏡煤素反射率（Vitrinite Reflectance），雖然可提供有用的溫度紀錄，但在應用上常受到樣本條件嚴苛、解析度不足與難以辨識多期熱事件等限制，特別是在沉積盆地與造山帶等熱歷史複雜的地區，往往無法精確還原其多階段的熱演化歷程。

為突破上述侷限，本研究提出一項結合顯微傅立葉轉換紅外光譜儀（micro-FTIR）的地質溫度計（IR Geothermometer）新技術。實驗系統採用 Linkam THMS600 加熱平台及 Bruker Hyperion Micro-FTIR 光譜儀，能在 30–600°C 範圍內以 1–10°C/min 的精確升溫速率進行實時監測。此方法結合連續升溫實驗與自動化數值分析，能即時偵測樣本中有機官能團隨溫度上升所產生的 IR 吸收率變動。實驗結果顯示，當樣本升溫至特定溫度時，會觀測到 IR 吸收面積的顯著變化，這些溫度正好反映出樣本過去所經歷的埋藏或變質溫度，進一步將吸收變化轉換為溫度曲線，便可辨識出樣本所經歷的多期熱事件，重建高解析度的熱歷史。經過與傳統地溫測量方法交叉驗證，這些 IR 地溫計測得溫度與已知地溫資料吻合，顯示其具高度的可信度與科學價值。

在應用層面，本研究開發的 IR 溫度計展現出在地質熱演化分析上的高度潛力。前處理與顯微技術的結合，使其可分析低有機含量樣本（如砂岩、頁岩與變質砂岩），加上 IR 光譜能快速取得高解析度數據，適用於地質溫度剖面與礦區初步調查等任務。此技術亦可作為熱定年的輔助工具，判別岩石是否曾超過礦物封存溫度，提升地質模型的可信度。此外在石油與天然氣勘探方面，透過監測樣本中 C–H、C=C、C=O 等官能團的 IR 吸收變化，可有效評估油母質成熟度，並補充或驗證傳統鏡煤素反射率指標。整體而言，本研究所發展的 IR 技術已從化學結構分析工具，發展為地質熱歷史與能源潛力解譯工具，具備對多階段熱事件的高靈敏度、快速辨識微量有機物的能力，以及在多種岩性中皆具良好適用性，未來可望成為地質、石油與材料科學等跨領域研究的關鍵技術。

中文關鍵詞：顯微傅立葉轉換紅外光譜、地質溫度計、熱歷史重建、油母質成熟度、油氣勘探

從光譜到熱史：紅外光譜技術在地質溫度重建中的新應用

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地質熱定年（Thermochronology）和地質溫度計在解析造山帶冷卻速率、地殼變動歷程及重建地球熱演化歷史方面，提供了關鍵的科學依據。傳統熱定年技術如核飛跡（Fission Track）與鏡煤素反射率（Vitrinite Reflectance），雖然可提供有用的溫度紀錄，但在應用上常受到樣本條件嚴苛、解析度不足與難以辨識多期熱事件等限制，特別是在沉積盆地與造山帶等熱歷史複雜的地區，往往無法精確還原其多階段的熱演化歷程。

為突破上述侷限，本研究提出一項結合顯微傅立葉轉換紅外光譜儀（micro-FTIR）的地質溫度計（IR Geothermometer）新技術。實驗系統採用 Linkam THMS600 加熱平台及 Bruker Hyperion Micro-FTIR 光譜儀，能在 30–600°C 範圍內以 1–10°C/min 的精確升溫速率進行實時監測。此方法結合連續升溫實驗與自動化數值分析，能即時偵測樣本中有機官能團隨溫度上升所產生的 IR 吸收率變動。實驗結果顯示，當樣本升溫至特定溫度時，會觀測到 IR 吸收面積的顯著變化，這些溫度正好反映出樣本過去所經歷的埋藏或變質溫度，進一步將吸收變化轉換為溫度曲線，便可辨識出樣本所經歷的多期熱事件，重建高解析度的熱歷史。經過與傳統地溫測量方法交叉驗證，這些 IR 地溫計測得溫度與已知地溫資料吻合，顯示其具高度的可信度與科學價值。

在應用層面，本研究開發的 IR 溫度計展現出在地質熱演化分析上的高度潛力。前處理與顯微技術的結合，使其可分析低有機含量樣本（如砂岩、頁岩與變質砂岩），加上 IR 光譜能快速取得高解析度數據，適用於地質溫度剖面與礦區初步調查等任務。此技術亦可作為熱定年的輔助工具，判別岩石是否曾超過礦物封存溫度，提升地質模型的可信度。此外在石油與天然氣勘探方面，透過監測樣本中 C–H、C=C、C=O 等官能團的 IR 吸收變化，可有效評估油母質成熟度，並補充或驗證傳統鏡煤素反射率指標。整體而言，本研究所發展的 IR 技術已從化學結構分析工具，發展為地質熱歷史與能源潛力解譯工具，具備對多階段熱事件的高靈敏度、快速辨識微量有機物的能力，以及在多種岩性中皆具良好適用性，未來可望成為地質、石油與材料科學等跨領域研究的關鍵技術。

中文關鍵詞：顯微傅立葉轉換紅外光譜、地質溫度計、熱歷史重建、油母質成熟度、油氣勘探

Seismic Risk Assessment for Taiwan Using Optimized Fragility Models: Insights from the 2016 Meinong and 2024 Hualien Earthquakes

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This study developed a high-resolution building exposure model and an optimized fragility model for seismic risk assessment in Taiwan, using the 2024 M_L 7.2 Hualien earthquake and 2016 M_L 6.6 Meinong earthquake as case studies for vulnerability validation, and subsequently established a Probabilistic Seismic Risk Assessment (PSRA) Model for Hualien. The exposure database was constructed using building footprints and tax data, providing detailed information on building locations, structural types, storeys, and construction ages. Fragility curves were adopted from the Global Earthquake Model taxonomy due to the lack of updated local data, and their applicability was validated through scenario assessments of recent earthquakes. To account for regional differences in building seismic performance, the models were further applied to Hualien and Tainan for cross-validation. Results show that applying the Hualien model to the Meinong earthquake slightly underestimates losses, indicating potential regional variability. For PSRA, we applied probabilistic seismic hazard models from the Taiwan Earthquake Model, along with optimal vulnerability models for Hualien and Tainan developed using historical earthquake simulations. Results indicate significantly higher seismic risk in Hualien City, likely to the active Milun Fault and dense urban development. Elevated risks were also observed in parts of the Longitudinal Valley, associated with active structures and relatively populated cities. The findings provide a valuable reference for earthquake risk management and policy-making in Taiwan.

Keywords:seismic risk, seismic design, building exposure database, vulnerability

MiDAS Vertical Arrays – Investigation and Observation

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Two seismic vertical arrays have been installed at the hanging wall and footwall of the Milun Fault, which caused the 2018 Hualien, Taiwan earthquake with a M_W of 6.4 and ruptured through downtown Hualien city. The Milun Fault is an active fault with a very short recurrence interval. To understand the local velocity structure, microtremor array measurements were adopted to investigate S-wave velocities at the two vertical array sites before drilling. Velocity logging was then used to measure P-wave velocities after drilling. Short-period, broadband, and strong motion sensors are equipment at the surface and at different depths in the two arrays. The measured V_S profiles are validated to be highly reliable using the observed ground motion data. The M_W 7.4 earthquake that occurred on April 3rd, 2024, was recorded by the two vertical arrays. The highest intensity was 6-strong at the site. Observed ground motion and nonlinear site amplification during this event are similar to the 2018 M_W 6.4 event. Uncertainties of the site-specific amplification factors (Φ_{lnAF}) at the sites are studied. The comparison with regional variabilities reveals possible regional differences in site amplification behavior.

Keywords:MiDAS, site amplification, vertical array

Using chemical composition of apatite to investigate the petrogenesis of the Bana igneous complex, western Cameroon

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Apatite [$Ca_{10}(PO_4)_6(OH,F,Cl)_2$] is a common accessory mineral in igneous rocks, capable of incorporating a wide range of elements. Its chemical composition is sensitive to magma composition, crystallization processes, element partitioning, and pressure-temperature conditions. Compared to whole-rock geochemistry, apatite composition provides additional insights into petrogenetic processes. Previous studies have used volatile components (OH, F, Cl), Sr, Mg, REE patterns, and trace element ratios of apatite to investigate magma evolution.

The Cameroon Line, central Africa is a sub-linear chain of volcanic fields and related intrusive complexes, presumably formed by magmatic activity along reactivated Pan-African faults. The Bana igneous complex includes volcanic rocks, plutonic rocks, and rocks abnormally rich in Fe, Ti and Al. Zircon U-Pb dating suggests formation of the complex involved incremental assembly of magmas over about three Myr in the Eocene (46.5 to 43.3 Ma).

This study is focused on apatite geochemistry of the Bana igneous complex. Apatite grains were separated from rock samples, and the grains were analyzed for major and trace elements by electron probe micro-analysis (EPMA) and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), respectively. All apatite grains are homogeneous in BSE images, mostly euhedral to subhedral, and many of them contain trapped inclusions. The newly obtained apatite compositional data will be combined with whole-rock major and trace element compositions determined by conventional X-ray fluorescence spectrometry and inductively coupled plasma-mass spectrometry (ICP-MS).

A total of 20 samples including granite, monzodiorite, monzonite, trachydacite, tuff, gneiss, and Fe-Ti-Al- rich rocks, were analyzed. Preliminary whole-rock geochemical data indicate that the silicate rocks have 53.0-72.6 wt% SiO_2, 0.02-1.29 wt% P_2O_5, and metaluminous to peraluminous compositions (ASI = 0.79-1.26). Yet, Fe-Ti-Al-rich samples have lower SiO_2 (31.5 and 41.9 wt%) but higher Fe_2O_3 (29.4 and 23.0 wt%), Al_2O_3 (26.7 and 24.2 wt%), and TiO_2 (6.41 and 2.21 wt%) contents.

Keywords:accessory mineral, geochemistry, element partitioning, volatile components, Fe-Ti-Al-rich rocks

Reconstructing Long-Term Tropical Cyclone Activity from Tree Rings: Insights and Interdisciplinary Perspectives

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Tree rings provide valuable records of past environmental processes, including disturbance events such as tropical cyclones (TCs), which are key drivers of forest dynamics. In the western North Pacific, changes in TC activity have been observed and are expected under future climate scenarios, but the direction and magnitude of these changes remain uncertain. East Asia, in particular, represents a region where both current and future TC impacts are of high scientific and societal relevance. However, instrumental records are too short to distinguish long-term natural variability from anthropogenic influence. High-resolution proxy records are essential for understanding TC variability over broader spatial and temporal scales. Tree-ring data offer unique potential to detect both individual events and their long-term impacts on forest growth, structure, and regeneration—factors crucial for understanding ecosystem resilience in a changing climate. In this talk, I will present dendrochronological approaches used to detect past disturbances, with an emphasis on methods applicable to TC reconstruction. I will also provide a global overview of forest disturbance agents as revealed by tree-ring datasets, followed by examples of studies using tree-ring data for the detection of TCs in East Asia and the southeastern United States. Finally, I will propose how integrating dendrochronological evidence with insights from climatology, ecology, and geosciences could advance our understanding of tropical cyclone dynamics and their long-term variability — offering promising directions for future interdisciplinary research.

Keywords:dendrochronology, typhoon, hurricane, proxy record

掬一把海中的眼淚－轉化浮石障礙為天賜恩典

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2021年8月日本小笠原群島海底火山爆發，噴發大量浮石。緊鄰北科大萬里校區附近有三座較為主要的漁港，該漁港及周邊海域不久之後都遭逢了此浮石的大自然災害。浮石散佈在港區及周邊時，對於漁船的推進器造成嚴重的損傷，影響漁船的出入。而當它們沖積在砂灘上時，對於景觀及砂灘遊憩，同樣有著嚴重的不良效益。海洋環境保護署雖然商請各相關縣市環保單位先治標性地盡量撈除，但是上百上千袋的浮石，卻成了另一惱人的海洋廢棄物，不知如何處理。

北科大團隊遂申請教育部第三期(112-114年)大學社會責任實踐計畫，計畫名稱為：漁村真本事－萬里野柳海岸地景保育與漁村文化永續。其中一項重點工作內容便是要視浮石為上天賜給我們的恩典資源，將其妥善應用，不僅可以解決環境問題，也可以達到資源利用之效。而此可以對應到『永續環境』議題，SDGs 14. 保育及永續利用海洋生態系，以確保生物多樣性並防止海洋環境劣化。

研究以田口方法進行規劃，將浮石當土壤改良劑，進行三種蔬菜等種植，與對照組進行生長情形比對，評估添加浮石對於植物生長的益處，結果顯示浮石確實能有效促進植物生長。浮石在農業中的應用有助於提高土壤結構性、通氣性和水分保持能力，從而增加農產品產量，並減少土壤侵蝕和土地退化的風險。此外，浮石也可用於過濾系統中，有益於去除水中的污染物，改善水質，降低水體的污染。此外，浮石的應用還可以減少水田中甲烷氣體的產生，有助于溫室氣體的減排。最後，浮石的使用可以創造或改善生態系統，提供野生動植物的棲息地，有益於保護生態多樣性，維護生態系統的穩定性。

本研究並完成計算浮石用於農業的環境效益與碳足跡分析，分析得出碳排值及環境衝擊值。數據顯示，自然取得的浮石與市售的培養土相比，浮石能創造更佳友善環境的價值。

中文關鍵詞：浮石、土壤改良劑、田口方法、社會責任

整合深度學習的即時微震監測系統

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建立即時且高解析度的地震目錄，對於瞭解地震序列發展過程及進行災害風險評估具有關鍵意義。本研究開發一套整合深度學習技術的即時微震監測系統，經測試及檢驗，確認透過該系統全自動化流程能快速提供可信的地震活動資訊。該系統主要資料處理流程包括：(1) 利用Seedlink接收來自中研院地球所及國震中心寬頻地震觀測網的連續波形資料，儲存並建成連續波形資料庫；(2) 透過以臺灣地震到時資料訓練的深度學習模型，判識及選取P波與S波到時並存成到時資料庫；(3) 根據監測區域選取適當地震測站組合，提取對應P波及S波到時進行地震事件關聯並定位，生成初步AI地震目錄；(4) 製作每日地震報告，透過電子郵件或LINE發送給相關人員。相較於現行的地震觀測網，本系統展現出在微震偵測解析能力與處理效率方面的優勢，特別適用於特定區域或需密集監測的場域，目前已建立三個即時微震監測系統：一、池上即時微震監測系統，觀測池上斷層滑移段及周圍地區的背景微震活動；二、花蓮地震即時微震監測系統，持續觀測2024M7.2花蓮地震餘震序列變化；三、嘉南即時微震監測系統，自2024年起嘉南地區陸續發生數個規模大於五的地震，因此於2025年初建立此系統，觀測該地區中大型地震的主餘震序列。即時微震監測系統可迅速提供地震活動的變化，並建立長期地震目錄，經進一步資料處理(例如絕對或相對重新定位)後的地震目錄，有助於後續地震地體構造解釋及其他地震參數研究，例如震源機制、地震規模、三維速度模型逆推等。綜合而言，本研究所提出之系統可作為現行地震觀測網的有效補強，顯著提升地震觀測的即時性與解析度。

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中文關鍵詞：即時微震監測系統、深度學習、自動化流程、地震目錄

小油坑步道噴氣孔移棲及其近地表熱液分布初步探查

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大屯火山群地區自1970年代起已進行多項研究，顯示其火山活動仍然持續，且具有再度噴發的潛勢。近半年來，研究團隊在小油坑地區已觀察到三次噴氣事件，並發現部分區域出現噴氣孔側向遷移，顯示淺層熱液系統可能正在發生變化。由於小油坑是熱門遊憩區，若發生熱液或蒸氣噴發，將對遊客安全構成威脅，因此監測熱液活動並勘查潛在噴發途徑實屬必要。

本研究於小油坑噴氣孔周圍區域設置兩條測線，採用高解析度地電阻影像法（Electrical Resistivity Tomography, ERT）進行連續觀測，定期獲取二維電阻率剖面。此方法對地層內含水區域、導電物質分布與構造變化具有高度敏感性，因此能有效監測熱液遷移所引發的電阻率變化，進而解析地下熱液活動及其對地層結構的影響。初步探查結果顯示，於2024年6月6日至7日，XP1測線水平距離0至20公尺處下方範圍之電阻率顯著升高，含水飽和度明顯下降，推測部分熱液發生氣化，氣體沿著該裂隙通道逸出至地表。從剖面分布來看，上部為低電阻率層、下部則呈現高電阻率區域，亦符合熱液作用形成的黏土蓋層下方存在氣體聚集的構造，因此推測此裂隙可能是當次噴氣活動的通道。此次事件觀測到與噴氣活動對應之電阻率異常，後續將持續監測。

此外，本研究亦觀察到降雨強度變化會影響噴氣活動的觀測性。降雨充沛時，地表入滲的水分有助於降低地下熱液溫度，會使高溫氣體易於冷凝而降低噴氣活動的劇烈程度，噴氣活動不易辨識。因此，未來在進行噴氣活動監測時，需同時將降雨事件納入考量，以更全面地了解降雨對地表與地下熱液動態的影響。

中文關鍵詞：地電阻影像法、小油坑、熱液活動、蒸氣噴發

Thermo-hydro-mechanical mechanisms in sandstone-derived fault gouges during simulated small-magnitude earthquakes from experiments and models

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Laboratory studies have shown that faults undergo dynamic weakening during large displacements (>1 m) at seismic slip velocities (>0.1 m/s). However, the role of this weakening in small-displacement induced earthquakes (M 3–4), such as those in the Groningen Gas Field (the Netherlands), remains unclear. We conducted seismic slip-pulse experiments on Slochteren sandstone gouges, from the gas reservoir, using a rotary-shear apparatus to provide decimeter-scale constraints on the dynamic fault slip of quartz-rich gouges. Pre-sheared gouge layers, confined between ~1.5 mm thick sandstone host blocks, were subjected to slip pulses under initial effective normal stresses of 4.9–16.6 MPa and pore fluid pressures of 0.1 and 1 MPa under undrained conditions. The experiments reached peak velocities of 1.8 m/s, accelerations up to 42 m/s², and displacements of 7.5–15 cm, using either dry Argon or water as pore fluid at ambient temperatures. Our results show that water-saturated gouges weaken rapidly from a peak friction of ~0.7 to ~0.3, accompanied by early fast dilatancy followed by slower dilation, with minimal dependence on normal stress, slip acceleration, or displacement. In contrast, Argon-filled samples showed only minor weakening. Microstructural analysis reveals no systematic relationship between the width of the principal slip zone (PSZ) and frictional work or power input densities, indicating that wear or heat production alone does not control PSZ growth. Instead, thermo-hydro-mechanical modeling suggests thermal pore fluid pressurization, potentially involving water phase transitions at asperity scales, drives weakening in short-displacement, induced seismic events.

Keywords:Fault zone rheology, Friction, Microstructures, Permeability and porosity, Induced seismicity

Monsoon systems: variability, processes, predictability, change and extremes

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The Asian summer monsoon (ASM) is a distinctive component of the Asian climate system due to orographic forcing. One of the main challenges to study ASM is the extensive domain of the ASM encompassing tropics, subtropics and midlatitudes and thus the complex space and time structures making it difficult to quantify the ASM variability. Despite the challenges, studying the evolution of ASM over hundreds or thousands of years is essential to build a comprehensive understanding on the monsoon behaviors and their associations with the general circulations. Many previous studies used geochemical proxy records from oceanic sedimentary or continental archives to reconstruct paleo-ASM indices by depending mostly on rainfall information retrieved from the records at some sporadic sites. The geochemical methods are valuable but still face inevitable issues in spatial coverage and the limited explanatory power for the overall ASM. In this study, we present a novel approach to reconstruct an ASM index from 1 degree x 1 degree latitude/longitude rainfall data reconstructed from historical Chinese documents in the REACHES (Reconstructed East Asian Climate Historical Encoded Series) database (Wang et al., 2018). First, the current observational Western North Pacific monsoon index (Wang et al. 2008, in Journal of the Climate) approach was used to calculate the wind fields (zonal and meridional winds at 850hPA) from 1950 to 2020 using ERA5 data and rainfall data from NOAA Precipitation Reconstruction over Land to construct the modern ASM index. Then, the ASM rainfall pattern was projected to the gridded REACHES rainfall data from 1368 to 1911CE. Thus, the reconstructed REACHES-ASM index is considered by both temporal and spatial variability. In addition, the linkage of REACHES-ASM index and extreme events such as flood and drought were examined. Therefore, the indication of the dominate large-circulation is able to be investigated through the multidecadal to centennial time scale.

Keywords:monsoon, summer, REACHES, rainfall

臺灣海域孕震構造之位置與滑移速率

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摘要

臺灣地區地震頻繁，若能掌握孕震構造的位置、發震規模與滑移速率，將可用於地震危害度模型的計算並降低災害損失。然而，由於海域地質調查不易，加上長期以來臺灣孕震構造研究多聚焦於陸域，使得外海構造與參數缺乏而形成評估盲區。為此，本研究整合已發表的震測剖面與海底地形資料，藉由分析不連續反射訊號是否延伸至海床，以及海床線型的側向延續性，辨識出臺灣海域54條孕震構造的位置。

透過地下構造截切關係與背景地震深度分布重建構造幾何，並可以利用三種經驗公式估計發震規模。在考慮海陸構造聯合破裂的情況下，所有海域構造皆有能力產生規模6.5以上的地震。本研究進一步根據構造運動型態及不同地質狀況下的假設，利用指準層變形速率以及構造兩側塊體的相對運動速率等方式，估算海域構造的長期滑移速率。計算結果顯示，琉球隱沒系統上盤與臺灣東部外海的構造活動速率較高，即使考慮無震潛移現象，其長期應力累積速率仍可能超過 15 mm/yr，地震再現週期小於1000年。其他海域的構造活動性則相對較低，滑移速率多小於 5 mm/yr，對應的再現週期多數大於6000年。

海域構造的滑移速率值是臺灣構造研究首次提出的重要資訊，若將外海與陸域構造在板塊運動方向上的水平速率相加，其總和與區域板塊縮短速率相符，進一步驗證本研究計算結果的可靠性。而滑移速率的空間分布也符合臺灣各區域的地質背景，例如相對穩定的臺灣海峽與北部外海的構造活動性較低；而東部外海構造活動速率較高且由南往北增加，此趨勢可能反映臺灣島的造山過程。

本研究建立的海域孕震構造位置與其滑移速率資料庫，不僅可補足臺灣現行地震危害度評估在外海構造上的欠缺，也為海洋資源開發與近海工程選址提供科學依據，此成果更有助於促進臺灣的地震科學研究朝向海洋發展。

中文關鍵詞：孕震構造、地震災害、地震規模、長期滑移速率、地震再現週期

The Role of Liquid and Vapor Water on the Fault Frictional properties in the Krafla Geothermal Field (Iceland)

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Understanding fault frictional properties is critical for the safe exploitation of geothermal energy. In this study, we investigate the role of hydrothermal fluids on the frictional properties of faults in a volcanic geothermal system at Krafla (Iceland). Our simulated fault gouges are derived from the drill cuttings in well IDDP-1 and include (1) altered basalt (e.g., chlorite, chlorite-epidote, epidote-actinolite), (2) poorly-altered basalt, (3) granophyre, and (4) rhyolite. All laboratory friction experiments are performed at sub-seismic slip rates (V) under realistic water temperature and pressure conditions, simulating the upper reservoir at <1 km depth (170˚C liquid water) and the lower reservoir at 1-2 km depth (300˚C liquid and 330-350˚C vapor water). Mechanical data show that gouges sheared under upper reservoir conditions exhibit stable sliding but with velocity-weakening behavior and low frictional healing. In contrast, gouges sheared under lower reservoir conditions always show stick-slip behavior with high frictional healing. Furthermore, the measured stress drops are significantly larger in liquid water than in vapor water, with the effect of liquid water on stress drop being more pronounced at effective normal stresses of 30-50 MPa. Our results agree with the seismological observations in Krafla and imply that both temperature and the physical states of water should be considered when interpreting seismicity in geothermal fields. To conclude, our results suggest that the re-injection of liquid water into deep geothermal reservoirs should be done cautiously, as the vapor-to-liquid transition could induce fault frictional instability.

Keywords:friction, hydrothermal fluids, geothermal system, seismicity

Near-real-time assessment of the ML6.4 Dapu earthquake-induced landslides

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Rapid assessment of potential landslides in regions of risk and their associated impacts following an earthquake is needed to provide crucial information to guide emergency responses. After the 2025 M6.4 Dapu earthquake in southern Taiwan, we applied a combined analysis of Newmark displacement and a decision tree model to rapidly identify slopes with a high potential for failure. Then, the coseismic landslide inventory taken in the weeks following the Dapu earthquake was compiled from satellite images in conjunction with field photographs. In total, 45 landslides were identified. According to the available near-real-time earthquake shaking proxies and landslide inventories, most landslides occurred within the 250 gal, 15 cm/s and 0.3 cm contour lines of earthquake shaking associated with peak ground acceleration (PGA), peak ground velocity (PGV) and peak vertical displacement of 3-s P waves (Pd3), respectively. In addition, we found that a peak vertical displacement (Pd) larger than 0.3 cm is a good indicator for identifying coseismic landslides and can provide sufficient lead times (LTs) of 3–5 s for emergency response. Our work can serve as a basis for advancing conventional susceptibility assessment after an earthquake occurrence to achieve a coseismic landslide early warning (CoLEW) system.

Keywords:Coseismic landslide, Lead time, Coseismic landslide early warning

潛在大規模崩塌地形特徵與關注場址活動度之評估與統計

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利用光達地形判釋大量潛在大規模崩塌，但為了有效管理與分配調查優先順序，須以地形地貌分析後分級分類，篩選出高崩塌潛勢和致災風險之場址。目前完成1,261處崩塌地形特徵分級表(LTFGF)評估，特徵項目包含崩崖、滑動體、兩側邊界、滑動體前緣坡型、潛勢區趾部、冠部與河岸侵蝕情形，並依總分高低區分為四個等級，A、B級分別6處與96處，C級為763處，D級為396處。依據評分分布、地理區域、攻擊岸與否、地層與岩性等統計評分，結果顯示，最多與最少被評為最高分的項目分別為滑動體和滑動體前緣坡型，反之，最多與最少被評為最低分的項目分別為河岸侵蝕情形和兩側邊界。以行政區域分布統計可知，雲嘉地區與高雄市統計結果非常接近且兩區域皆有較高總分平均值(約50分)，而臺中市與南投縣較低(約45分)，新北基桃地區為最低之區域(約40分)，應受到長期降雨與地震作用所影響。再者，河岸侵蝕為地形演育中一個長期且具有顯著影響之作用，故被評為A、B級之攻擊岸與非攻擊岸案例分別為21%和3.6%；反之，D級之攻擊岸與非攻擊岸案例分別為5.9%和40.2%。最後，以不同岩性類別進行統計發現，中新世砂岩(觀音山砂岩、糖恩山砂岩、深坑砂岩)為主之案例有最高之平均總分，反之，最低平均總分為上新世與更新世沉積岩(卓蘭層與頭嵙山層，含一處凝灰角礫岩)，岩性與膠結程度影響材料強度和抗侵蝕能力，故對地形特徵有影響。

進一步對A級與關注場址，利用潛在大規模崩塌活動度評分表(PLAAF)依據破壞機制(重力邊坡變形(GSD)、弧形滑動(RS)、平面滑動(PS)與巨厚崩積層(TC))分類，並評估活動度(量化指標：關鍵不利穩定因素、歷史崩塌數量、裸露面積比例、滑動體應變)為高、中、低。GSD、RS、PS、TC案例數量為13、11、9、7，其高活動度案例分別為5、1、1、3處。TC為量化數量較高之類型，而PS則皆為數量最低，故最大與最小平均活動度為TC和PS。最終，LTFGF與PLAAF之評分結果大致呈正比，雖偶有例外案例仍須謹慎評估，本研究可有效篩選高崩塌潛勢和致災風險之場址。

中文關鍵詞：潛在大規模崩塌、分級分類、地形特徵、破壞機制、活動度

地電阻影像法應用於地下水污染場址之回顧與展望

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多波道形式的地電阻影像法儀器研發於1985年，加速了二維及三維地層電性資料的取得，使地電阻影像法更具備快速描繪地層電性影像的優勢，成為淺層地球物理探勘技術最常使用的方法之一。台灣於1990年代引進多波道地電阻設備，初期主要研究地層與地質構造；而當時，美國太平洋瓦電公司，以及國內RCA與南崁漏油等重大污染事件陸續揭發，使得學術界更重視土壤及地下水污染的影響，也是應用地球物理探勘技術協助解決土壤及地下水污染問題的開端，國內應用地電阻影像法於地下水污染場址的啟蒙者正是先師　楊潔豪教授。

本研究回顧若干個地電阻影像法應於地下水污染之案例，首先探討在調查面上訊號判釋的學習經驗，接續討論在地下水整治時如何擴大使用跨孔地電阻影像法監測與時序分析評估整治藥劑流布，進而提高整治成效。現今跨孔地電阻影像法發展也已相當成熟，國際已有用應用於碳封存模場之經驗，本研究最後將研析應用跨孔地電阻影像法在碳封存場址的預期效益，並提出執行面上可能面臨的問題以及必要的措施與投資，期待與會的先進共同討論，提出建言。學生同時以此研究感念恩師　楊潔豪教授。

中文關鍵詞：地電阻、污染、地下水、碳封存、CCS

A multi-proxy lacustrine record of late Holocene climatic variability from north India

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In spite of dedicated efforts to reconstruct the past variability in the strength of Indian Summer Monsoon (ISM), that is the rainfall intensity, a complete picture of the ISM variability and its forcing mechanisms remains elusive mainly because of large spatial inhomogeneity of the ISM precipitation. The Ganga Plain, which ranks among the world's most densely populated areas, and is well-known for its agricultural fertility and habitats for humans since early days, remains less explored in terms of paleoclimatic conditions. We conducted a multi-proxy (grain size, major elements geochemistry, clay mineralogy, and stable carbon ($\delta^{13}C$) isotope compositions of organic matter) study of the sediments from an AMS radiocarbon-dated mid-late Holocene trench from the Salona Tal (lake) in the Central Ganga Plain, India to quantify the changes in monsoonal precipitation. Temporal variabilities in our results suggest intense ISM precipitation during ~5 ka to ~4 ka, which was followed by continuous weakening of ISM precipitation until ~2 ka. After that, an amelioration of ISM precipitation occurred towards modern-day conditions.

Keywords:ISM precipitation, Lake sediments , Sediment geochemistry, Grain size, Ganga plain

Enhanced Kuroshio influence during ~1.9–1.5 Ma revealed by well-preserved planktonic foraminiferal assemblages and geochemical evidence from the Gutingkeng Formation in Kaohsiung City, Taiwan

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Global temperatures during the Late Pliocene to Early Pleistocene were ~3°C higher than pre-industrial levels, this period provides a valuable potential analog for future climate scenarios. The zonal sea surface temperature (SST) gradient across the equatorial Pacific and the depth of the thermocline plays a crucial role in controlling the mean climate state and variability. Previous studies reveal the development of the modern east-west SST gradient in the equatorial Pacific reached a modern-like gradient by 1.8-1.2 million years ago (Ma). The Gutingkeng Formation, consists of marine dark gray mudstone with interbedded thin sandstone layers in southwestern Taiwan , making it an ideal location for understanding how long-term El Niño-like condition which may impact Taiwan. We collected mudstone samples from the Gutingkeng Formation and selected *Globigerinoides ruber* and *Neogloboquadrina dutertrei* to conduct $\delta^{13}C$, $\delta^{18}O$ and Mg/Ca ratios analyses for reconstructing sea surface and thermocline temperatures. Results indicate that from ~1.9-0.5 Ma, surface and thermocline water temperatures at the study site were around 25.5 and 18.1 ºC, comparable to the modern conditions. The relative abundance of surface species shows a steady increase between 1.9 and 1.1 Ma, while subsurface species show two peaks in abundance during 1.9-1.5 Ma. These findings suggest that as the east-west SST gradient in the equatorial Pacific increased, the Kuroshio Current also intensified, resulting in greater heat transport toward high latitudes.

Keywords:Gutingkeng Mud Rock Formation, Planktonic foraminifera, Stable isotopes, Mg/Ca ratios

Surface condition of the middle Pliocene warm period in the southwestern equatorial Pacific Ocean

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In this study, we present bimillennial-resolved reconstructions of surface temperature and hydroclimate variability from the southwestern margin of the Western Pacific Warm Pool, spanning 3.23 to 3.06 million years ago (Ma). The data are based on geochemical-proxy analyses of planktonic foraminifera *Globigerinoides ruber* and *Trilobatus sacculifer* from ODP Hole 1115B (9°11'S, 151°34'E; water depth 1149 m). Temperatures reconstructed from *G. ruber* Mg/Ca ratios range from 26.8 to 29.5 °C, consistently warmer than those derived from *T. sacculifer* (24.3 to 27.4 °C) . Both temperature records indicate a notable ~2°C cooling event during Marine Isotope Stage (MIS) KM2 (~3.15–3.12 Ma), suggesting glacial influence. Seawater oxygen isotope ($\delta^{18}O_{sw}$) values derived from both mixed-layer species display similar trends and magnitudes, consistent with their present-day ecological preferences. The long-term decline in $\delta^{13}C$ values observed in both species, reaching a minimum during MIS KM2, may reflect reduced nutrient utilization and increased surface nutrient availability. This interpretation is supported by stable $\delta^{13}C$ values from deep thermocline-dwelling species, indicating minimal change at depth. When comparing this mid-Pliocene warm period (mPWP) to Quaternary interglacials, the reconstructed sea surface temperatures are comparable to Holocene levels, but remain lower than those observed during super-interglacials (e.g., MIS 5e, 11c, 31).

Keywords:Equatorial Pacific Ocean, mid-Pliocene warm period, Planktonic foraminifera, Mg/Ca ratios

Systematic comparison of sinking velocities between Globigerinoidesella fistulosa and Trilobatus sacculifer using 3D models generated from μ-computed X-ray tomography

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Globigerinoidesella fistulosa, a short-lived planktonic foraminifera found in tropical regions, is believed to have evolved from the stable Miocene species *Trilobatus sacculifer*. Previous research suggests that as vertical ocean temperature gradients weakened and seawater viscosity decreased during the Pliocene, foraminifera had to adjust their morphology—particularly shell size and sinking rates—to maintain stable Reynolds numbers, potentially contributing to the extinction of certain species.

In this study, we reconstructed 3D models of fossil shells using μ-computed X-ray tomography at TPS 31A beamline of National Synchrotron Radiation Research Center, Taiwan and created adjustable replicas via 3D printing. Sinking experiments at different temperatures (19, 21, 24, and 27 ^{o}C) and shell sizes (~2-6 cm) were conducted to assess how various morphologies influence drag and behavior in the water column. Results suggest that *T. sacculifer* evolved larger morphologies under warmer, less viscous seawater, while *G. fistulosa* developed finger-like projections that increased drag without adding excessive mass. These adaptations may have allowed it to maintain a favorable sinking rate under low-viscosity conditions. However, as the east–west sea surface temperature gradient increased and sub-surface waters cooled, higher viscosity likely reduced the effectiveness of this morphology. This shift may have made the finger-like structure less adaptive, contributing to the eventual extinction of *G. fistulosa* and reflecting the ecological consequences of long-term climate change.

Keywords:Planktonic foraminifera, X-ray tomography, 3D model

Extreme environmental conditions revealed by the benthic foraminifer Allinatina variabilis in a Holocene lagoon system in Tainan City, Taiwan

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This study examines sediment cores collected from the former Tainan Taijiang Inland Sea and the adjacent Qigu Lagoon region—areas that now correspond to the present-day Tainan Science Park. By conducting foraminiferal counts, trace metal analyses, SEM picture and μ-computed X-ray tomography images, we aim to assess how Holocene environment and ecological interactions in this region. Results from Core 690 indicate that sediments at a depth of approximately 2,000 cm contain exclusively reworked foraminifera, suggesting a high sediment supply from riverine sources during deposition. In contrast, Core 691 reveals that around 4,000 years ago, the site likely represented a nearly desiccated lagoon. These findings suggest that the modern location of Tainan Science Park may have complicated interactions of lagoon and dynamics river systems during the middle to late Holocene. Notably, Core 691 is dominated (>95%) by a single benthic foraminiferal species, *Alliatina variabilis*, pointing to an unusual ecological setting. High Mg/Ca (>20 mmol/mol) ratios suggest elevated salinity, likely driven by regional uplift and a halt in sea-level rise, which led to lagoon contraction and near-desiccation. Additional SEM imagery and 3D structural data further highlight the unique morphology of *A. variabilis*, supporting the interpretation of an exceptional paleoenvironmental condition.

Keywords:Benthic foraminifera, Extrem environment, Holocene

Mechanical properties of the formation rocks at the enhanced geothermal system in Yuanshan, northeastern Taiwan

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Enhanced Geothermal System (EGS) is a promising renewable energy option in Taiwan. However, fluid injection may raise pore pressure, lower effective stress, and potentially induce seismicity. Understanding mechanical properties of the reservoir rocks thus is essential in evaluating potential seismic risks. Since 2024, the Yuanshan geothermal pilot hole (Y-1) in Yilan County has been operating for EGS exploration. This study focuses on obtaining mechanical properties of the formation rocks expected along the pilot hole path. Rock specimens were prepared from outcrop samples or whole-round cores recovered from the Hongchailin boreholes, including HCL-1 and HCL-2. Conventional triaxial compression tests were conducted on four formations: Kankou (KK), Szeleng Sandstone (SL), Hsitsun (HS), and Chungling (CL). Tests were performed at confining pressures (Pc) from 0 to 15 MPa and at room temperature or 150°C. To evaluate effects of pore pressure (Pp), an additional test was performed at Pp of 5 MPa and Pc of 10 MPa. Results show that KK has the weakest peak strength of 148 MPa and exhibits Young's modulus (E) of 15-35 GPa and Poisson's ratio (ν) of 0.34-0.38. SL and HS show similar peak strengths of 276 MPa and 274 MPa, respectively, at Pc of 10 MPa and Pp of 5 MPa. SL has E of 30–70 GPa and ν of 0.3–0.45. The averaged values of friction coefficient of KK and SL are 0.65 and 0.86, respectively, which reside in the Byerlee level. Our analysis indicates that orientations of cleavages may affect the mechanical properties. We will further investigate the effects of intrinsic structures on mechanical behaviors for EGS explorations.

Keywords:Enhanced Geothermal System, triaxial compression test, Yilan geothermal energy, mechanical behaviors

The Yuli-belt-rock-bearing Milun fault and its implication for local structural evolution

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The 2018 Hualien earthquake (Mw 6.4) triggered the Milun Fault, but the lack of outcrop of the Milun Fault limits our understanding of fault mechanics and hazard assessment. The Milun Fault Drilling and All-inclusive Sensing project (MiDAS) penetrated the Milun Fault Zone. The fault zone exhibits an asymmetric structure, characterized by 29-m-thick altered spotted schist and non-cohesive serpentinite in the damage zone, and 20-m-thick foliated grey to black gouges in the fault core. While the fault core samples were characterized in detail, the origin of both altered spotted schist and non-cohesive serpentinite and associated alteration processes remain unclear. We conducted XRD, Raman spectroscope, and XRF analyses to characterize the borehole samples. Our results show that the unaltered serpentinite fragments contain antigorite, talc, chlorite, magnesite, epidote, clinozoisite, actinolite, and nephrite, similar to the non-cohesive serpentinite. Chemical characteristics as a result of serpentinite to nephrite transformation and fluid-rock interaction of serpentinite are complex and need to be discussed carefully. Overall, this suggests that fluid-rock interactions occurred that reduced the cohesion of the rocks. Based on the rock assemblages, which are similar to the outcrop in the Fengtian area of Hualien, we suggest that the Milun fault is made by Yuli belt rocks. However, the outcrop of the Yuli belt is located about 23 kilometers to the south of the study area. We suggest that the development of a "Christmas tree" structure may be a possible explanation for the uplift of the Yuli belt in this area, although direct evidence remains limited. More evidence is needed.

Keywords:MiDAS, Milun Fault, Yult belt, fluid–rock interaction

臺灣西南部泥火山有機地球化學特徵及潛在噴發行為探討

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泥火山是沉積盆地、聚合邊緣和隱沒帶深層物質向上遷移的重要途徑，亦是甲烷排放的主要通道之一，可指示地下潛在的油氣藏，常伴生在斷層或褶皺軸附近。 本研究聚焦於臺灣西南部泥火山，涵蓋範圍包括:古亭坑背斜區、旗山斷層帶及海岸平原區三個代表性區域。有鑑於泥火山流體中之有機物組成、來源、成熟度及其與噴發行為的關聯性仍未獲充分理解，本研究以有機地球化學之角度與時序觀測數據，利用氣相層析質譜儀（GC-MS）進行飽和烴、芳香烴及生物指標鑑識，目的在於建立臺灣西南部泥火山之有機地球化學特徵，闡述與噴發行為間的關聯性和地質意義。

研究結果顯示:(1)有機物來源研究結果指出古亭坑背斜區之烷烴分布呈現雙峰分布（C_{11}-C_{19}/C_{20}-C_{33}）具混合來源特徵，海岸平原區則以輕質成份為主導（C_{12}-C_{15}），由類異戊二烯（Isoprenoids)之Pr/C_{17}與Ph/C_{18}分析結果得知古亭坑背斜區泥火山以Type II/III混合型有機物為主;旗山斷層帶泥火山以Type II有機物類型為主;海岸平原區泥火山則以Type II/III混合型有機物為主。(2)成熟度時空變異性研究結果顯示，所有泥火山之有機物皆屬於成熟階段，其成熟度依序由高至低為旗山斷層帶、海岸平原區與古亭坑背斜區泥火山，值得注意的是，小滾水泥火山自 2023/01起MPI-1值增加37%，反映深部高成熟有機物輸入，這也與飽和烴的分析結果相符，證實泥火山有機物來源在時空上具有顯著時空變異。(3)噴發行為之探討:各泥火山樣品呈現顯著差異之烷烴分布，其中以較輕有機物主導者多見於停止或不活躍噴發狀態，而以較重有機物主導者則與穩定噴發狀態相關，旗山斷層帶C_{30} $\beta\alpha$/C_{30} αβ hopane比值（0.23-0.30）顯著低於海岸平原區（0.30-0.36），指示深部流體遷移路徑差異。

本研究成果不僅有助於釐清臺灣西南部各區域泥火山之有機質來源與成熟度資訊，亦為深入理解泥火山系統中流體遷移機制提供了重要依據。未來研究將結合有機與無機地球化學數據，建立泥火山流體來源、遷移路徑與噴發行為之關聯模型，進一步為區域油氣資源評估提供科學依據。

中文關鍵詞：生物指標、泥火山、有機物來源、成熟度、氣相層析質譜儀

Microbial Biodegradation and Nanomaterial-Based Oil Removal Strategies for Marine Oil Spill Remediation

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Marine oil spills pose severe ecological and economic challenges, necessitating effective remediation strategies. This study explores the interplay between microbial diversity shifts and oil degradation efficiency in marine ecosystems following oil spills. Through next-generation sequencing (NGS), we analyzed microbial community responses to hydrocarbon contamination in a heavily polluted coastal region. Our findings reveal that indigenous bacteria, particularly Staphylococcus saprophyticus and Bacillus megaterium, significantly contribute to the biodegradation of hydrocarbons, including unresolved complex mixtures (UCMs). Additionally, we evaluated an innovative green-technology approach using hydrophobic crystalline calcite nanoparticles for oil-water separation. The synthesized calcite exhibited near-superhydrophobicity and demonstrated rapid and efficient oil adsorption, with over 99% removal efficiency. The results suggest a dual strategy of bioremediation and advanced nanomaterials as a sustainable and cost-effective approach to mitigate oil spill contamination. This study underscores the importance of integrating microbial ecology with engineered materials for enhanced environmental recovery.

Keywords:Marine oil spill, Microbial biodegradation, Hydrocarbon removal, Nanomaterial adsorption, Environmental remediation

應用分類分級方法評定潛在大規模崩塌之潛勢分級與活動性

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經濟部地質調查及礦業管理中心(以下稱地礦中心)過去已判釋出全臺2500處潛在大規模崩塌，但缺乏合適之分類分級標準，有鑑於此，本研究綜整日本地滑學會及挪威地質調查所之方法，針對本土潛在大規模崩塌進行分類分級方法學之研擬。

目前本研究已建立適用於潛在大規模崩塌之崩塌地形特徵分級表(後稱Level 1表格)，利用各項崩塌地形特徵進行評分並給予相對應之潛勢分級(A級：100至85分、B：84至70分、C：69至40分、D：39至0分)。截至目前已完成1261處Level 1表格實作，若分級屬於A與B級者，則為本研究擬定需進一步分析與關注之潛在大規模崩塌，故需填寫潛在大規模崩塌活動度評分表(後稱Level 2表格)。Level 2表格主要參考Varnes(1978)與Hungr et al.(2014)所提出之崩塌機制，將潛在大規模崩塌分成四種類型：重力邊坡變形、弧形滑動、平面滑動及巨厚崩積層，再依據不同類型設計相對應之不利穩定特徵項目給予評分，並以可量化之活動度評估項目，如歷史崩塌數量累積、裸露面積佔比及滑動體位移量等，以綜合評估潛在大規模崩塌之活動度。

本研究亦繪製由Level 1表格至Level 2表格之完整填表流程圖，並建立Level 1表格填表之標準作業程序，以清楚描述潛在大規模崩塌之潛勢分級與活動度評估之整體概念。亦選定Level 1表格評分為B級之潛在大規模崩塌做為示範案例，詳細說明Level 1表格填表標準作業程序之操作方式，與不同崩塌特徵項目之評分在光達陰影圖上所對應之樣貌，並接續填寫Level 2表格，以評估此潛在大規模崩塌之活動度。期本研究所建置之潛在大規模崩塌分類分級資料庫，能夠提供予相關單位進行防災策略規劃，以及作為山崩與地滑地質敏感區劃設及修正之參考依據。

中文關鍵詞：潛在大規模崩塌、分類分級、潛勢分級、活動度評估

Geochemistry and geochronology of middle Paleozoic-early Mesozoic granite in the southern Truong Son terrane, central Vietnam

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The Truong Son terrane in central Vietnam is a key geological structure within Indochina block, delineated by a series of northwest-southeast trending folds, thrusts, and shear zones. The southern part of the terrane is bounded by the Dai Loc - Khe Sanh shear zone to the north, Tam Ky - Phuoc Son suture zone to the south, and the Poko suture zone to the west. The U-Pb dating results of granitic rocks collected in this region yield ages of 428 Ma, 416 Ma, 296 Ma, 255 Ma, and 240 Ma, demonstrating that the southern part of the Truong Son terrane preserves evidence of both the evolution of a Paleo-Tethys Ocean and Indosinian Orogeny during the middle Paleozoic to early Mesozoic. Geochemically, these rocks can be classified into two groups: (1) collisional-related granites, including 428 Ma, 296 Ma and 255 Ma samples and (2) post-collisional granites comprising of 416 Ma and 240 Ma samples. The collisional-related granites are characterized by metaluminous to peraluminous compositions, magnesian to ferroan affinities, calcic to alkali-calcic, medium to high potassium contents, and are interpreted to have been derived from pelitic crustal melting mixed with minor leucosome triggered by post-orogenic slab failure, while the post-collisional granites exhibit peraluminous, ferroan, calc-alkalic to alkali-calcic and high in potassium contents, suggesting formation through crustal partial melting under low-pressure conditions in an orogenic setting. Specifically, the Silurian (428 Ma) and Devonian (416 Ma) granites are attributed to the northwest-directed subduction of the Tam Ky - Phuoc Son branch of the Paleo-Tethys Ocean beneath the Truong Son terrane; the Early Permian (296 Ma) granites associated with the continued oceanic subduction; the Late Permian (255 Ma) granites are linked to the closure of the Tam Ky - Phuoc Son Ocean, marking the onset of subduction-collision process during the Indosinian Orogeny; and the Middle Triassic (240 Ma) granites were generated during the widespread appearance of the Indosinian magmatism across the Indochina block.

Keywords:Truong Son terrane, collisional granite, post-collisional granite, U-Pb dating, Indosinian Orogeny, Paleo-Tethys Ocean

七星山火山爆裂口火山岩岩心之岩象與地球化學研究

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大屯火山群位於臺灣北部火山活動帶，近年來被認為是活火山，根據前人定年研究得知，大屯火山群中的七星山亞群與磺嘴山亞群皆為最年輕的火山亞群之一。在七星山小油坑周邊，東西兩側各有一條明顯由的數個火山爆裂口所組成的線性爆裂帶，前人研究認為其為蒸氣噴發的結果。東側爆裂口在前人研究中已進行了岩象學與全岩地球化學分析，本研究針對七星山亞群西側爆裂口之鴨池和金露天宮兩地進行鑽井，並選取新鮮火山熔岩流樣本，進行岩象、地球化學與年代學的分析，並將分析結果與東側爆裂口之樣本進行比對，以期了解大屯火山群近期噴發區域之火山熔岩或岩漿通道中火成岩的組成，嘗試推論大屯火山岩漿行為。

本研究自鴨池和金露天宮不同深度之岩心熔岩流樣本採樣，進行岩象學、全岩地球化學、鍶釹同位素分析以及Ar-Ar定年分析。薄片觀察結果：東西兩側爆裂口樣本礦物組成比例相當類似。西側之鴨池和金露天宮樣本，斑晶和基質的比例以及礦物組成沒有深度上的垂直變化，且皆有礦物破裂情形、其可能為岩漿上升時快速減壓所造成。另外斜長石與角閃石分別出現resorption zone和volumetric decomposition構造，其可能為岩漿上升過程中減壓、增溫或有不同的岩漿成分摻入時造成。根據全岩地球化學、鍶釹同位素分析和Ar-Ar定年結果得知，東西側樣本為安山岩，岩漿為中鉀鈣鹼性岩漿；微量元素有輕稀土元素富集之狀況，蛛網圖顯示了大離子親石元素富集和ＴＮＴ虧損狀況，為島弧岩漿特徵；而樣本鍶釹同位素值集中，表東西兩側樣本成份均一，且在七星山亞群中較偏向原始岩漿成分，較少地殼物質混染；根據Ar-Ar定年結果，七星山樣本近期噴發年代為約為12至14Ka。

中文關鍵詞：大屯火山群、岩心、岩象學、地球化學、氬氬定年

2D Stratigraphic Forward Modeling – Methodologies and Applications

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In carbon capture and storage (CCS) projects, building a geological model based solely on sparse well data and traditional geostatistics property modeling methods can lead to significant uncertainties. To mitigate these uncertainties, 2D Stratigraph Forward Modeling using the Geological Process Modeling (GPM) module in Petrel offers a powerful predictive approach. GPM enables simulations of sedimentary processes and geological formations, providing critical insights into sediment distribution for characterization of potential carbon storage sites.

This study presents a structured methodology for 2D Stratigraphic Forward Modeling, including:
1. Establishing the geological age of the formation.
2. Analyzing depositional environments and sequence stratigraphy based on well and seismic data.

3. Creating paleo-topographic models of depositional surfaces.
4. Defining sediment diffusion parameters.
5. Performing iterative simulation runs and validating outcomes against existing well and seismic data, followed by model adjustments as necessary.

The results generated through this method can facilitate constructing 3D geological models by providing characterizations of lithology distribution. An example application using the public dataset demonstrates the efficacy and practical application of 2D Stratigraphic Forward Modeling, highlighting its capability in accurately delineating lithological variations within two-dimensional geological frameworks.

Keywords:Stratigraphic forward modeling, Carbon capture and storage, CCS, Petrel, Geological model

P-T condition study of dynamic recrystallization during shear zone mylonitization using quartz microstructural analysis: a case study of Hoping mylonite, northeastern Taiwan

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Crustal strength plays an essential role of manipulating deformation mechanisms, deformation behavior, such as brittle faulting and ductile mylonitization. During shear zone development, dislocation creep is one of deformation mechanisms with specific differential stress, temperature, and strain rate, which can give insights into evaluating the crustal strength conditions. The backthusting Hoping mylonite in the northeastern Backbone Range of Taiwan orogeny provides a unique chance to understanding the crustal strength conditions of hinterland as an example from the classic arc-continental collision. Since grain size distribution of new recrystallized grains is related to differential stress during dislocation creep, while deformation temperature influences both the dislocation creep types and quartz slip systems. Electron backscatter diffraction analysis will be used to quantify grain size and crystallographic preferred orientation. Recrystallized grains were identified by evaluating the distribution patterns of Grain Orientation Spread values through a Gaussian mixture model. Preliminary results show that grain sizes in the Hoping shear zone (13.32–19.23 μm) are smaller than those in the wall rock (16.42–31.41 μm), consistent with grain size reduction observed in mylonitic shear zones. Estimated differential stresses range from 84.13–109.14 MPa in shear zone and 59.39–94.10 MPa in wall rock. Opening angles of quartz c-axis range from 68°–76°, suggesting deformation temperatures between 520°C and 570°C.

Keywords:Ductile shear zone, dislocation creep, EBSD, differential stress, deformation temperature

臺灣變質岩區近斷層帶之磁性組構特性研究

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臺灣位於歐亞板塊與菲律賓海板塊之斜向聚合轉換帶，由於造山擠壓作用與弧後張裂之影響，臺灣造山帶有許多的剪切帶。這些剪切帶通常為高應變區，不僅是地震活動的重要構造要素，也對地下工程設計與地質災害評估具有關鍵影響。針對剪切帶應變量之量化分析，過去多以壓影構造分析為主，但常受限於變質度或礦物特性，不易進行分析工作，且許多剪切帶難以倚賴中視尺度露頭地質調查完整辨識其範圍。因此，本研究嘗試從應變分析的觀點切入，透過磁性組構分析方法，針對前人文獻提出之剪切帶位置，驗證剪切帶之應變是否如預期顯著高於其圍岩，間接推估其應變狀態與分布，進一步判識潛在剪切帶位置。

本研究針對位於中央山脈西側板岩帶及東側大南澳變質雜岩中的三條剪切帶進行分析，包括花蓮和平溪韌性剪切帶以及中橫公路脫序逆衝斷層F1與F2，利用磁感率異向性和磁滯曲線分析，探討跨越不同剪切帶的磁性組構、磁性礦物和應變橢球的分布狀況與變化，進而比較其變形差異，討論橫跨斷層帶的變形特性。

研究結果顯示磁性組構與岩石組構兩者的位態相符，可將磁感率橢球體視為應變橢球，作為岩石最終變形程度指標。中橫公路脫序逆衝斷層之板岩的形狀參數與校正異向性之趨勢路徑顯示隨著校正異向性增加，形狀參數會從橢球狀接近平板狀，其趨勢符合岩石變形路徑演化圖。和平溪韌性剪切帶內的校正異向性相較圍岩有明顯的上升，符合預期中剪切帶內變形高於圍岩變形之趨勢。在中橫公路脫序逆衝斷層　F1與F2，能指示變形程度之校正異向性值在接近斷層時反而呈現明顯下降，與預期模型不符，推測可能受後一期劈理開始發育，並疊加前期劈理所致。

由於本研究目前採樣密度仍不足，未來將增加採樣密度以提高數據的代表性，以利更完整地理解剪切帶的應變狀態與分布和更精確地識別剪切帶位置。

中文關鍵詞：中央山脈、磁性組構、磁感率異向性、剪切帶

山腳斷層滑移風險評估及地下孔隙壓力擴散模擬

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山腳斷層的活動性一直以來都備受討論，因其地理位置橫越台北盆地，若重新活動可能會對北部地區造成嚴重的地震災害。同時，北部的大屯火山群擁有豐富的地熱資源，隨著近年來地熱能源開採技術日漸成熟，能源開發公司也有著盡可能將地熱資源開採至地表進行利用的願景。隨著許多場址像是宜蘭土場、台東金崙等地區開發完成，台灣的地熱發電占比也日見上升。然而，在地熱探勘及發電時，不管是在發電後的尾水回注，或是因開採不易設置的加強型地熱系統，都會對地層進行注水的步驟。注水造成暫時的的高孔隙壓力上升會擴散至近地區並使地層穩定度下降，若附近遭遇斷層時，上升的孔隙壓力會導致斷層的正向力及剪切力比值產生變化。當此數值大於斷層的摩擦係數時，就會誘發斷層的重新活動導致高頻率的地震。

本文章將參考先前國外學者對於誘發斷層重新活動之模擬，利用蒙地卡羅法(Monte Carlo method)在合理區間內生成隨機亂數的斷層資料並進行模型收斂，並優化斷層及注水相關參數的自由度。同時利用先前國外之研究進行驗證，後續以斷層滑移潛勢(Fault slip potential, FSP)作為風險指標，進行多注水井組合注水後之模擬結果並視覺化。期許未來該軟體開發完成時能夠對其他地區的地層進行完整且具信心水準之模擬。

中文關鍵詞：注水工程、蒙地卡羅法、斷層滑移潛勢、莫爾-庫倫破壞準則

金瓜石硫砷銅礦、呂宋礦和黃鐵礦金－銀碲化物和銅－鉍硫化物包裹體之電子顯微組織與可能生成機制

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本研究以SEM-EDS-EBSD分析金瓜石本山礦體硫砷銅礦、呂宋礦和黃鐵礦之金－銀碲化物和銅－鉍硫化物微米包裹體的礦物組成和組織，以探討其可能成因與機制。本山礦體不同高層矽化安山岩礦脈硫砷銅礦、呂宋礦和少數黃鐵礦含有金－銀碲化物包裹體，碲化物包裹體礦物組合包含(1)碲銀礦(hessite, Ag_2Te)、碲金銀礦(petzite, Ag_3AuTe_2)或碲金礦(calaverite, $AuTe_2$)單相組成、(2)碲銀礦＋碲金銀礦、碲金銀礦＋自然金、碲銀礦＋自然金、碲金礦＋自然金二相組成和(3)碲銀礦＋碲金礦＋自然碲三相組成。產狀上見有碲銀礦單相和碲銀礦＋碲金銀礦二相負晶包裹體、碲銀礦和碲金銀礦單相液滴狀包裹體和碲銀礦＋碲金銀礦和碲金銀礦＋自然金二相液滴狀包裹體，這些礦物組成可填滿包裹體空間，局部可見張裂洩漏或衛星包裹體組織，符合熔體包裹體特徵，暗示熱液曾形成可吸納熱液金、銀之碲熔體(熔點452℃)，推測熔體包裹體亦可能吸納母晶中之貴金屬和碲，於波動性熱液系統中相繼結晶不同碲化物礦物，增添熱液成礦系統少見之碲熔體富集貴金屬實例。本山礦體五坑、六坑及九坑黃鐵礦含有銅－鉍硫化物包裹體，尤其五坑黃鐵礦含有單相至三相礦物組成完整填滿負晶狀、液滴狀和不規則狀包裹體，暗示曾為熔體包裹體，礦物組合包含(1)單相硫化銅(Cu_xS, $1 \leq x \leq 1.67$)、三硫鉍銅礦(wittichenite, Cu_3BiS_3)或硫鉍銅礦(emplectite, $CuBiS_2$)，局部與方鉛礦共生、(2)二相銅藍(covellite, CuS)＋硫化銅、硫鉍銅礦＋硫化銅、三硫鉍銅礦＋硫化銅或三硫鉍銅礦＋硫鉍銅礦和(3)三相銅藍＋三硫鉍銅礦＋硫鉍銅礦。這些銅－鉍硫化物熔體包裹體局部伴隨大小不一之幾何或圓弧形貌孔洞，吻合熱液沸騰流體包裹體之特徵，形成熔體與氣、液相流體共存之獨特現象，硫化銅非均一性銅硫比例可能與非均勻性流體組成相關。銅藍＋三硫鉍銅礦＋硫鉍銅礦三相負晶包裹體呈現銅藍先於三硫鉍銅礦＋硫鉍銅礦結晶之生長組織，暗示熱液溫度曾達500℃以上。金瓜石本山礦體之金－銀碲化物和銅－鉍硫化物熔體包裹體為高硫化型礦床目前仍少見之發現。

中文關鍵詞：貴金屬、碲化物、硫化銅、硫鉍銅礦、熔體包裹體

Elasmobranch assemblage of the Lower Pleistocene Cholan Formation, northern Taiwan

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The waters around Taiwan nowadays hold one of the most diverse elasmobranch faunas in the world. To understand how this fauna formed, evidence from palaeontological approach is crucial; however, the relevant fossil records in Taiwan are limited, especially in the northern region, where only one study has been conducted. This study aims to investigate elasmobranch assemblage of the Cholan Formation in northern Taiwan, a geological formation renowned for its various marine and terrestrial fossils. From 2023 to 2025, outcrops of Cholan Formation in the Dahan River section were sampled during multiple fields works and over 300 kilograms of sediments were collected for elasmobranch teeth. Four orders are recorded: Carcharhiniformes (ground sharks), Rhinopristiformes (guitarfishes), Rajiformes (skates), and Myliobatiformes (sting rays). The presence of *Negaprion* (lemon sharks) teeth represents the first Taiwanese occurrence, and notably, this genus is not common in current natural environment in the same region. The collection also includes uncommon taxa such as *Carcharhinus leucas* (bull shark), *Rhizoprionodon* (sharpnose sharks), *Sphyrna lewini* (scalloped hammerhead), and *Myliobatis* (eagle rays). The entire taxonomic composition suggests a nearshore, shallow marine, environment with sandy bottom, which aligns with the presence of rich sand dollars in the samples. These findings provide further insights into the formation of the current elasmobranch fauna and biogeographic pattern of several taxa over geological time.

Keywords:Cholan Formation, Elasmobranchii, Taxonomy, Biogeography

同步輻射奈米顯微術在發光礦物的譜學研究

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本研究利用台灣光子源TPS 23A光束線實驗站的同步輻射X光奈米探針技術，系統性探討以稀土元素摻雜之合成發光礦物的發光特性與機制。研究材料為當前最常見的長餘輝型鹼土金屬鋁酸鹽合成礦物($SrAl_2O_4$: Eu, Dy與$Sr_4Al_{14}O_{25}$: Eu, Dy)。透過X光螢光光譜(XRF)、XRF面掃、X光吸收光譜(XAS)、X光激發光致發光(XEOL)及其面掃技術，區分出六種主要發光中心，分別為Eu^{2+}、Eu^{3+}、Dy^{3+}、Cr^{3+}、Mn^{2+}及F中心(F center)，並將其歸納為三大類型：稀土離子發光中心、過渡金屬離子發光中心及缺陷發光中心。

以Eu^{2+}為主的發光中心，產生位於493 nm的寬頻發光帶，對應於$4f^65d^1 \rightarrow 4f^7$能階躍遷是產生強烈藍綠色磷光的主要成因；$Eu^{3+}$與$Dy^{3+}$則產生多組4f-4f躍遷所形成的窄線發射峰，涵蓋560－770 nm波段。F中心(氧空位捕捉電子形成)則對應408 nm的發光；由Cr^{3+}的$^2E \rightarrow {}^4A_2$躍遷產生特徵性R線(R line)發射(692.1與693.7 nm)，而Mn^{2+}的螢光訊號雖於XAS偵測中確認，但在發光光譜中被Eu與Dy掩蔽。本研究透過同X光奈米探針技術精確量測元素價態與螢光空間分佈，補足新證據來解釋並修改前人研究的發光機制模型，本研究成果將有助於發光材料的鑑定與進一步拓展至其他螢光礦物的研究應用。

中文關鍵詞：同步輻射、鋁酸鹽、稀土元素發光、XEOL、XAS

Employing Bayes' Theorem to Estimate the Effect of Precursor: a Case Study of Japanese Folklore linking Deep-Sea Fish Appearance with Earthquakes

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There are many hypotheses regarding certain observed anomalies that can serve as precursors to large earthquakes. Many of those hypotheses involve the unusual behavior of animals. While there are times those precursory situation happen, they are seldom consistent. However, the confirmation bias might lead people to believe those unverified hypotheses and cause unnecessary panic. One way to demonstrate the validity of those hypotheses is to calculate their precursory effect based on the past data.

We propose a new framework based on Bayes' theorem to quantify the effect of precursory anomalies on large earthquake events. Using the Japanese folklore of deep-sea fish as a case study, the derived probabilities and probability gains achieve reasonable and consistent results in both seismological sense and statistical sense. We believe the proposed framework can provide a primary test for the various precursory hypotheses. Also, quantitative probability can serve as a powerful tool to communicate with the general public.

Keywords:earthquake precursor, statistical inference, Bayesian statistics

Cave drip-water's response to precipitation: a preliminary analysis

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Studies of stalagmite oxygen isotopes often treat variations in the record as direct reflections of changes in climate conditions. When looking at single stalagmites, this interpretation gives useful results. However, our study of several stalagmite sites in a cave in Southern peninsular Thailand suggests that this model may need a reexamination when looking at multiple stalagmites within one cave-site. Our preliminary work shows that the karst aquifer above a stalagmite's cave can have a very complex relationship with the precipitation. When looking at the drip rates in the cave we see non-linear reactions to rain volume, where some internal hydrological thresholds appears to trigger extremely large changes in drip rate. Crucially, different stalagmite locations in the same cave system exhibit different behaviors. We present some initial attempts at modeling the karst flow with the aim of turning what is initially a complicating factor into another source of information. With different stalagmite records from the same cave, each with a unique response to precipitation, we hope that comparing oxygen isotope records will allow for new inferences about the changes in regional climate. For the purposes of characterizing each stalagmite drip site we use a combination of drip rate monitoring as well as analyzing changes in oxygen isotope in both drip water and rain water outside the cave

Keywords:karst, hydrology, speleothem, paleoclimate, oxygen

極端事件前後多時序降雨誘發山崩特性分析

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誘發山崩之極端事件包括強震與極端降雨，極端事件會造成坡地的大量崩塌裸露，即使未崩塌的坡地也可能比極端事件前更不穩定。為了探討極端事件後續崩塌地的變化特性，並分析事件間共效應的影響，本研究以陳有蘭溪流域及其鄰近15處研究區，進行集集地震前/後多時序降雨誘發山崩分析；另以全臺10處研究區進行極端降雨前/後逐年降雨誘發山崩分析，極端降雨標準參考中央氣象署及國家災害防救科技中心之標準。

研究結果顯示，強震部分:(1)地震誘發山崩之區位與降雨誘發山崩之區位略有不同，地震誘發山崩偏向稜線處，降雨誘發山崩則多位於坡趾如溪流兩側。因此，(2)集集地震前/後降雨新生山崩崩壞比與降雨量關係大致相近，強震對後續降雨誘發新生山崩影響小。(3)僅膠結較為鬆散的頭嵙山層火炎山段，受集集強震誘發大量山崩後，部分坡面可能岩體強度降低或有較多鬆散土石堆積，地震後降雨崩壞比略為提高。

極端降雨部分:(1)極端降雨後2至3年間可能有降雨引致新生山崩崩壞比略為增加的極端降雨效應，也就是遭遇極端降雨後，會有一段新生崩塌率上升的不穩定期，但崩壞比增加的幅度並不大。(2)坡度大於35度地區，極端降雨後山崩擴大率上升的極端降雨效應比較明顯。

極端事件為後續多時序崩塌地帶來最重要的影響，主要仍是山坡上大量由極端事件所誘發的崩塌裸露面，這些裸露面受到後續降雨沖刷仍會有大量土砂產出而造成危害。依據本研究分析結果，相關特性包括: (1)強震後5年內，愛氏震度2 m/sec以上受創較重地區，大量地震誘發山崩之影響仍大。(2)愛氏震度2 m/sec以下且平均坡度小於40度地區，地震2年後山崩多可植生復育。(3)強震約5年後，崩塌裸露面上之崩積物可能沖刷至較少，使山崩裸露範圍較為固定。(4)極端降雨約2至3年後，其所誘發的大量崩塌裸露面上之崩積物可能沖刷至較少，使得山崩裸露範圍較為固定。

中文關鍵詞：極端事件、極端降雨、多時序降雨事件、極端降雨效應

區域性地電訊號與地震活動之關聯研究：以花蓮與嘉義為例

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地震電磁現象為地球科學中兼具挑戰性與應用潛力的重要課題。近年來，地電訊號（geoelectric signals）作為地震前兆之一受到廣泛關注，尤其在台灣、日本等板塊活躍地區，長期穩定的地電觀測有助於揭示地震活動與地電變化間的潛在耦合機制。本研究比較分析花蓮與嘉義兩個近期地震頻繁區域的地電訊號與地震能量，以探討其時空關聯性與可能的物理機制，進而評估地電訊號在地震預測上的應用潛力。

花蓮位處歐亞板塊與菲律賓海板塊交界，是地震頻率高、構造活動強烈的地區；嘉義則位於集集斷層與梅山斷層附近，地震活動略低但仍具潛在風險，且2025年亦發生具破壞性地震。兩地均設有地電觀測站，並累積近10年連續觀測資料，為本研究提供良好數據基礎。本研究使用之資料包括中央氣象署地震目錄與地電觀測站所收錄之南北（NS）與東西（EW）方向電場強度變化，涵蓋2014至2024年。研究方法主要為：(1) 地電訊號前處理與異常特徵分析（如變異數、偏度、峰度與功率譜）；(2) 與地震能量變化的時序比對與統計關聯分析；(3) 跨區比較，探討不同地質與觀測條件下地電與地震關聯性的差異。

初步結果顯示，在花蓮與嘉義地區，部分觀測站於累積規模5.0以上事件發生前數日至數週可觀測到地電異常，包括低頻功率增強、偏度與峰度變化等。透過統計分析與事件篩選（如震源深度小於30公里、震央距離小於50公里）發現兩地皆呈現異常出現機率上升的趨勢，惟其時空分布及顯著性仍有差異。另外，地質構造差異、觀測環境干擾（如降雨、地下水變化與人為噪訊）與儀器穩定性等非地震因素亦可能影響地電訊號判讀。本研究亦進行初步辨識與排除，並建議未來研究應結合地磁場、地溫、氡氣等多參數觀測與機器學習技術，以提升地震前兆辨識的可靠性。

綜合而言，本研究透過花蓮與嘉義地區的地電與地震資料比較，驗證地電訊號在特定條件下可能具有前兆特徵，對區域性地震預警模型與多重前兆資料整合具有參考價值，並強調長期觀測與跨領域整合之必要性。

中文關鍵詞：地電訊號、地震活動、功率譜、統計矩、格蘭傑因果關係檢定

金屬奈米顆粒的局域表面電漿共振效應：奈米尺度礦物著色新機制的表徵、模擬與再現

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局域表面電漿共振(Localized Surface Plasmon Resonance, LSPR)效應是金屬奈米顆粒受光激發時產生的共振現象，能引發選擇性吸收、散射與局部電場增強，成為奈米尺度下礦物著色機制的重要突破。本研究從天然與人工材料兩方面出發，分別以拉長石中的銅奈米顆粒與人工合成之金奈米顆粒與奈米銀顆粒塗層為例，結合球差校正穿透式電子顯微鏡(Aberration-Corrected Transmission Electron Microscope, AC-TEM)、電子能量損失譜(Electron energy loss spectroscopy, EELS)、能量色散X光譜(Energy-dispersive X-ray spectroscopy, EDS)與原子力顯微鏡(Atomic Force Microscope, AFM)等多種高解析度微觀表徵技術，能清楚觀察金屬奈米顆粒的形貌與成分，確認其與局域表面電漿共振效應色彩表現的對應關係。

藉由時域有限差分法 (Finite-Difference Time-Domain, FDTD)模擬，分析與模擬奈米顆粒的形狀、尺寸與介電環境對於調控共振波長與強度的影響，進一步預測與再現天然樣品中觀察到的光學行為。再現實驗部分，採用共濺鍍與單靶濺鍍結合退火處理的方式，於鑽石基底成功製備分散型銀奈米顆粒，顯示局域表面電漿共振效應可由人工設計實現特定色彩。

本研究不僅揭示奈米尺度下礦物顏色生成的機理，亦建立一套結合電子顯微鏡表徵、電磁模擬與再現技術的研究流程。此研究亦期望能結合臺灣熱液礦床研究，進一步探討天然奈米結構形成條件與其局域表面電漿共振效應效應之關聯。

中文關鍵詞：LSPR、金屬奈米顆粒、FDTD、奈米顯微表徵、礦物著色

Effect of clay content on frictional behavior of simulated gouges at seismic rates: Binary and ternary mixtures of quartz, illite, and kaolinite

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Mineralogical phases are one of the factors that control the frictional behavior of gouges. While frictional behaviors of fault gouges with single-phase mineral composition is influenced by fluid drainage, those with multi-phase mineral composition remain unknown. Here, we systematically shear synthetic gouges, from pure end-member to binary and ternary mixtures of quartz, illite, and kaolinite, to investigate the frictional behaviors at seismic rates and the corresponding mechanisms. All experiments are conducted at a normal stress of 10 MPa and a velocity of 1 m/s under fluid-drained conditions. In general, our results show that an increase in clay content leads to a decrease in the peak friction coefficient, from ~0.59±0.01 for pure quartz to an average value of ~0.30± 0.07 for clay-bearing gouges. In addition, when kaolinite exceeds 10% in either binary or ternary mixtures, the steady-state friction coefficient drops to 0.22, whereas other mixtures exhibit higher values of 0.23-0.32. Microanalytical results show the presence of clast-cortex aggregates and grain size reduction, suggesting the formation of a high-strain zone that can be considered as the principal slip zone (PSZ). In addition, clay minerals were thermal-decomposed (dehydroxylated) and were aggregated into larger grains in the PSZ. Because quartz, illite, and kaolinite are the most common minerals within fault zones at shallow crustal depth, our work provides a dataset on frictional properties of natural faults and offers valuable insights into the mechanics of active crustal fault zones during earthquakes.

Keywords:Quartz, Illite, Kaolinite, Fault gouges, Frictional behavior

Assessing Temporal and Spatial Variations in Orientation and Seismic Noise in the Littoral Zone with Ocean-Bottom Nodes

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Seismic surveys in Taiwan have predominantly focused on land and sea environments, leaving a critical knowledge gap in the littoral zone — the dynamic interface between land and sea. The SUBTIDE project addresses this gap using various ocean-bottom nodes (OBNs) and seismic sources to optimize experimental layouts in this high-noise environment. Our setup included 2 commercial OBNs (SmartSolo & GPR) and a custom-developed OBN with distinct instrument responses. We implemented power spectral analysis to standardize and integrate amplitudes across instruments. To investigate seismic signal propagation characteristics in the littoral zone, we used 3 active sources: offshore airguns, onshore seismic vibrators, and mudguns. Despite high noise levels, we detected refracted and reflected wave signals, enabling evaluating seismic energy transmission. Through cross-spectral analysis, we identified frequency bands where instruments show sensitivity to the mudgun source, enabling precise horizontal orientation estimation. We applied a rotation matrix to align the horizontal axes by maximizing coherence between the verticals and horizontals. Our analysis revealed both temporal and spatial variations in instrument orientation, likely induced by tide and wave dynamics. This study provides novel insights into seismic noise characteristics and instrument stability in the high-noise littoral zone while validating various sensor technologies for nearshore geophysical applications. Future work will use the GPR's pressure sensor to quantify how littoral currents and tidal cycles affect seismic recordings, enhancing experimental designs for littoral seismic investigations.

Keywords:Littoral seismic signals, Nodal seismometers, Background noise analysis, Instrument horizontal orientation, Data assimilation

Source Characterization of Microseismic Noise in the middle of the Pacific Ocean using NoMelt Ocean Bottom Seismometer Experiment

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Microseisms are primarily generated by the coupling of ocean gravity waves with the seafloor. Investigating the source characterization of ocean bottom seismometers (OBSs) offers a more comprehensive understanding of noise behavior and origin compared to land stations. This study explores the spatiotemporal patterns of microseism sources in the central Pacific Ocean, extending southwards to Hawaii. We utilize continuous three-component broadband data from 16 OBSs of the NoMelt array, along with ERA5 ocean and atmosphere model data and WAVEWATCH III p2l model data. Our analysis includes power spectral density (PSD), frequency-dependent polarization analysis, beamforming, and correlation with ocean and atmospheric model data for the vertical components of OBSs. Our findings reveal that secondary microseisms (0.6–10 s) are strong and dominate the background noise, with peak broadening at shorter periods (0.6-0.3 s) and clear peaks at longer periods (4-10 s). Primary microseisms (10–20 s) are also observed at most OBS sites. Particularly, secondary microseisms at shorter periods (~0.6-2 s) and longer periods (~4-10 s) show a strong correlation with ocean wave heights and wind speeds, indicating that local and regional wave interactions are the primary causes of microseisms in these periods. The results of polarization analysis, beamforming, and spatial cross-correlation coefficients of the time-varying PSDs with ocean wave heights and p2l sources indicate that, besides the influence of remote sources, there is a significant presence of locally produced microseisms near the monitoring stations. This finding suggests omnipresent sources in the Pacific with seasonal variability, showing stronger sources in the Northern and Eastern Pacific during winters and summers, respectively. The wind-generated microseisms in the short periods can be attributed to the class I mechanism, while the longer periods are due to the class II mechanism, resulting from the interference between incident and coastal reflected waves.

Keywords:Ocean Bottom Seismometers, Microseism, Central Pacific

2024年0403花蓮地震序列於東華大學井下地震儀觀測到之場址特性與非線性反應

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2024年4月3日於花蓮發生的芮氏規模7.2地震是台灣25年來最大之地震，其引致之強烈地震動在花蓮太魯閣觀測到超過1.5 g 之最大地表加速度（PGA）及80 cm/sec之最大地表速度（PGV），北台灣多個區域都達到5弱以上的震度。主震發生後的兩個月內，數千個密集餘震持續的撼動著花蓮北部，其中包含七個規模6以上的餘震。國家地震工程中心自2015年6月起，在國立東華大學校區內裝設有一組井下地震儀陣列，包含地表及深度分別為20公尺、30公尺及70公尺的四組加速度型地震儀，此井下地震儀陣列距離0403震央僅6公里，並於主震時在地表觀測到271 gal之PGA，其後也紀錄到近千筆餘震之地震動反應。本研究利用東華大學（NDHU）井下地震儀陣列所觀測到的大量0403地震序列之地震歷時，分析探討此區域地層在不同大小地震動下之土壤非線性反應。從水平向PGA來看，在10 gal以下之弱震下，地表PGA約為深度70公尺處之2.4倍，隨著輸入地震動的提高，土層放大倍率逐漸降低，在0403主震的井下輸入地震（181 gal）時，放大倍率縮小為為1.5倍。地表與井下地震歷時之富氏譜比則可視為實測之地層轉換函數，弱震之第一放大主頻出現在2.0 Hz，隨著地震動強度的增加，第一主頻逐漸降低至1.35 Hz；富氏譜比峰值則是從弱震的約3倍逐漸提高，在地震動100 gal附近有大幅度的反轉，在強震時轉為壓抑放大。此外，實測地層轉換函數也能明顯觀測到第二及第三地層放大頻率及峰值之變化情形。最後，我們透過原始鑽探及井測資料建立之地層剖面，以強震之井下歷時作為輸入進行STRATA場址反應分析，綜合比對理論與實測地層轉換函數之異同，進一步評估近地表地層之場址放大與非線性反應。

中文關鍵詞：0403花蓮地震、井下地震儀、強地動、非線性反應、場址特性

玄武岩對環境水體的礦化封存可行性評估

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自工業革命以來，化石燃料大量燃燒導致大氣中 CO_2濃度上升、氣候變遷加劇，凸顯淨零排放的迫切性。台灣 2050 淨零排放路徑中，碳捕捉、利用與封存（CCUS）技術被視為長期減碳關鍵。礦化封存因穩定與安全性受到關注，冰島 CarbFix 計畫已證實其可行性，將 CO_2 與淡水混合注入玄武岩層促成礦化反應，但此技術需消耗大量淡水。若以富含陽離子（Ca、Mg 等）之環境水體替代，除可降低用水壓力，亦能促進碳酸鹽生成、提升封存效率。

本研究模擬常壓與高壓（1000 psi）條件下CO_2 與玄武岩的礦化反應，並比較不同環境水體（鹽化地下水、海水、鹵水）對封存效率的影響。模擬深部壓力條件下，CO_2 可轉化為液態、提升其在水中溶解度，形成碳酸根或碳酸氫根離子，進一步與玄武岩或環境水體中Fe、Mg、Ca等陽離子反應生成碳酸鹽沉澱。實驗中，pH變化與陽離子濃度上升顯示反應進行的程度，於常壓條件下，所有系統pH皆呈現先降後升的趨勢，說明初期CO_2 溶解形成碳酸、後期礦物溶出反應。淡水反應中Mg、Na、Ca濃度逐漸上升，其中Mg上升最多至22 mmol/kg，與pH升高趨勢一致，顯示玄武岩溶解反應持續進行。相較之下，常壓海水中Ca濃度反而降低，顯示反應系統內部Ca有沉澱，而海水可作為Ca離子來源。壓力則進一步強化礦物溶解速率，以Si濃度變化為例，常壓淡水反應140天後Si上升至0.85 mmol/kg，而高壓淡水反應下僅14天便達3.04 mmol/kg，顯示高壓能顯著提升玄武岩溶解效率。進一步以XRD分析確認反應產物，高壓條件反應後之玄武岩皆可觀察到碳酸鹽礦物特徵峰，證實沉澱生成。最後，透過熱重分析（TGA）進行反應產物量化，500–780 °C區間的重量損失對應碳酸鈣分解，但是未反應玄武岩及淡水反應玄武岩反而出現重量上升，依據文獻與SEM-EDS分析，應為Fe^{2+} 氧化為Fe^{3+} 所致。TGA結果可估算碳酸鈣平均日生成量，常壓淡水為0.01g/day，常壓海水為0.046g/day，高壓海水則提升至0.054g/day，顯示高壓與含陽離子（Ca、Mg 等）環境水體皆能有效促進碳酸鹽生成、提高封存效率。本研究可協助尋找最佳礦化封存條件，為台灣碳封存策略與負碳技術發展提供重要依據。

中文關鍵詞：碳封存、礦化封存、玄武岩、環境水體

結合攝影測量與離散裂隙網路模型分析關子嶺裂隙特性及連通性

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臺南關子嶺地區的地熱發展歷史悠久，早期以溫泉觀光資源的利用為主，隨著近年地熱發電議題的興起，該地區也成為研究與探勘的重點區域。過去研究指出，熱液通常經由裂隙通道自深部儲集層或熱源遷移至淺部地層，此一過程有助於降低地熱資源的開發成本並提升整體經濟效益。由於關子嶺地區存在多處構造，且已知熱源位於背斜深部岩層中，因此本研究針對該區域進行岩體裂隙調查，探討地層中裂隙通道的發育特性。本研究運用運動回復結構（Structure from Motion, SfM）與多視立體（Multi-view Stereo, MVS）等攝影測量技術，將野外拍攝之露頭影像轉換為高密度空間點雲，並利用開源程式 Discontinuity Set Extracter （DSE）對點雲進行不連續面辨識與分組，並對位態、密度等做統計分析。比對 DSE 辨識結果與野外實地量測的裂隙資訊顯示，兩者結果高度一致，惟 DSE 可取得更全面的資料，故本研究採用其結果進行後續的離散裂隙網路分析。裂隙模擬部分則使用開源程式 ADFNE，依據辨識裂隙生成三維離散裂隙結構，並分析其裂隙連通性，藉此深入了解關子嶺地區岩層中裂隙的特性與連通行為，為地熱資源探勘提供可靠之參考依據。

中文關鍵詞：關子嶺溫泉、運動回復結構（SfM）、Discontinuity Set Extracter、離散裂隙網路（DFN）、地熱開發

Geometrical & hydrological dependence of seamount subduction on slip tendency: Does it promote or suppress interplate locking?

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In the Nankai Trough, frequent slow earthquakes occur, some of which are closely related to the subduction of seamounts. Hyuga-Nada, having no magnitude-8 class earthquake, is subducted by the Kyushu-Palau Ridge (KPR) since several Ma B.P. Outcrop observations, numerical calculations, and experiments suggest that seamount subduction deforms and fractures the overlying strata, causing stress and strength heterogeneity (e.g. Dominguez 1998; Sun et al., 2020).

Heat flow marks a sharp contrast across KPR; to the east it is 50-100 mW/m2 and 25-45 mW/m2 to the west. Near the KPR we observed a negative heat flow anomaly; heat flow outside is ~45 mW/m2, whereas it is ~25 mW/m2 above the subducted KPR. We hypothesize that the seamount subduction caused a stress contrast between the leading and trailing sides, encouraging a poroelastic fluid flow around the sediment above seamount.

Failure along a fault can occur if the shear stress exceeds the effective normal strength, or a slip tendency (Ts) exceeds its friction coefficient. In order to these, we need to assess its geometry as well as the effective stress field. The geometry of subducting seamount is imaged from a series of seismic data. Assuming a uniform regional stress field around this area with sigma1 parallel to the plate conversion vector, estimated Ts is generally high on and around the subducted seamount where the tremor frequence is large, too. In some frequent tremor areas, especially to the NNW of seamount, Ts is not high enough. This may indicate the needs for overpressures in that area.

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Keywords:Seamount subduction, slow earthquake, heat flow, slip tendency

以統計類比法探討瑞林地區地熱發電潛能

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本文利用體積評估法、發電潛能評估計算公式以及蒙地卡羅模擬方法(Monte Carlo simulation)進行花蓮縣瑞林地區之地熱發電潛能初步評估，其具地熱潛能之區域為搭配利用「區域地熱探勘與重點潛能評估-花蓮地區」計畫執行的28處MT施測結果，並取得MT法三維電阻率模型，分析較為精確的目標區地下儲層的低地電阻區分佈空間，取代粗略的面積與厚度估計。以近年新增鑽探之GSMMA-RS-1、GSMMA-RS-2兩口調查井井溫資料及前人調查溫度資料(如中油2口深井、5口淺測溫井、工研院1口鑽井、鄰近溫泉井等)建置溫度場模型。取MT量測電阻率小於40Ω-m、50Ω-m、65Ω-m，且溫度場模型之溫度高於100°C之塊體形貌，作為蒙地卡羅模擬之地熱潛能區塊體上限值、最可能值和下限值。本文依現階段調查資料初步估計瑞林地區之發電潛能約落在9.73MWe(P5)－27MWe(P95)間(90%信賴區間)，統計平均值約為17.15MWe，最可能值約為13.9MWe，其結果未來應再依更多調查資料成果的加入，而進行滾動式修正。

中文關鍵詞：花蓮、地熱發電潛能評估、蒙地卡羅模擬

海域Canning盆地北部地層劃分及對比

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Canning盆地位於澳洲西北部，盆地整體架構呈現西北-東南向。在其北部凹陷兩側高區的古生代地層中已有許多油氣發現。相比之下，此盆地海域尚無顯著發現，且探勘較不成熟，僅有6口鑽井及少量2D震測線。要在此前沿區域進行探勘活動之前，需先評估其探勘潛力，此又建基於對其地層、構造及盆地演化的認識程度。

有鑒於此，本研究使用此盆地6口海域井的井下資料，包括電測、岩屑及生物地層，並根據最新的區域構造地層架構，嘗試對此6口井進行地層劃分及對比。初步結果顯示：(一)所有井皆鑽遇古生代地層，然凹陷內中生代地層較厚，高區較薄。因此，在凹陷內的井僅鑽遇石炭紀早期地層，高區上的井則鑽至泥盆紀晚期地層。(二)研究區域存有兩個主要不整合，分別為古生界頂部不整合及中石炭系不整合。與區域構造歷史相比，可將此二不整合分別對比至二次轉換擠壓事件，即Fitzroy Transpression及Meda Transpression。

中文關鍵詞：Canning盆地、古生代地層、油氣探勘

First Observation of a Lightning-Induced Isotropic Microseismic Event at Depth: Evidence from the MiDAS Seismic Monitoring System, Taiwan

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Cloud-to-ground lightning can dissipate energy into the ground. The dissipated electric current density can be enriched and drive physical and chemical processes along fractures. While geologic evidences of lightning-induced processes (e.g., melting and the solidified melts) have been recognized along fractures at depth, the seismic signals associated with the process remain undetected. Here, we report a lightning-induced microseismic event detected at a depth of 84 m within the Milun Conglomerate Formation by the MiDAS monitoring system in Hualien, Taiwan. The event immediately after a lightning strike was captured solely by the distributed acoustic sensing (DAS) system. The DAS waveforms display a clear P-wave moveout between nodes at depths ranging from 48 to 140 m, with no observable S waves. The peak strain rate amplitude was extremely low, approximately 3×10^{-6} s^{-1}. By comparing the observed waveforms with synthetic strain-rate data generated via finite-difference simulations, we suggest that the event had a magnitude of M_w –0.94 located approximately 20 m horizontally from Hole A. The event exhibited an implosive isotropic focal mechanism. We speculate that the dissipated high electric current, which traveled along fracture or fragment boundaries, may have concentrated at a depth of 84 m and evaporated pore fluids through intense heating, causing the pore space to collapse inward. This explains the observed implosive isotropic (no shear component) seismic source. We present the first direct evidence of lightning-induced microseismic events, revealing that lightning's subsurface impact can extend to much greater depths than previously recognized.

Keywords:Distributed acoustic sensing, Lightning-induced seismic event, Isotropic source

澳洲W礦區碳酸鹽岩震測解釋

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本研究根據蒐集並取得W礦區相關二維震測資料來進行碳酸鹽岩探勘標的之解釋。一般而言，地台的邊緣、造礁體、淺灘等環境，會有較粗顆粒的碳酸鹽岩堆積，孔隙率大的可能性也較高，但依舊會再受到成岩作用與後期構造運動而改變其儲集岩品質。利用塔里木盆地喀斯特礁體之震測特性來類比此礦區，解釋結果顯示礁體區分成兩個沉積族群，其一為靠近次盆地側略成東北－西南帶狀分布之礁體，經營人提供之石灰岩坑礁體則屬於此族群，另一族群則屬於被深水圍繞呈點狀分布之礁體。

中文關鍵詞：礦洲礦區、震測特性、礁體

地熱儲集層數值模型初探-以臺東紅葉地區為例

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我國地熱發電預估2025年將有20 MW正式商轉，同時規劃至2030年地熱開發目標須達1.2~1.5 GW，亦代表地熱發電著實於目前能源轉型扮演重要的角色。臺灣位處西太平洋火環帶與年輕的造山帶，所形成的火山帶以及板塊碰撞使得地殼劇烈抬升，的確蘊藏了豐富地熱資源，加上近年來政府相關部門積極以各項先進技術調查並建置地熱潛能區的地熱地質模型，預期將帶動整體地熱發展前景。本研究所提到的地熱儲集層模擬則是將科技探查結果數位化之後，透過模擬技術來重建熱水儲集層在不同階段的時空演變，是地熱發電潛能評估與營運管理階段非常關鍵的技術。

本方法研究流程係利用紐西蘭Seequent公司開發的三維地質建置軟體(Leapfrog)建構兼顧展示與銜接儲集層模擬的三維地熱概念模型，並轉換成能提供做為儲集層熱流模擬之用的三維網格，其次則串聯紐西蘭奧克蘭大學地熱研究所開發的熱流模擬器(Waiwera) 進行模型參數設定(包含起始/邊界條件設定、地層參數設定等)，搭配現有地質探勘觀測井的量測數據，以運跑合理的自然狀態模型(Nature Steady model)，目前階段亦藉由該研究流程瞭解紅葉地區地下流體熱潛能及壓力分布。

後續待地熱案場進入開發階段後，則地熱儲集層管理擬轉換為探討開發行為對於地熱案場可能造成的影響，利用現有生產井/回注井生產歷程建立符合觀測數據的生產歷史模型(Production history model)，而後依據不同地熱能源的開採策略建立未來情境模型(Future Scenario model)，預測地熱發電若干時間後，生產井熱能及壓力的變化(包括生產井每小時能生產的熱水或蒸氣的總量、回注井灌注的熱水溫度壓力對於生產井的影響)，提供未來生產熱水/ 蒸氣策略上的改變及成本效益的計算。

中文關鍵詞：地熱儲集層模擬、自然狀態模型、生產歷史模型、未來情境模型

東台灣變質沉積岩之地球化學與來源特徵研究

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位於台灣東部的金崙為國內重要之地熱區，該地區潛藏之地熱能來自於底下構造活動的熱岩，並進一步加熱當地的地下水。金崙地區的地層以中新世的知本層(或稱盧山層)和始新世的新高層(或稱畢祿山層)為主，其中知本層被視為地熱水之儲集層。知本層與新高層的岩性皆是變質砂岩和板岩，其中，金崙地區的知本層又細分成真里武留段(M3)、虷全山段(M4)、介達段(M5)與葉那把里山段(M6)；而新高層則是砂岩段(E1)與板岩段(E2)。

金崙地區的變質砂岩相對板岩有更高比例的SiO_2，顯示石英比例較高。另外，變質砂岩的燒失量(L.O.I.)也相較板岩更低，同時化學蝕變指數(CIA)亦低於板岩。當結合CIA及組成變異指數(ICV)進行討論，可得知板岩成熟度較變質砂岩更高，也能推估沉積物原岩與花崗岩或花崗閃長岩有關。另一方面，結合判別函數分析法(DFA)協助辨識沉積物原岩類型，該方法能推估金崙地區變質砂岩及板岩的原岩，與酸性火成岩、石英沉積岩有關連；然而，新高層不論板岩還是變質砂岩均源自酸性火成岩，而知本層主要為石英沉積岩來源。該結果顯示出新高層應為酸性岩一次風化堆積作用而成，而知本層應屬於再次沉積作用產生。從微量元素濃度變化分析得出，知本層與新高層有相似的稀土元素(REE)特徵，且相對於後太古宙澳大利亞頁岩(PAAS)的重稀土(HREE)更加貧瘠，以及相對國際標準砂岩、頁岩也具貧瘠現象，此特徵與台灣其他地區之變質沉積岩相同，可能暗示台灣區域的沉積物來源具同源性。儘管如此，台灣區域沉積物的來源仍需更多數據佐證。未來將運用同位素特徵，進一步區分並判釋台灣沉積物的來源親緣性。

中文關鍵詞：變質沉積岩、岩石地球化學、微量元素、親緣性、金崙

基於深度學習地震目錄揭露2025年台灣西部大埔地震序列之發震構造

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本研究探討2025年台灣西部大埔規模6.4地震相關的三維發震構造。基於台灣寬頻地震網、台灣強地動觀測網及中央氣象署地震觀測網的資料，本研究透過深度學習驅動的地震目錄建構方法，在2025年1月20日至31日期間共辨識出6,805個地震事件。值得注意的是，這次地震序列涉及一已存在的斷層系統的重新活動，其特徵為一條位於5至10公里深、傾角27°的東傾斷層（可能對應至木屐寮-六甲斷層），以及一條位於10至15公里深、傾角37°的西傾盲斷層。餘震與誘發地震的分布顯示出影響鄰近活動斷層的複雜應變累積模式。這些研究結果突顯出持續監測的重要性，有助於更深入了解並可能減輕該區域未來的地震災害。

中文關鍵詞：2025大埔地震、深度學習、發震構造

Source rupture model analysis of the 2025 Dapu earthquake, Taiwan

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A joint source inversion analysis integrating teleseismic waveforms, near-field GNSS coseismic displacement, and strong ground motion data was performed to investigate the rupture process of the 2025 M_L 6.4 Dapu earthquake in southwest Taiwan. The inversion incorporated two nodal fault planes determined by the real-time moment tensor system, with results indicating that the west-dipping fault plane provided the best fit across all three datasets. Rupture initiated at approximately 10 km depth and propagated southwestward. A single prominent asperity was identified ~10 km from the epicenter in the southwestern region, characterized by a compact slip area with a maximum slip of ~30 cm and an estimated stress drop of 1.0 MPa. The inversion results suggest that the primary seismogenic structure is a west-dipping blind thrust fault in the middle-to-deep crust beneath the detachment. This fault does not reach the surface and exhibits limited interaction with the shallow east-dipping structures. These findings highlight the need to reassess deep structures beneath the detachment in southwest Taiwan.

Keywords:2025 Dapu earthquake, Joint source inversion, Source rupture model

索馬利蘭裂谷石油系統分析

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索馬利蘭位於非洲東北端之非洲之角，此地區地質演化及石油系統與一海之隔的石油生產國葉門相似。本研究透過板塊重建軟體GPlates，恢復各年代板塊位置以了解索馬利蘭地層在亞丁灣張裂前的沉積環境變遷。另本研究也透過文獻回顧，將位於亞丁灣北岸的葉門油氣產狀類比到南岸的索馬利蘭，期能辨識具潛能的遠景區類型。進一步參考全球裂谷盆地的石油系統分析文獻，將索馬利蘭裂谷對應到已歸納的石油系統中。

本研究製作了9個年代的古板塊復原圖，與文獻中的古沉積環境進行比較。而在亞丁灣兩側的對比中，將1980年代Canoxy公司在葉門Shabwa-Hadhramaut 盆地中取得的14號礦區類比到索馬利蘭，其無岩鹽相關構造、屬於發育中止的陸上裂谷等特性，與索馬利蘭地區相似。

本研究將索馬利蘭裂谷對應到發育中止的陸上裂谷石油系統。關於生油岩（頁岩）、儲集岩（砂岩），其應不致缺乏；其可能因缺乏後張裂時期的地層而缺乏廣泛的蓋岩；構造則是因張裂所形成傾斜斷塊中的封閉構造。

中文關鍵詞：索馬利蘭、裂谷盆地、石油系統

Principal Slip Zone Characteristics of the Milun Fault from Microstructural and Mineralogical Observations

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Principal slip zone (PSZ) accommodates most of the displacement during coseismic events and is where physico-chemical processes occur. The Milun fault has been triggered by multiple earthquakes in the Hualien region in the past decades and is considered an active fault. Here, we characterize the principal slip zone of the Milun fault collected from the Milun fault Drilling and All-inclusive Sensing (MiDAS) borehole cores using microanalytical methods, including optical microscopy, field emission scanning electron microscopy (FESEM), focus ion beam transmission electron microscopy (FIB-TEM), synchrotron X-ray diffraction, Raman spectroscopy, and particle size analysis. A 12-cm black gouge layer was observed in MiDAS Hole-A borehole cores at 522 m. The mineral assemblage of all the samples includes quartz, feldspar, calcite, illite, kaolinite and chlorite, while carbonaceous material (CM) and amorphous material (AM) are observed within the black gouge. Microstructures of the black gouge are characterized by grain size reduction and injection vein with melting structures. In particular, nanoscale fibrous minerals were identified as lime (CaO) through FIB-TEM. The presence of lime along with reduction of calcite and enrichment of CM indicate recent rapid slip under relatively dry condition within the black gouge. Our observations thus suggest strain localization as well as partial melting within the black gouge. While the black gouge is identified as the recent PSZ of the Milun fault, the preservation of lime may provide insights into the fluid activities of the Milun fault over seismic cycles.

Keywords:Milun fault, principal slip zone, strain localization, lime

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由財團法人國家實驗研究院台灣海洋科技研究中心（簡稱:海洋中心)所引進臺灣首套工業級長支距多頻道震測（Long-offset Multi-Channel Seismic，簡稱: LMCS)系統，2018年與勵進研究船磨合成功後，不斷地改善LMCS系統，以發揮其系統最大性能，同時配合科學家不同的研究目的，調整適合之設備與實驗參數（如:空氣槍容積、炸測間距與固態浮纜長度等)，以蒐集高品質之震測資料，並逐步朝著穩定長時間運作系統蒐集資料方向前進。2019-2025年之間已經完成14個航次，在此期間LMCS系統於台灣週遭海域 （如:臺灣海峽與臺灣東部海域等)進行探測，以及搭配勵進研究船遠航的能力，至太平島、菲律賓海域與南海中部海域等遠洋區域蒐集震測資料。目前已達到階段的里程碑，終於突破1萬公里！ 共計蒐集約10,761公里長之震測測線。未來我們將繼續戮力發展LMCS設備之探測能量，不僅能夠穩定支援臺灣國內學術與政府單位對於大地科領域相關之海洋地球物理調查研究（如：碳封存場址與孕震構造等議題)，同時配合陸上與潮間帶探勘技術發展，共同為國家海洋地球物理探勘研究注入新能量。

中文關鍵詞：空氣槍、固態浮纜、長支距多頻道震測、勵進研究船

The Surface Deformation and Ruptures of the 2024 Hualien Earthquake along the Hualien River, Eastern Taiwan

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The 2024 Hualien Earthquake (M_L=7.1) which also named as 0403 Hualien Earthquake occurred on Apr. 3 in the Shoufeng, Hualien. After the violent quake, although no surface rupture was found on the active faults near the epicenter, multiple building damage disasters, landslides, ground fissures, and soil liquefaction were observed in eastern Taiwan. The discontinuous ruptures and sand boils were found in the riverbed from the estuary to Fenglin along the Hualien River valley near the Lingding Fault. Most of the rupture locations were close to the watercourse and generally trending N20~30°E which parallel to the river channel. More significant co-seismic ruptures and deformations occurred in the Shoufeng Township. In the Wuchuan area, the liquefaction of old channels resulting in the slide and crack eastward on the west bank of the Hualien River, then formed ruptures and subsidence parallel to the river channel. In the sandy area of the Hualien River in Fengping, lateral spreading ruptures and subsidence occurred and formed subsided lowlands. The slumped sediments showing sediments arching were found being pushed and protruding eastward towards the current river channel.

The discontinuous lateral spreading ruptures located at the edge of the river channel also appeared in the Mizhan to Tsaobi area, and some ruptures and sand boils cutting obliquely across the current river flow near the Jianying Bridge in Fenglin. These co-seismic ruptures and deformations mostly occurred at the edges of existing river channels, old riverbeds, or the boundaries of silted ponds, which caused by lateral spreading due to strong ground motion or fissures due to river channel subsidence.

Keywords:2024 Hualien Earthquake, Lingding Fault, rupture, Eastern Taiwan

台東成功外海海洋能潛勢區之地質初探

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為配合政府淨零排放目標之海洋能發展，海洋中心使用勵進研究船搭載之各種探測設備進行海域先期基礎調查。先選擇可能有黑潮經過之台東成功外海近岸進行調查，蒐集長支距多頻道震測 (Long-offset Multi-Channel Seismic，簡稱: LMCS)、底質剖面儀(Sub-Bottom Profiler，簡稱: SBP)影像、水深與流速等資料，做為未來發展海洋能時的海域背景基礎資料，並提供這些相關資料給予國網中心，合作建立海洋能深海工程之動態運算平臺。從船載聲學都卜勒流速剖面儀 (Acoustic Doppler Current Profiler，簡稱: ADCP)所蒐集的流速資料中，得知海水面下38公尺之海流除靠近岸邊的海流之外，大部分海流以50公分/秒的流速往東北方向流動，較未受海底地形影響。而從SBP影像中，得知此區域海床大多為砂質底質較不易穿透，且有V型海底峽谷向陸延伸，初步研判可能為濁流侵蝕，且越往下游切蝕越深，並發現有陷落的正斷層產生，且斷層皆出露於海床，代表此區域構造可能仍在活動。此外，從LMCS影像資料中，觀察到約1.6公里厚 (P波速度約2公里/秒)的沉積層，且測線南端發現大量的崩塌物。因此，初步研判此區域可能仍有地質脆弱帶分布，需要未來持續進行資料蒐集與進階分析等，將詳細的地質脆弱帶位置確認與劃分，藉以作為選擇適合的海域場址設置海洋能發電機具位置之背景資料。

中文關鍵詞：黑潮、長支距多頻道震測、海洋能、底質剖面儀

從淺層沉積構造探討枋寮海底峽谷上游發育與崩塌作用

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位於臺灣西南海域之枋寮峽谷，峽谷上游並未有陸上河川連接，卻能夠往下切約400公尺的深度，且周圍遍佈泥貫入體的構造，其峽谷形成原因可能為泥貫入體抬升，導致滑移崩塌與底流的運輸，逐漸形成枋寮峽谷，且峽谷下游也受到泥貫入體影響分支為二後進入深海平原區。本研究利用勵進研究船T56、T57與LGD2503等航次所蒐集之多音束聲納 (Multi-Beam Sonar)與底質剖面儀(Sub-Bottom Profiler)等資料，進行分析後得到淺層沉積構造影像。從淺層沉積構造影像中發現許多正斷層構造，以及受到泥貫入體影響，可觀察到許多氣體通道逸散現象。進而，觀察其崩塌範圍有兩種不同方式，其一為於枋寮峽谷上游西北側向西滑移崩塌，範圍約5公里寬；另一種為峽谷兩側向內崩塌，且受到泥貫入體抬升作用與分布範圍影響，西側峽谷較東側崩塌範圍大。此外，峽谷頭部形狀呈現V字型，至中游逐漸變為U字型。因此，我們推測若底流機制持續存在，將崩塌物持續運輸至深海平原，枋寮峽谷上游未來會逐漸變寬且坡度逐漸趨於緩和，峽谷頭部形狀逐漸呈現U字型，並可能造成峽谷向陸侵蝕延伸。

中文關鍵詞：枋寮海底峽谷、泥貫入體、滑移、底質剖面儀

Instrument Response of the IES Differential Pressure Gauge and a Seafloor Compliance Study for the Northern Okinawa Trough

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To support future seafloor compliance research, we calibrated the instrument response files of differential pressure gauges (DPGs) deployed by the Institute of Earth Sciences, Academia Sinica, in the northern Okinawa Trough (NOT) during 2018-2019. The calibration process comprised two main steps: phase correction and amplitude (constant) correction.

First, we treated the system as a single-order filter to remove phase offsets that would otherwise distort signal timing. The decision to use a first-order approach was guided by observing the slope of the phase shift in the frequency domain, and identifying the corner frequency as the key boundary of the system's frequency response. We then segmented the data on an hourly basis and applied coherence analysis to pinpoint intervals where pressure and vertical displacement signals showed strong similarity. By maximizing cross-correlation within these intervals, we determined the optimal corner frequency.

Second, we conducted an amplitude (constant) correction by comparing the spectral ratio - derived from teleseismic Rayleigh waves as measured by seafloor pressure signals and vertical acceleration - with theoretical expectations. Minimizing discrepancies between observed and predicted ratios yielded the gain factor required to ensure that measured pressures accurately reflect actual conditions.

Following phase and amplitude corrections, the final dataset effectively removes distortions in both signal timing and amplitude, thereby enhancing measurement reliability. We have also performed a preliminary calculation of seafloor compliance for these stations, and in the next step, we will employ a Markov Chain Monte Carlo (MCMC) inversion approach to resolve the sedimentary velocity structure beneath the northern Okinawa Trough.

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Keywords:Differential pressure gauges, Seafloor compliance, Instrument response calibration

基於臨界吸應力與降雨閾值曲線建立淺層邊坡預警系統之研究

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本研究旨在建立一套具物理基礎、操作簡便並且對於參數要求低的淺層邊坡預警系統，有別於傳統預測模型未考慮前期降雨效應與假設降雨均勻分布可能的預測誤差。本研究基於極限平衡法與統一有效應力理論建立臨界吸應力深度剖面，再配合數值模擬掌握不同降雨條件下的破壞條件與機制，建立出具有物理意義的降雨閾值曲線，並提出「前期降雨延時」估算方法，作為評估降雨開始前坡體穩定性的依據。本研究透過降雨量時間分布特性修正 I-D 閾值曲線，提升對極端或突發性降雨的預測能力，並以歷史邊坡滑動事件進行驗證，顯示本預警系統對預測破壞時間具備有效性。本研究主要貢獻為發展一套具物理基礎且參數要求低之淺層邊坡預警系統，提出前期降雨延時估算方法，及定義簡單明確的參數與操作流程，能夠突破資料數缺漏之限制並合理考量物理機制，強化傳統預測方法不足。本研究方法可應用於缺乏監測設備之淺層邊坡，透過即時氣象預報，提供淺層邊坡動態預測與災害風險管理之參考。

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中文關鍵詞：淺層邊坡、I-D閾值模型、前期降雨延時、預警系統

透地雷達應用於道路坍塌之案例探討

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透地雷達法（簡稱GPR），主要為發射高頻電磁波訊號，藉由不同地層間介電常數差異所產生之反射波，分析反射時間、波型、振幅等資料，以判別反射體的性質與位置。其應用性是最廣泛的淺層地球物理探勘技術，主要原因在於儀器具有非破壞性、解析度高、設備輕便、施測快速的優勢，在工程地質、公共工程、環境污染、建築結構、古蹟等方面已有廣泛之應用與成效。

國內因氣候、地質、管線劣化及新建工程因素，重要道路及水利堤防陸續發生坍塌事件（俗稱天坑）引發各界關注，雙北市已針對新建工程周邊道路實施全面性地下孔洞檢測，建立雙階段透地雷達檢測機制，建商需於放樣勘驗前與竣工前檢測確保道路安全，業界檢測已開始大規模實施，但各類型孔洞、坍塌與灌漿修復後的雷達圖型與資料處理，仍是相當具有複雜性及研判難度的議題。

因應都會區多重環境干擾，坍塌前兆不易早期偵測，每處天坑可能是由不同的成因所致，研究案例探討從實際坍塌圖型、修復灌漿初期階段、地質灌漿改良階段，不同類型透地雷達圖形比對與實務規劃執行，設備包含二維透地雷達、雙頻透地雷達、陣列式透地雷達、車載陣列式透地雷達等技術，探討實務會面臨到之地層受損圖形，其不均質反射特徵具有多元變化的特性，提供道路檢測與地質改良成效重要參考。

中文關鍵詞：透地雷達、工程地球物理、天坑、道路坍塌

An Experimental Study on Fracture Slip and Healing Processes in Geothermal Environments

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Enhanced geothermal systems (EGS) use fluid injection to extract heat from deep depths. Fluid injection after healing may cause fracture slips (small earthquakes), corresponding to fault reactivation. To investigate frictional behaviors of fracture slip and their healing processes, we conducted direct shear experiments under a triaxial configuration on the crushed Chungling formation rocks, a potential target lithology for the EGS operations in the Yilan area. We prepared the gouge samples from the crushed rocks and conducted an X-ray diffraction analysis to obtain their mineralogical composition. We performed experiments under water-saturated and room temperature conditions, at effective normal stress of 10 MPa, and at a slip velocity of 1 μm/s. The Chungling formation is clay-bearing and composed of minerals including quartz, illite, and kaolinite. We obtained frictional healing from variations in static coefficient of friction, $\Delta\mu$, before and after an individual slide-hold-slide test with a hold duration (t_h) of 100 and 100 seconds. The Chungling formation shows steady-state friction coefficient (μ_{ss}) of 0.642, peak friction coefficient (μ_p) of 0.645, healing rate (β) of 0.0015 with t_h of 100 s, and μ_{ss} of 0.641, μ_p of 0.636, and β of -0.002 with t_h of 1,000 s. Extending t_h will obtain a more complete trend of healing. We will compare the results across the triaxial and rotary shear apparatus on other formation rocks, including the Hsitsun formation, expected along the Yuanshan geothermal pilot hole (Y-1) in the Yilan area. Our findings of fracture-slip behaviors can potentially apply to seismic monitoring during EGS operations.

Keywords:fracture slip, healing, slide-hold-slide tests, enhanced geothermal system

BOTDR光纖監測技術應用於剪切帶變形之頻移-剪切位移轉換研究

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BOTDR光纖監測技術應用於剪切帶變形之頻移-剪切位移轉換研究

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摘　要

近年來，分布式光纖感測技術逐漸應用於地工變形監測，其中以BOTDR（Brillouin Optical Time Domain Reflectometry）為基礎之感測系統，具備單端量測、長距離佈設與高穩定性等特點，特別適用於邊坡與剪切帶之長期變形觀測。然而BOTDR所量測之布里淵頻移與實際土體之剪切變形之間並無直接對應關係。因此，本研究旨在建立布里淵頻移與剪切位移間之轉換公式，期望提升光纖感測技術在災害預警與變形量化評估之應用潛力。

本研究初期以室內實驗為主，將分布式光纖預先埋設於水泥柱試體中，待水泥硬化後將試體置入大型直剪設備中進行剪切試驗，模擬地層剪動過程下光纖所受之變形行為，並透過BOTDR持續量測頻移變化，嘗試建構頻移與剪切位移之對應關係。進一步將此對應關係套用在位於新竹土場之邊坡鑽孔中已埋設光纖所量測之布里淵頻移資料，進行剪切位移轉換與初步比對，作為模型實用性驗證之依據。

初步室內試驗結果顯示，布里淵頻移在剪切過程中呈現穩定且具趨勢性的變化，具備建立轉換模型的潛力。部分階段頻移變化與施加位移間具良好對應性，顯示本方法可用於反映剪切行為之細部變化。然而，受限於實驗設備與光纖特性，仍存在需進一步改善之處，例如光纖在剪斷或大變形後可能發生局部損傷，影響頻移讀取精度，另光纖與試體材料間之耦合狀態亦對量測品質有關鍵影響。

整體而言，試驗流程與轉換概念已具初步驗證成果，後續將持續優化試體設計、剪力施加方式與光纖敷設細節，並導入更穩定之耦合介質與封裝結構，以提升系統耐剪性與資料穩定度。此外，預計針對現地頻移資料進行更長時間之觀測與分析，進一步驗證模型在實務工程條件下之適用性與穩定性，最終建立可廣泛應用於地工監測之頻移-位移轉換機制，提供一套兼具理論性與實用性的災害監測技術。

中文關鍵詞：BOTDR、光纖感測監測、剪切位移轉換

臺灣周圍海域離岸風場海域洋流及地質環境分析-桃竹苗外海海底地質特性

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臺灣因應全球碳淨零排放趨勢，提出 2050 淨零排放政策路徑藍圖推動綠色轉型，其中離岸風電為重要再生能源供應來源，開發進程正穩步推進，目前政策已進入第三階段「區塊開發」，惟臺灣西南海域風場將逐漸趨於飽和，未來風電場址選擇將擴展至臺灣島周邊更廣泛的海域，海洋地質環境資料遂成為離岸風電場址規劃的基礎。本研究聚焦桃竹苗外海潛力場址，海能風場與海洋風場周圍海域，透過彙集公開地質調查資料，利用GIS系統整合相關地質圖資，進行海底地質特性與潛在風險分析，建立更全面的區域性基礎資料，並提出潛在風險及工程相關建議。臺灣海峽的潛在地質風險主要包含淺層斷層、 海床淺部堅硬岩盤、 軟質變形以及海床地形變動。桃竹苗外海初步海底地質分析，反射震測剖面顯示湖口斷層、新竹斷層與新城斷層向往西南延伸方向有大量淺層斷層分布，斷層頂部接近末次冰期不整合面，可能為更新世活動斷層，風場建置前應增加高解析度物理探勘密度，確認淺部斷層分布。此外，海床表面觀測到明顯強反射訊號，震測相具有連續性不佳、厚度較薄且較為混亂等特徵，推測為礫石為主的河道沉積物，建議取樣確認，並於未來架設風機時採用具該類岩性礫石層鑽掘能力的鑽機。底質剖面中觀察到大量反白帶分布，主要位於海床淺層且多呈球枕狀，似由沉積物受荷重沉降所產生，需進一步以岩心採樣，並確認風場內具軟質變形風險的位置後，進行地質改良或避免在上方設置風機。苗栗外海有少量沙波分布，沙波遷移可在短期內對海床地形產生改變，須持續監測掌握沙波遷移特性。

中文關鍵詞：離岸風電、海底地質特性分析、海能風場、海洋風場

Finite Fault Solutions of the 2025 ML 6.4 Dapu Earthquake and Its Aftershock Spatiotemporal Distribution

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The occurrence of the ML 6.4 Dapu earthquake on January 20, 2025, in southwest Taiwan provides an opportunity to better understand the mechanisms and deformation style of Taiwan's orogeny. We employ the WASP (Wavelet and Simulated Annealing SliP; Goldberg et al., 2022) package to jointly invert finite fault solutions using teleseismic body and surface waves, along with near-field strong motion data. Our results indicate that the mainshock rupture propagated southwestward on a circular asperity approximately 10 km in diameter, with a maximum slip of about 0.6 m. Although long-period seismic data do not clearly favor one nodal plane over the other, we conclude that the east-dipping plane is the more plausible fault plane; otherwise, short-wavelength structural heterogeneity would be required to explain the observations. To monitor the Dapu earthquake sequence, we deployed 24 SmartSolo stations around the source area by 18:00 on January 21 (local time). Analysis of two weeks of post-mainshock data from this temporary SmartSolo array reveals that events with ML greater than 2.0 exhibit a westward migration pattern along a shallowly east-dipping plane, constrained by the local décollement. We anticipate that continued monitoring of the Dapu earthquake sequence will allow for a more refined delineation of the seismically active boundary.

Keywords:The 2025 Dapu earthquake, Finite Fault Solution, Spatiotemporal Distribution, SmartSolo Array

以姑仔崙山濕地多指標紀錄探討過去 1630年來南臺灣氣候與環境變化

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姑仔崙山濕地位於臺灣中央山脈西南側海拔約1500公尺處。本研究鑽取總長200公分之沉積物岩芯並對其進行花粉分析、總有機碳(TOC)、總氮(TN)、碳氮比(C/N)、穩定探同位素(δ13C)、磁感率以及黑碳含量等多指標分析以重建過去約1600 cal yr BP以來的古環境變遷。

基於花粉資料的類群分析可將本紀錄分為四個時期(Zone I~IV)。結果顯示該地區1600年來，主要以木本花粉為優勢，並以闊葉樹種昆欄屬(*Trochodendron*)及殼斗科(Fagaceae)等樹種佔優勢，顯示植群為穩定的亞熱帶常綠闊葉林。在Zone I時期(1630~1090 cal yr BP)，海洋性物種刺甲藻屬(*Spiniferitaceae*)的出現反映了該時期台灣具有較多的颱風風暴事件。Zone II時期維持亞熱帶常綠闊葉林，環境無明顯變動。Zone III時期(710~280 cal yr BP)木本花粉減少，莎草科花粉(Cyperaceae)增加以及C/N比的下降，顯示當時較為潮濕的氣候。本時期可能與與東亞地區小冰期期間夏季季風增強有關。Zone IV時期(280cal yr BP~近代)則是呈現TN上升、C/N比下降與黑碳含量上升的特徵，顯示近代人類及野生動物活動的顯著影響。

中文關鍵詞：花粉、古環境、小冰期、臺灣南部、颱風

Insights from the 2025 M7.7 Mandalay Earthquake and Their Application to Seismic Hazard Modeling

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We analyzed shake maps from the 2025 M7.7 Mandalay, Myanmar, earthquake to evaluate seismic models for the Sagaing Fault and to revise our probabilistic seismic hazard assessment based on insights gained from this event. An earthquake scenario was also assessed by incorporating rupture parameters and site conditions characterized by V_{S30} (the average shear-wave velocity in the uppermost 30 meters), producing updated shake maps. Our results indicate that areas intersected by the rupture experienced intense ground shaking, with Modified Mercalli Intensity values exceeding VIII. Notably, severe shaking occurred in western Mandalay and southern Sagaing—densely populated regions with critical infrastructure—including downtown Sagaing, the Sagaing Bridge (which collapsed during the earthquake), and western Mandalay.

To further assess seismic hazards along the Sagaing Fault, we constructed a magnitude–frequency distribution of regional seismicity. While events with $M < 6.0$ generally follow the Gutenberg–Richter law, larger events deviate from this trend, likely due to catalog incompleteness. The 2025 earthquake ruptured multiple segments, highlighting a deviation from conventional PSHA assumptions that large earthquakes occur along isolated, individual faults. To account for this complex rupture behavior, we applied the Seismic Hazard and Earthquake Rate in Fault Systems (SHERIFS) model. This approach enabled a refined seismic hazard assessment across Myanmar, particularly in metropolitan areas.

A comparison of the updated shake maps with Myanmar's 2016 building code reveals that most regions did not experience shaking levels exceeding design standards. This finding underscores the importance of continued adoption and enforcement of modern seismic building codes to enhance resilience against future large earthquakes.

Keywords:Mandalay earthquake, Myanmar, Sagaing, PSHA

Reconstruction of Rainfall Events and Empirical Rainfall Threshold Modeling for Landslide and Debris Flow Forecasting

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This study proposes a robust and regionally adaptive method for estimating rainfall thresholds for landslide and debris flow hazards. High-resolution rain gauge data and seismologically confirmed events were integrated using an automated tool (CTRL-T) for rainfall event reconstruction and threshold calculation. The approach emphasizes site-specific parameter adjustment and distance-based rainfall weighting to improve model reliability.

Rainfall events were classified by Taiwan's seasonal climate, with dry-period thresholds adjusted for cold (Oct–Apr) and warm (May–Sep) seasons. To match gauge resolution and reduce uncertainty, thresholds for minor rainfall exclusion were revised from 0.2 mm to 0.6 mm, and sub-event totals from 1 mm to 3 mm.

A proximity-based weighting method was used to assign rainfall to each event. Thresholds were estimated using bootstrap resampling and a frequentist approach, and following a power-law form as expressed in Equation (1):

$$Etype=(\alpha\pm\Delta\alpha)xDtype^{(\gamma\pm\Delta\gamma)} \qquad \text{Eq. (1)}$$

The parameters were derived from 100 resamples, with $\Delta\alpha$ and $\Delta\gamma$ representing the uncertainty. Most debris flows had <300 mm rainfall and <60 hr duration; the 35% exceedance threshold was $ED\,F = (14.6\pm2.9)DDF^{(0.56\pm0.1)}$. Landslides events showed a higher γ and lower $\Delta\alpha$, suggesting greater rainfall sensitivity and more consistent threshold behavior. The findings indicate that hazard-specific thresholds improve early warning system performance.

This framework highlights the importance of regional parameter calibration and spatial rainfall assignment in threshold modeling and will be applied to real-time monitoring and early warning systems to support disaster risk management and response.

Keywords:landslide, debris flow, rainfall thresholds, early warning

馬槽地區地熱水源判釋與水文系統研究

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本研究經由分析大屯火山區域之河水、地熱泉水、地熱井水的氫氧同位素並彙整前人分析的水化學特性資料，以探討地熱水源及水文系統。穩定氫氧同位素是適合判釋水源類型的工具，可探討各區域地熱泉水的來源(源於天水、地層水或岩漿水等)，並能判別與氣體混染及圍岩反應影響程度，以評估影響區域地熱泉水性質變化的因素，瞭解該溫泉露頭的水文系統。

透過氫氧同位素分析結果，馬槽地熱井井頭水$\delta^{18}O$最富集，而地熱井水次之皆較天水富集；針對馬槽地熱井水樣進行陰陽離子組成分析，結果為富含氯離子及硫酸根離子的酸性泉水，此地熱井水水樣特性應為五指山地層水受高溫與圍岩反應所形成。

根據前人文獻於龍鳳谷、地熱谷、小油坑及大油坑地區，分析得富硫酸根離子的酸性泉水，其氫氧同位素明顯較區域天水富集，與受高溫水岩反應、熱蒸氣加熱及硫化氫混合形成特性有關；在馬槽及冷水坑地區，分析得含碳酸鹽的弱酸性泉水，其氫氧同位素與區域天水相近，推測此區域地熱泉水受天水混染顯著；在金山及新北投地區，分析得富氯離子的酸性泉水，其氫氧同位素較區域天水些微富集，與入滲天水受高溫水岩反應形成地熱泉水的特性有關。區域地熱水以五指山層鹵水受火山流體影響，形成富氯離子及硫酸根離子的酸性泉水，經高溫蒸發產生硫化氫，與入滲的天水混合形成富硫酸根離子的酸性地熱水，此類型地熱水δD相對原酸性泉水富集，而部分酸性泉水與安山岩反應後形成弱酸性含碳酸氫鹽的地熱水。

馬槽地熱井的井頭水及井下水樣，其化學組成成分與金山、新北投等地相當，而氫氧同位素分布與大油坑、小油坑等活躍的地熱泉水相近；而馬槽地熱泉水，其化學組成中鈉、鉀及氯離子含量遠低於井頭水，碳酸氫根、鈣及鎂離子含量也略低於井頭水。代表本次地熱井取得的馬槽地熱水，與富氯酸鹽泉相近，且與安山岩反應後形成含有碳酸氫根的地熱水，此地熱水至近地表處受入滲天水混染，使得地熱泉水的氫氧同位素與區域天水相近。

中文關鍵詞：馬槽地區、氫氧同位素、地熱、水源判釋、水文系統

運用2,3-DMP/2,4-DMP比值探索輕質油品成熟度

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台灣西北部的油氣田主要分布於西部麓山帶和新竹外海，以東北—西南向的背斜構造或斷層背斜構造封閉為主要儲油氣構造。本研究針對五個礦區（A、B、C、D及E）的凝結油進行分析，探討輕質油品中單一化合物比值與成熟度的關係。研究結果顯示，這些礦區依序為A（1.0-1.7%Ro）、B（0.9-1.6%Ro）、C（0.7-0.8%Ro）、D（0.8-0.9%Ro）、E（0.6-0.8%Ro）。分析2,3-二甲基戊烷（2,3-DMP）及2,4-二甲基戊烷（2,4-DMP）的比值，發現其均值與各礦區最低熱成熟度呈現良好的線性關係（R^2=0.92）。這種比值方法可作為評估熱成熟度的替代指標，特別適用於缺乏生物指標化合物的情況。然而，應用此方法時需考慮地質條件的相似性，且需要更多數據進行驗證。

中文關鍵詞：輕質油、油品成熟度、C7異構物

High-Resolution Attenuation Tomography with SALUTE: Unraveling Fault Systems and Forearc Deformation in the Southern Taiwan Collision Zone

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The **S**outhern **A**rray for the **L**ithosphere and **U**plift of **T**aiwan **E**xperiment(SALUTE) provides an amphibious broadband network that crosses the subduction-collision transition in southern Taiwan, offering an exceptional opportunity to probe crust-mantle architecture. We analyze *P*- and *S*-waveforms (1–10Hz) from regional earthquakes ($M_L \geq 3.5$) recorded by SALUTE together with permanent BATS and CWASN stations to construct a frequency-dependent attenuation model with kilometer-scale resolution. Residuals of wavelet-integrated spectral amplitudes relative to those predicted by 1-D synthetics that account for a Brune-type and moment tensor source radiation and elastic wave propagation effect are used to constrain a 1-D frequency-dependent, depth-varying Q profile. This 1-D model serves as the reference for a subsequent 3-D inversion to image the attenuation structure of the crust and uppermost mantle across the transition zone.

The resulting attenuation model reveals pronounced lateral contrasts in the uppermost 15 km of the crust: low-Q anomalies coincide with low-velocity sedimentary basins beneath the Western Foothills and the Longitudinal Valley, whereas high-Q anomalies track high-velocity metamorphic rocks of the Central Range. Sharp attenuation gradients delineate major active faults, refining their geometry and dip. A north–south–striking low-Q_P corridor, dipping gently (~15°) northward from 10km to 40km depth between the eastern coast and the Luzon Arc, likely reflecting the underthrusting deformed forearc domain resulting from the ongoing oblique collision of the Luzon arc with the Eurasian continental margin.

By integrating dense onshore and offshore observations, this study demonstrates that high-resolution attenuation tomography is a powerful complement to velocity imaging. The new model illuminates crustal sutures, identifies fluid-rich zones associated with tremor activity, and refines the geometry of seismogenic faults, thereby improving constraints on seismic-hazard assessment and advancing our understanding of collision-zone deformation in southern Taiwan.

Keywords:SALUTE broadband array, Seismic attenuation tomography, Southern Taiwan collision zone, Fault architecture, Forearc deformation

Broadband Calibration of Ultrasonic Transducers Using Generalized Ray Theory, Finite Element Method, and Laser Doppler Vibrometry

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Broadband ultrasonic transducers are extensively employed across engineering, laboratory, and medical applications. While these sensors excel in qualitative comparisons, their use in quantitative applications requires comprehensive calibration across their operational frequency range.

Here we present a broadband calibration methodology for acoustic emission sensor systems, with a focus on absolute amplitude response characterization of the Olympus V103-RB ultrasonic transducer up to 1 MHz. Using controlled ball drop impacts on PMMA and steel plates as calibration sources, we characterize the acoustic emission and sensor response across 1 kHz to 1 MHz through three complementary techniques: generalized ray theory, finite element analysis (FEA), and laser Doppler vibrometry (LDV).

We compare theoretical simulations and LDV measurements against independently recorded acoustic emission signals from the ultrasonic transducer. This approach allows us to evaluate amplitude response consistency and accuracy across different frequency bands. Our results demonstrate each technique's distinct advantages in specific frequency ranges, with their integration enabling more robust sensor characterization. This methodology contributes to establishing a practical and accurate framework particularly valuable for laboratory-scale seismic source experiments that require high precision and reproducibility, especially for laboratory earthquakes where corner frequencies fall within the 1 kHz to 1 MHz range. Additionally, this calibration reveals whether the transducer is most appropriate as a displacement, velocity, or acceleration sensor in different frequency bands. The framework can be further extended to characterize attenuation frequency response of the medium, another important aspect for accurately estimating corner frequencies.

Keywords:Acoustic sensor calibration, Broadband frequency response, Generalized ray theory, Finite element method, Laser Doppler vibrometer

Earthquake Rupture Initiation Location and Fault Overstress Geometry Shape the Evolution of Source Time Functions

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The dynamic behavior of fault rupture is strongly influenced by rupture initiation location and initial stress distribution. This study addresses a critical gap in earthquake source mechanics by investigating how rupture initiation positions interact with different geometries of overstress zones to affect the source time function (STF), a previously understudied factor that substantially influences earthquake characteristics even under identical stress distributions.

Using the open-source software uguca, which implements spectral boundary-integral method for numerical simulations, we model circular, rectangular, and elliptical overstress geometries—defined as regions where initial shear stress exceeds the fault's residual strength. Shear stress remains constant within high-stress regions and decreases linearly toward surrounding areas, while a uniform strength profile is maintained through a consistent friction law. By systematically varying rupture initiation locations, we analyze rupture propagation behavior and energy release patterns.

Our results show that rupture initiation conditions and shear stress heterogeneity significantly influence the seismic energy release mechanism, directly shaping the STF and determining the rupture propagation directions. We identify three distinct phases in the rupture process: 1) growing phase, where STF amplitude increases as rupture initiates and expands; 2) steady phase, characterized by relatively constant STF amplitude, strongly dependent on overstress zone geometry; and 3) arrest phase, where STF amplitude gradually diminishes to zero. These effects become particularly pronounced when rupture initiates near overstress zone boundaries, where rupture propagation and STF characteristics clearly reflect the geometry of the overstress zone.

This enhances our understanding of natural earthquakes and improves our ability to infer rupture patterns and fault stress distributions from observed STF characteristics in seismic records.

Keywords:Earthquake rupture dynamics, source time function (STF), overstress zone geometry, rupture initiation location, spectral boundary-integral method

梨山斷層磁性組構與變質溫度之研究

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梨山斷層作為雪山山脈與脊樑山脈的邊界斷層，與台灣島的造山歷程密切相關，亦與地熱資源的分布密切相關。梨山斷層沿線分布多處溫泉，如排谷溪、紅香與芃芃溪等，顯示其與地熱資源有相當的潛在關聯，因此透過了解梨山斷層與熱液上升路徑的關係，可以有效縮小梨山斷層沿線地熱調查的範圍。然而，過去研究多聚焦於區域尺度的構造演化，針對梨山斷層的高密度研究較為稀缺，使得其精確位置仍存不確定性。

前人研究指出，磁感率異向性（AMS）為敏感的應變指標，可用於辨識褶皺軸部與斷層活動帶位置；而雷射拉曼碳質物測溫（RSCM）則可推算岩石的最高變質溫度，補足構造活動之熱演化資訊。

本研究將針對雪山山脈與脊樑山脈交界區進行高密度定向採樣，製作AMS定向方磚樣本，並以磁感率測磁儀量測橢球體三軸方向與大小，推算其磁性參數。另一方面，製作定向薄片，藉由量測岩石中碳質物的拉曼散射訊號，進而估算其所經歷之最高變質溫度。最終將透過交叉比對AMS 異常高峰值與RSCM溫度明顯變化之位置來評估梨山斷層活動的空間範圍。

本研究將透過高解析度 AMS 與 RSCM 數據整合分析，補足過去研究資料密度不足之處，精確界定梨山斷層位置，進而釐清其對地熱資源的控制作用。研究成果將有助於縮小地熱潛勢區範圍，提高選址準確性，為未來地熱資源開發提供更科學的依據。

中文關鍵詞：梨山斷層、非均向磁感率、雷射拉曼光譜碳質物測溫

上新統－更新統地層界線對比再研究

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國際地質科學聯合會在2009年將更新世起始年代（等同於第四紀起始年代），由1.805百萬年前修訂為2.588百萬年前。這改變意味著國際地層年代表國際版及地方版也要更新。此外，在閱讀2008年前之第四紀地層文獻，也要額外注意論文內容之第四紀定義與現今有顯著區別。本團隊有幸於2024年9月與當地合作者一同訪問均在義大利境內的新（杰拉期底界）及舊（卡拉布里亞期底界）第四紀國際標準剖面（金釘子）考察並採取界線上下地層樣本，一共帶回10個樣本，總重約20公斤。計畫將樣本分成超微化石及微體化石兩個部分研究，前者用於生物地層對比與臺灣地層接軌，後者主要探討界線上下生物多樣性變化及生物滅絕及復甦模式。

修訂臺灣第四紀地層定義，對金釘子剖面再研究是迫切必要的。雖然在臺灣研究第四紀地層之團隊眾多，但有親自考察上新世-更新世界線金釘子剖面之學者鮮矣，能採集岩樣並帶回臺灣者更如鳳毛麟角。有鑑於樣本之稀缺性及對臺灣地質之重要性，本研究將會提升臺灣第四紀地層對比精度，有助於將臺灣新生代地球歷史研究呈現在世界舞台上。

中文關鍵詞：金釘子剖面、杰拉期、卡拉布里亞期、生物地層對比、地中海

使用多重震波屬性及類神經網路識別泥貫入體之應用研究

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以往於台灣西南海域海床下發現許多泥貫入體分布，傳統上藉由人工判釋地層反射訊號之有無，圈繪出其位置。目前已發展出許多震波屬性用來輔助識別地層特徵，亦有借助多重震波屬性及類神經網路進行斷層及氣囪識別之研究。本研究之前已藉由結合反射振幅、反射連續性及反射頻率等不同的震波屬性，利用商業軟體的類神經網路分析工具對震測影像進行分類，嘗試出識別出泥貫入體之位置。

震測特徵的描述區分為反射振幅、反射連續性及反射頻率等三類，本研究其對應的震波屬性採用均方根振幅(RMS Amplitude)、震測包絡線(Envelope)、方差(Variance)、渾沌(Chaos)、主頻率(Dominant Frequency) 、瞬時頻率(Instantaneous Frequency)及甜度(Sweetness)等。本研究再加上反映震波訊號角度變化的震波屬性如傾角(Dip) 、傾角偏差(Dip deviation)、 曲率(Curvature)等作為類神經網路的輸入資料進行分類。本研究設定不同的屬性組合及調整參數進行分析並探討其影響，嘗試判釋出泥貫入體及其相關的地質構造與現象。

中文關鍵詞：震測解釋、震波屬性、類神經網路、泥貫入體

Comparison of Cenozoic Rift-Drift Transitions in the Northern Taiwan Hsuehshan Trough and Southern East China Sea Shelf Basin: Insights from Detrital Zircon Analysis

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Understanding sedimentary provenance is crucial for reconstructing basin evolution. In rift settings, syn-rift phases typically reflect locally derived sedimentation due to active faulting, while post-rift stages, influenced by thermal subsidence, exhibit polymodal detrital zircon age spectra from more distal sources. However, provenance shifts linked to basin evolution have been largely overlooked in studies of Taiwan, which have focused mainly on drainage changes. To address this gap, we examined the source-to-sink history of the Hsuehshan Trough by compiling published data and conducting new detrital zircon U-Pb dating (LA-ICP-MS) on samples from the Wuchihshan to Shihti Formations (Oligocene to Lower Miocene) in the well-exposed Waimushan Profile. We applied the bivariate discrimination model introduced by Baham et al. (2022, *EPSL*) and integrated it with multidimensional scaling (MDS) to differentiate syn-rift, transitional, and post-rift stages. This approach was benchmarked using the extensively studied Songliao Basin (e.g., Song et al., 2022, *Geoscience Frontiers*; Wang et al., 2024, *Terra Nova*).

Our analysis indicates that the Hsuehshan Trough transitioned from a syn-rift to a post-rift basin in the Early Miocene, with clear post-rift signatures during the deposition of the Taliao Formation. In contrast, the southern East China Sea Shelf Basin remained in syn-rift to transitional stages from the Paleocene through the Early Miocene, likely not reaching post-rift conditions until the Middle or Late Miocene. These findings highlight the utility of the bivariate discrimination model in distinguishing not only tectonic regimes but also in resolving finer-scale basin evolutionary stages. The prolonged syn-to-post-rift transition in the Hsuehshan Trough, compared to the extended transitional state of the East China Sea Shelf Basin, reflects fundamentally different tectonic histories across the two regions.

Keywords:Basin evolution, Hsuehshan Trough, East China Sea Shelf Basin, Detrital zircon U-Pb geochronology

Analyzing Gas Seepage Structures offshore SW Taiwan : Acoustic and Seismic Insights into gas plume

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Gas seepage is a widespread geological phenomenon at continental margins, but its spatial distribution and formation mechanisms in nearshore environments remain unclear. This study investigates the spatial distribution, characteristics, and controlling factors of gas seepage offshore southwestern Taiwan. EK60 singlebeam echosounder data (2000-2021) from three cruises abroad R/V *Ocean Researcher I* were analyzed to identify gas plumes and potential cold seep sites. Multibeam water column images and multichannel reflection seismic data were used to validate these sites and assess their geological background. Three distinct gas seepage sites were identified: (1) East of Shoushan Canyon, a 180 m-high plume at 360 m depth; (2) Kaoping Submarine Mud Volcanoes Group, a 200 m-high plume at 800 m depth; (3) Passive Margin sites, a 150 m-high plume at 850 m depth. In the active margin, gas seepage occurs atop mud diapiric ridges, likely driven by tectonic compression and elevated pore pressure, facilitating rapid gas migration. In the passive margin, seepage is primarily sourced from biogenic methane, likely released via gas hydrate dissociation or organic matter degradation. The gentler slope of the bottom-simulating reflector (BSR) and stable temperature-pressure conditions in the passive margin likely result in a slower gas release rate and lower gas column heights compare to the active margin. To assess the impact of gas seepage characteristic on sound transmission, we used a 3D parabolic acoustic model, varying methane concentrations, plume heights, and sizes at different water depth. The simulations reveal greater transmission losses in shallow waters than in deep waters under equivalent conditions. Higher methane concentrations and shorter source-to-flare distances further increase sound attenuation, providing insights into optimal sound sources and hydrophone array placements for monitoring gas seeps. Future studies will validate gas flare characteristics through fleid experiments. The objective is to reduce uncertainties in sound propagation from gas emissions, aid geohazard mitigation and ocean monitoring, and improve understanding of gas seepage dynamics for subsurface exploration and risk assessment.

Keywords:Gas seepage, Singlebeam Echosounder, SW Taiwan, 3D parabolic model, Sound propagation

Unraveling Geological Complexity in Southern Taiwan Through Eikonal Tomography and Dense Seismic Arrays

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Southern Taiwan is characterized by a complex network of fault systems that play a crucial role in its tectonic dynamics. In previous studies, observing these fault systems through seismic tomography was challenging due to the sparse distribution of seismic stations. To overcome this, the study employs an advanced Eikonal tomography approach, utilizing data from approximately 300 seismic stations deployed over three different time periods, with an interstation spacing of ~1.5 km. By integrating multimode surface waves derived from ambient noise, this method significantly improves image resolution in both horizontal and vertical dimensions. The results reveal prominent anisotropic patterns that align with regional stress directions and fault orientations, providing critical insights into the tectonic forces shaping Southern Taiwan’s subsurface structures. These findings provide critical insights into the tectonic forces shaping Southern Taiwan's fault systems. Furthermore, this innovative approach enhances our understanding of subsurface structures and fault interactions, while offering a scalable framework for investigating complex geological environments in tectonically active regions worldwide.

Keywords:Eikonal tomography, dense arrays, Southern Taiwan, noise interferometry

Exploring the Geological Structures in the Aseismic Zone of Taiwan Orogenic Belt

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The southern Central Range (CR) of Taiwan hosts a prominent aseismic zone adjacent to areas of active tremor and shallow seismicity, offering a unique opportunity to investigate the interplay between crustal structure, deformation, and fluid processes in an active orogenic belt. This study investigates the subsurface structures and tectonic evolution of the aseismic zone beneath the Central Range (CR) and Longitudinal Valley (LV) in eastern Taiwan, integrating seismic travel-time data, gravity observations, and temporary seismic network deployments. By employing a sequential inversion technique, we refined three-dimensional Vp and Vs velocity models and their associated Vp/Vs ratios, enhancing the resolution of both shallow and deep subsurface structures. Our results reveal a broad mid- to lower-crustal domain of elevated Vp/Vs ratios (>1.8) beneath the aseismic zone, interpreted as a fluid-rich, thermally weakened environment.

In contrast, low Vp/Vs anomalies with reduced Vp dominate the eastern flank of the CR, corresponding to high-attenuation (low-Qp and Qs) zones identified in previous tomographic studies. These features are attributed to crustal fluids residing in unsaturated microcracks, likely associated with long-term crustal thickening and fracturing. Tremor activity occurs at the structural margins of the aseismic zone, spatially confined to the edges of high Vp/Vs domains and within adjacent low Vp/Vs regions, suggesting a role for fluid overpressure and mechanical heterogeneity in modulating episodic slip.

Shallow crustal slices further reveal several high Vp/Vs anomalies that align with surface exposures of serpentinite and mafic intrusions, magnetic highs, and shallow Curie point depths. These observations point to the tectonic emplacement of ultramafic bodies, which may continue to influence local rheology and deformation. Together, our findings highlight the complex rheological and fluid-driven processes that govern the distribution of seismicity in the southern Central Range, and offer new constraints on the evolution of aseismic deformation in collisional mountain belts.

Keywords:Aseismic zone, Seismic tomography, Gravity inversion, Sequential inversion

臺南台地高樓層建物頻譜反應與震動模式之探討

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臺灣位處於環太平洋地震帶，地體構造活動頻繁、斷層系統分布綿密且具高度活動性，致使地震災害風險長期存在。而針對地震事件中較易受震波影響之高樓層建築，進行震動模式分析與探討，不僅有助於建立地震災害風險評估之標準，亦可藉分析成果建立結構健康監測（SHM）系統，幫助地震事件發生後即時精確掌握建築物受損狀況，提升災後損害評估之準確性與應變效率。

本研究以位處臺南都會區，樓高12層之國立成功大學資源系系館為研究場域，以觀察台南台地上高樓層建物於地震時所受之影響。藉由於建物1樓、7樓、9樓與12樓裝設之Palert加速度儀與三分量速度感震器，成功建立水平及垂直地震儀陣列，並紀錄數筆嘉義、臺南、花蓮地區之地震紀錄。根據該紀錄，本研究提供台南台地之中高樓層建物各樓層震度放大效應之參考，並分析與比較不同規模、不同震央位置之地震對於建物產生之加速度和旋轉率的差異，完整觀察狹長形結構物在地震事件中產生之反應。此外，本研究亦針對非完全對稱之狹長形結構物，其建物各點位在地震事件中的加速度與旋轉率差異進行完整記錄與分析，並比較透過水平陣列推估與旋轉地震儀直接量測所得之旋轉率差異。透過本研究之分析結果，可將其應用於高樓層結構物之設計優化與數值模擬精度之提升，以提升建物之抗震性能與韌性。

中文關鍵詞：高樓震波資訊、震動頻率、樓層放大效應、旋轉率

High-precision dating using palaeomagnetic secular variation Its applications and limitations for deep-sea sediment geochronology: A case study from the Japan Trench

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The sedimentary sequence in the axial basin of Japan Trench over 7,000 m water depth involves unique earthquake-induced turbidite. To understand to relation between such deposits to historical documented earthquake events, detailed age of turbidites is essential. However, standard radiocarbon dating based on calcareous fossils and organic carbon is challenging due to poor preservation and lack of material in the ultra-deep basin. On the other hand, we found that excellent paleomagnetic secular variation (PSV) record, which is resultant from a character that the earth's magnetic field changes, are preserved well in the Japan Trench sediment. This PSV, especially declination during the past 3,000 years revealing a distinctive feature of large oscillation, offers also an opportunity to make precise stratigraphic correlations to the master curve, resulting in good age control.

Additionally, we found that if sedimentation rate is slower than 50 cm/ka, such sediments are not suitable to extract unique PSV. Also, turbidite does not record precise paleomagnetic direction at the timing of deposition probably due to affection of strong turbulent during deposition. In order to extract PSV, it is necessary to distinguish event deposit interval based on lithological and physical information.

Once PSV record is extracted successfully, the turbidite ages can be constrained by referring an individual PSV curve to the reference PSV curve such as the Lake Biwa PSV record back to 10,000 years ago (Ali et al., 1999). Especially, the ages of turbidite units regarded as induced by the “Jogan earthquake” (CE. 869), which is considered as M9 earthquake can be well recognized.

Keywords:Turbidite, Paleomagnetic secular variation, Japan Trench, Historical earthquake

整合沉積物中多環境指標探討1680 cal. BP以來臺灣北部環境變遷

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本研究使用採集自大屯火山群七星山鴨池的沉積物岩芯，分析沉積物總有機碳（TOC）、碳氮比（C/N）、有機碳穩定碳同位素（$\delta^{13}C_{TOC}$）、黑碳（BC）、黑碳穩定碳同位素（$\delta^{13}C_{BC}$）與磁感率（MS），來重建 1680 cal. BP 以來臺灣北部山區環境變化。基於多指標變化趨勢，可劃分為四個時期。在 1680－1000 cal. BP，沉積物中 $\delta C\text{-}13_{TOC}$ 維持在 −26～−27‰，指出顯示周圍植群以C3植物為主，較低含量的BC顯示反映潮濕的氣候。在 1000－530 cal. BP（中世紀暖期），沉積物中 $\delta C\text{-}13_{TOC}$ 降低到 −28‰，顯示 C3 植物比例增加。BC 上升顯示此時亦不乏有野火發生，且 $\delta^{13}C_{BC}$ 的增加表明此時野火燃燒物以草本植物為主。可推論出此時期氣候較溫暖，但降雨季節不均，主要集中在夏季，冬季較為乾燥，可能與冬季風的減弱有關。650－530 cal. BP 間，BC 濃度的下降表明野火減少，可能暗示此時降雨增加。530－330 cal. BP 則可以對應到小冰期初期，此時東亞進入寒冷的階段。而 $\delta^{13}C_{TOC}$ 增加到 −23‰ ，表示顯示周圍植群轉變為以 C4 植物為主。較高的 BC 顯示頻繁野火的發生，代表較為乾燥的氣候。而 330 cal. BP 至今，較高的 $\delta^{13}C_{TOC}$ 顯示周圍依然以 C4 植物為優勢。而 MS 的顯著上升以及較多的安山岩碎屑的存在，意味著顯示較多山崩事件的存在。本岩心紀錄所紀錄的山崩事件，可能與《裨海記遊》所載西元 1694 年台北地區發生大地震有關。而另一個可能則是與台灣北部小冰期晚期以來，較多颱風事件有關。而顯著減少的 BC 含量，也反映該時期可能有較多的降雨。

中文關鍵詞：中世紀暖期、小冰期、古環境重建

Dominant myctophid otoliths indicate late Miocene coastal upwelling in Panama

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Marine fossils from the late Miocene Chagres Formation in northern Panama offer critical insights into the paleoenvironmental conditions and ecological responses just prior to the separation of the Atlantic from the Pacific by formation of the Isthmus of Panama. Here we present a systematic study based on more than 6,200 otoliths collected from a coastal exposure near the town of Piña, Colón. This assemblage is remarkable for the extraordinary dominance of the family Myctophidae, constituting over 96% of specimens. The otolith density in the sediments is the richest known globally. The taxonomic composition is represented by 33 taxa across 13 families, including several newly described species. Taphonomic evidence, combined with abundant predatory marine vertebrate fossils and extensive burrow ichnofossils, indicates a dynamic and highly productive near-shore ecosystem. The dominance of myctophids and multiple lines of evidence support the existence of a late Miocene coastal upwelling system in the region, highlighted by efficient trophic transfer channeled from high primary production to apex consumers. These findings provide a nuanced understanding of Neogene marine ecosystems prior to the final emergence of the Isthmus of Panama.

Keywords:Neogene, Chagres Formation, Mesopelagic fishes, Teleosts, Chondrichthyes

A new Miocene marine fish assemblage from the Penghu Archipelago, Taiwan

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This study documents a newly investigated Miocene marine fossil assemblage from the Penghu Archipelago, Taiwan, based on field collections conducted in 2024 and 2025. Approximately 200 kg of semi-consolidated, fossil-bearing sandstones from Dongyupingyu and Qimei islands yielded abundant marine fossils, including highly diverse mollusks, echinoids, fish teeth, and particularly well-preserved fish otoliths. Preliminary analyses identified a rich otolith assemblage comprising croakers (Sciaenidae), codlets (*Bregmaceros*), cardinalfishes (Apogonidae), and flatfishes, indicating a predominantly shallow marine paleoenvironment, consistent with sedimentological and taphonomic evidence of high-energy depositional conditions. Mesopelagic or deep-water fish are absent in the collection. Notably, the occurrence of several otolith-based extinct Miocene sciaenid taxa provides strong evidence of faunal connectivity between Penghu and the previously described isolated Late Miocene assemblage from northern Taiwan. This discovery significantly extends our understanding of regional fish paleobiodiversity and biogeographical linkages during the Miocene in the western Pacific.

Keywords:Miocene, Penghu Archipelago, Marine fossil assemblage, Shallow marine paleoenvironment, Otoliths

Site-specific Probabilistic Seismic Hazard Assessment in Mamuju, West Sulawesi, Indonesia: Implementation of Time-averaged Shear Wave Velocity (Vs30) from Multichannel Analysis of Surface Waves (MASW)

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The time-averaged shear wave velocity down to 30 meters depth (V_{S30}) is recognized as an essential factor in determining soil amplification when using a ground motion model. However, its process and implementation have not yet been fully optimized in seismic hazard analysis. This study aims to obtain V_{S30} and apply it to site-specific Probabilistic Seismic Hazard Assessment (PSHA) in Mamuju, West Sulawesi, Indonesia. Dispersion curves of phase velocity have been derived from Multichannel Analysis of Surface Waves (MASW) and were used to perform inversion for V_S profiles, from which V_{S30} values were calculated. To overcome the limitation of reliable inverted depth from MASW, two extrapolation methods: bottom constant velocity and statistical extrapolation were proposed. Seismic catalogues from ISC (1976-2009) and BMKG (2009-2023) were integrated to perform PSHA. Using the b-value stability to initiate the magnitude of completeness, only events with $M_W \geq 4.6$ were included in the analysis. To represent shallow crustal seismic activity, this study proposed a combination of area source and smoothing model to reduce epistemic uncertainty. To estimate fault rupture probability, both truncated exponential model and pure characteristic model were implemented. In addition, this study also applied two different temporal models: Poisson and BPT. GMMs from NGA-West2 were examined by comparing the estimated ground shaking with the RotD50 observations of the 2021 M_W 6.2 Mamuju earthquake. GMPEs were then weighted based on the Euclidean distance-based ranking. Different V_{S30} datasets, derived from topographic slope, geomorphology, and MASW, were individually tested as site models.

Keywords:Shear Wave Velocity, MASW, PSHA

Evaluating Variability in Seismologically-Estimated Stress Drop in Earthquake Ruptures with Negative Overstress Boundaries

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Stress drop is a fundamental parameter in seismology that quantifies the average decrease in shear stress during seismic energy release. Despite its importance, substantial uncertainty remains in stress drop estimations, particularly related to the effects of rupture geometry and nucleation conditions.

This study employs dynamic rupture simulations using spectral boundary-integral method with linear slip-weakening friction law to systematically investigate stress drop variability in earthquake ruptures. Unlike previous numerical studies that predominantly use velocity-strengthening or high fracture energy boundaries to arrest rupture propagation, we implement an approach based on recent laboratory earthquake observations. We control rupture extent through negative overstress zones, also referred to as “earthquake arrest zones”, defined as areas where initial stress is lower than residual strength.

Using this framework, we explore how various source characteristics, including the geometry of the overstress patch, rupture initiation location, and other features in initial stress distribution, influence stress drop estimations through seismological methods. By comparing theoretical predictions with simulation results, we evaluate whether commonly derived seismic parameters (corner frequency f_c and spectral decay rate n) follow expected relationships under different rupture conditions. Our findings contribute to understanding the limitations and uncertainties in current stress drop estimation methods, particularly when applied to earthquakes with more realistic initial stress distribution.

Keywords:stress drop, earthquake arrest zones, linear slip-weakening

以深度學習自動化地震目錄建構

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台灣位於活躍的弧陸碰撞帶，地體構造複雜，地震活動性高，因此對於發震構造的深入了解，不僅有助於探討造山構造的演化歷程，也對地震防災具有重要意義。而完整的地震目錄，不僅能有效呈現區域性發震構造，亦有助於分析地震活動的時空分布與物理行為。過去十餘年來，台灣地震觀測系統大幅提升測站密度，並逐步採用連續資料方式記錄地震波形，為震源參數的精確估算與地震目錄的建立提供豐富資料來源。目前氣象署地震目錄的製作流程仍高度仰賴人工進行地震波相的挑選，此過程不僅耗費大量人力資源，亦可能因主觀判讀造成波相誤判或遺漏，為提升處理效率與波相辨識的準確性，本研究將導入機器學習方法，自動化波相挑選流程。針對中央氣象署CWASN、BATS、強震儀測網（TSMIP）近年來所累積之連續地震波形資料，以機器學習方法進行的自動化地震事件偵測、波相判讀與地震目錄建構，能夠有效改善過去方法的限制，進一步提升地震目錄的完整性與精度。

首先我們利用機器學習模型在連續波形上判識 P 波與 S 波到時的機率分布，並透過反投影法將其定位於三維速度模型中以獲得初始震源位置，再進一步進行精確定位，定位使用三維速度模型建立的走時表以提高定位精確度，並使用網格搜索法進行地震定位，透過到時差來計算可能的震源，使用機率密度函數疊加所有可能找出最可能的震源位置。

初步分析數個月的觀測資料後，與中央氣象署的地震目錄比較顯示，我們自動化建立的地震目錄事件數約為官方目錄的兩倍左右，顯示本方法能顯著提升事件偵測能力。然而，仍有少部分事件遺漏，未來將根據測試結果，調整震源定位流程中的門檻與篩選條件，以建立更完整、可靠的地震目錄，本研究成果可望促進對台灣區域孕震構造與地震物理行為的深入理解，並強化地震監測能力。

中文關鍵詞：地震目錄、地震定位、機器學習

混合式數值模擬方法對情境地震的應用

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為瞭解台灣西南部地震波傳遞特性以及地震波在不同頻率段的震動特性，本研究使用三維數值模擬情境地震及歷史地震在台灣西南部地震波傳遞過程及地動分布，以低頻及高頻震波探討致災因子。過去相關單位已針對不同區域的震度分布使用地震波歷時資料模擬地層受震時的反應，但因現有之地震觀測站數量有限，且地下構造複雜，進而直接影響受震評估的準確度。前人研究中指出，利用情境地震模擬可以有效模擬區域的地面震動特性。因此，本研究目標為使用低頻的波傳數值方法建置三維地震動模擬，藉由高頻的經驗格林函數模擬的地震波形，將低頻與高頻訊號透過混合式方法計算，模擬區域範圍內地震動的過程。

本研究首先嘗試使用經驗格林函數法，將數值模擬方法(如譜元素法)所模擬之低頻地震波形與區域地震的經驗格林函數進行計算來驗證1022嘉義地震的震度分布。本研究將比較疊積法與線性疊加法在模擬上的優缺點，並與觀測資料進行比較以驗證其可信度與可行性，最後模擬台灣西南部的災害情境地震，對地震所可能造成的災害及影響進行評估與討論。因此，本研究目標係利用情境地震設定，分別計算低頻及高頻的地震波歷時，藉由混合式的方法計算含有低頻與高頻資訊的寬頻地震波歷時，進而得到較接近真實的震度估算，未來可將計算結果及方法、流程應用於地震風險及建物災損評估。

中文關鍵詞：台灣西南部、三維數值模擬、譜元素法、致災因子

石榴子石對於地球內部熱演化之影響

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石榴子石對於地球內部熱演化之影響

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摘要

石榴子石(garnet)為地球內部重要的礦物組成之一，存在於海洋地殼、上部地函以及過渡帶中，其深度範圍約在200~700公里。Ringwood (1962)的高壓實驗模擬地球內部的礦物組成，建立了輝橄欖岩模型(pyrolite model)，其中橄欖石(olivine)、輝石(pyroxene)及石榴子石為上部地函主要的礦物組合，並表示石榴子石與其高壓相(majorite)在地函過渡帶中的體積占比達到約30~40%。Irifune et al. (1986)於隱沒板塊深度與矽酸鹽類礦物相平衡關係實驗中，將榴輝岩(eclogite)作為模型中隱沒海洋地殼深部受壓力擠壓轉變為變質岩時的主要成分，在此模型中，石榴子石與其高壓相(majorite)的體積占比高達80%，且能夠穩定存在於最深800公里處。石榴子石的熱傳導性質對於了解上部地函熱演化至關重要，本研究透過高溫高壓及光學實驗方法，量測石榴子石於海洋地殼中的熱傳導係數變化，藉此窺探地球內部熱演化過程。

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中文關鍵詞：石榴子石、熱傳導率、地球動力學

利用地電阻法監測農田土壤乾燥歷程水分變化之研究

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地電阻法（Electrical Resistivity Tomography, ERT）是一種非破壞性的土壤電阻率量測技術，與土壤含水量呈現高度反向關係，相較於接觸式水分計可能因開挖安裝造成的土壤擾動與量測區域受限等問題，地電阻法能有效克服此類不確定性與侷限性。本研究於彰化縣竹塘鄉一處水田，以及臺中市霧峰區農試所內各一處水田與旱田，共三處農田進行為期一整年的地電阻監測，涵蓋兩期作物生長週期，研究重點在於探討不同土壤條件、作物種類與灌溉操作下，農田電性變化所反映的水文意義。

在每次灌溉結束後，隨農田乾燥過程，土壤電阻率呈上升趨勢，本研究以指數函數對該變化歷時進行迴歸分析，三處場址之判定係數分別為0.98(竹塘水田)、0.96(農試所旱田)與0.89(農試所水田)，顯示所建立之電阻率歷時曲線具良好擬合度，能有效量化不同農田間的水文特性差異。分析結果顯示，竹塘水田歷時曲線斜率小於農試所水田，顯示其排水效率較慢，經鑽井資料比對，推論與當地土壤材料差異有關；而比較農試所兩處試驗田中，水田之排水效率高於旱田，儘管其土壤材料分布相似，由於水田長期處於較濕潤環境，導致其導水能力有所差異，此交互比較結果驗證土壤材料與含水狀態對農田導水特性的影響。

綜合上述成果，本研究建立之土壤乾燥歷時曲線可提供兩項重要應用：(1) 快速評估次回灌溉時間，提升農業水資源利用效率；(2)分析農地排水能力，作為滯洪效能評估之量化指標，對農田的水文調控與防災應用具實質意義。整體而言，本研究證實地電阻法可作為有效監測土壤水分變化的工具，並可進一步探討其電性參數與水力傳導特性之關聯性，為農業水資源管理與極端氣候下的調適提供科學依據，助益農業永續經營發展。

中文關鍵詞：地電阻探測技術、農田土壤水文特性、農業水資源、滯洪防災

Enhancing Time-Lapse Vertical Seismic Profiling (VSP) Monitoring Efficiency through Survey Design for Carbon Storage at the Changbin Candidate Site in Taiwan

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Time-lapse seismic surveying is essential for tracking the evolution of injected CO_2 plumes and detecting potential leakage at carbon storage sites. Monitoring the wellbore zone and the overlying aquifer above the storage reservoir enables early leakage detection. Moreover, optimizing survey geometries can significantly improve monitoring efficiency and reduce operational costs. This study evaluates the effectiveness of Vertical Seismic Profiling (VSP) monitoring at the Changbin candidate site through forward modeling of time-lapse seismic data to determine a feasible survey design range.

The workflow of VSP effectiveness evaluation in this study involves several steps. First, large-scale single-well reservoir storage simulations were conducted using TOUGH3, simulating an injection rate of one million tons of CO_2 per year for 50 years under high, median, and low reservoir permeability scenarios. Then, we combined the simulated reservoir results with the Changbin wellbore data to build the corresponding seismic velocity models using the conventional rock physics parameter conversion methods. However, these velocity models assume rigid pores, which differ from real conditions. Therefore, consideration of laboratory experiments on local core samples could refine our understanding of how compliant pores influence rock properties. Next, the synthetic seismic survey response data for various VSP survey geometries given these velocity models were generated using finite-difference simulations in Seismic Unix. The processed data produced VSP profiles under different survey configurations for the reservoir simulation scenarios. By comparing these responses, we can identify the optimal survey designs.

The preliminary results indicate that a 1 km source interval is enough to detect CO_2 plumes given the large-scale injection rate while reducing the interval below 200 m improves image clarity and leakage detection.

Keywords:Seismic velocity modeling, Carbon storage, CO_2 plume monitoring, Rock physics modeling

利用數值模擬建構並分析關子嶺地區地熱儲集層位態

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本研究針對台南白河地區之關子嶺地熱系統，進行地熱儲集層位態之建模與模擬分析。該區地形屬西低東高之丘陵地貌，區內分布多條主要構造線，如枕頭山斷層、崙後斷層與凍仔腳斷層等，構造活動頻繁，斷層裂隙系統發達。過往地熱鑽探報告顯示，井底溫度可達攝氏160度，顯示該地區具備發展中高溫地熱資源之潛力。鑑於構造裂隙對熱液傳輸具決定性影響，本研究嘗試透過數值模擬方法，建構區域性地熱儲層模型，並進一步評估熱液流動路徑、熱儲分布及潛在鑽井區位。

應用 TOUGH3 數值模擬軟體進行多相流與熱傳行為之模擬，並選用 EOS3 狀態方程模組，以模擬地層中氣液共存之地熱環境。模擬工作結合 PetraSim 軟體進行三維模型建構與結果視覺化處理。地質模型建立整合地電阻剖面資料、鑽井記錄、斷層構造參數與地層岩性分布，重建熱儲層在地下之空間分佈與物理條件。模擬範圍涵蓋主要熱源區與潛在熱液通道，評估不同深度與地質條件下熱液的流動方向、壓力分布與溫度場變化。

研究成果可提供關子嶺地區地熱開發之初步選址依據，亦可作為後續鑽探規劃、熱儲容量推估及地熱發電可行性評估之基礎。未來建議整合更多監測資料與長期產注模擬，以優化地熱資源開發策略，並進一步強化本區地熱系統之理解與應用潛能。

中文關鍵詞：地熱儲集層、數值模擬、關子嶺溫泉

An annual report of Real-Time Moment Tensor Monitoring System

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The Real-Time Moment Tensor Monitoring System (RMT; https://rmt.earth.sinica.edu.tw/) is a seismic monitoring platform developed to automatically detect earthquakes in Taiwan in real time. Within two minutes of an event, the system provides key source parameters, including origin time, centroid location, moment magnitude, and focal mechanism. RMT integrates centroid moment tensor (CMT) inversion techniques, grid search algorithms, 3D Green's functions computed using the spectral element method, and real-time broadband seismic recordings. The monitoring region spans 119.2°E to 123.0°E and 21.0°N to 26.0°N, covering depths from 2 to 180 km. Grid spacing is less than 0.05° horizontally and approximately 2 km vertically, varying with depth. The initial version of RMT, operational from 2012 to 2015, employed 1D Green's functions and was upgraded to a 3D Green's function implementation in 2015. This study compares RMT solutions from 2015 to 2024 with those also reported by the Central Weather Administration (CWA) and the Broadband Array in Taiwan for Seismology (BATS) CMT catalog. CLVD and isotropic components of RMT solutions were also preliminarily analyzed. In previous studies, the RMT centroid solutions for the 2022 Chihshan, 2024 Hualien, and 2025 Dapu earthquakes were found to align well with asperities identified in their respective finite-fault models. This system was verified to be capable of providing timely and accurate earthquake source information for medium to large earthquakes to support rapid earthquake hazard assessment and emergency response.

Keywords:real-time monitoring, moment tensor inversion, source parameters, 3-D Green's function, computational seismology

The surface hydrological climate changes in the East China Sea over the past 2000 years based on organic biomarker temperature proxies

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In the East China Sea (ECS), a marginal sea in the western Pacific, hydroclimate variability is primarily driven by East Asian Winter Monsoon (EAWM), Kuroshio Current (KC), Taiwan Warm Current (TWC), China Coastal Current (CCC), and the Changjiang Diluted Water (CDW). This study reconstructs seawater temperatures using organic biomarker proxies from sediment samples of gravity core CJ121279 on the ECS shelf. The age model is based on 25 AMS ^{14}C dates from depths where each sample contains at least 7mg of benthic foraminiferal shells. Age uncertainties were quantified with the COPRA algorithm, which assumes normally distributed errors, excludes outliers at a 95% confidence level, and generates 2000 Monte Carlo age distributions per depth to convert dating errors into proxy uncertainties. The sea-surface and subsurface (~200 m) temperatures (SST and Sub-T) were estimated using alkenone $U^{k'}_{37}$ and GDGT TEX_{86} proxies. The CJ121279 SST record indicates significant cooling around 500 BP, likely linked to the major 536CE volcanic eruptions and supported by tree-ring and ice core sulfate evidence. During the Little Ice Age (LIA; 1400-1900CE), $U^{k'}_{37}$ SSTs declined while TEX_{86} Sub-Ts increased. Furthermore, the GDGT/alkenone ratio and temperature difference ($\Delta T = U^{k'}_{37} - TEX_{86}$) imply that an intensified EAWM drove cold, fresh CCC and CDW southward onto ECS shelves, while saline, warm waters from branches of KC and TWC form a salinity barrier that dampened mixing and reinforced stratification. Our results suggest that centennial-scale ECS hydroclimatic variability may be driven by volcanic forcing from ice core sulfate records and solar forcing from ^{10}Be-based total solar irradiance reconstructions. Our high-resolution millennial record provides new insights into joint western Pacific climate forcing and refines the intercontinental timing of the Medieval Climate Anomaly (MCA; 950–1250 CE), Sui-Tang Warm Period, and LIA cooling.

Keywords:East China Sea, Sea Surface Temperature, Subsurface Water Temperature, Uk'37, TEX86

無參考站方法分析台灣北部區域場址放大特性

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台灣位於弧陸碰撞帶，地震活動頻繁，氣象署、中研院地球所及國震中心皆設有地震觀測站，透過密集的地震觀測網可獲得豐富的地震資料。由於北台灣為人口稠密區，且包含台北盆地與宜蘭盆地等沖積層較厚的區域，因此沖積層所造成的地震波放大效應，對這些區域的災害潛勢評估與防災工作具有重要意義。近年來，台灣各區域的場址特性已獲得相當仔細的調查研究，並已建置相當完整的場址參數（如近地表30公尺平均剪力波波速V_{S30}和剪力波速低於 1 km/s 的沖積層厚度$Z_{1.0}$）資訊，近期的研究也更精確地定義台灣的通用岩盤條件（Kuo and Abrahamson, 2023）。因此我們得以採用無參考站方法（Non-Reference Site Approach, NSA）來分析線性場址放大函數。本研究匯集北台灣高密度測站資料，使用2018至2019年間芮氏規模介於4.5和6.5的地震事件進行分析。傳統頻譜比方法需要在分析測站附近找到合適的參考岩盤測站來分析場址放大特性，實際應用時常有困難，且參考測站的條件並未被清楚地定義。透過NSA方法，使用特定地震事件的通用岩盤條件地動模型計算各測站的事件內殘餘值，作為場址線性放大效應指標，以了解台灣北部區域的高解析度場址分布特性。未來，可進一步納入設計地震效應並考量非線性場址效應，將可作為耐震設計規範的微分區更新之參考，乃至擴大研究區域範圍，有助於提升台灣對在區域場址效應分析上更深入的研究。

中文關鍵詞：無參考站方法、場址放大效應、VS30、標準通用岩盤

大雪山天池沉積物內矽藻與有機物分析所揭示之千年來水文環境變遷

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大雪山天池位於海拔2600公尺之針葉林內，直至西元1911年以來才開始有大規模的林業發展及開發。本研究分析大雪山天池之46公分短岩芯內，矽藻化石與有機物之總有機碳(TOC)、黑碳(BC)、穩定碳同位素($\delta^{13}C_{org}$)、沉積物磁感率(MS)等紀錄，並根據^{210}Pb與^{14}C年代深度模式及矽藻鑑定分析，將其分成3個矽藻帶，分別涵蓋中世紀暖期(Zone 1)、小冰期(Zone 2)與近代(Zone 3)，呈現出顯著的優勢種類轉變。

Zone 1有以*Navicula subalplha*為主的中性物種，伴隨TOC、$\delta^{13}C_{org}$、BC變化；Zone 2轉為以*Eolimna minima*為優勢的鹼性環境，TOC、$\delta^{13}C_{org}$由此時起趨於穩定，BC與*Eolimna minima*的濃度於相近的時間出現短暫波動；Zone 3矽藻種類回到中性物種主導的環境，各項地化指標趨於穩定，直到近百年。以矽藻結合地化指標分析，得以重建當地近千年來水文氣候、森林與水域生態系的變遷。

中文關鍵詞：矽藻、水文氣候變遷、古環境重建

苗栗鐵砧山二氧化碳封存之環境影響監測與評估

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本研究旨在釐清二氧化碳(CO_2)封存過程對環境可能造成的影響，特別聚焦於地下水水質與逸散氣體特性之潛在影響因素。透過基線調查，建立試驗場址之長期環境背景數據，並訂定水質安全範圍，作為警示機制，以利後續與注儲期間數據進行比對，進而驗證CO_2封存之安全性與可行性，並提供作為風險管理與緊急應變計畫之參考依據。現階段計畫仍處於CO_2注入前的監測階段，監測項目主要分為兩大項，分別為監測井連續監測以及地下水水質與逸散氣體分析。

長期水質監測結果顯示當地強降雨事件明顯影響地下水位、濁度、溶氧量、氧化還原電位以及元素濃度，透過幾個關鍵參數瞭解，雨水滲透進地層間接影響井體時間約為7日，影響持續時間約11-16日。本研究進一步分析不同監測井（M1、M2、M3）之水質特性與地下水來源差異。結果顯示 M1 屬於深層地下水類型，且富含有機物；而 M2 與 M3 的整體濃度趨勢傾向鄰近淺井五福國小，暗示其三口井的地下水來源更相近，其水源應為天水或淺層地下水補注為主。整體而言，水質皆低於《地下水污染管制標準法》第二類管制標準。此外，本區域地下水之逸氣碳同位素端元穩定，$\delta^{13}C_{CO2}$（‰）= -21.55‰，可作為後續封存CO_2後追蹤碳來源與遷移歷程的重要指標。

未來CO_2地下水監測將著重於碳酸鹽平衡系統與碳源鑑別，並結合已建立的自然變異範圍，進行洩漏風險評估與異常警戒值設立。此監測策略將有助於灌注階段迅速識別異常狀況，驗證封存系統之安全性，並奠定長期環境管理之基礎。

中文關鍵詞：碳封存、地下水監測、地球化學、碳同位素

以鴛鴦湖沉積物內多指標分析重建台灣東北部山區600年來水文氣候變遷

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鴛鴦湖位於海拔1670公尺之台灣扁柏林中，因地處偏僻，過去幾乎未受人類擾動，並於1973年設立為自然保護區至今。

本研究分析台灣東北部棲蘭山區鴛鴦湖沉積物內矽藻化石與有機物之TOC、TON、TOC/TON比、δ^{13}Corg(‰)與碳屑紀錄，重建近600年來，水文氣候變遷對當地森林與水域生態系之影響。本研究使用長40公分之短岩芯(YYL20-1)，基於^{210}Pb與^{14}C之定年結果所建立之年代深度模式，此岩芯包含過去600年古環境記錄。研究結果顯示此區域之三個主要環境變化階段：小冰期早期、小冰期晚期與近代。第一階段為小冰期早期，西元1340~1600年間，矽藻優勢種為*Cymbella naviculiformis*，代表中性及優養化水質；其TOC與TOC/TON比值於1560年前呈現穩定狀態，碳屑紀錄顯示有森林火災事件，顯示此時期為乾燥氣候，而在1560年可見TOC急遽增加且δ^{13}Corg(‰)變重，反映出湖中有機質沉積物增加，推測有一強降雨或颱風事件將大量TOC之物質沖刷至湖中沉積；第二階段為小冰期晚期，西元1600~1900年間，矽藻優勢種為*Eunotia bilunaris*屬於廣適應型，此時的TOC/TON比值稍微降低且δ^{13}Corg(‰)些微變輕，表示湖中有機物來源逐漸改變為水生藻類與C3植物，顯示出氣候逐漸轉為濕潤；第三階段為西元1900~2020年，TOC與TON於此階段有兩次增加，TOC/TON降低，δ^{13}Corg(‰)變輕。矽藻優勢種為酸性種且代表寡養水質的*Brachysira brebissonii*對應酸雨的影響；並在1970年轉為中性種且代表低至中優養化水質的*Tabellaria fenestrata*。

中文關鍵詞：古環境、矽藻、碳屑、小冰期

Probabilistic seismic hazard assessment for Taiwan: TEM PSHA2025

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To develop the next generation Taiwan probabilistic seismic hazard assessment, we refined earthquake and seismogenic structure databases and updated seismic source parameters to reflect the latest information. The areal sources surrounding Taiwan was divided into 30 zones to estimate seismic hazards, and seven earthquake catalogs from 1900 to 2023 were combined to calculate background seismicity, excluding foreshocks and aftershocks. Onshore and offshore structures have been updated in the model, as well as newly identified multiple structure ruptures based on Coulomb stress and historical evidence. The slip rate determination for onshore structures now incorporates geodetic rates alongside geological evidence-based calculations for a more comprehensive assessment. Seismicity in the Ryukyu and Manila subduction zones was reassessed with updated parameters, and intraslab seismic activity was reanalyzed using a 3D plate model.

Choosing a ground motion prediction equation is a key step. Based on new strong ground motion databases from 1991 to 2020, this study uses weights to ensure that the amount of data is consistent across a variety of magnitudes and distances. The model was objectively evaluated using log-likelihood function values (Log-Likelihood, LLH, Scherbaum et al., 2009) and modified Euclidean distance-based ranking (EDR, Akkar and Kale, 2014). The performance of each model is comprehensively sorted in order to determine the weight of the logic tree based on the matching degree of 16 domestic and foreign crustal and subduction zone earthquake models under various natural vibration periods.

Finally, by utilizing the aforementioned parameters combined with a new database of the average shear-wave velocity in the top 30 meters at each site and considering uncertainties caused by different GMPEs, we have developed a seismic hazard map. The results of this study will contribute to subsequent research on seismic risk assessments and the promotion of disaster prevention strategies in the public sector (such as earthquake scenarios, disaster evacuation and rescue drills, etc.).

中文關鍵詞：機率式地震危害度分析、Probabilistic seismic hazard assessment、Ground motion prediction equation、地動預估式、Hazard map

Linking lacustrine, dendrochronological, historical, and instrumental records: Pitfalls and potentials

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Reconstructing past climatic and environmental conditions is of great importance for our understanding of how future climate changes will influence society. In particular, in a place like Taiwan, with its steep topography and heavy dependence on the monsoon rains for irrigation, industry, and drinking water, climatic shifts can be devastating. Unfortunately, longer terrestrial climate archives are rare and often cumbersome to interpret. For its size, Taiwan has surprisingly few lakes, and those that exist are small and often fill up very rapidly due to the extreme erosion rates caused by the steep topography and heavy precipitation. Because the lakes fill up fast, lake size, geometry, and water depth change rapidly over the lakes' lifetimes. It is, therefore, imperative to verify interpretations based on paleolimnological archives by independent proxy-archives. Taiwan's geology and geographic location don't allow for the formation of climate-proxy archives such as speleothems or ice cores, and the coral records that do exist tend to record marine conditions at the outlying islands rather than the climate on Taiwan itself. Available climate archives are, therefore, in practice reduced to instrumental records, historical documents, dendroclimatological archives, and lake sediments. However, all these archives come with severe limitations in terms of chronostratigraphic range and temporal and spatial resolution. Instrumental data may have diurnal resolution but only reach back 150 years or so, and the further back in time we go, the fewer stations existed. Historical documents may have daily to seasonal resolution and reach back several hundred years but are spatially and temporally heterogeneous. Dendrochronological records have sub-annual resolution and, where fossil material is preserved, may reach back several thousands of years. In Taiwan, though, they rarely extend beyond the last 400-500 years. Lacustrine records, in contrast, typically have a decadal-to-millennial-scale resolution and may reach back beyond the Holocene. A major limitation is that many lakes have been anthropogenically influenced over the last few hundred years. Another limiting factor is the lake-inherent processes such as siltation and lake succession, that may gradually change the environment independently from any climatic trends. The question thus becomes: How can we verify paleoclimatological interpretations based on lacustrine records? I will use three examples to show potential solutions and pitfalls:

- Lake Tienchi on Lanyu: dendrochronological data constrain lake formation.
- Cuifeng Lake in Taiping Mountains: Historical records and instrumental data used to constrain forest fires and deforestation proxies.
- Meihua Lake on the Ilan Plain: Historical archives used to explain sedimentological changes

Keywords:Paleolimnology, sedimentary archives, dendrochronology, historical archives, instrumental records

臺灣弧前基盤缺失的熱-機械力學耦合數值模型

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台灣地處歐亞大陸板塊邊緣並與菲律賓海板塊交界，菲律賓海板塊以每年70到80毫米的速度向西北方向移動並與歐亞大陸板塊聚合，形成呂宋島弧與台灣造山帶。但在台灣造山帶中段呂宋島弧與歐亞大陸邊緣直接相連，缺失弧前基盤，此弧前基盤缺失現象亦廣泛出現於類似板塊聚合區域。過去研究認為此弧前基盤已隱沒至於菲律賓海板塊與歐亞大陸板塊之間。為了探討弧前基盤隱沒的機制，我們利用熱-力學耦合數值模擬，並結合地質資料，模擬岩石圈尺度的板塊隱沒到碰撞過程來探討台灣造山帶中段弧前基盤隱沒的動力學機制。

模擬結果表明，當隱沒板塊由海洋地殼過渡到大陸地殼時，因大陸地殼材質密度較輕，不易隱沒而造山形成的巨大塊體阻擋菲律賓海板塊向西北前進，讓弧前地殼撓曲下凹形成一個弧前盆地，盆地內開始堆積大量的沉積物。直到盆地中心破裂形成縱谷斷層，盆地東側島弧區域逆衝至盆地西側弧前基盤之上方，推擠盆地內沉積物快速抬升，最終弧前基盤隱沒至菲律賓海板塊之下。此模型解釋了弧前基盤缺失的原因、縱谷斷層形成的時間點，以及海岸山脈沉積物記錄到的劇烈上下運動。

中文關鍵詞：弧陸碰撞、弧前基盤缺失、動力模型、臺灣、數值模擬

裂隙內寬與滲透率演變於雙孔隙介質之水-力耦合模型技術開發

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對於放射性廢棄物最終處置場的設計，國內主要採用近地表坑道處置及深地層處置概念以防止放射性核種外洩造成生物與環境危害。然而，處置母岩本身與受力產生之裂隙，為放射性核種外釋的主要通道。由於地層中的裂隙可能受到壓溶作用(Pressure dissolution)與自由表面溶解作用(Free surface dissolution)的影響，使得裂隙內寬(Aperture)與滲透率發生變化，進而影響核種傳輸特性。因此，瞭解裂隙內寬與滲透率受到外在條件影響而隨時間發生之變化，有助於評估放射性核種外釋可能性，進而確保放射性廢棄物處置場之安全性。

本研究採用Liu et al. (2006)之岩體裂隙幾何運算方式，藉多重物理量耦合分析軟體(COMSOL Multiphysics®)建置二維水力-力學雙孔隙介質機制模型，將水-力數值模擬結果引入商業數學軟體MATLAB®中進行裂隙幾何變化計算，再將裂隙演變結果代回數值模式中進行迭代運算，以模擬石灰岩裂隙在受到壓溶作用與自由面溶解下，裂隙內寬隨時間變化的情形，並針對其結果計算等效水力傳導係數(K_{eq})以評估該區域之流體傳輸特性。在本研究設定條件下，以每1小時為時間間隔進行1500小時之模擬中，分別以地下水(pH~8)及蒸餾水(pH~6)之水化學環境進行模擬。

研究顯示，因裂隙接觸點受到較高的局部應力影響，導致壓溶作用較自由表面溶解作用顯著，造成裂隙內寬逐漸下降。其中在地下水環境中，由於溶液含有鎂離子(Mg^{2+})並吸附在石灰岩表面阻礙了水與表面之化學反應，進而降低溶解速率，最終導致等效水力傳導係數降低約1.5%；在蒸餾水環境中，由於沒有鎂離子之作用且較多的氫離子(H^{+})與石灰岩反應，因此有較快的溶解速率，最終導致等效水力傳導係數降低約10%。未來將透過考慮岩體於不同環境條件下之影響進行參數計算，以建置完整裂隙演變幾何模型，並期望能應用於現地的安全評估工作中。

中文關鍵詞：岩體裂隙內寬、壓溶作用、自由表面溶解作用、水-力耦合、等效水力傳導係數

結合多重沉積指標重建臺灣東北部山區全新世水文氣候變遷

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本研究旨在重建臺灣東北部地區的古氣候與古環境，選擇位於海拔約2100公尺的宜蘭三星妹池作為研究地點。該區年降水主要來自春夏之際的梅雨鋒面、夏季颱風以及冬季的東北季風。自池深約50公分處採集長達250公分的沉積岩心，並利用^{210}Pb與^{14}C方法進行年代定年。定年結果顯示該岩心涵蓋過去約11000年的沉積紀錄。本研究分析碳氮元素、穩定碳同位素、粒徑分布及矽藻組成等資料。沉積物移除無機碳後經由EA-IRMS分析，以獲得碳氮比(C/N)、總有機碳含量 (TOC)與δ^{13}C值；矽藻則於光學顯微鏡下進行分類鑑定與計數。並以粒徑資料進行端元模型分析 (End-member modeling analysis, EMMA)，結合前人所提供之花粉紀錄，進一步進行多項指標間的相關性分析。

研究結果將三星妹池岩心紀錄分為六個時期。在SXMP 1時期 (約11100-9900 cal BP)，氣候寒冷乾燥，森林覆蓋率低，濕地面積小。SXMP 2時期 (約9900-8300 cal BP)，氣候由寒冷轉為涼爽，降雨量增加，森林覆蓋率上升，濕地開始擴張。SXMP 3時期 (約8300-5700 cal BP)，氣候溫暖濕潤，降雨量增加，濕地面積擴大，但森林覆蓋率逐漸下降。此時期與全新世氣候最適宜期相對應。SXMP 4時期 (約5700-3100 cal BP)，氣溫略微上升，濕度仍然很高，濕地持續發展，但森林覆蓋率沒有明顯恢復。SXMP 5時期 (約3100-1800 cal BP)，降雨量減少，氣候轉為乾燥，氣溫略微下降，濕地面積縮小，森林覆蓋率恢復，環境逐漸向湖泊過渡。SXMP 6a (約1800-800 cal BP)，濕度增加，氣溫可能與前期持平，濕地面積略微擴張，森林密度較低。SXMP 6b (約800 cal BP至今)，森林覆蓋範圍再次擴大，湖泊水量增加，水位穩定，水體條件及保存狀態良好。約430 cal BP開始出現矽藻保存，此時可分成兩個矽藻帶。SXMP D1時期 (約AD 1540-1910)，環境變化主要受到自然因素控制。SXMP D2時期 (約AD 1910至今)，開始受到較多的人類活動影響，尤其是AD 1970後的大規模森林砍伐。

中文關鍵詞：全新世、古氣候、矽藻、碳氮元素、穩定碳同位素

澳洲西北海域潛在生油岩層生油模擬研究

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生油模擬可用來推估生油岩油氣生成與排移的歷史，可增加我們對油氣探勘區域石油系統的理解，以減少探勘風險。澳洲西北海域是澳洲重要的油氣產區，本研究針對Roebuck、Offshore Canning、Browse、Bonaparte盆地中具油氣開發潛力的Bedout、Oobagooma、Caswell、Vulcan次盆地，進行油氣生成與排移模擬，進而了解這四個次盆地可形成儲集油氣構造的時期。

本研究先蒐集並整合四個次盆地的地球化學資料，利用TOC vs S_2分布圖識別潛力生油岩層，並透過二維震測剖面建立地質模型，再使用PetroMod軟體對潛在生油岩層進行生油模擬，了解油氣生成及排移歷史。結果顯示，Bedout次盆地的主要生油岩層位於三疊紀，大多於晚三疊世至早白堊世達到油窗階段並開始生成油氣，且排移自晚三疊世開始，自三疊紀地層最底部逐層向上進行。Oobagooma次盆地的生油岩層位於石炭系及二疊系，於三疊紀達到成熟並開始生成油氣，並於晚三疊世發生排移。Caswell次盆地的生油岩層分布於侏羅紀及白堊紀，侏羅紀地層在早白堊世至晚白堊世期間達到油窗階段並開始生成油氣，白堊紀地層則於古新世至漸新世達到成熟並開始產生油氣；侏羅紀最底層的Plover Formation於晚白堊世開始發生排移，其餘地層則至古近紀才有少量排移。Vulcan次盆地的生油岩層與Caswell次盆地相似，侏羅紀地層於晚侏羅世至始新世達成熟並開始生成油氣，Plover Formation於晚白堊世發生排移，白堊紀地層則尚未成熟。

四個次盆地的生成、排移時間受到各生油岩層的沉積年代、油母質類型及區域構造歷史等差異而有所變化。總結來說，Bedout次盆地在三疊紀期間；Oobagooma次盆地在石炭紀至晚三疊世期間；Caswell次盆地在早侏羅世至晚白堊世期間；以及Vulcan次盆地在早侏羅世至早白堊世期間形成的封閉構造，較有機會有油氣聚集。

中文關鍵詞：澳洲西北海域、生油模擬、生成排移史

Preliminary geochemical results from orogenic peridotites from Eastern Alaska and Northern British Columbia

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During the Late Paleozoic to Early Mesozoic a number of allochthonous continental-arc and oceanic terranes (Atlin, Cache Creek, Slide Mountain) were accreted to the western margin of Laurentia. The oceanic terranes from the northern portion of the North American Cordillera are composed of sedimentary rocks (e.g., metachert, argillite), volcanic rocks (greenstone), plutonic rocks (leucogabbro), and serpentinized peridotite. Serpentinized peridotites (harzburgite, dunite) were collected from the Slide Mountain Terrane (Seventymile Terrane) of Eastern Alaska (Eagle) and the Atlin Terrane of Northern British Columbia. The peridotites are considered to be the tectonized remnants of the mantle section of oceanic crust, although they may not be related to an ophiolitic assemblage. The harzburgites from Eagle are moderately (~20%) to highly (>50%) serpentinized whereas the rocks from Atlin are highly serpentinized (50-60%). The harzburgite bulk rock compositions from both locations are similar (Mg# = 90.4-92.0; MgO = 39.0-43.3 wt%; CaO = 0.1-1.6 wt%; Ni = 2142-2371 ppm; Co = 112-121 ppm; V = 18-33 ppm; Zn = 42-56 ppm) whereas the dunites are more magnesian (Mg# = 91.8-93.4; MgO = 41.2-43.1 wt%; CaO < 0.12 wt%). The Mg# and Al_2O_3 (0.39-1.17 wt%) contents of the harzburgites are consistent with oceanic peridotite (Mg# = 90.2-91.5; Al_2O_3 > 0.60 wt%), but the Al_2O_3 (wt%) content from some Atlin rocks overlaps with oceanic trench peridotite (Al_2O_3 < 0.60 wt%). The preliminary results suggest that the harzburgites are indicative of oceanic crust, but that the Atlin rocks may be representative of an oceanic trench system whereas the Eagle rocks are indicative of an ocean basin system.

Keywords:North American Cordillera, Orogenic peridotite, Late Paleozoic, Oceanic terran, Geochemistry

大屯山地熱概念模型及弱酸性儲集層分佈研究

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大屯山地熱系統屬於火山型地熱，透過歷年地熱探勘研究成果，已確立馬槽地區具有最高之地溫梯度，安山岩相比鄰近區域較厚且地下具有弱酸性儲集層之分佈。

本研究藉由馬槽新鑽井之鑽井數據，更新地下等溫面、沉積岩不整合面與弱酸性儲集層分佈，此井鑽深758公尺至816公尺為連續取岩心段，岩性皆為安山岩質火成岩，產狀為火山角礫岩和熔岩流交錯出現。依據井下熱液換質礦物相分析結果，鑽深約750公尺以下為地熱系統中之弱酸性儲集層，並延伸至1,100公尺鑽遇五指山層不整合面。恢復試驗及井測結果證實井下儲集層溫度可達245°C以上，且在儲集層之深度具有裂隙帶分布，此井具有開發地熱能源之潛力。

地表露頭採集之泉水透過$\delta^{18}O$與δD同位素分析，其結果具有同位素分化現象，原因推測與硫化氫、高溫水岩反應或熱蒸氣相關，而區域泉水皆有受地表天水混染的特徵。依分析數據可以區分為三種不同之補注來源或混染特性，分別為七星山西南側、七星山東北側和大油坑及小油坑，其中七星山西南側泉水補注源海拔應於400至600公尺處，七星山東北側之泉水具有與地表天水明顯混染現象，大油坑及小油坑之泉水則是受到顯著之水岩反應和火山氣體混染，分析結果應用於建立地下水文循環模型，並整合於本研究之地熱概念模型。

本研究所建立之大屯山馬槽地區地下三維概念模型，主要為岩性分布、火成岩和沉積地層不整合面分布、弱酸性儲集層分布和地下等溫面等，藉由建立之模型評估馬槽地區地下弱酸性儲集層之體積及分布範圍，其弱酸性儲集層體積約為3.4 km^3，然而其邊界仍待新鑽井證實是否有向外延伸之可能性。

中文關鍵詞：大屯山、火山型地熱概念模型、弱酸性儲集層、氫氧同位素分析

大屯山馬槽井(CGS-MT-01)溫度剖面研究

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依據2024年台灣國際地熱論壇經濟部宣示，在2050年淨零碳排12項關鍵戰略中，地熱發電是潔淨能源的重要項目，自111年起中油公司與地調所(現為地礦中心)合作於大屯山馬槽地區鑽鑿一口科學研究井，於113年1月初鑽鑿至深度1195公尺後進行恢復試驗後進行井下恢復試驗量測溫度及壓力，以期能了解該地之井下溫度及可能的地熱潛能，爾後因井下地質狀況導致無法繼續鑽進，因此進行完井。

本次恢復試驗共進行四次井下量測，分別在停泵後24小時、36小時、48小時及60小時下放溫度壓力計進行量測，分別下放了深度1110公尺、1143.5公尺、1110公尺及1050公尺，其中直接量測之最高溫為第四次投放時，於井下1050公尺時量測到243.9℃。

恢復試驗之分析原理為在已知最後一次泥漿的循環時間下，利用霍納圖(Horner Plot)推算地層原始溫度的方法，該方法是假設地層溫度會隨時間將井內泥漿加溫，而時間無限大的時候，地層溫度會與泥漿溫度平衡，因此可推算地層原始溫度。

本研究單純以恢復試驗及霍納圖進行分析時計算出原始地層溫度，在1050公尺深之計算結果為約270℃，但經霍納圖計算後發現在700公尺左右計算出大約285℃左右之高溫，與井下岩屑礦物分析高溫儲層頂之深度約在750公尺不一致，推測可能有兩個原因: (1)700公尺左右確實有一高溫流體通道，但換質黏土不明原因消失，(2)因泥漿抗溫性質無法在高溫下長時間保持性能，導致久泡後產生對流，使推算之溫度高溫段不正常向淺處延伸。

本研究透過泥漿耐溫的特性及井下溫度-深度及壓力-深度曲線特徵，判斷該井使用之泥漿應無法長時間抵抗高溫，推測應為泥漿性能失效之原因，故本研究最後地層溫度剖面結果依此進行修正。

中文關鍵詞：大屯火山群、火山型地熱、恢復試驗、井內溫度剖面

利用GPS資料分析縱谷中段震間變形

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菲律賓海板塊每年以約8公分速度向西北方的歐亞板塊移動，並造成臺灣東部的花東縱谷地區極為活躍的構造活動。透過地質與地球物理等研究方式，我們對位於縱谷東側的縱谷斷層之活動特性已有相當程度的了解，但對於位在縱谷西側的中央山脈斷層系統來說，我們對於其運動速率、斷層鎖定深度等特性仍所知有限。為瞭解中央山脈斷層系統於間震期的活動特性，本研究利用中央研究院佈設於縱谷中段區域GPS連續與移動站的觀測結果，求得各站點於間震期的移動速率，分析縱谷中段區域於2022年關山—池上地震前的間震期速度場，並結合震後地表破裂調查成果與孕震斷層模型後，利用彈性半空間模型推算中央山脈斷層系統於縱谷中段於2022年以前的間震期活動特性，以瞭解該斷層在間震期時斷層鎖定區域的分布，以及中央山脈斷層系統與鄰近斷層活動的關聯特性。

本研究結果顯示，相對於縱谷中央，縱谷斷層上盤海岸山脈側的運動速度可達20-30 mm/yr，方向為320-340°；而中央山脈斷層系統上盤相對縱谷中央的速度則為7-12 mm/yr，方向為160-190°，速度越靠近下盤有越慢的趨勢。在二維模型的模擬中，中央山脈斷層系統在走滑方向上的速度為15 mm/yr，沿傾角方向則為25 mm/yr，鎖定深度約為10公里。三維模型結果同樣顯示斷層鎖定深度約在10-15公里之間，且靠近瑞穗似有鎖定深度變深的趨勢。此結果證實中央山脈斷層中段淺部在2022年關山—池上地震前30年間處於震間閉鎖狀態，且閉鎖區間與2022年地震的破裂區間約略相符，與其東側的縱谷斷層活動特性有明顯的差異。雖其閉鎖深度因GPS測站分布限制而難以精確控制，但與2022地震破裂帶深度應可相互映證。此一結果顯示中央山脈斷層系統為縱谷中極為重要的活動與孕震構造，建議須對其上盤中央山脈東麓區域進行長期的大地變形監測。

中文關鍵詞：GPS測量、震間變形、中央山脈斷層、玉里斷層

以花粉紀錄重建的臺灣中部全新世環境史

葉宛鑫[1]、汪良奇[1]

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頭社盆地位在南投縣魚池鄉埔里盆地群境內，屬於晚更新世到全新世時期的封閉型湖盆，約形成於末次冰期，隨後一路陸化，約在1,700年前完全乾涸至今。氣候深受東亞夏季季風系統影響，現今周圍森林植被主要由亞熱帶常綠闊葉林主導，為樟科-殼斗科群系。因應高解析度古氣候資料的研究需求，本研究分析採自臺灣中部頭社盆地內長8公尺之泥炭岩芯，由於擬針對全新世大暖期其時間分佈與氣候狀態進行確認與事件探討，因此僅分析岩芯之其中4公尺，且以2公分為間距取樣，進行連續樣本的孢粉分析，共鑑定出72個孢粉種屬分類單位，參考CONISS群聚分析結果將10,300-3,500 cal BP間的孢粉紀錄劃分為4個孢粉帶(TS19-1~TS19-4)，其結果可對應全新世早期至全新世中期，且以濕地植物莎草科(Cyperaceae)為整個時期的主要優勢物種。根據有機物分析結果顯示在陸生植物為主的環境下，以C3植物為整個時期的主要優勢植群，配合岩性、有機物、炭屑的分析資料，重建並探討臺灣中部地區頭社盆地在環境-植被-人類活動之間的交互作用。TS19-1(10290-8060 cal BP)對應全新世早期，氣溫逐漸上升，東亞夏季季風增強，森林快速擴張，加上排水不良的環境，沼澤在缺氧的情況導致有機物質持續堆積，造就適合泥炭發育的有利條件；TS19-2~TS19-4(8060-3550 cal BP)對應全新世大暖期，暖/乾氣候條件下，高大冠層覆蓋率和適當野火頻率使森林植被多樣性提高，濕地陸化程度加劇，造就適合人類活動的環境，且人類活動通過反覆燃燒上層土壤和植被，引起顯著碳損失。

中文關鍵詞：頭社盆地、全新世、孢粉、有機物、炭屑

應用傅立葉神經算子於地震波形自動辨識與波相挑選

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地震偵測和波相判識在地震定位與後期災害防治中扮演關鍵的角色，傳統作法是使用人工辨識或STA/LTA方法進行波形辨識，但前者具有耗時性的問題、後者則有不準確性的憂慮，亦因此，機器學習方法以經歷大量資料的訓練方式具有針對人工判識之缺陷的潛力和優勢。

本研究希望探索傅立葉神經算子（Fourier Neural Operator,FNO）模型進行訓練，其中傅立葉方法的使用將機器學習所探索的資訊直接建立於頻率域的訊息上，使模型可明確的學習頻率訊息與目標波相的關聯性，同時，也讓模型得以學習頻率域與時間域的資訊。

在資料使用上，本研究採用公開的地震資料集STEAD（Stanford Earthquake Dataset）作為模型訓練與測試的資料來源，STEAD是一個大型的全球性資料集，包含已標記的地震波形及不含地震訊號的地震背景噪音波形。本研究中使用了約30萬筆地震波形與6萬筆非地震訊號，這些資料來自距震中350公里以內的測站所記錄之地震事件與背景噪音。其中對於訓練集、驗證集和測試集，於資料中分別是訓練集使用了20萬筆地震波形與5萬筆非地震波形；驗證集使用了4萬筆地震波形和1萬筆非地震波形；測試集約略為4萬筆地震波形和1萬筆非地震波形。每筆波形長度為一分鐘，取樣率為100Hz。

初步測試解果顯示，FNO模型在STEAD資料集上的recall於P波與S波上皆有0.999的表現，而precision於P波為0.970而S波為0.954，F1 Score於P波為0.984而S波為0.976；以此成績證實FNO在地震波相判讀上存在可行性與潛力，希望在進行適當的參數調適與資料篩選下可表現出更好的穩定性和泛化能力。

展望未來，研究將納入台灣本地的地震資料，以展現模型在台灣環境下的適應能力以增加其在台灣地區的實用性。另外也考慮加入其他資料類型，以進一步提升模型的準確性與實用性。同時，也將探討資料增強技術以及考慮FNO與其他神經算子架構對模型效能的提升空間，以希望能建立出一套適用於實際應用的地震波相判識系統，輔助地震即時監測與快速反應，強化地震災害的預警與防護能力。

中文關鍵詞：傅立葉神經算子、地震波形辨識、波相挑選

應用屬性分析技術於透地雷達地下結構探測

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透地雷達是探測近地表地下結構的利器，該技術已被廣泛應用於工程、地質、考古等領域。傳統透地雷達訊號判釋工作多仰賴雷達波的振幅資訊，然過往研究指出僅依據振幅資訊可能錯失重要的地下目標物、甚至造成誤判。為進一步探討雷達波對於不同地下結構物的響應，本研究首先利用750 MHz 的透地雷達天線針對已知的樹根、地下管線及空洞區域進行二維剖面資料收集；其次藉由包含零點修正、訊號增益、背景雜訊移除、頻率濾波、解迴旋、移位及傾角濾波等資料處理步驟提升訊號品質；最後針對透地雷達成果剖面進行屬性分析，以能量、瞬時振幅、瞬時頻率、瞬時相位及相似度等五種屬性為例，探討樹根、地下管線及空洞在透地雷達剖面上的訊號響應特性。研究結果顯示低相似度及瞬時相位變化處與樹根空間位置對應良好；地下管線多具有高瞬時振幅及瞬時相位變化的特徵；空洞則有明顯的頻率衰減現象。相較於傳統透地雷達判釋方法，屬性分析技術可有效提取更多隱藏於透地雷達資料中的地下結構資訊，有助於地下結構判釋，提升透地雷達地下結構調查的準確性。

中文關鍵詞：透地雷達、屬性分析、樹根、地下管線、空洞

Study on the Organic Carbon Content of Sediments in the Mangrove Areas of Taiwan and Its Controlling Factors

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Mangrove ecosystems, with their anoxic sediments formed by tidal flooding and high productivity from photosynthesis, support long-term accumulation and storage of organic carbon, therefore, mangroves are considered one of the most promising blue carbon sinks globally. Between April and November 2023, sediment cores were collected from Guandu, Wazihwei, Xinfeng, and Sicao mangrove sites. Results indicate that total organic carbon (TOC) in the upper 0.3 m sediments are consistently higher than those in deeper layers, showing a decreasing trend with depth. The highest TOC values are observed in Guandu (2.07%), Sicao (1.97%), Wazihwei (1.48%), and Xinfeng (1.33%), suggesting carbon is primarily accumulated in surface sediments. Labile organic carbon (LOC) accounts for 55–70% of TOC, indicating low carbon stability. Stable carbon isotope of organic carbon results reveal that sedimentary carbon mainly originates from algal sources rather than mangrove vegetation, highlighting the dependence of western Taiwan's mangrove carbon sinks on external organic matter inputs. Grain size analysis shows strong positive correlations between TOC and the silt to clay portions ($r>0.75$), indicating that fine-grained sediments facilitate organic carbon adsorption and preservation. Estimated carbon stocks in upper 1 m sediments are highest at Wazihwei (163.90 Mg C/ha) and lowest at Xinfeng (100.43 Mg C/ha), reflecting spatial variations controlled by grain size, primary productivity sources, and depositional dynamics. Although mangrove sediments in Taiwan are dominated by LOC with limited long-term stability, their short-term carbon sequestration potential remains ecologically valuable.

Keywords:Mangroves, Total organic carbon, Carbon sequestration, Grain size distributions, Stable carbon isotope of organic carbon

Applying Triple Oxygen Isotopes of Nitrate to Quantify Gross Nitrification Rates in an Oligotrophic, Freshwater Environment

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Vertical profiles of concentrations and isotopic compositions of nitrate, including the triple oxygen isotopes ($\Delta^{17}O$), were determined twice in a same year, June and October 2024, to quantify gross nitrification rates in an oligotrophic water column of Lake Towada (depth = 326.8m), Japan. Based on the $\Delta^{17}O$ values of nitrate obtained in this study, we first estimated mixing ratios between atmospheric nitrate and nitrate produced through nitrification in the lake water column to be 8.9 ± 0.8% on average. That is, the majority of nitrate had been supplied through in-lake nitrification. Then, we quantified dynamics of nitrate in the lake water column during the observation interval from June to October, by dividing the lake water column into shallow (0m to 50m) and deep (> 50m) layers. Based on the deposition rate of atmospheric nitrate over the lake surface, we quantified the gross quantity of nitrate supplied through nitrification to be 37 ± 7 Mmol and that of nitrate removed through biological consumption, such as assimilation and denitrification, to be 39 ± 8 Mmol, while the net change of nitrate was small, from 9.5 to 8.3 Mmol.

These findings highlighted the importance of internal nitrogen cycling in sustaining availability of nitrogen in oligotrophic environments. Unlike the traditional ^{15}N tracer method, which requires tedious and time-consuming incubation experiments to quantify accurate dynamics, the application of triple oxygen isotope analysis provides a powerful approach to quantify dynamics of nitrogen and assess the balance between external inputs and internal transformations in lake ecosystems.

Keywords:biogeochemistry, triple oxygen isotopes, nitrification, nitrate

顯著地震事件引致易液化土層孔隙水壓激發之初步研究

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為瞭解顯著地震事件引致易液化土層中孔隙水壓激發行為，本研究團隊特於全臺七處曾發生土壤液化之區域(或土壤液化高潛勢區域)建置土壤液化監測站。透過設置於場址井下不同深度地層之孔隙水壓計及地表三軸加速度計與地表沉陷計等感測器，監測地震事件發生時場址土層的受震反應行為。結果顯示地震引致土層孔隙水壓激發程度，除與場址本身的地層條件(諸如:土壤性質、地下水位深度等)相關外，亦受到地震事件之震動特性影響(包括：振動強度、振動頻率及持續時間)。本研究嘗試建立場址監測資料間之相互關係，將有助於更準確的掌握地震引發土壤液化之機制及其影響程度。

本研究基於2024年4月3日花蓮地震(M_L=7.2)及其後續一系列之餘震所測得之實際觀測數據，針對地震規模(M_L)、最大地表加速度(PGA)等特性與所激發之超孔隙水壓，具體建立場址尺度之統計關係。研究成果以花蓮監測場址為例，針對0403花蓮地震及其餘震事件，其孔隙水壓激發值與PGA值具有良好的統計迴歸關係，可提供各界參考運用。

中文關鍵詞：土壤液化、顯著地震事件、孔隙水壓激發

利用地表變形時序探討2022年關山、池上地震之發震構造

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台灣東部縱谷地區位於歐亞板塊與菲律賓海板塊的交界處，是全球地震活動最頻繁的區域之一。2022 年 9 月 17 日與 9 月 18 日，縱谷南段關山、池上區域先後發生 Mw 6.4 與 Mw 6.6 地震，對縱谷中南部造成嚴重破壞與地表變形。由於遙測技術可快速且大範圍獲取地表變形的時序資訊，本研究藉此方法探討地震前後發震構造的差異及活動特性的變化，並收集 2020 年 1 月至 2024 年 3 月期間共超過 200 幅哨兵一號（Sentinel-1）雷達衛星影像，先以差分合成孔徑雷達（Differential Interferometry Synthetic Aperture Radar, D-InSAR）方法處理同震變形資料，並結合小基線子集法（Small Baseline Subset, SBAS）處理超過 600 對干涉影像，以獲取震前及震後地表變形的時序資訊；同時透過升軌（Ascending）與降軌（Descending）的視衛星方向（Line of Sight, LOS）位移與速度場進行二維分解，以解析東西方向和垂直方向的變形特徵。研究結果顯示，同震期間地表變形主要集中於玉里至關山一帶，且呈現分段特性，顯示在不同區塊內，發震構造的行為存在差異。以玉里地區震後變形為例，在跨過中央山脈斷層兩側的垂直變形速率具有8 cm/yr的差異，顯示震後應力調整持續進行。為了深入探討發震斷層的幾何特性與震後變形機制，本研究分別採用網格搜尋法（Grid Search）與貝氏方法（Bayesian approach）進行同震斷層參數反演，兩者皆以 Okada 所提出的彈性半空間錯移模型（dislocation model）為基礎，以探索可能的斷層參數組合。前者透過對多個區域切剖面進行模擬；後者則使用大地測量貝氏反演軟體（Geodetic Bayesian Inversion Software, GBIS）對整個縱谷區域進行反演。GBIS 所採用的演算法是基於馬可夫鏈蒙地卡羅法（Markov Chain Monte Carlo, MCMC），結合 Metropolis-Hastings 演算法與自動步長選擇機制，以提升後驗機率分布中的取樣效率。初步反演結果顯示，在玉里區域的剖面進行網格搜尋時，主要斷層面為北偏東10°、向西傾斜約為 55°；而運用 GBIS 於整個縱谷區域所反演的同震地表變形，則顯示主要斷層面走向約為北偏東 28°、向西傾斜 60°。後續將依據各區域反演所得之斷層參數，模擬震前與震後滑移量的變化，以探討不同區域之斷層活動特性。

中文關鍵詞：2022關山池上地震、地表變形、D-InSAR、SBAS、斷層模擬

多光譜無人機與機器學習應用於區域碳存量估算

謝秉皓[1]、郭昱廷[1]、陳嘉俞[1]

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科學證實氣候變遷已對人類生命、財產安全以及自然環境構成嚴峻威脅，過去幾年氣候議題引發國際高度重視，而減碳為重點討論項目之一，各國陸續提出「2050淨零排放」的宣示與行動，我國也於2022年3月正式公布「臺灣2050淨零排放路徑及策略總說明」，提供至2050年淨零之軌跡與行動路徑，而要達成此一目標，碳盤查是重要並需全面統計的，若能快速且精準計算，更有利於規劃整體之減碳策略。

本研究提出一套快速自動化分析流程，用以分析中正大學校園內的一區黑板樹之碳存量總和。該流程利用配備RTK定位功能的多光譜無人機拍攝正射與傾斜影像，藉由影像重建產製高密度三維點雲，並以機器學習DBSCAN密度式聚類演算法辨識單株樹木。再透過擬合圓技術與地面高程資訊快速估算樹木的胸高直徑（DBH）與高度，兩者估算誤差分別在 ±10% 與 ±2% 以內，顯示即便無需昂貴感測器也可取得高準確幾何資訊。此外，本研究利用卷積神經網路（CNN）對灰階影像、R/G/B合成影像與NIR/R/G合成影像進行樹種分類訓練，其中R/G/B合成模型整體準確率最高達98%，而NIR/R/G模型整體準確率為69%，但其驗證準確率為98%，因本研究區域相對單純，未展現NIR/R/G合成影像於複雜場域中的優勢。最終，整合DBH、樹高與樹種等資訊，應用農業部農村發展及水土保持署公開的碳存量估算公式完成碳存量推估，得出本研究區域的黑板樹碳存量總量約為 28136 ± 29% 公斤，證實本研究流程具備低成本、高效率與可擴展性，適用於大尺度都市林地監測與智慧城市綠覆管理。

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中文關鍵詞：無人機、點雲分析、樹種分類、碳存量估算、都市綠地

應用深度學習辨識岩石薄片影像：以Segformer模型與U-Net模型為例

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傳統辨識岩石薄片多半採用點記法，時常耗費大量時間與精力，因此本研究應用深度學習方法進行岩石薄片的影像分割(image segmentation)，針對石英、長石、岩屑、基質與孔隙等五種岩石組成成分進行分類，期望藉由深度學習方法，使模型能夠快速且大量的自動辨識岩石薄片，提升岩石薄片分析的工作效率。本研究主要有兩項貢獻：第一，透過影像資料擴充與小模型訓練的策略，優化人工標註影像標籤的工作流程；第二，比較Segformer模型與U-Net模型的訓練結果，分析兩種模型在岩石薄片影像辨識的成效。

前人研究顯示，由於石英與長石的礦物特徵相近，常導致AI模型辨識困難，進而影響整體準確性，為改善此問題，本研究提出結合資料擴充與小模型預訓練的影像標籤前處理方法。前者透過旋轉、鏡射及改變影像切割方向，大幅提升訓練資料的多樣性，使訓練資料量增加為原本的144倍；後者使用少量的已完成標註岩石薄片影像，訓練初始的小模型，輔助進行人工標註影像標籤，降低約80%的工作時間。經前處理後的資料集，在後續訓練深度學習模型時，可有效提升模型的學習品質，並增強對礦物細部特徵的辨識能力。

在深度學習模型方面，本研究分別採用Segformer模型與U-Net模型兩種架構，其主要差異在於影像特徵的擷取方式：Segformer模型利用自注意力機制（self-attention）提取多尺度特徵，U-Net模型則透過卷積(convolution)與最大池化(max pooling)建構特徵圖層。根據模型的訓練結果，Segformer模型的準確率達82.7%，並展現出良好的礦物解釋能力及整體影像分割合理性；U-Net則達96.9%，雖具較高的準確性，但在部分區域常出現不合理的解釋，可能與向下取樣(downsampling)的模型結構設計有關。本研究為Segformer首次應用於岩石薄片分析，研究成果驗證其在岩石薄片影像辨識上的潛力，未來可望推動岩象自動辨識與分析技術的進一步發展。

中文關鍵詞：深度學習、岩石薄片、影像分割、自注意力機制

Development of an Ergodic Ground Motion Model for Estimating 5% Damped Spectral Acceleration in Northern Vietnam

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Northern Vietnam is a tectonically active region marked by numerous active faults; however, the limited availability of recorded ground motions presents significant challenges for seismic hazard assessment and engineering design. To address this limitation, this study develops an ergodic Ground Motion Model (GMM) by regionalizing the global ASK14 model, ensuring appropriate magnitude and distance scaling, particularly for large earthquakes. Through comparison with global models, the study highlights key differences in ground motion scaling for small-magnitude events, which are dominant in the region. Due to the absence of direct shear wave velocity in the upper 30 meters (V_{S30}) measurements, site conditions are estimated using horizontal to vertical (H/V) spectral ratios, which show strong correlation with global site response models. The proposed GMM corrects misfits observed in the original ASK14 predictions and significantly reduces aleatory variability, which can improve performance in Probabilistic Seismic Hazard Analysis (PSHA). Future research will aim to incorporate basin effects, improve site characterization, and refine near-source modeling using detailed fault geometry.

Keywords:Ground Motion Model(GMM), Site Effects (H/V Ratio, VS30), Probabilistic Seismic Hazard Analysis (PSHA), Regionalization, Northern Vietnam

台灣中部陸海域碳封存潛能評估-以台中電廠為例

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因應2050淨零碳排政策，減碳已成為台灣重要課題。隨高科技產業發展，電力需求日益增加，而台灣主要電力來自火力發電，因此協助火力電廠減碳至關重要。台中火力發電廠為全台最大火力電廠與碳排放源，若能有效降低其排放，將為邁向淨零的重要指標。

本研究以台中電廠為案例，結合文獻與數值模擬技術，評估其進行碳封存的可行性，探討源頭與封存場址合一的設計。在碳封存可行性方面，首先須確認地層是否具備良好的封存層與蓋岩。資料顯示，台灣西部沿海為沉積環境，台中電廠下方地層自淺至深包括錦水頁岩、桂竹林層、觀音山砂層、打鹿頁岩及北寮層。其中，錦水頁岩為良好蓋岩，桂竹林與觀音山砂層則具高孔隙與滲透性，適合作為封存層，深度約2200公尺，整體封存系統厚約450至500公尺。本研究以電測資料選定桂竹林與觀音山層內的4個高孔滲區段作為注入目標層。

本研究設計三種注入情境：(1)陸域注入：位於電廠陸域內；(2)海域注入：電廠西側9公里處海域；(3)混合注入：同時於陸域與海域各設一井。各井貫穿四個封存層段，注入條件為不超過地層原始壓力1.25倍，最高每年注入100萬噸二氧化碳，模擬注入期20年，並觀察封存效果30年。

模擬結果顯示，陸域案例可封存4213萬噸二氧化碳，海域為3439萬噸，兩者團塊移棲範圍皆約30平方公里；混合注入案例中，陸域與海域分別封存4058萬噸與3235萬噸，團塊移棲範圍無明顯擴大，且兩團塊未接觸，壓力亦無顯著交互影響，顯示混合注入具良好安全性與分散效果。

本研究結果指出，台中電廠區域之地層結構具備碳封存潛力，且透過混合注入可有效降低井間干擾，提供火力電廠進行碳封存的重要參考與實務應用潛能。

中文關鍵詞：二氧化碳地質封存、淨零碳排、數值模擬、封存潛能評估

利用噪訊成像技術反演觀音山地區剪力波速度模型

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觀音山位於淡水河的西南方、林口臺地的東北方，前人的地質調查指出在該地區內發現火成性的侵入岩體，因此觀音山被認為是一座古火山，而觀音坑則為已坍塌的破火山口。近年來環保意識提升，再生能源的提倡使地熱發電成為重要的發展項目之一，而地熱發電的前置探勘工作是不可或缺的一環，觀音山地區作為一個休眠火山，具有潛力成為地熱能源的開發地區，然而相較於大屯火山群而言，觀音山地區下方淺層速度構造的研究較為缺乏。

本研究在觀音山地區應用噪訊成像技術(ambient noise tomography)，於觀音山地區佈設了55個簡易地震儀（SmartSolo）組成的觀測陣列，平均測站間距約0.8公里，並結合Formosa Array的部分測站（9個）組成我們的觀測網，噪訊紀錄時間範圍為2022年9月18日至2022年10月17日以及2022年11月9日至2022年12月7日，使用了約兩個月長的噪訊紀錄進行分析，首先將兩兩測站對的連續波形紀錄進行互相關後並疊加，萃取各測站配對之間的基態雷利波格林函數（Green’s Function）；接著使用多重濾波法（Multiple Filter Technique, MFT）得到週期0.5－6秒間的群速度及相速度的頻散曲線；最後使用快速推進法（Fast Marching Method, FMM）計算測站配對之間的波線路徑以建構反演矩陣，並反演得出各週期的基態雷利波二維群、相速度模型，再將模型做第二次反演得到三維的剪力波速度模型。在最終三維剪力波速度模型中，觀音山頂峰至觀音坑的區域，於深度0－0.6公里為相對高速異常，指示出火成岩或岩脈入侵；而到了深度0.8公里以下後，俯視的同一區域則變為低速異常，暗示這個範圍有較高的地溫梯度。

中文關鍵詞：周遭噪訊、層析成像、快速推進法

A rapid tectonic plate reorganization event dynamically modelled by changes in subduction location

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The occurrence of tectonic plate reorganization events is evident throughout the geologic record and appears to be associated with the cessation of mature and/or initiation of new subduction. Subduction initiation that produced the bend in the Hawaii-Emperor seamount chain resulted in the most recent upheaval of plate motion and engendered dramatic changes in plate velocities. Here, applying a method for identifying plate boundaries in a numerical global mantle convection model, we calculate Euler vector time series of self-consistently generated plates over a period of approximately 144 Myr. During this period, global evolution is characterized by two dominant convergent boundaries and the number of major plates identified varies between 9 and 13. Using a 2 Myr sampling rate to track the histories of three enduring plates that share a common triple junction, we observe a major plate reorganization event occurring over approximately 6-8 Myr. The catalyst for the event is identified as the development of a deep thermal feature intrinsic to internally heated convection. A buildup of heat enveloping a mature mantle downwelling accumulates a buoyancy that resists ongoing plate motion and eventually forces the over-riding plates on a new trajectory.

Keywords:mantle convection, Euler pole, tectonic plate, reorganization, internal heating

馬槽區域地熱流體化學分析

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因應氣候變遷的影響與日俱增，為保障人類現居的環境能永續發展，「2050淨零排放」、「能源轉型」為我國不分你我攜手戮力以赴的指標。台灣中油股份有限公司順應世界潮流不落人後，以穩定能源供應、提供多元服務與追求永續發展為使命。配合政府能源政策，在地熱項目之中，為研究馬槽區域地熱流體特性與評估大屯火山地熱資源，增進該區地熱開發可行性的資訊，本研究分析本公司與地礦中心於馬槽地區合作之地熱探勘井(CGS-MT-01)，於民國113年12月底至114年1月現場進行產能測試工程期間，前往採集井口流體樣本，包含冷凝水、不凝結氣體以及二相流體，量測項目包括：氣體成分組成與含量、液體(冷凝水)的陰陽離子成分與濃度，以及酸鹼值、氧化還原電位與導電度。本公司設有數台儀器可應用於地熱流體分析，例如感應耦合電漿發射光譜儀(ICP/OES)、離子層析儀(IC)與自動滴定儀，可對水樣中的陰陽離子做定性與定量分析；地熱氣體分析儀(GC-TCD/FID)可獲知樣本的氣體種類與含量。

結果顯示液體分析的陽離子以鈉離子、鉀離子、鐵離子與矽離子的濃度較高；而陰離子中以氯離子和硫酸根離子為主要成分，量測到的pH值約為4，其結果顯示若要於該地熱區開發地熱，儘管從井口採集的冷凝水pH值較地表溫泉水(約為2)高，日後仍須評估其弱酸性流體對管材與發電設備的影響。氣體檢測結果與大屯火山氣體的相關研究類似，水氣最大宗，其次為二氧化碳、氮氣與甲烷。流體特性分析成果可判斷流體來源，日後可應用於熱焓計算以及管材腐蝕模擬，有助評估管材的選用，獲得最佳地熱開發方案。

中文關鍵詞：地熱開發、地熱流體、馬槽

Environmental Seismology for Landslide(I): Universal Machine Learning Model for Landslide Detection

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Rockfalls pose a significant threat to infrastructure and human safety in mountainous terrains. While seismic monitoring offers a promising solution, the generalization capability of recent advanced machine learning models often falters across diverse sites and noise conditions, particularly for those relying on color spectrograms or single seismic inputs. To address this limitation, we introduce a generalizable and scalable bi-binary classification framework for robust rockfall detection. Our method leverages elevation-derived, dual-station black-and-white spectrograms, processed with a masking algorithm to isolate high-power spectral signatures. Trained on an extensive dataset of 76,548 concatenated spectrograms from the Daman landslide (Taiwan), the model achieved a training accuracy of 0.99. Subsequent evaluation on an independent dataset of 18,385 manually reviewed events yielded superior recall (0.98) and precision (1.0) for rockfall events after excluding controllable conditions such as engineering activity, flooding, rainfall, and earthquakes. Only 12 small-scale, low-risk rockfall events were misclassified. Significantly, we demonstrate the model's robust transferability and performance on diverse, unseen datasets from Riou Bourdoux (France), Dongao (Taiwan), and a 27-day continuous monitoring campaign at Kukuan (Taiwan) without any retraining. These findings establish the feasibility of an elevation-driven, dual-station seismic configuration as a foundational element for a universally applicable and practically deployable machine learning model for landslide detection.

Keywords:Machine learning, Rockfall detection, Universal model

Sequential Inversion of Seismic and Gravity Data for Full-Crust Imaging in Taiwan

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Taiwan, located at the convergent boundary between the Eurasian Plate and the Philippine Sea Plate, is one of the most tectonically active regions on Earth. While previous seismic velocity models have greatly advanced our understanding of large-scale crustal structures, the resolution of shallow features remains limited, particularly in mountainous regions. This study integrates seismic travel-time tomography and gravity inversion through a sequential framework to generate a high-resolution, full-crustal model of seismic velocity and density.

We analyzed over 19,000 local earthquakes recorded between 2012 and 2020 by the Central Weather Administration (CWA) and the Taiwan Strong Motion Instrumentation Program (TSMIP), using a grid-based event selection strategy to ensure uniform spatial coverage. Seismic velocity inversion was conducted using the tomoDD algorithm, which enhances structural resolution by minimizing common ray-path effects through double-difference methods. The resulting Vp and Vs models were then converted into density using an empirical velocity–density relationship to provide initial input for gravity inversion.

The gravity model was constructed using free-air gravity anomaly data derived from terrestrial, airborne, and marine surveys. Unlike conventional approaches that use Bouguer anomalies and assume fixed densities for topographic corrections, our method treats above-surface rock as part of the active inversion domain. This allows the model to account for both surface relief and subsurface variations in density, yielding a more physically consistent representation of the crust.

Through iterative updates of seismic and gravity models, the sequential inversion achieves mutual consistency between two distinct datasets. The final model reveals a weak and deformable lower crust beneath the Taiwan orogen. Interestingly, zones of deep crustal thickening do not coincide with the surface drainage divide, suggesting a structural decoupling between surface topography and deep lithospheric deformation. This asymmetry may reflect ongoing eastward subduction of the Eurasian Plate beneath the orogen, displacing the crustal root eastward relative to the topographic crest. Geological observations near the Puli Basin—including slate collapse structures, abrupt topographic depressions, and localized crustal thickening—may indicate the northern boundary of this eastward subduction.

Keywords:Sequential inversion, Seismic tomography, Gravity anomaly, Taiwan orogeny

台灣中部山區小集水區沉積物收支分析

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本研究對台灣中部阿里山地區的四個小型集水區，分別為乾坑溪、哈比哈拿溪、愛玉子溪和出水溪，進行了沉積物收支的分析，以探討積物在其中的移動情形，以及其影響因子。在分析時，先初步將沉積物收支分為生產和輸出，接著再向下拆分為幾個細項進行討論。沉積物的生產主要來自坡面的崩塌和沖刷。 其中，崩塌是使用面積-體積的經驗公式來估算坡面崩塌產生的沉積物；沖刷則是使用MUSLE（Modified Universal Soil Loss Equation）公式來估算降雨造成的土壤流失。 沉積物的輸出則是分為土石流流出和河川搬運。 其中，土石流流出是透過軟體RAMMS（Rapid Mass Movement System）來模擬土石流事件造成的沉積物移動；河川搬運則是使用河道輸砂公式來估算懸浮載與河床載的體積。 每一次的分析都會使用最接近事件發生時間的地形，以考慮不同時期的地形變化，並減少在同個地形不斷疊加的估算造成的誤差。 本研究針對2000年-2024年間在特定集水區發生的土石流事件，進行其沉積物收支的分析，也觀察了不同環境因素，如地質條件或降雨特性等，對集水區中沉積物變遷造成的影響，以進一步了解存在於中部山區的小集水區中不安定土砂的變化情形。

中文關鍵詞：沉積物收支、崩塌、坡面沖蝕、輸砂量、土石流

Environmental Seismology for Landslide (II): A Power-Law Relationship Governing the Propagation of Rockfall-Induced Seismic Waves

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Seismological monitoring is a valuable tool for detecting rockfalls over broad spatial scales. However, the fundamental relationship between rockfall characteristics and the limits of seismic detection remains a key area for investigation. This study presents a controlled experimental approach, involving 22 rockfalls with a kinetic energy range of 24.0–497.8 kJ, recorded by a dense linear array of 39 seismic stations with source-to-station distance ranging from less than 1 m to 1,476 m. Our analysis reveals a power-law scaling relationship between rockfall kinetic energy (E_k, in kJ) and horizontal seismic signal propagation distance (X, in meters), described by $E_k=7\times10^{-6}\ X^{2.592}$, with a maximum detection range of 1,159 m observed for the highest energy event. By integrating our experimental data with existing field observations, we extended the analyzed source-to-station distances to 10.7 km and refined the power-law model to $E_k=8\times10^{-6}\ X^{2.578}$, highlighting the consistency across different scales. Considering the influence of geological heterogeneity on seismic wave propagation, we further establish practical upper and lower bounds for detection limits ($E_k=1.5\times10^{-5}\ X^{2.578}$ and $E_k=3\times10^{-6}\ X^{2.578}$, respectively). These experimentally derived and validated relationships provide a crucial foundation for optimizing seismic network design before hazard occurrence and enhancing the efficacy of real-time rockfall monitoring and hazard mitigation strategies in vulnerable mountainous regions.

Keywords:Rockfall experiment, Seismic signal, Kinetic energy, Station deployment strategies

利用PlanetScope影像探討2022年緬甸景棟地震同震山崩空間分布特性

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摘　要

2022年 7月，緬甸東部景棟地區發生規模 5.9的地震，誘發廣泛分布的山崩事件，為該區近年較具規模之地震型山崩事件。本研究旨在探討此次地震所引發之同震山崩的空間分布特性，進一步釐清該區域地震觸發山崩的控制因子。為此，本研究以高解析度光學衛星影像PlanetScope為主要資料來源，分析地震發生前後的地表植生變化，以判釋山崩發生區域。本研究選定景棟地震震央周圍半徑約 100公里範圍作為分析區域，選用地震發生前後之衛星影像進行常態化差異植生指標差異（dNDVI）偵測可能之山崩區域，並輔以人工影像判釋，建立緬甸景棟地震的同震山崩目錄，作為後續空間分析之基礎資料。

初步結果顯示，本次地震所觸發之山崩皆位於美國地質調查局所模擬的震度IV以上的範圍，與前人研究所提出的地震觸發山崩閾值結果相符。然而，山崩在空間上卻並非呈現以震央為中心的對稱同心圓模式，而是具有顯著的方向性分布特徵。山崩密集分布於震央西側至西南側的山區，範圍可延伸至距離震央約 70公里，其餘方向上則相對稀疏。此種不對稱分布的現象，可能顯示地震實際的地表強震分布與模型預估的震度圖因斷層破裂所伴隨的方向效應（directivity effect）而有所落差；另一方面，其分布也可能受到區域地質條件的影響。本研究將進一步結合區域地質圖資與地震序列資料進行深入分析，以探討地震破裂機制與地質條件共同作用下對山崩空間分布的控制效果。

中文關鍵詞：地震誘發山崩、衛星影像、常態化差異植生指標(NDVI)、方向效應

結合Scoops3D與TRIGRS評估嘉義中心崙大規模崩塌潛勢邊坡之穩定性

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極端降雨事件常誘發山坡地崩塌，對公共設施與人民生命財產造成威脅，因此瞭解邊坡在降雨過程中的穩定性至關重要。採用極限平衡法作為計算理論的數值分析方法，是目前常見的邊坡穩定性評估方法之一。本研究結合美國地質調查所（USGS）開發的 TRIGRS 與 Scoops3D 兩套數值分析軟體進行模擬：TRIGRS 可模擬降雨期間地下水位隨時間變化的動態過程，Scoops3D 則可建立考量地形與地質條件的三維穩定性模型以計算安全係數。本研究以嘉義縣竹崎鄉中心崙的潛在大規模崩塌邊坡（編號 T003）為研究案例，建立其水文與地質模型。透過 TRIGRS 模擬降雨引致的地下水位變化，並將結果輸入 Scoops3D 進行邊坡穩定性分析。模擬結果顯示，在 2024 年凱米颱風期間，邊坡安全係數隨降雨開始下降，並於降雨後第 25 小時趨於穩定。其中，西側 M1 塊體安全係數約為 1.08，處於極限狀態；東側 M2 塊體安全係數低於 1.0，顯示處於不穩定狀態；L 塊體安全係數約為 1.04，同樣接近極限狀態。此外，為比較不同雨型對邊坡穩定性的影響，研究另設計前鋒型與後鋒型降雨事件，與凱米颱風所屬之中鋒型雨型進行比較。三種雨型模擬結果皆顯示安全係數在降雨初期快速下降，至最低點後趨於穩定，其中前鋒型雨型下降最快，後鋒型則最慢。綜合模擬結果可知，結合 TRIGRS 與 Scoops3D 的數值分析方法，能有效模擬邊坡在降雨期間安全係數的變化歷程，並評估地形與雨型對穩定性的影響。模擬顯示中心崙地區多數塊體安全係數偏低，呈不穩定狀態，具高度崩塌風險，顯示該區應加強監測與防災應變準備。

中文關鍵詞：大規模崩塌、極限平衡法、TRIGRS、Scoops3D

歐亞板塊在台灣中部隱沒作用的特徵分析：來自 SALUTE 地震資料的觀察

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台灣造山帶位於菲律賓海板塊與歐亞板塊之交界，板塊快速聚合與頻繁地震活動顯示該區域造山作用極為活躍。雖然已有眾多研究探討台灣中部與南部的板塊交互作用，但對於其最佳構造模型仍未有定論。其中一項關鍵問題，是歐亞板塊於台灣中部向東隱沒的範圍與延續性，以及其與向西北隱沒的菲律賓海板塊之間的互動關係。為了釐清此一構造特徵，我們佈設了密集的地震觀測網，包含29座陸地寬頻地震站與8座寬頻海底地震儀，東西向橫跨整個台灣南部及其東側近海地區，南北向則沿潮州斷層兩側分佈，範圍涵蓋由隱沒過渡至碰撞的構造帶。研究利用來自不同方位角，規模大於5的遠震事件之P波走時和振幅異常進行分析。

結果顯示，位於西部麓山帶的地震站出現明顯延遲，而中央山脈的地震站則顯示提早到達，反映出地底存在橫向變化的速度異質性，與隱沒—碰撞過程密切相關。結合振幅異常與直達P波多重路徑的觀測結果，我們推論台灣中部下方存在一隱沒板塊。進一步的波形模擬將有助於描繪該板塊的幾何形態與物理性質，深化對區域地體動力學的理解。

中文關鍵詞：southern Taiwan、travel-time anomalies、multi-pathed waveforms、finite difference method、amplitude anomalies

Environmental Seismology for Landslide (III): A Seismic-Based Warning System for Rockfall Mitigation on Roadside Slopes Impacted by the 2024 Hualien Earthquake

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Temporary Path No. 37, a controlled access road connecting Kukuan and Deji, traverses a geologically unstable mountainous region affected by the 1999 Chi-Chi Earthquake and subsequent seismic activity and typhoons, leading to frequent rockfall hazards. The 2024 Hualien Earthquake further destabilized slopes, triggering substantial coseismic rockfalls. Understanding rockfall activity following this significant earthquake is important for effective hazard mitigation and management. To monitor the 5.5 km road section between the 17k and 22.5k milestones (k, kilometer), we installed a micro-seismic observation network in 2024, comprising four stations (two broadband and two geophone seismometers). Complementing this seismic monitoring, the Highway Bureau conducts multiple daily road inspections to ensure road safety. Their records from April to November 2024 documented 107 rockfall events on the road, primarily triggered by the Hualien Earthquake and subsequent rainfall. Our seismic signal analysis identified 73 rockfall events, including 13 coseismic rockfalls. The inventory revealed 25 large-scale events recorded by all four seismic stations, posing a high risk to road users. We implemented the GeoLoc method, using milestone locations at 100m intervals as a grid, to determine the source locations. This approach successfully detected and located potential hazard sections with an approximate error of 1-2 km, representing a novel technique for reducing traffic risk through improved hazard management. Beyond rockfall monitoring, we also analyzed sustained high-power seismic energy to estimate flood wave velocities along the adjacent Dajia River. This allowed for a potential flood warning to be issued up to 40–70 minutes in advance for a critical road section at the 12k milestone. This integrated seismic monitoring approach demonstrates its potential to provide near real-time assessment and early warning for both rockfall and flooding hazards along this highly vulnerable transportation artery, offering crucial information for enhanced road safety and disaster mitigation.

Keywords:Seismic signals, Rockfall activity, 2024 Hualien Earthquake, Hazard management

Sequential Inversion of Seismic and Gravity Data for Full-Crust Imaging in Taiwan

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Taiwan, located at the convergent boundary between the Eurasian Plate and the Philippine Sea Plate, is one of the most tectonically active regions on Earth. While previous seismic velocity models have greatly advanced our understanding of large-scale crustal structures, the resolution of shallow features remains limited, particularly in mountainous regions. This study integrates seismic travel-time tomography and gravity inversion through a sequential framework to generate a high-resolution, full-crustal model of seismic velocity and density.

We analyzed over 19,000 local earthquakes recorded between 2012 and 2020 by the Central Weather Administration (CWA) and the Taiwan Strong Motion Instrumentation Program (TSMIP), using a grid-based event selection strategy to ensure uniform spatial coverage. Seismic velocity inversion was conducted using the tomoDD algorithm, which enhances structural resolution by minimizing common ray-path effects through double-difference methods. The resulting Vp and Vs models were then converted into density using an empirical velocity–density relationship to provide initial input for gravity inversion.

The gravity model was constructed using free-air gravity anomaly data derived from terrestrial, airborne, and marine surveys. Unlike conventional approaches that use Bouguer anomalies and assume fixed densities for topographic corrections, our method treats above-surface rock as part of the active inversion domain. This allows the model to account for both surface relief and subsurface variations in density, yielding a more physically consistent representation of the crust.

Through iterative updates of seismic and gravity models, the sequential inversion achieves mutual consistency between two distinct datasets. The final model reveals a weak and deformable lower crust beneath the Taiwan orogen. Interestingly, zones of deep crustal thickening do not coincide with the surface drainage divide, suggesting a structural decoupling between surface topography and deep lithospheric deformation. This asymmetry may reflect ongoing eastward subduction of the Eurasian Plate beneath the orogen, displacing the crustal root eastward relative to the topographic crest. Geological observations near the Puli Basin—including slate collapse structures, abrupt topographic depressions, and localized crustal thickening—may indicate the northern boundary of this eastward subduction.

Keywords:Sequential inversion, Seismic tomography, Gravity anomaly, Taiwan orogeny

臺灣海峽北部高解析震測沉積構造和斷層構造研究

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從2018年開始，我們在臺灣海峽北部進行多次的多頻道反射與海底地震儀震測，以探討臺灣海峽北部的沉積構造、斷層位置、深度與型態(正斷層或逆衝斷層)以及海底火成活動的分布。本研究聚焦於2024年9月NOR2-0132航次搭載電火花為震源在觀音地台收集的18條高解析反射震測剖面與8部海底地震儀資料。我們將分析觀音地台穩定與被侵蝕的沉積構造、正斷層的走向與活動斷層的存在。研究成果可探討觀音地台的北緣邊界線及整合臺灣海峽北部的淺部沉積與斷層構造。在海底地震儀資料分析上，因淺層沉積構造的P波速度較小，因此將通過沉積構造的理論折射波與反射波走時疊加在以2.5公里/秒化減速度顯示的海底地震儀震測資料上，選取來自淺層沉積層的折射波和反射波走時。從折射波走時反演觀音地台北部的淺部沉積構造，並從反射波走時反演高解析沉積層界面的位置，最後透過海底地震儀震測P波速度模型疊加於高解析反射震測深度剖面，以辨識兩者沉積界面是否吻合。根據已建立的P波速度模型，觀音地台北部深度1公里內淺部沉積層P波速度為1.5-2.2公里/秒，可探討觀音地台北部淺部沉積層穩定與被侵蝕的低速帶或高速帶存在及是否受到正斷層影響的沉積構造。我們也發現，受到臺灣造山帶荷重的影響，沉積層界面向陸地方向逐漸變深(0.4-0.9公里深)，且越靠近陸地的沉積層，會有較複雜的速度變化(1.8-2.2公里/秒)。

中文關鍵詞：斷層構造、觀音地台、P波速度-界面模型、沉積構造

地表斷層錯動量觀測與評估間之合宜性探討

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在工程實務上，對於跨斷層設施或是維生管線的建設，除了地震動所可能造成的危害之外，斷層地表錯動也是工程上對於線形基礎設施可能遇到的危害之一。然而，台灣的地震斷層錯綜複雜、地震活動頻繁，但對於已知斷層錯動造成地表破裂的地震事件資料紀錄並不完整，因此在斷層錯動量之評估上，目前仍借助國際間已發展的斷層錯動模型(Fault Displacement Models, FDMs)作為參考，例如Youngs et al. (2003)、Petersen et al. (2011)、Moss and Ross (2011)等。現階段國際上發展不同斷層型態的斷層錯動模型，資料庫主要來自SURE或FDHI等跨國計畫之產出，資料庫彙整了國際各地發生的地表破裂地震事件，包含台灣1999集集地震資料(Lee et al.,2003)。有鑑於台灣近年來已發生多筆地震事件具有豐富的地表錯動量，包括2018花蓮外海地震及2022池上關山地震的斷層位移資料(Huang et al.,2022; Wang et al., 2024)，此為一個機會進一步檢視國際錯動量評估模型於台灣的斷層可能引致之錯動量評估的合理性，進而探討其在實務工程應用上的建議。本研究統整上述三筆地震的觀測錯動量，用以比較國際錯動量評估模型的推估值。據此用以探討在台灣地質環境上，應用目前國際地表錯動量評估模型的合理性，以及對應的建議，作為工程實務應用之參考。

中文關鍵詞：斷層錯動、工程地震、地震危害

結合離散式升學感測與多通道表面波分析技術之初探

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近年來，隨著基礎建設的快速發展與地震監測需求的提升，非破壞性地盤勘測技術的重要性日益增加。多通道表面波分析（Multichannel Analysis of Surface Waves, MASW）作為一種非破壞、高效率且應用廣泛的方法，透過分析地表瑞利波之頻散特性，可反算地下各深度之剪力波速度（Vs），然而，傳統 MASW 多仰賴地震檢波器（Geophone）逐點布設，測試範圍與空間解析度受限，難以因應大範圍或長期連續監測的需求。

為解決此一限制，近年來分布式聲學感測技術（Distributed Acoustic Sensing, DAS）逐漸受到重視。DAS 運用光纖並透過雷利散射原理，將一般光纖轉化為連續分布之感測陣列，兼具大範圍、高解析度與即時監測等特性，相較於傳統 Geophone 具更高之應用潛力。若能將 DAS 技術結合 MASW 法，藉由對地表振動訊號的高密度量測，不僅可提升空間解析度，也能減少人力與時間成本，對地盤穩定性評估與地震工程具重大意義。

本研究旨在探討 DAS 於 MASW 測試中的可行性與反演精度，建立利用 DAS 量測地表振動以推估 Vs 分布之整合技術。研究方法包含透過 COMSOL Multiphysics 進行理論模擬，並於中央大學國泰樹草坪進行現地試驗，同步以 Geophone 測試作為對照。經由對時域與頻域訊號分析，並結合 Surfsei6 軟體反演，可評估 DAS 數據的品質與適用性。預期本研究可證實 DAS 應用於 MASW 的潛力，提高地層剪力波速度量測的準確度與空間解析度。

綜上所述，本研究不僅為 DAS 在地盤勘測領域的實務應用奠定基礎，也可拓展至地震工程、管線健康監測與場址安全評估等領域。透過本研究所建立之方法框架，將可為地盤穩定性評估與工程設計提供更有效的技術工具，並促進 DAS 與 MASW 於地質探測與災害防治方面的深層應用。

中文關鍵詞：Distributed Acoustic Sensing、Multichannel Analysis of Surface Waves、Inversion

Structural Evolution of the Eastern Taiwan Collision Zone: Insights from 2D Thermo-Mechanical Simulations

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We employ two-dimensional thermo-mechanical numerical simulations to model the arc-continent collision between the South China Sea (SCS) and the Philippine Sea Plate. Our results elucidate the progressive structural evolution along the collision zone, which can be interpreted as representing a south-to-north transition. The model captures the initial subduction of the SCS oceanic crust beneath the Philippine Sea Plate at the Manila Trench, leading to the formation of the Luzon Arc (LA). As the more buoyant transitional crust of the SCS resists subduction, horizontal compressive stress is redirected into the overriding plate. This induces buckling of the forearc basin into a syncline and the development of an east-dipping fault—the Taitung Trough fault—which enables the LA to overthrust basin sediments and basement rocks. In cross-section, the Taitung Trough fault converges with the North Luzon Backthrust, forming an inverted-V geometry that buries forearc structures to depths of 20–40 km. As convergence continues, the North Luzon Backthrust steepens to near-vertical below 10 km, while the Taitung Trough fault deepens to 15 km, coinciding with the emergence of the Longitudinal Valley Fault (LVF). A new backthrust develops farther east, aligned with the Central Range Fault (CRF) and possibly connecting with the Chimei Canyon thrust at shallow depths. This tectonic evolution results in a highly intricate fault network beneath the Longitudinal Valley, fundamentally shaping the region's seismotectonic architecture. The modeled shear zones correlate well with the observed aftershock distribution, supporting the validity of our forward modeling approach in capturing key tectonic structures.

Keywords:geodynamics, arc-continent collision, longitudinal valley fault, central range fault

台灣西南海域台南盆地之演化模式再探討

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過去已有許多研究與報導指出台灣西南海域海床下蘊藏大量的天然氣水合物及游離氣，近幾年來，台灣中油公司也曾利用震測及地質資料進行解釋，認為除了富含大量的天然氣水合物及游離氣之外，也有可能蘊藏豐富的傳統油氣資源，使得本地區的油氣探勘潛力獲得進一步重視。為了更深化對台灣西南海域台南盆地演化的認知，本研究使用位於台南盆地的震測與地質資料進行整合研究，對前人提出之台南盆地演化模式進行探討，進一步詮釋盆地自白堊紀以來，在不同的演化階段下（前張裂期、同張裂期、後張裂早期、後張裂晚期、前陸盆地）各構造單元間的演育過程，有助提升對盆地石油系統的認識，並根據前人研究結果更新盆地演化模型示意圖，以更符合對演化歷程的認知。此外，本研究也分析可能的沉積物來源及輸送方向，探討盆地沉積物的充填過程，並指出自中新世早期以後在盆地不同部位可觀察到大量濁流岩、盆底扇、陸坡扇及水道等沉積特徵，這些碎屑沉積岩可成為油氣的儲集岩，也是世界各地深水油氣探勘的主要目標層類型。

中文關鍵詞：深水油氣探勘、台南盆地、盆地演化

澳洲西北海域W礦區之構造與封閉探討

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澳洲西北海域的W礦區主要位在古生代張裂的坎寧盆地(Canning Basin)內的Oobagooma次盆地，次盆地內呈現南北兩側高且中央低的樣貌。礦區東側為與次盆地類似形貌的Fitzroy地槽，為礦區內沉積物供給的主要來源方向。西側則是羅巴克盆地(Roebuck Basin)內的Bedout次盆地，近年在下部中生界有重大油氣發現的Dorado油氣田即位在其中。本研究利用澳洲西北海域坎寧區域在2022年新採集的2D震測資料、8條1980與1990年代的震測剖面與W礦區周圍的井測資料，對礦區進行合成震波比對與震測資料解釋，並搭配封閉構造內的震波屬性分析，礦區周圍的井下電測資料計算，以及過往在同一區域的研究成果進行礦區內構造與封閉地分析探討。

根據震測資料解釋與井測資料分析的結果，構造解釋解析了自中生界至上部古生界的5個目標面：白堊系頂部、侏羅系頂部、三疊系頂部、二疊系頂部與石炭系Meda不整合面。綜整目標面分析與文獻資料，本研究認為礦區中部的古生界四方圈和與礦區南部的古生界碳酸鹽岩礁體有成為構造封閉的潛能。震波屬性分析在古生界碳酸鹽岩礁體內有觀察到AVO異常，推測是碳酸鹽岩礁體與周圍碎屑岩岩性差異或與油氣有關的訊號。礦區內中生界則是三疊系地層封閉與侏羅系砂岩為具有油氣儲集潛力的構造，井下電測資料計算結果顯示侏羅系有厚層砂岩，據此推測礦區內應同樣有此系列厚層砂岩。但由於資料密度不足，三疊系地層封閉與侏羅系砂岩尚難以明確地界定其區域範圍。

研究結果認為W礦區中生界與上部古生界內有4個具油氣儲集潛能的構造與封閉，分別為(1)礦區南部古生界碳酸鹽岩礁體，(2)礦區中部古生界四方圈合，(3)三疊系地層封閉與(4)侏羅系砂岩層。其中礦區南部古生界碳酸鹽岩礁體是探勘相對風險較小的標的，其他構造與封閉則有明顯地周圍地層封阻問題或缺乏良好的石油系統等因素，探勘風險相對較高。

中文關鍵詞：澳洲西北海域探勘、震測資料解釋、構造與封閉、碳酸鹽岩礁體

CO2地質封存監測技術生命週期整合應用評估

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本研究探討了CO2地質封存監測技術的全生命週期應用策略與系統優化方法。在技術層面，不同地球物理監測技術各具特色且相輔相成。震測技術能提供高解析度的地下構造圖像，但受限於較高成本和地表條件；重力測量適合大尺度CO2遷移監測，但解析度相對較低；電力和電磁方法在淺層監測方面表現突出。特別值得注意的是時間序列電阻率斷層掃描技術(TL-ERT)，該技術在初期監測中表現優異，具有即時成像、高解析度等特點，能有效監測CO2移棲流佈行為。然而，研究強調單一技術難以滿足全面監測需求，必須採用多重技術交互應用的策略。例如，將地震監測與電磁監測結合可同時獲得地層結構和流體分布資訊，結合重力測量和微地震監測則可實現多尺度監測。從生命週期角度，封存過程可分為三個關鍵階段，每個階段都有其特定的監測需求。注入前期需重點進行地質條件調查和基準值建立，為後續監測提供參考基準；注入期間需進行密集監測，重點關注CO2擴散行為和封存安全性；注入後期則需轉向長期監測，關注CO2的穩定性，提升監測精度、降低成本，開發更適合長期監測的新技術，以支持CO2地質封存專案項目的規模化應用。本文強調監測系統的優化設計需要綜合考慮場址特徵、技術可行性和經濟性，包括監測點位布置、頻率安排和資料採集方式等要素。同時，監測策略應建立動態調整機制，根據不同封存階段特點靈活調整。研究建議建立標準化的監測流程和控制體系，確保監測數據的可靠性和可比性，方可最大限度控制碳封存風險，助於利害關係人參與，增進公眾對CCS技術信心，確保環境安全與公眾利益。

中文關鍵詞：CO2地質封存、地球物理監測、多技術協同監測、生命週期監測、場址特徵評估

SEISYNC：基於人工智慧驅動的模組化地震監測系統同步地震預警與地震目錄製作

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我們於此發表 SEISYNC 的beta版本（基於人工智慧驅動的模組化地震監測系統同步地震預警系統與地震目錄製作），這是一個基於人工智慧與微服務架構的平台，目標為同步地震預警系統與地震目錄的建立。系統核心採用 深度學習模型RED-PAN，可從即時串流資料中提供地震P波的即時資訊以及地震P-S波對(P-S pair)的到時資訊。SEISYNC 包含兩個主要子系統，分別對應不同的操作時間尺度：SEISYNC-EEW（地震速報子系統）：即時處理P波到時的偵測，並執行地震預警相關演算法。SEISYNC-CAT（製作震後目錄子系統）：處理暫存的 P 波與 S 波到時資訊，透過較長的時間視窗進行更完整的波形分析，達到穩定且高品質的震源參數估算與地震目錄建檔。SEISYNC 採用分散式微服務架構，每個模組皆可獨立運作，並透過 Apache Kafka 進行通訊協調。此設計確保系統具備良好的擴充性、容錯能力與非同步資料流傳輸特性。此外，SEISYNC 各模組皆具備可替換性，僅需維持一致的輸入與輸出格式，即可無縫整合更先進的演算法模組。最終產品將儲存於結構化 SQL資料庫中，便於長期存取、視覺化展示與與其他外部工具整合。透過結合深度學習與模組化軟體架構，SEISYNC 提供一套完整的解決方案，兼顧地震預警與地震目錄製作的雙重需求。

中文關鍵詞：深度學習、地震監測、地震預警、地震目錄

霧社水庫集水區邊坡大規模崩塌活動性時序觀測

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霧社水庫上游集水區包括南投縣仁愛鄉廬山、清境地區等，主要為廬山層板岩分布，其中板岩常見重力邊坡變形作用，常致岩體破碎進而可能發生山崩現象，即此類重力變形區域多為潛在大規模崩塌之位置。在國內地質災害的研究，此議題也受到各界關注，自有其重要性。莫拉克颱風災後，藉由空載光達技術產製之臺灣全島高解析度數值地形資料，進一步地形計測與視覺化加值處理後，可以判釋出植覆之下受崩塌作用影響所致的變形表徵，進而圈繪出潛在大規模崩塌之範圍，但對於其關鍵的地下地質本質仍所知有限，尤以活動性更為關注重點。

本研究以多期數值地形、無人機影像及手持光達掃描設備(viDoc RTK rover)，進行地形變異分析。經由結果顯示，一般消費級搭載光達相機之行動裝置，再搭配手持RTK裝置後，可將絕對精度範圍提升至公分等級，約略為1-5公分範圍，可進一步提供野外地質調查與山崩活動性觀測等使用，加上手持裝備攜帶方便，具野外調查之機動性，未來應為野外地質調查或山崩調查之一大利器。無人機進行坡面測量部分，以本年度測量結果來看，2期無人機影像可能時間間距不大，位移量與誤差值接近，可能無法直接表示為崩崖附近之地表位移量，唯點位之主要位移方向確實與坡面位移方向符合，此部分仍可待持續測繪多期地形資料進行比對。地形資料變異分析部分，初步也顯示多期數值地形資料搭配高解析度正射影像，確實可以觀察潛在大規模崩塌地區之地表活動性。

2023年卡努颱風事件造成霧社水庫集水區範圍內所見之土砂災害，主要受短延時強降雨之降雨型態所影響，山崩類型以淺層崩塌為主，尤其在力行產業道路沿線密集之土石流與淺層崩塌，反映短延時強降雨型態造成之地質災害特性，另本區所分布之潛在大規模崩塌與廬山北坡等屬較深層岩體滑動地區，以現地調查及部分觀測儀器顯示，多未有明顯位移或活動之現象，意味此降雨型態可能未及岩體滑動之活動門檻，未有較深層岩體滑動之山崩發生。本研究在數值地形資料判釋、無人機多時序影像比對與現地調查顯示未來可比對近年來已發生的大規模崩塌，增進潛在大規模崩塌的判釋和調查能力，更能進一步探討重大坡地地質災害的可能成因和規模或影響範圍，做為未來坡地災害防救策略上亟需的重要資訊。

中文關鍵詞：空載光達、數值地形模型、坡面重力變形、潛在大規模崩塌

Monitoring Rainfall-Induced Landslides and Post-Disturbance Vegetation Dynamics Using Multi-Temporal Satellite Analysis

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Subtropical Taiwan frequently experiences intense rainfall from typhoons and tropical storms, triggering widespread landslides, often categorized as Multiple-Occurrence of Regional Landslide Events (MORLE). Rapid detection and post-event assessment of these hazards are essential for disaster mitigation and land management, as they can cause extensive economic loss, numerous fatalities, and significant damage to natural resources. The vast volume of publicly available remote sensing data offers valuable opportunities to monitor and analyze such events with no barrier to spatio-temporal constraints. Rainfall-induced landslides (RILs) differ in their mechanisms and spatial patterns from earthquake-triggered landslides, necessitating tailored inventories for accurate analysis. This study presents a semi-automated time series algorithm that integrates Sentinel-2 optical imagery with GPM-IMERG rainfall data to detect RILs in Taiwan. NDVI time series are analyzed at the pixel level to identify abrupt vegetation losses, which are then temporally correlated with extreme rainfall events within a defined time window. The methodology was validated through previously published landslide inventories demonstrating strong performance using moderate-resolution Sentinel-2 data. Beyond detection, the study examines the vegetation's regrowth pattern following landslides using long-term NDVI time series. By applying a model inspired by Newton's law of cooling, the framework relates recovery rates to the NDVI contrast between disturbed and surrounding areas, offering a physically intuitive representation of ecosystem resilience. This integrated analysis not only enhances our ability to map RILs rapidly and accurately but also contributes to understanding vegetation stability in the face of recurrent landslides. Together, these insights support disaster response planning, ecological restoration, and sustainable land use strategies in Taiwan's dynamic landscape.

Keywords:Sentinel-2, GPM-IMERG, rainfall-induced Landslides, time series analysis, vegetation recovery rate

Ocean Heat Transport Variability in the WPWP During Deglaciation: Insights from TraCE-21ka

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Western Pacific Warm Pool (WPWP), defined as a region where annual sea surface temperature exceeds 28°C, is characterized by high heat and moisture content, influencing regional and global climate. Extensive research has focused on WPWP under modern climate conditions and future global warming scenarios; however, comprehensive assessments of the WPWPs heat budget and energy balance in past climates remain limited, especially during major warming transitions.We analyze the the WPWP heat budget evolution during the last deglaciation (21–9 thousand years ago) using the TraCE-21ka transient climate simulation. Results show that horizontal OHT dominates the WPWP heat budget in terms of both deglacial trends and millennial-scale variability. The meridional OHT across the southern (~13°S) and northern (~16°N) boundaries emerges as the primary driver of heat convergence during deglaciation.

During Northern Hemisphere cold periods, such as Heinrich Event 1 and the Younger Dryas, northward heat transport across both southern and northern boundaries increases and is primarily carried by the Kuroshio Current and the New Guinea Coastal Undercurrent. On millennial timescales, variations are mainly driven by changes in mass transport, whereas overall deglacial trends are more closely related to ocean warming. Our findings offer new insights into mechanisms governing WPWPs heat redistribution during deglaciation and provide a framework for interpreting regional proxy records in the context of large-scale ocean–atmosphere interactions.

Keywords:Millennial-scale Variability, Deglaciation, Ocean Heat Transport (OHT) , TraCE-21ka, Western Pacific Warm Pool (WPWP)

Intrinsic uncertainty of noise cross-correlation functions and its implications for source properties

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This paper presents a quantitative approach for evaluating the intrinsic uncertainty (IU) of the noise cross-correlation function (NCF) and applies it to realistic NCFs obtained from broadband seismic arrays in Taiwan. The evolution of the standard deviation of the NCF waveform with increasing correlation time closely aligns with theoretical predictions, confirming the validity of the method. The derived IU provides an objective metric for assessing NCF quality, particularly for coda waves, which are widely used to monitor temporal structural variations. Through an analytical procedure applied to a synthetic experiment, the results demonstrate that the distribution and excitation strength of noise sources strongly influence the IU. Consequently, combining IU estimates with NCF amplitudes derived from different normalization approaches enables a comprehensive assessment of ambient noise source characteristics. Using the proposed approach, this study reveals the excitation mechanisms of short-period secondary microseisms, primary microseisms, and single-frequency microseisms.

Keywords:seismic interferometry , seismic noise , theoretical seismology.

The Field Cases of the Potential Large-scale Landslide Classification and Grading in Western Taiwan

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The method of potential large-scale landslide classification and grading were design by the preliminary revision of forms in 2024, which called as Landslide Topographic Feature Grading Form (LTFGF, Level 1 form) and Potential Large-scale Landslide Hazard Assessment Form (PLHAF, Level 2 form). The sites of landslides will be classified and graded by topographic feature (Level 1 form) first, the grading results with high activity (Grade A or B) in the Level 1 forms will continue to Level 2 form scoring. In this study, 7 potential large-scale landslide sites in Hsinchu, Taichung, Nantou, and Kaohsiung. The Level 1 form evaluation results showed that the sites in Shaonian Stream, Taoyuan and Namasia were classified as the highest activity level Grade A, the Meihua, Lushan and Taoyuan Stream were classified as Grade B high activity. The other 2 sites of Toubiankeng and Huangzhukeng were classified as lower activity Grade C.

The 5 Grade A or B cases with high activity were continues analyzed to Level 2 form scoring. The results showed that the sites in Lushan and Namasia were classified as high activity, the remaining 3 sites were classified as medium activity. For the subsequent refinement work of potential large-scale landslide classification and grading, it is crucial to clarify the definitions of the key topographic feature items. The score ranges for determining activity levels also should be analyzed statistically by the increasing field cases and adjusted the threshold scores to the optimal level. Various related issues still need further discussion and research to improve the grading form.

Keywords:Potential large-scale landslide, Classification, Grading, Western Taiwan

運用多頻道反射震測資料分析花蓮外海的米崙斷層構造

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花蓮東北海域鄰近歐亞板塊與菲律賓海板塊的交界，並位於琉球隱沒帶的最西端，因此地震頻繁，且其中許多的地震都與米崙斷層有關。米崙斷層貫穿花蓮市，東側地層有明顯抬升，被稱為米崙台地，且易受地震誘發導致破裂。在2018年2月6日發生的花蓮地震(芮氏規模6.4)震央位於花蓮海脊北邊的米崙斷層。花蓮海脊屬於花蓮近岸東北部的一背斜構造，並從陸地向海上延伸約11公里遠。2018年花蓮地震可能是由震央北部的一個南傾斷層造成的，再藉由地震破裂面影響東邊的西傾斷層，最後海域的西傾斷層再影響位於陸地的米崙斷層。另外位於新城海脊下方增積岩體與琉球島弧之間的2018花蓮地震，也可能是因為呂宋島弧隱沒滑脫面附近的逆衝斷層而引發的。本研究分析2023年10月NOR2-0113航次在花蓮外海收集的32條多頻道反射震測資料，探討並建立花蓮外海的斷層構造，以及判別米崙斷層的位置和走向。將本研究的花蓮外海沉積地層震測剖面與已發表的花蓮外海研究進行比較，確認米崙斷層的位置與走向、發現新的海域斷層或延伸已發現的海域斷層。結合各測線震測剖面與前人研究建立花蓮外海的斷層分布，連接相關聯的斷層構造，發現花蓮海脊南部與米崙台地為相連的滑移壓縮斷層系統。在花蓮外海的米崙斷層屬於左移活動斷層，在近岸的米崙斷層兩邊各有一背斜構造，並且在外海約12公里處，分岔成向北北東與東北兩個方向的左移斷層。北北東方向的米崙斷層在最北端與一東西走向的南傾正斷層相連。此南傾正斷層可能是地震帶下方的底侵運動或地震帶上覆板塊的側向擠壓，使琉球島弧地殼出露形成的。另外在部分海域，因未觀察到沉積層花狀構造，認為該處米崙斷層的逆衝分量較左移分量明顯，所以看起來像是逆斷層。本研究成果將有助於對米崙斷層與其附屬斷層的認識，防範未來可能發生的地震。

中文關鍵詞：米崙斷層、2018年花蓮地震、花蓮海脊、新城海脊、走滑斷層

The geological structures of the Manila forearc region from latitude 16°N to 18°N

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The Vigan High is located in the forearc basin of the Manila Trench off west Luzon Island, where the Eurasian Plate subducts eastward beneath the Philippine Mobile Belt. The Manila Trench and its forearc basin exhibits complex structural features, including onshore faulting, seamount subduction, or possible slab tearing. To investigate the forearc basin between ~16°N and 18°N, we analyzed multi-channel seismic reflection, Sparker seismic reflection, and bathymetric data collected during R/V *Legend* cruises in 2022 and 2023. We also include multi-channel seismic data from R/V *Ocean Researcher 5* in 2014. Based on structural features, the study area can be divided into two regions: a northern region dominated by thrust faults and a southern region characterized by normal faults. Located in the north region, the Vigan High is mainly associated with thrusts and strike-slip faults that dip toward its center, forming a positive flower structure indicative of transpression. The strike-slip component could be the offshore extension of the Philippine Fault Zone. South of 17°N, seismic data reveal a series of normal faults, with steep slopes and uplifted features in the frontal wedge reflecting the deformation due to seamount subduction. These uplifted structures likely result from the subduction of seamounts in the South China Sea. Additionally, multi-channel seismic data indicates an unconformity which separates the normal faults at top strata from the compressed structures beneath. It suggests a transition from a compressional regime to an extensional regime. The stress regime change could be ascribed to a seamount subduction. The contrasting structural styles between the northern and southern regions of our study area might reflect variations in stress regimes in the Manila forearc basin.

Keywords:Vigan High, Stewart Bank, Multi-channel seismic reflection, Sparker seismic reflection

南墨西哥灣Macuspana次盆地北部之古沉積環境與盆地演化初探：井下岩屑所含有孔蟲化石群落之啟示

簡至暐[1]、蘇清全[1]、俞舜文[1]、邱維毅[1]

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位於北美洲南部大西洋側的墨西哥灣係由盤古大陸於中生代時期張裂而形成，歷經至少兩次的張裂事件與兩次的造山運動，以及中侏羅統岩鹽層在盆地演化中後期的鹽構造活動（halotectonics）等影響，造就其不對稱的特殊形貌與複雜的構造演化。此區域素以富含油氣而著稱，其中南墨西哥灣已知最大的坎塔雷爾（Cantarell）油田便位於該海域的坎佩切灣（Campeche Bay），是墨西哥最重要的石油產區之一；不過，相較於已高度探勘及開發的北墨西哥灣，南墨西灣有不少區域—包括本研究所探討，位於坎佩切灣東南盆地（Sureste Basin）最東側的Macuspana次盆地北部區域—則仍處於尚待探勘的階段。

本研究所分析之樣本為位於Macuspana次盆地北部一探勘鑽井之井下岩屑，該探勘井深達5800公尺，基於微體化石之生物地層指示井底附近之層序屬下中新統，其上則為厚逾3000公尺的中－上中新統。底棲性有孔蟲化石群落指示研究區域在中新世時期多屬較深水的上陸坡環境，至上新世早期進入較淺水的中－外陸棚環境，至更新世以後則變為內陸棚－濱海環境。中新統區間樣本的浮游性有孔蟲化石群落常同時包含早中新世、中中新世與晚中新世之指準化石，可有兩種解釋：（1）晚中新世（Tortonian期）為盆地的主要發育時期，並具有可供應早中新世再積性（reworked）移置化石之沉積物源；或（2）較年輕之化石屬於來自井壁崩移（caving）的移置化石，因此厚層的中新統為受地質構造影響而使地層重複出現之結果。以上兩種解釋涉及截然不同的盆地沉陷速率、沉積速率、構造形貌及其活動性，待更多分析結果釐清後，將可對Macuspana次盆地的演化過程及機制有進一步的了解，有助於對南墨西哥灣區域地質之認知及探勘風險之評估。

中文關鍵詞：墨西哥灣、井下地質、有孔蟲、微古生物地層、沉積盆地

Assessing adaptive abilities of the orange coral Tubastraea aurea to ocean acidification using geochemical proxies

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Ocean acidification (OA) poses a significant threat to reef-building corals; however, a notable gap remains in our understanding of how non-reef-building coral species, such as *Tubastraea*, respond to OA under future climate change scenarios. Understanding adaptive ability of non-zooxanthellate therefore help to better estimate the overall impact of OA on marine ecosystems. In this study, we investigate *Tubastraea aurea* from the coastal Fulong and Keuishan Island hydrothermal vent (HV) areas to assess the potential adaptive mechanisms of this coral species. Specifically, we used: 1) boron isotopes to evaluate pH regulation ability, and 2) SEM images to assess the calcification production of *T. aurea* populations in different pH conditions. We further compare the pH regulation and calcification responses to both zoozanthellate and non-zooxanthellate corals and evaluate the adaptive ability of this species.

The $\delta^{11}B$ isotopic composition revealed the ability of *T. aurea* to maintain high calcification fluid pH (pH_{CF}) regardless of ambient seawater pH_{SW}. Further examination of the $CaCO_3$ skeleton revealed no evidence of skeletal dissolution. Additionally, coral colony size varied between sites, suggesting an energetic trade-off favoring pH homeostasis over growth. Compared to literature results, our findings highlight the remarkable physiological resilience of *T. aurea* to extreme acidification. Overall, this study provides novel insights into the physiological resilience and response of *T. aurea* in extreme acidic environments of HV areas and future OA scenarios.

Keywords:boron isotopes, Tubastraea aurea coral, ocean acidification

池上光纖地震儀訊號特性分析

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分散式聲波感測儀（又稱光纖地震儀，Distributed Acoustic Sensor，DAS）因具備高時間與高空間解析度，近年來逐漸成為地震監測的新興利器。將光纖鋪設於井中或地表，不僅能長期、連續地監測地震事件，也能透過模版偵測（template matching）技術，捕捉到更微弱的微震活動。在斷層帶應用方面，井下 DAS 有助於掌握破碎帶內震波傳遞的細微變化，進而達成傳統井下地震儀所難以達成的空間連續監測與高解析度構造成像。在台東池上多維尺度觀測計畫中，已鑽設多口穿過池上斷層的井，並在井內佈設對應的光纖。本研究將分析跨斷層帶，來自各方位傳入之區域地震波形差異，探討斷層破碎帶對震波傳遞的影響。除此之外，我們將利用高效模版事件偵測方法，直接在原始連續紀錄中自動偵測重複發生的微震波形，而無須事先提供模版地震。對於成功偵測出的模版事件，嘗試進行微震定位，並解析其震源機制。預期此流程將有效降低微震檢出之規模閾值，補足單一稀疏測站所遺漏的小事件，新建立的模版資料庫與跨斷層的波形變化，將提供斷層帶破裂活動的資訊，也能運用於後續斷層活動的長期監測工作中。

中文關鍵詞：光纖地震儀（DAS）、模版事件偵測（template matching）、池上斷層

Preliminary comparison of triggered factors of coseismic landslides from the 2024 Hualien earthquake, 2022 Taitung earthquake, and 1999 Chi-Chi earthquake

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On April 3, 2024, a strong earthquake with M_L 7.2 struck Shoufeng Township in Hualien County, located in eastern Taiwan. This earthquake resulted in 18 fatalities and triggered 3,232 coseismic landslides (CLs), affecting a total area of 41.74 km². Prior to this, the M_L 6.6 Guanshan and M_L 6.8 Chihshang earthquakes in Taitung County, which occurred on September 17 and 18, 2022, triggered a total of 303 CLs, collectively referred to as the 2022 Taitung earthquake. Furthermore, the 1999 Chi-Chi earthquake, recorded at M_L 7.3, caused significant casualties and widespread building collapses across central Taiwan, triggering 25,136 CLs. Given their high destructive potential, CLs have long been a critical focus of geohazard research. Establishing representative and consistent landslide inventories is essential for a better understanding of their spatial distribution and triggering mechanisms. This study mapped landslide inventories for the 2024 Hualien, 2022 Taitung, and 1999 Chi-Chi earthquakes utilizing high-resolution satellite imagery captured before and after the seismic events. The inventory for the Chi-Chi earthquake was based on data provided by the Central Geological Survey of Taiwan. The total areas affected by the identified landslides for the three seismic events were 41.74 km², 0.93 km², and 136.8 km², respectively. Additionally, the study analyzed the spatial distribution patterns and controlling factors of the landslides to investigate the variations under different geological contexts and seismic conditions. A total of 14 factors were examined, categorized into three primary groups. The topographic factors included elevation, aspect, slope, plan curvature, profile curvature, distance to drainage (DTD), topographic position index (TPI), and terrain roughness, which were calculated as mean values for each polygon. The geological factor assessed was lithology, while the seismic factors encompassed peak ground acceleration (PGA), peak ground velocity (PGV), distance to fault (DTF), distance to the epicenter (DTE), and azimuth from the epicenter to the slope (AZI).

The findings reveal the comparative analysis of the 14 factors in relation to the CL inventories from the 2024 Hualien earthquake, the 2022 Taitung earthquake, and the 1999 Chi-Chi earthquake. The distribution of CLs was predominantly concentrated in areas where PGA exceeded 250 gal and PGV surpassed 30 cm/s. Landslides triggered by the 2024 Hualien earthquake were primarily observed at elevations ranging from 500 to 1,500 m, on slopes oriented from east to south, with inclinations between 45° to 55°. These CLs were predominantly associated with marble and schist formations. In contrast, the CLs resulting from the 2022 Taitung earthquake were mainly located at elevations below 1,000 meters, particularly on southeast and south-facing slopes with steep gradients of 45° to 55°. The CL affected regions were primarily composed of schist and epiclastic rocks in the 2022 Taitung earthquake. The affected regions in this case were primarily composed of schist and epiclastic rocks. The CLs linked to the 1999 Chi-Chi earthquake were found at elevations below 1,000 m, predominantly on east to southwest-facing slopes with gradients ranging from 35° to 45°, and were primarily located in sandstone, shale, and conglomerate formations. The mean elevations of the CLs associated with the 2024 Hualien earthquake are observed to be greater than those of other seismic events, while the mean elevations of the CLs from the 2022 Taitung earthquake are comparatively lower. Additionally, the mean slope of the CLs for both the 2024 Hualien and 2022 Taitung earthquakes exceeds that of the CLs from the 1999 Chi-Chi earthquake. The mean plan and profile curvatures of the CLs from the 2024 Hualien and 2022 Taitung earthquakes exhibit characteristics indicative of a hollow foot slope type, whereas the CLs from the 1999 Chi-Chi earthquake are representative of a nose slope type. The TPI of the CLs from the 1999 Chi-Chi earthquake is higher than that of the other earthquakes; however, the terrain roughness of these CLs is lower in comparison. The DTD for the CLs across the three earthquakes shows similar patterns. Notably, the DTE and DTF for the CLs from the 2022 Taitung earthquake are shorter than those observed in the others earthquakes. The AZI of the CLs from both the 2022 Taitung and the 1999 Chi-Chi earthquakes predominantly trends toward the north-northeast, while the AZI of the CLs from the 2024 Hualien earthquake is oriented toward the north. This

comparative analysis underscores both the similarities and differences in the distributions of topographic, geological, and seismic factors. The results highlight the significant influence of multi-factor interactions in assessing landslide susceptibility and provide a valuable reference for susceptibility analysis and disaster mitigation strategies in seismically active regions.

Keywords:2024 Hualien earthquake, 2022 Taitung earthquake, 1999 Chi-Chi earthquake, Coseismic landslide inventory

雲林地區地表變形之探討

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雲林地區長期受到地下水位變化與孕震構造活動等多重因素影響，導致地表持續發生變形，對居民生活安全與基礎設施穩定性構成潛在威脅。因此，發展高效率且具長期觀測能力的地表形變監測技術，對於瞭解地表變動成因與評估災害風險至關重要。根據水利署歷年統計，自民國81年至113年間，雲林縣累積最大地層下陷量已達約200公分，最高的每年下陷速率甚至可達12.2公分／年。儘管近年下陷速率呈下降趨勢，但是局部區域的地層下陷現象仍持續發生，顯示需進一步透過高解析度的雷達衛星時間序列資料探討其成因與下陷趨勢。本研究感謝國立中央大學太遙中心提供民國107年至109年間的20幅TerraSAR-X衛星影像，利用GMTSAR軟體的雷達差分干涉技術（Differential Interferometry Synthetic Aperture Radar, DInSAR），產製19幅差分干涉的影像對，並透過StaMPS軟體的永久散射體差分干涉技術（Persistent Scatterer InSAR, PSI）進行分析，計算出雲林沿海地區這三年間的視衛星方向（Line-of-Sight, LOS）地表形變速度場。研究結果顯示，於該時段內遠離衛星方向之最大形變區主要集中於雲林縣四湖鄉，與歷年水準測量資料相符，反映地層下陷現象仍相當顯著，初步分析造成變形機制的主因應該與研究區域內水文地質條件、地下水抽取行為等因素密切相關。本研究進一步整合地下水水位、水準測量、地質構造和地層材質等資料，進行空間與時間關聯性分析，探討地表變形的潛在驅動機制與主控因子。期望透過本研究成果強化對地表變動之理解，並為地質災害防治、基礎建設規劃及永續土地利用提供具體的科學依據。

【學生壁報比賽】參與者於摘要尾端註記

中文關鍵詞：雲林地區、地表變形、雷達差分干涉技術、永久散射體差分干涉技術

Intermophological Vital Effects Reveal by Geochemical Evidence of Planktonic Foraminifera Genus Pulleniatina

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As modern populations of *Pulleniatina* are almost right-coiling, the occurrence of past left-coiling events has long been a subject of interest in paleoceanographic research. Here, we compared both coiling groups across five size fractions (250–300, 300–355, 355–425, 425–500, 500–600 μm) of the core ODP Hole 1115B in the Solomon Sea to evaluate geochemical differences among coiling and size groups during the two left-coiling events of L5 at 2.15–1.88 Ma and L6 at 2.20–2.18 Ma. A total of 11 depth intervals were selected, spanning 2.20–1.65 Ma, and geochemical analyses included $\delta^{13}C$, $\delta^{18}O$, and Mg/Ca ratios.

The results indicate that left-coiling specimens exhibit a gradual rise in $\delta^{13}C$ values as their size increases, whereas the right-coiling group does not display a comparable trend with size. The $\delta^{18}O$ isotope values for both coiling groups do not show significant trend with size. Mg/Ca ratios for left-coiling specimens range from 2.37 to 3.67 mmol/mol, and for right-coiling, from 2.47 to 3.82 mmol/mol which correspond to 20.5-25.2°C and 20.8-25.6°C, respectively. Notably, the 355–425 μm fraction exhibits the lowest Mg/Ca ratios, indicating cold conditions for both the coiling groups. Mg/Ca data suggests the possible vertical migration of *Pulleniatina* in the water column. We speculative biological processes rather than physical conditions cause the ecological barriers between the two *Pulleniatina* coiling groups. These findings provide new insights into environmental drivers of coiling behavior.

Keywords:ODP Hole 1115B, Pulleniatina, left-coiling events, stable carbon and oxygen isotopes ($\delta^{13}C$ and $\delta^{18}O$), magnesium/calcium (Mg/Ca) ratio

Stress inversion of focal mechanism solutions in the Philippine island arc using k-means clustering

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The Philippine island arc represents a mosaic of N-S trending subduction zones that runs semi-parallel to each other. Aside from the on-going subduction, several tectonic elements are responsible for generating high seismicities. We used stress inversion to determine the dominant stress regimes along this region.

1760 focal mechanism solutions were retrieved from the Global Central Moment Tensor catalog. Based on the average crustal thickness of the Philippine island arc from PHILCRUST 3.0 (Parcutela et al, 2020), we considered seismicities that have depths of 40 km and above. We employed k-means algorithm using FMC (Alvarez-Gomez, 2019) to determine the clustering of the seismogenic zones. However, the elbow method only returned two clusters, which we deemed insufficient for the configuration of the region. Therefore, we continued doing k-means for higher k values. We ended up with k=20, while we excluded clusters with seismicities that are less than 10. Then we used StressInverse (Vavrycuk, 2014) to calculate the stress directions using the fault instability constraints of the focal mechanism solutions.

In Western Luzon, the direction of σ1 rotates from the northern part (NW-trending) downwards (NE-trending in southwestern Luzon). This follows the curvature of the Manila Trench. The same trend has been observed for the stress regimes along Negros Trench and Zamboanga, and along Cotabato Trench going inland to Central Mindanao. In the Mindoro Collision Zone, σ1 becomes EW-trending, while in eastern Luzon, it becomes NE-trending. Lastly, the northernmost portion of the Philippine Trench down to the Mindanao Pacific Cordillera is governed by an almost EW-trending σ1.

Keywords:stress inversion, Philippine island arc, k-means clustering

Application of Magnetotelluric Methods in Geothermal Exploration and Investigation of Geological Structures: A Case in Tatun Volcano Group, Northern Taiwan

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Geothermal systems become viable when conditions, like appropriate temperature ranges, geological structures, and petrophysical properties, exist less than 3-5 km near surfaces. Assessing these factors is crucial for identifying economically viable geothermal resources. A key aspect of this evaluation is understanding subsurface electrical resistivity, which plays a pivotal role in characterizing geothermal systems. This study focuses on investigating geothermal resources and sites for geothermal power plants in the Tatun Volcano Group (TVG) in Northern Taiwan. Magnetotelluric (MT) methods, in particular, have emerged as a fundamental and powerful tool in geothermal exploration and subsurface architecture beneath geothermal areas. By performing 3D resistivity inversion of MT data collected from 47 measurement stations, this research develops a comprehensive model of subsurface electrical resistivity. Cross-sections and maps at various elevations are generated from this model to identify resistivity patterns essential for geothermal sites and to construct geological cross-sections for advancing geothermal exploration, such as further drilling.

The study highlights three potential geothermal areas with a high-resistivity core beneath a low-resistivity clay cap. Moreover, this study establishes several cross-sections across the north tip of Taiwan. A comparison between magnetization-derived airborne magnetic surveys, gravity-derived density models, and current 3D resistivity models leads to completing these cross-sections. They manifest subsurface architecture and elucidate the structural development. These results offer important new information for developing geothermal research in the TVG area.

Keywords:Tatun Volcano Group (TVG), geothermal exploration, Magnetotelluric (MT), 3D Resistivity

Improving Seismic Tomography of Southern Taiwan and Eastern Offshore Regions from the SALUTE Amphibious Array and Machine Learning-Based Arrival Time Analysis

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Southern Taiwan marks a geodynamically complex region where the Eurasian Plate subducts beneath the Philippine Sea Plate and transitions into the arc-continent collision zone. To better resolve subsurface structures associated with this transition, we enhanced seismic coverage by deploying the amphibious SALUTE (Southern Array for Lithosphere and Uplift of Taiwan Experiment) network since October 2021. This dense array, spanning the transition zone, supplements existing seismic stations and significantly improves data density, especially in previously under-monitored mountainous areas.

A machine learning (ML) workflow was implemented to accurately pick P- and S-wave arrivals from three-component waveform data recorded at 236 stations. We utilized the EQTransformer model within the SeisBench framework for initial phase picking, followed by event association and hypocenter determination using the PyOcto algorithm and subsequent relocation via the hypo3D algorithm in a 3D velocity model. Compared with the Central Weather Administration (CWA) catalog, this method yielded approximately a twofold increase in the number of detected events within a one-month window, and arrival picks rose by ~1.4 times for P phases and ~1.5 times for S phases, underscoring the effectiveness of AI-enhanced seismic processing in augmenting earthquake catalogs.

After rigorous validation and quality control of the automated picks, we performed 3D travel-time tomography using the LOTOS-12 inversion program, which jointly refines seismic velocities and relocates events. The resulting models reveal a sharp ±20% velocity contrast in the upper 20 km across the Chaochou Fault, with slower velocities characterizing the western sedimentary basin and higher velocities beneath the Central Range. These findings align with previous studies. In addition, low-velocity zones deepen eastward and appear underlain by high-velocity structures, likely reflecting the subducting Eurasian lithosphere. Offshore data contributed by the SALUTE OBS stations further reveal shallow, localized low-velocity anomalies beneath the Southern Longitudinal Trough and Luzon Arc. The expanded coverage provided by SALUTE notably enhances structural resolution both laterally and vertically, promising deeper insights into the tectonic architecture of southern Taiwan and its offshore margin.

Keywords:travel-time tomography, earthquake catalog, machine learning, southern Taiwan, SALUTE

台灣東北地區碰撞—隱沒-弧後張裂孕震構造分析

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台灣東北部位於歐亞板塊與菲律賓海板塊的交界處，菲律賓海板塊以每年約8公分的速度向西北推進，並在台灣東北外海向北隱沒至歐亞板塊之下。約在600萬年前，呂宋島弧與歐亞板塊於台灣北部發生碰撞，進而引發台灣的造山運動。此區域涵蓋了琉球隱沒帶、沖繩海槽的弧後擴張作用，以及呂宋島弧與台灣碰撞帶的交互影響，形成一個由板塊隱沒逐漸過渡至弧陸碰撞的構造環境。包含台灣東北地震活動、發震構造、縱谷平原的聚合構造等，顯示此區域地殼變形與地震機制的高度複雜性。

研究區域範圍為東經 121.5°–123.0°，北緯 23.5°–25.25°。該區地震活動頻繁，不同構造單元間的交互作用對震源特性有顯著影響，對地體構造與地震潛勢評估具有高度研究價值。然而，傳統地震定位受限於測站分布與人工波相挑選的精度，對於小型地震及深部震源的空間解析仍有不足。本研究在中央氣象署（CWB）使用CWASN 測網的地震資料的基礎上，計劃納入臺灣強地動觀測網（TSMIP）與台灣地區寬頻地震觀測網 （BATS）資料，以獲取更完整的測站覆蓋，擴充資料數量以提升地震事件的定位精度。地震資料處理方面，將應用RED-PAN機器學習模型進行地震波相自動挑選，提升小型地震的檢測能力，事件定位採用NonLinLoc非線性定位方法，透過系統網格搜尋或Metropolis-Gibbs 採樣，配合三維速度模型，計算定位的概率密度函數，來估算震源位置的不確定性。相較於傳統HYPOELLIPSE線性定位，非線性方法可處理靠近速度梯度的震源，在測站稀疏或資料數量有限的條件下有更好的定位結果，相較於線性定位方法能提升震源位置與深度估計的準確性。對於具有複雜速度結構的區域尤為重要。

預期透過本研究，我們將能更精確地描述台灣東北部隱沒—碰撞轉換帶的地震活動特性。以更全面、精密的研究方式，能更準確地解析研究區域的構造特性，以探討弧後張裂對板塊運動的影響，並評估該區域的地震潛勢。我們預期的研究結果將有助於深入理解台灣東北部碰撞與隱沒轉換帶中，板塊作用如何主導該區域的構造演化，能為地震災害防範與減災規劃提供科學依據。

中文關鍵詞：地震定位、弧陸碰撞、孕震構造

Low-frequency ocean gravity waves triggered by tropical cyclones via seafloor distributed acoustic sensing

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Low-frequency ocean gravity waves, including infragravity (IG) and internal waves, affect ocean dynamics and energy transfer within the ocean. Recently, tropical cyclones (TCs) have become more frequent and significantly impact the generation and propagation of the two waves. We investigated the two wave dynamics during TC Lan in 2023, utilizing a distributed acoustic sensing (DAS) system along a submarine fiber-optic cable off Cape Muroto, Japan. The 128-km cable is deployed across diverse topographic features, including fore-arc basins, topographic highs, and continental slopes. We apply frequency-wavenumber analysis with slant stacking techniques on DAS data to quantify the apparent phase velocities over time.

Our findings demonstrate distinct wave behaviors: seaward-propagating IG waves exhibited increased amplitude across all topographic features while landward-propagating IG waves showed variable phase velocities ranging from 60 to 190 m/s. Moreover, internal waves intensified significantly before and after landfall, particularly in topographic high regions, with phase velocities varying between 10-48 cm/s. Post-cyclone observations revealed persistent wave characteristics. IG wave amplitudes return to a background level, with landward amplitudes continuing to receive large amplitudes. Simultaneously, internal waves sustained a strong presence in topographic high areas. Moreover, tidal modulation enhanced wave amplitudes, particularly for M_2 and O_1 constituents. The study highlights the modulation of seafloor topography on wave propagation during a TC. We introduce DAS technology as a valuable ocean-bottom observatory for studying the ocean dynamics in deep seas.

Keywords:Infragravity waves, Internal waves, Tropical cyclones, Distributed acoustic sensing

Mantle perspective on the boundary between the Eurasian continent and the Philippine Sea plates in Taiwan

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Xenolithic and ophiolitic peridotites around Taiwan are geochemically investigated to provide constraints on clarification of the boundary between Eurasia and Philippine Sea Plates in eastern Taiwan. Major-element contents show ETO ophiolitic peridotites fit to global ophiolitic and abyssal peridotites. But QSR ophiolitic peridotites from the Yuli belt is similar with orogenic peridotites. TSU ophiolitic peridotites are similar with that of ETO peridotites. Lutao and Lanyu xenolitic peridotites display LREE-enriched REE patterns with enrichment of LILE and negative HFSE anomalies in the spidergrams, typical of subduction mantle wedge characteristics. Both QRS and TSU ophiolitic peridotites from the Yuli belt display U-shaped REE patterns; the former show enriched LILE and LREE in the spidergrams with negative HFSE anomalies, but the latter have mainly enriched LILE and LREE without negative HFSE anomalies in the spidergrams. ETO ophiolitic peridotites show both LREE-depleted and U-shaped REE patterns. In terms of PGE concentrations, except for one Lutao and Lanyu xenolitic peridotites are cumulate, all other peridotites in this study are mantle residues which can directly reflect source mantle characteristics. The subchondritic $^{187}Re/^{188}Os$ and $^{187}Os/^{188}Os_i$ ratios reinforce that most of these peridotites are mantle residues but not cumulate. T_{RD} model ages yielded from $^{187}Re/^{188}Os$ and $^{187}Os/^{188}Os_i$ ratios of these Miocene-Pleistocene peridotites, ranging from 173-266, 614-726-915 and 1173-1296 Ma, are much older than their formation ages (QSR, TSU and ETO peridotites) or ages of host basalts capturing them (Lutao and Lanyu peridotites). Therefore, mantle source where ETO peridotites formed is LREE-depleted, whereas LREE-enriched mantle source is where Lutao and QRS peridotites were formed. Mantle source for TSU peridotites has both LREE-enriched and depleted features. In addition, ETO peridotites are abyssal affinities. Lutao and Lanyu peridotites are mantle-wedge origin above the subducted South China Sea plate in the Luzon Arc system. QSR ophiolitc peridotites from the Yuli belt are supra-subduction zone (SSZ) affinities. Some TSU peridotites are suggested their intermediate feature between the abyssal and SSZ affinities. Preliminary isotope results further show ETO, Lutan, Lanyu and QSR peridotites are definite Philippine Sea plate affinity, but parts of TSU peridotites might be involved with South China Sea affinity.

Keywords:lithospheric mantle, ophiolitic peridotite, xenolithic peridotite

Applying a Weighted Template-Matching Algorithm (WTMA) to Investigate the Seismogenic Structures and Microseismic Activity of the 2025 ML6.4 Dapu Earthquake Sequence in Taiwan

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This study analyzes seismic activity related to the 2025 ML 6.4 Dapu earthquake sequence in Chiayi County and Tainan City, Taiwan. By integrating a machine learning-based earthquake catalog with the Weighted Template Matching Algorithm (WTMA), over 40,000 microseismic events were detected, many of which were previously undetected due to waveform overlap with other seismic events. These microseismic detections enhance the understanding and interpretation of detailed aftershock distributions. Additionally, Centroid Moment Tensor (CMT) solutions were analyzed for further insights into the underlying seismogenic structures. In particular, the mainshock region exhibits complex structural features characterized by both east-dipping detachment faults and reactivated west-dipping basement faults occurring at varying depths. These findings highlight the intricate structural dynamics within Taiwan's actively deforming orogenic belt. The results also suggest that interactions within the fault system triggered progressive seismic activity, gradually propagating to adjacent areas. Such insights are critical for refining seismic hazard assessments and contribute to enhanced understanding of regional tectonic processes.

Keywords:Dapu Earthquake , Weighted Template-Matching Algorithm (WTMA) , Seismogenic Structures

池上斷層傾角統計與分析結果

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針對特定場址執行機率式地震危害評估(PSHA)工作時，斷層幾何的設定為整體評估工作的首要作業。斷層傾角除了是描述斷層幾何形貌的參數之一，場址的地震危害度亦對斷層傾角的緩陡有極高的敏感度。在有限的地質與地物調查結果下，斷層傾角的設定常具有較高的不確定性，亦連帶廠址危害度也具有較大的不確定性。本研究利用傾角資料統計及二維幾何模型疊加剖面，同時探討斷層傾角分佈的不確定性(Aleatoric unctertainty)與評估模型的不確定性(Epistemic uncertainty)，由二維幾何模型疊加剖面評估斷層由淺至深的幾何位態，並對比斷層傾角資料統計結果，探討兩者間的差異多寡及不確定性範圍為何。

經蒐集池上斷層沿線之地質與地物相關調查之斷層傾角結果，建立斷層傾角資料表。經常態分佈檢定(偏態與分位數檢定)後，確認傾角資料分佈呈常態分佈，便可依統計方法可得出篩選前之池上斷層傾角上界/中值/下界為35°/54°/73°，權重分別為0.3/0.4/0.3 (ESM 法)或 30°/54°/78°，權重分別為0.2/0.6/0.2 (EPT 法)。篩選後之池上斷層傾角上界/中值/下界為47°/60°/73°，權重分別為0.3/0.4/0.3 (ESM 法)或 44°/60°/76°，權重分別為0.2/0.6/0.2 (EPT 法)。而池上斷層二維幾何疊加剖面顯示池上斷層的傾角上界/中值/下界為45°/60°/75°。

二維幾何疊加剖面的結果為中值60，範圍為±15°，對比統計結果顯示篩選前的資料受到鑽井及槽溝的緩傾角(15°~30°)影響，中值較二維幾何疊加剖面之結果略低(54°)，範圍也較大(±19°~±24°);篩選後的資料則與二維幾何疊加剖面之結果相近，中值相同(60°)，範圍亦較接近(±13°~±16°)，最接近的上、下界僅有1度的差異。結合二維幾何疊加剖面與EPT統計法之結果可得出，池上斷層淺部傾角的上界/中值/下界為45°/60°/75°，權重為0.2/0.6/0.2 之設定較為符合傾角統計分析之結果。

中文關鍵詞：PSHA、斷層傾角、常態分佈、池上斷層、權重

Unraveling eruptive history and magmatic evolution of the Huangzuei complex through 3D geomorphological mapping, 40Ar/39Ar dating and geochemistry

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The Huangzuei complex is one of the younger volcanoes of the 25 km-wide Tatun Volcanic Group (TVG) that pose a potential hazard to the Taipei metropolitan area. It has well-preserved landforms with three sequences of andesitic flows that radiate northwestward, northeastward and eastward up to six km from beneath the 250-m tall Mt. Huangzuei crater.

Very high-resolution topography from a LiDAR-based DEM enabled detailed demarcation and characterization of individual flows, including volume, thickness, and profiles. In our first year of work, we began to constrain volcanic evolution through $^{40}Ar/^{39}Ar$ dating, petrologic and geochemical analysis of key lava flows.

The northwestern flow sequence is composed of two overlapping flows. Two $^{40}Ar/^{39}Ar$ dates indicate eruptions at 116.6 ± 2.0 ka and 128.8 ± 1.8 ka. The northeastern flow sequence comprises three distinct overlapping flows with pronounced ogives, pending results for $^{40}Ar/^{39}Ar$ dating. The eastern flow sequence extends 3 km east and then another 3 km north from the summit. It includes five distinct flows and associated levees. The second oldest flow erupted 85.4 ± 2.3 ka.

Our preliminary results indicate that the Huangzuei complex has undergone at least three eruptive episodes. In light of reaction rims surrounding variably resorbed olivine, and the more mafic bulk-rock composition of the younger lava flows, we propose a working hypothesis where the evolving magma reservoir was periodically replenished by basaltic magmas, followed by mixing of magmas and eruption of the variably mixed magma.

Keywords:TVG, LiDAR, geomorphology, 40Ar/39Ar dating, magma mixing

以水岩反應器模擬花蓮瑞穗地區之地熱儲集層特性

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全球地熱發電廠幾乎都以火山或侵入岩為熱源，花蓮瑞穗溫泉區是少數位於隱沒混同層，且因造山抬升而擁有極高地溫梯度的地熱潛能區。瑞穗溫泉區在極小的範圍內(約960公頃)可分為內溫泉及外溫泉，且泉質無論是碳酸氫根、氯離子、鈉離子、鐵離子等濃度差異極大，暗示地下儲集層可能具有多組構造裂隙，提供熱液循環之通道，且流體因與不同岩石進行不同程度的水岩反應，而造成地表特性各異的溫泉。

本研究選用花蓮瑞穗地區具有代表性的岩石樣本，如：黑色片岩、綠色片岩、蛇紋岩、大理岩、變質輝長岩等進行水岩石反應，改變溫度參數、時間，模擬不同岩性的礦物在熱液環境下經歷水岩反應前後之流體變化以及礦物成分變化更進一步評估二氧化矽、鈉-鉀、鈉-鉀-鈣等地質溫度計是否在實驗條件下能達平衡以及其適用性。實驗以水質檢測計測酸鹼度、氧化還原度、電導度、電阻值、鹽度、總溶解固體量以及離子層析儀、感應耦合電漿光學發射光譜儀用測量水樣內的元素，並用X射線繞射儀和掃描電子顯微鏡觀察礦物相之變化。

初步研究結果顯示：不同岩性的樣本在水岩反應後的水化學有相當程度的差異，唯一共同點是樣本在反應後碳酸氫根離子、氯離子、硫酸根離子會隨著時間拉長，濃度也顯著升高，其中大理岩的水岩反應時間從24小時拉長至48小時後流體的碳酸氫根離子濃度上升最為顯著；黑色片岩細分為含有鈉長石斑晶（斑點片岩）和無鈉長石斑晶，兩者在經過水岩反應後的硫酸根離子皆有顯著增加，而含有鈉長石斑晶的黑色片岩之氯離子濃度相較無斑晶者更為顯著，且水中pH值降低更多，推測是受到黃鐵礦氧化成為硫酸影響導致；變質輝長岩、綠色片岩、蛇紋岩在水岩反應前後也有少量氯離子、硫酸根離子的增加，相較黑色片岩，並沒有顯著變化，推測此次設定的溫度、時間條件下並未達到水化學平衡，後續會進一步探討反應時間、溫度、岩石粒徑等操作變因之影響，來釐清瑞穗地熱系統。

中文關鍵詞：瑞穗溫泉區、水岩反應、隱沒混同層、地質溫度計

地球物理探勘在臺灣土壤地下水污染調查整治之實務精進應用

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地球物理探勘在臺灣土壤地下水污染調查整治之實務精進應用

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摘要

土壤及地下水污染調查整治往往因無法充分掌握地下環境地質異質性變化，而錯估污染分布或難以預測污染傳輸流布，造成整治無效或失敗。環境部環境管理署自2008年正式採用地球物理技術於「運作中工廠土壤及地下水含氯有機溶劑污染潛勢調查及查證計畫」，並連續多年獲致高查證率；後續擴大應用於全國大型場址與工廠調查評估（如廢棄工廠、航空站、加油站、油庫、廢棄物掩埋場、工業區或加工區等）；2013～2016年連續辦理兩期「地球物理探勘應用於土壤及地下水污染場址之調查驗證作業及整治技術評估計畫」，因應複雜場址進行各式傳統與新型地球物理技術之精進應用與交互佐證，建立調查、查證及整治成效評估方法，並編撰本土地球物理探勘應用技術手冊。

複雜的地質條件，特別是低滲透性地層或高度異質性地層將造成灌注的整治藥劑或菌種無法有效傳輸至污染目標區。一些地下環境複雜場址，實應發展更「精確」（Surgical）的整治方法，瞭解地下三維污染分布、地質分布、生化等資訊；及搭配更佳的整治傳輸技術或工法，並能即時掌握空間整治成效。本文探討一處應用「精確整治」（Surgical Remediation）之含氯有機溶劑污染場址，地質屬砂、坋黏土互層，地質滲透性可達2～3個數量級，地下水遭受1,2-二氯乙烷與氯乙烯嚴重污染（超過管制標準達數百至上千倍）。透過高解析調查評估技術，如多深度污染物採樣分析、多深度氡分析、菌相分析、多深度微水試驗、井測、多深度單井流速流向測定及地電阻影像法等，評析三維水文地質特徵及污染團空間-時間變化。有關整治成效評估，結合時間序列跨孔式地電阻影像法（Time-Lapse Cross-Hole Electrical Reisitivity Tomography, TL-CHERT），評析整治期間藥劑傳輸之變化與整體空間-時間改善成效。本研究證實精進地物探勘技術的應用，可在複雜場址的整治中扮演關鍵角色，協助動態調整整治設計，加速整治成效與整治成功。

中文關鍵詞：地質異質性、精確整治、跨孔式地電阻影像法

First fossil record of pufferfish Arothron (Tetraodontiformes: Tetraodontidae) from Southern Taiwan

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This study presents two semi-articulated fossil specimens of pufferfish—comprising an almost complete skull and fragmentarily preserved remains of jaws discovered in the Liuchungchi Formation deposits (Early Pleistocene, 1.90–1.35 Ma) in Niubu, Chiayi County, Taiwan. The specimens are permanently stored in the Chiayi Municipal Museum. The fossil site is well known for its abundant marine fauna, including crustaceans, echinoderms, elasmobranchs, and bony fishes. The specimens under consideration were identified as members of the family Tetraodontidae (pufferfish) based on their distinctive beak-like jaws, separated to four individual skeletal elements. Based on the morphology of the opercle, preopercle, pterygo-quadrate complex and proportion of the neurocranium both specimens can be assigned to the contemporary genus *Arothron* Müller, 1841. Notably, they represent the first pufferfish fossil record in Taiwan, which enhances the understanding of marine palaeobiodiversity in the region.

Keywords:Teleost, Tetraodontidae, Pleistocene, Chiayi

震測反演苗栗近岸-離岸的淺層地殼

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本研究區域涵蓋西部麓山帶的苗栗，以及其近岸到離岸的台西盆地北部。苗栗的沉積層多受到褶皺而變形及逆衝斷層切割，在苗栗離岸的沉積層則多受正斷層切割，且地層平緩。2022年9月，我們由新海研一號空氣槍陣列（930立方英吋體積）為震源，於臺灣海峽北部的苗栗外海蒐集5條多頻道反射震測剖面。在進行多頻道反射震測的同時，苗栗陸上佈署的43部地震儀，也同步接收自新海研一號發出的震波。本研究利用蒙地卡羅界面與速度不確定性分析生成的眾多模型，進行走時反演。透過建立苗栗離岸-近岸地區沉積層與地殼P波速度-界面模型，以探討苗栗海陸交界的沉積與地殼速度構造。我們發現前陸盆地底層的不整合面深度在苗栗離岸約為0.4－0.9公里深，在近岸處深度為2.5－4.5公里深，前陸盆地的厚度向臺灣方向（東南邊）有漸增的趨勢。苗栗近岸-離岸的沉積層與地殼大致向臺灣方向傾斜，且海陸交界處只在中新統以下的地層可見隆起。我們也在地震儀資料識別一視速度約為8公里/秒之初達波波相。經走時反演二維P波速度模型後，研判屬於位於5－14公里深，速度為7.25－8.75公里/秒的深部構造。該構造使苗栗海陸交界處的地殼有隆起的跡象，但根據速度與界面不確定性分析的結果，其最高速度可能僅7.75公里/秒，或甚至更低。推論苗栗近岸-離岸地區在中新世前，有火成岩侵入或有地殼向上繞曲，使現在的海陸交界處有一隆起的高速帶。本研究利用海上的人工震源與陸上佈署地震儀的方法，使得施測條件受限的海岸線附近與城市下的沉積層與地殼構造得以成像。

中文關鍵詞：地殼構造、斷層構造、P波速度-界面模型、多頻道震測

Rapidly assessing coseismic landslides using logistic regression model and initial P-wave amplitude

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This study assesses the susceptibility to coseismic landslides (CLs) triggered by the April 3, 2024, M_L 7.2 Hualien earthquake using a slope-unit-based logistic regression (LR) framework. A total of 3,191 CL and 3,191 non-CL (NCL) samples were derived from satellite imagery captured before and after the event. Geological, topographic, lithological, and seismic-related factors were considered, and stepwise regression with multicollinearity checks was used to select explanatory variables.

The initial model (Model 1) was developed to maximize classification accuracy. SHapley Additive exPlanations (SHAP) were applied to interpret variable importance and identify predictors contributing to false positives (FPs) and false negatives (FNs). Two biased variables—collapsed area and minimum slope—were removed to construct a refined Model 2.

Although Model 2 did not significantly outperform Model 1, SHAP interpretation revealed structural bias and informed threshold-adjustment strategies. By applying sensitivity or specificity constraints, the model was tuned to prioritize reducing FNs or FPs based on application needs.

The LR model was also integrated into an early warning system using Network Triggered signals and PhaseNet AI to detect P-wave arrivals and compute initial amplitude (Pd). When Pd exceeds 0.3 cm, an alert is issued with several seconds of lead time.

A high-recall susceptibility map was produced to identify failure-prone slopes and support early warning implementation for nearby infrastructure and communities. This study highlights the integration of interpretable modeling and seismic monitoring for enhanced landslide hazard assessment and mitigation.

Keywords:coseismic landslide (CL), logistic regression (LR), SHAP (SHapley Additive exPlanations), susceptibility mapping, early warning system

蛋殼力學反映已滅絕鳥類與非鳥類恐龍多樣的生殖策略

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硬殼蛋（Rigid-shelled eggs）是現生鳥類不可或缺的特徵，研究團隊在先前的研究中，在排除形狀與尺寸的影響後，將蛋殼相對剛度（Stiffness）定義為無因次參數C（以下稱為C值）。現生鳥類的C值趨近一致，顯示其蛋殼設計具有固定標準，能在雛鳥破殼所需力量與成鳥孵蛋施加壓力之間取得平衡。本研究以有限元素分析（Finite Element Analysis, FEA），將C值應用於其他硬殼蛋種類，包含已滅絕的巨型鳥類蛋殼（例如恐鳥及象鳥），以及非鳥類恐龍蛋殼，並以安全係數（Factor of Safety）評估成體接觸孵蛋（Contact incubation）的安全性。巨型鳥類研究結果分為兩種生殖策略，一種為呈現逆雌雄二型性（Reversed Sexual Size Dimorphism, RSSD）的類群，具有較薄的蛋殼與較低的C值，該策略由體重較輕的雄鳥負責孵蛋，顯著提升接觸孵蛋的安全係數；另一種非逆雌雄二型性，蛋殼C值接近現生鳥類平均值。非鳥類恐龍蛋C值分布範圍較廣，其中幾種恐龍類群的C值與蛋重呈現負相關，可能反映了蛋殼主成分鈣的供應限制，或是大型恐龍採用r策略（r-strategy）的轉變。另外，不同恐龍類群的C值反映了恐龍生殖策略的多樣性。例如，鴨嘴龍蛋的C值顯示其可能採取埋藏的生殖策略。竊蛋龍類的蛋具有不同大小與C值，其中最大型的蛋，其C值顯示該類群可能不適合接觸孵蛋。結合蛋窩模型實驗，傷齒龍的C值與其蛋窩的安全係數符合接觸孵蛋的標準。恐龍蛋C值的多樣性顯示恐龍生殖生物學中複雜的演化路徑，此一發現與近期的研究結果相呼應，指出不同恐龍類群可能各自獨立演化出硬殼蛋。研究結果同時也顯示可進行接觸孵蛋的體重上限約為2000 公斤。

中文關鍵詞：有限元素法、平胸鳥類(ratite)、恐龍蛋、接觸孵蛋

以海床地電阻影像探尋掩埋的水下文資目標物

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調查水下文資目標物的所在，對於海域探測起步較慢的我們，具有相當程度挑戰性，運用非侵入式水下探測技術，較人力潛水目視觀測安全且可行性高，然而，各種探測儀器都有它可以反映的物理特性及限度。在不同儀器、不同精度下可解析出不同的物質特性，相同儀器在不同的頻率、不同水域底質環境影響下解析程度亦有不同。因此，本研究透過研習國外經驗，搭配區域海域海床環境特性，以正演海床地電阻模擬探測參數為起點，進而至澎湖馬公海域執行海床地電阻影像調查任務，提供給依海床聲納探測或人員搜查監看之水下考古調查，另一項海洋地球物理技術運用之參考。

本計畫首先彙整過往研究中，於海域地電阻技術的經驗，對應到澎湖海域的海床環境，配合預設的目標物的所在條件，埋深、尺寸大小、材質等的電磁場傳播特性，以及探針設置於海床上的排列差異，模擬施測之前的情境及實驗規劃。目前本研究所完成之二維地電阻模擬的結果，發現1、針對不導電陶瓷探測最佳為WS及EG電極排列法，DD電極排列法對於較深異常解析度較差。2、針對高導電金屬調查為目標時，整體成果針對較深異常成像成果，EG電極排列法優於其他兩種電極排列法。3、針對濕木頭，EG電極排列法優於其他兩個電極排列法。此外，考量應用地電阻影像方法於調查評估時，現場調查成果分析考量三維效應、異常物尺寸、掩埋深度影響，我們進一步利用三維地電阻模擬，結果發現1、在電極間距2　公尺的調查方式，邊長3公尺的立體模型大小，金屬與陶瓷等異常，可以EG電極排列法為最佳排列方式，透過電阻率法描繪出來。2、在電極間距2 公尺的調查方式，1公尺及半公尺邊長的立體模型大小所造成的的異常，電極排列法分辨率皆不佳而難以描繪辨識出來。因此，綜合目前模擬成果，後續實地測量將考慮採用兩種以上電極排列法，透過結合反演方法補足各個電極排列法的優勢，期望能夠進一步地將底質沉積物中的待測物偵測及描繪出來。

中文關鍵詞：海洋地電阻探測、水下文化資產調查、海床底質基礎調查

鈣鈦礦結構錫酸鍶高溫結構相變與晶格動力學研究——粉末繞射與拉曼光譜分析

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$SrSnO_3$ 為具 $GdFeO_3$ 型結構的鈣鈦礦材料，常溫下屬空間群 *Pbnm* 的斜方晶系，其晶格參數關係（$a/\sqrt{2} \approx b/\sqrt{2} \approx c/2$）展現偽立方（pseudo-cubic）特徵。以鍶、錫、氧離子半徑決定出 $SrSnO_3$ 的容差因子（Goldschmidt tolerance factor）落在 $t = 0.97$，意味著結構中頂點相連的 SnO_6 八面體排列呈現扭曲，使其偏離理想立方鈣鈦礦結構的 $t = 1$；隨著溫度升高，$SrSnO_3$ 的結構將經歷一系列趨向更高對稱性的變化，相變歷程與天然礦物 $CaTiO_3$（斜方 *Pbnm* → 四方 *I4/mcm* → 立方 *Pm-3m*）類似 [1]，惟 $CaTiO_3$ 缺乏易解析的拉曼光譜資料，因而 $SrSnO_3$ 更適合作為探討鈣鈦礦結構相變與晶格動力學行為的理想材料。

本研究使用國家同步輻射中心提供的高解析粉末繞射技術，在常溫到高溫 1173 K 的範圍內進行晶格結構測量，Rietveld 精修結果顯示 $SrSnO_3$ 晶軸的非等向性膨脹行為，並在 853 K – 893 K 的溫度區間發生斜方對稱性 *Pbnm* 至 *Ibmm* 的連續轉變，隨後於 1013 K – 1033 K 附近轉變為四方晶系 *I4/mcm*，惟在實驗條件的限制下，未能觀察到文獻中推斷在更高溫度可能觀察到的 *Pm-3m* 立方相 [2]；此外，藉由分析資料重新建構了 SnO_6 八面體扭曲行為的演化過程。另一方面，成功合成 $SrSnO_3$ 單晶樣本並進行偏光拉曼光譜測量，完整獲得各晶軸方向之振動模態訊號，輔以第一原理計算結果完成振動模態指認（$7A_g + 5B_{1g} + 7B_{2g} + 5B_{3g}$），補足文獻中粉末樣品無法提供非均向性資訊且僅能指認 A_g 模態的限制 [3]。高溫單晶拉曼分析進一步揭示結構振動行為與對稱性變化的關聯，包括模態紅移、寬化等過程；值得一提的是，$SrSnO_3$ 單晶的高溫拉曼光譜特徵在 *Pbnm* 到 *Ibmm* 的相變邊界發生明顯變化，對比粉末繞射資料可提供更有力的對稱性演變證據，更暗示類似結構的 $CaTiO_3$ 在 *Pbnm* 至 *I4/mcm* 之間經歷其他相的可能性。

綜合粉末繞射與拉曼光譜結果，本研究更詳細呈現 $SrSnO_3$ 拉曼振動模態在高溫下的結構演變與晶格動力學行為，這些成果可進一步用於晶格動力學的諧性與非諧性探討，對於理解鈣鈦礦結構在溫度影響下的轉變機制與熱穩定性提供重要參考。

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中文關鍵詞：鈣鈦礦結構、相變、X 光結晶學、拉曼光譜學、晶格動力學

PS-InSAR技術在離岸風機基樁穩定性監測之應用

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隨著全球能源需求的增加及環保意識的提升，風力發電作為可再生能源的重要發展方向，尤其在台灣海峽的天然風力優勢下，風力發電的潛力巨大。然而，海上風力發電機基樁在施工過程中可能因地下地質的非均質性而發生「溜樁」現象，說明台灣海峽地質的不穩定，可能會對風力發電機的長期穩定性構成威脅。特別是在台灣地震和颱風等自然災害頻發的背景下，風力發電機基樁穩定性的監測顯得尤為重要。本研究旨在探討使用雷達衛星影像中之永久散射點差分干涉技術（Persistent Scatterer Interferometric Synthetic Aperture Radar, PS-InSAR）進行風力發電機基樁穩定性監測的可行性與應用潛力，並以彰化外海台電一期示範風場為研究區域。過去PS-InSAR技術多應用於陸地監測，對立於海面之垂直構造物如風機基樁的應用仍屬新興領域。本研究首先針對雷達回波影像中風力發電機基樁之永久散射點進行判識，進一步建立適用於基樁監測之時序變形分析方法。此外，為排除解纏混疊所導致的數據失真，本研究不採用套裝軟體進行資料處理，而是針對單一基樁提取PS點，先確立其訊號處理與時序分析的程序，再藉由比較長期、多時序（主要為C波段Sentinel-1 與X波段TerraSAR-X）之基樁變形資料，來探討此研究方法之信效度，以及颱風和地震等外部事件對基樁穩定性的影響。在與重大災變事件進行交叉比對與驗證後，據以評估各基樁的穩定性與潛在脆弱性，並進一步提出具體的分級管理與優先維修建議，以作為風場營運單位與政府主管機關規劃維護策略與資源配置之參考依據。本研究預期將為台灣離岸風力發電基礎設施的安全營運與永續發展提供創新技術支援，亦對未來高風險區域之風場開發提供實證依據與預警機制，有助於提升整體能源轉型過程中的韌性與可靠性。

中文關鍵詞：離岸風電、基樁穩定性監測、雷達衛星、PS-InSAR、時序分析

臺灣西部麓山帶的東苗栗構造活動性再評估

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臺灣島坐落於歐亞板塊與菲律賓海板塊的聚合性板塊邊界上，為評估臺灣的地震風險，由國科會資助的臺灣地震模型(TEM)計畫與其團隊，利用多種研究方式提供地震潛勢的科學評估基礎資訊，其中一項工作即是根據構造地形特徵建立了臺灣的孕震構造資料庫。然而，這些構造中有些僅依據地形特徵所辨識，可能還需要更詳細的地質分析。

在苗栗區域，TEM辨識出了七條可能的孕震構造，其中除了東苗栗構造以外，其他構造在過去均有詳細的地質與地形調查，提供這些構造的支持證據。相比之下，東苗栗構造仍未有詳細調查，其可能的構造崖成因也存有爭議。為解決此問題，本研究重新評估了東苗栗構造，以構造地形概念為基礎，使用5米解析度的數值地形模型分析階地面，並透過RTK-GNSS測量關鍵的地形崖，同時在野外針對關鍵的地形崖沿線進行地質與地層調查，並分析紅土化階面探討區域抬升速率特徵。

根據河階面的河拔高與紅土分析的結果，東苗栗構造部分上盤地區的抬升速率較快，與推測的構造活動影響一致，但此一現象並不一定要由該構造活動造成。該構造南端的福基階崖過去被認為是其活動的主要證據，測量結果顯示其崖高可達 18 公尺。為驗證此地形崖的成因，本研究比對階崖下方的地層，結果發現基盤岩層並未顯示明顯的累積位移，表示此處可能未經歷長期的構造錯動。河階的分布顯示，後龍溪過去曾大幅改道，造成一超過九十度的轉彎，此情形反而表示福基階崖亦可能由河川侵蝕形成，而非構造作用的結果。另一方面，東苗栗構造下盤的沖積層厚度並沒有明顯增加，甚至偶有底岩出露於河床上，表示其沒有對後龍溪流域造成明顯的沉積差異。根據這些觀察結果，本研究認為沒有足夠證據能夠證明東苗栗構造必須存在，其更不可能是區域中主要的孕震構造。而區域內河階面的抬升速率差異，則不一定需由東苗栗構造所造成。

中文關鍵詞：東苗栗構造、臺灣地震模型、苗栗、後龍溪、構造地形

以地表構造線型與裂隙活化趨勢探討臺中谷關地熱潛能

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因應我國2050淨零碳排政策之規劃，使國內再生能源需求量提升，因地熱能可作為基載電量其前景備受矚目。近年來彙整高精度遙測判釋與區域應力反演分析，進而繪製地熱潛能圖之技術已逐步研發並應用至我國多個案場，然而遙測圖資精度高低可能受限於成本、尺度、機密性等因素進而影響分析結果，為了協助地熱產業界瞭解對應圖資之分析成效，本研究將量化並比較不同圖資解析度之分析差異，以利國內地熱產業發展。

本研究基於前人方法，於臺中谷關地區使用高精度數值高程模型並肉眼判釋地表裂隙線型，以三角網格法進行位態計算。為評估潛在導水裂隙位態，使用震源機制應力反演結果進行裂隙不安定性、擴張趨勢與滑動趨勢分析。進一步，以野外實際導水裂隙位態反算各活化分析之閥值，繪製臺中谷關地區潛在導水裂隙空間分布圖。為比較圖資解析度對裂隙判釋結果的差異，以20米及6米解析度之數值高程模型分別套疊6米及1米解析度之坡度圖與多向陰影圖為底圖，以線型判釋結果比對位態、數量及長度等特性並量化其差異性。此外，本研究亦篩選大於活化趨勢閥值之裂隙進行上述對比，以期釐清線型特性與導水裂隙之間的可能關聯。

本研究初步完成兩種解析度衍生圖資之地表線型判釋、區域應力反演及裂隙活化分析。線型判釋結果顯示20米圖資以西北-東南走向為主，而6米圖資則具多組走向，兩者傾角皆為高傾角。長度與數量分布顯示20米圖資之長度眾數落在300至400米區間，而6米圖資之長度眾數則多落在100至200米間，且兩者大於500米之線型數量並沒有明顯差異。應力反演結果顯示谷關地區以走向滑移斷層應力場為主，最大主應力軸為東南傾向之近水平。裂隙活化分析結果顯示西北-東南向之近鉛直為高潛能裂隙面，野外查核結果顯示導水裂隙位態大致為西北-東南方向之中至高傾角。

本研究將進一步比對不同解析度之高活化裂隙於各線型特性中所占範圍，評估地熱探勘尺度下所需最小圖資解析度，並結合其他地熱前期探勘方法，以提高我國地熱開發競爭力。

中文關鍵詞：地熱、谷關溫泉、地表線型判釋、裂隙活化分析、解析度差異

2021花蓮壽豐地震序列之地震活動性探討

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台灣東部的花東縱谷是歐亞板塊和菲律賓海板塊碰撞的縫合帶，一直是熱門的研究區域，其原因無非是地質構造複雜、地震活動頻繁，歷史上也發生過許多起致災的地震事件。花蓮北部在過去，常常發生延綿好幾天，甚至超過一個月的地震群，然而，從 2021 年 4 月起,花蓮縣壽豐鄉斷斷續續觸發一系列的地震群，最後延綿了 4 個多月才停歇。據中央氣象署地震測報中心統計，地震序列期間共發生多達11次規模5以上的地震，且有逐漸往東、往北、由深入淺移動的趨勢。由於此地震序列持續相當長一段時間，本研究欲探究其發震原因、狀態，以及地殼流體是否在其中扮演著重要角色。

為了研究此地震序列的孕震構造、地震機制及物理行為等，及評估流體在此次序列扮演什麼角色，本研究以中央氣象署地震目錄作為原始資料，並使用以機器學習演算法為基礎的流程，盼減少地震波相誤檢、漏檢率，以獲得高精度、數量的地震目錄。本研究有三種地震目錄，分別是NonLinLoc (Lomax et al., 2000,2014)、震源機制解和GrowClust3D (Trugman et al., 2017,2023) 地震目錄。本研究以NonLinLoc目錄為基礎，運用研究流程而計算出震源機制解和GrowClust3D地震目錄。在後續的分析中，以震源機制解地震目錄為基礎來計算應力的影響狀態，本研究運用V´aclav Vavry∨cuk (2014) 的應力反演 (Stress Inversion) 計算應力場、Toda等人提出的庫倫應力變化 (Coulomb Stress Change)計算地震序列的庫倫應力變化。而GrowClust3D地震目錄則是以分析流體為導向，計算後續的地震時空變化 (Spatiotemporal distribution)、b值及Vp/Vs ratio比較，以及分析精細剖面。

本研究透過研究結果發現，庫倫應力變化與地震分布高度吻合，且在地震時空分布的結果中發現有兩區可能的流體源，因此本研究推斷2021地震序列是因流體觸發深部中央山脈斷層的主震後，因釋放流體並往淺部遷徙、淺部庫倫應力增加，進而觸發靠近縱谷斷層的一系列地震群。未來將進行b值及Vp/Vs ratio比較的解算，以及比對研究區域地質，增加對研究區域發震及流體解釋的有力證據。

中文關鍵詞：高精度地震目錄、庫倫應力變化、流體

應用Sentinel-1和鑽探資料初判山腳斷層位置

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摘要

台灣北部自中新世至上新世開始沉積，山腳斷層大約是在更新世早期形成(至今約100-78萬年前)，山腳斷層屬於盲斷層，所以一直以來對於山腳斷層的研究只能利用鑽井資料進行推測，目前推測出山腳斷層約為33公里，從樹林延伸到金山一帶，中間有一段深埋於大屯火山群之下，以及推測出山腳斷層為台灣少數的正斷層系統，並且以山腳斷層區分出了林口台地和台北盆地。本次研究是應用衛星影像資料和鑽井資料初判山腳斷層位置，研究使用的衛星影像為Sentinel-1 IW，Sentinel-1的優點就是不會受到天氣和日夜的影響，可以方便監測地表變形，其中的影像攝取模式為IW，為四種影像攝取模式的其中一種。之後在SNAP上進行輻射校正、雜訊移除、將由單觀點轉變為多觀點以及地型校正的影像處理，處理完衛星影像之後發現有一條的明顯的構造線，並且此構造線剛好區分了林口台地和台北盆地，之後再應用鑽井資料進行判斷，發現有些地方的剪裂帶確實和雷達影像處理完後判斷的構造線有重合，但有些地方確實也有一些誤差，但大致上都可以和雷達影像所判斷出的構造線一致，可以先推測出我們從雷達影像看到構造線與目前推測的山腳斷層位置有關連。

中文關鍵詞：山腳斷層、Sentinel-1、鑽探資料

2025年Mw 6.1大埔地震是否與1964年Mw 6.4–6.9白河地震破裂區重疊？對台灣西南部地震潛勢之啟示

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2025年1月20日嘉義大埔地區發生一起芮氏規模Mw 6.1地震，其震央位於台灣西南部的褶皺逆衝斷層帶內部。本文比較2025年大埔地震與1964年Mw 6.4–6.9白河地震的破裂特性，分析破裂體積之重疊情形，以探討區域孕震構造與應變釋放潛勢。研究採用震源模型、餘震分布與經驗尺度關係，重建兩起地震之三維破裂體積。結果顯示，大埔地震破裂體積約重疊白河地震Mw 6.9情境破裂體積之15.72%，若白河地震採Mw 6.4情境，重疊比例則為36.39%。該重疊程度說明部分應變已釋放，但大部分區域可能仍具未釋放殘餘應變。大埔主震後餘震呈現明顯西南向遷移，進一步支持破裂方向與應變傳遞之空間一致性。以GPS縮短率約13 mm/yr以及最大滑移量1.5 m估算，白河區域地震回復週期約115年，顯示該區仍具未來中大型地震潛勢。本研究強調以三維破裂體積為基礎的重疊分析，可有效提升對逆衝斷層地震行為與潛勢的認知。

中文關鍵詞：大埔地震、白河地震、三維破裂分析、地震潛勢、破裂體積重疊

Upper ocean stratification changes in the western tropical Pacific for the last 4 Myr

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Climate conditions during the Plio-Pleistocene is characterized by a gradual global cooling and Northern Hemisphere Glaciation. Sea surface temperature (SST) records at mid- and high-latitudes and the Eastern Tropical Pacific showed long-term cooling. On the other hand, those at the western Pacific warm pool (WPWP) showed only minor cooling, resulting in a gradual increase of latitudinal SST gradient as well as longitudinal gradient at the tropical Pacific. However, SST reconstruction at the WPWP is still controversial because the amplitudes of SST cooling inferred from different proxies are inconsistent.

Here, we conducted Mg/Ca-based temperature reconstructions using two mixed layer species of planktonic foraminifera, *Globigerinoides ruber* and *Trilobatus trilobus*, at IODP Site U1488 to reconstruct sea surface temperature. Because the calcification depth of *G. ruber* is generally shallower than *T. trilobus*, Mg/Ca of *G. ruber* is more suitable for SST reconstruction. The reconstructed temperature by *T. trilobus* shows consistent results with a previously published one by *T. sacculifer* at ODP 806, whereas that of *G. ruber* showed slightly warmer SST and a different pattern from *T. trilobus*. Therefore, we infer that *G. ruber* and *T. trilobus* Mg/Ca record surface and subsurface temperature, respectively. Our results indicate that the vertical temperature gradient in the WPWP has been closely related to the latitudinal and longitudinal temperature gradients for the last 4 Myr.

Keywords:sea surface temperature, Plio-Pleistocene, tropical Pacific, planktonic foraminifera

Machine Learning for High-Accuracy Co-Seismic Landslide Prediction Using Multi-Parametric Data: A Case Study of M7.2 Hualien Earthquake

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Taiwan is highly prone to earthquake-induced landslides due to its tectonic setting. This study evaluates landslide susceptibility triggered by the April 3rd, 2024 Hualien earthquake using machine learning. A dataset of seismic, topographic, and geological features was divided into 70% training and 30% testing sets. Variables were selected using Random Forest and Boruta, removing the dominant "area" variable to avoid overfitting, resulting in 25 selected features, including elevation, slope, and distance to the epicenter.

Four base models—Random Forest (RF), Support Vector Machine (SVM), Gradient Boosting Machine (GBM), and K-Nearest Neighbors (KNN)—were trained. KNN was excluded due to lower accuracy (0.883). Among individual models, SVM showed the best performance (accuracy: 0.9775), followed by RF (0.9728) and GBM (0.9645). A Weighted Voting ensemble integrating RF, SVM, and GBM with F1-score-based weights achieved balanced results (accuracy: 0.9749), effectively reducing the limitations of single models.

To further enhance prediction, a two-layer Meta-Learning framework was constructed using the predicted probabilities from RF, SVM, and GBM as features for second-layer models: XGBoost (XGB) and Logistic Regression (LR). Although LR showed higher AUC, XGB outperformed LR in most classification metrics. Nevertheless, both meta-models did not surpass the Weighted Voting ensemble. Results suggest that while Meta-Learning captures refined patterns, direct ensemble voting of strong base learners yields more stable and interpretable predictions. This study highlights the strength of ensemble and meta-learners for reliable co-seismic landslide prediction in high-risk regions.

Keywords:Co-Seismic Landslide, Machine Learning, Ensemble Model, Meta-Learning, Feature Selection

印尼西爪哇東部火成岩的地球化學與年代學

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印尼爪哇島是巽他島弧的一部分，巽他島弧是印澳板塊向北隱沒至歐亞大陸板塊下所形成。爪哇島分為西爪哇、中爪哇以及東爪哇，本研究區域在西爪哇的東部。前人有針對西爪哇東部進行全岩地球化學的研究，但過去受到技術與儀器精準度的因素，鮮少有鋯石鈾鉛定年法的研究。因此，本研究在西爪哇東部的八座火山岩體(Ciremei火山群、Guntur火山群、Galunggung火山群、Cikuray火山群、Papandayan火山群、Malabar火山群、Patuha火山群、Tangkuban Parahu火山群)共 採集54個火成岩樣本，並利用鋯石鈾鉛定年結合全岩地球化學的分析方法，來探討西爪哇東部的岩漿地球化學特徵與來源成因以及火山岩體自新生代以來岩漿活動隨時間的演化。

根據鋯石鈾鉛定年的分析結果顯示，西爪哇東部在新生代以來的岩漿活動分為四期，依序為中新世(5.6百萬年)、上新世(3.7-3.5百萬年)、早更新世 (1.2-0.8百萬年)以及晚更新世(0.5-0.1百萬年)。全岩地球化學的分析結果顯示，西爪哇東部的四期岩漿皆為次鹼性序列，岩性涵蓋基性的玄武岩到酸性的流紋岩。微量元素都呈現輕稀土元素(LREE)富集與高場力鍵結元素(HFSE) 虧損以及鈮鈦鉭極度虧損的現象，此為島弧岩漿的典型特徵。

藉由分析結果得知，前三期的火山體在空間分佈上由南到北有越年輕的趨勢，第四期的火山岩體則散佈於整個西爪哇東部。北方Rear-Arc的火山岩體(Ciremei、Tangkuban Parahu)相較於南方Volcanic Front火山岩體(Guntur、Galunggung、 Malabar、Cikuray、Papandayan、Patuha)其LREE/HREE的值較大，此表示Rear- Arc相較Volcanic Front所受到的部分熔融程度較小。未來將執行放射性同位素的分析方法，以利於深入瞭解各時期岩漿來源的特徵。

中文關鍵詞：西爪哇東部、巽他島弧、全岩地球化學、鋯石鈾鉛定年法

氣候變遷對澎湖海岸環境的影響:結合多源多光譜影像與機器學習的應用

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近年來，全球氣候變遷引發海平面上升與極端氣候頻率增加，對離島地區的沿海環境造成嚴重衝擊。澎湖群島地勢低平、沿海地形容易受到東北季風影響，造成堆積或是侵蝕，面對環境變遷的風險日益提升，因此建構長期、精確且高效率的監測系統成為重要課題。本研究旨在運用遙測技術結合機器學習方法，建立澎湖地區的近岸地形與海岸線變遷監測機制，以掌握氣候變遷下的海岸環境變化。本研究採用2016年至2024年間SPOT-6與SPOT-7多光譜衛星影像，利用可見光（紅、綠、藍）及近紅外波段特性，計算NDWI及NDVI等指標，並與可見光波段交叉比對，以進行潮線提取與淺水區域水深反演，初步建立水陸邊界與水深變化之判釋規則。進一步結合監督式機器學習（Supervised Machine Learning）方法，建立分類模型自動辨識海岸線邊界與近岸地形，並估算不同時間點之水深分布與地形變化趨勢。為驗證模型準確度，輔以無人機（UAV）所拍攝之高解析度影像與無人船（USV）水深實測資料進行交叉比對與誤差評估，建立澎湖周邊之淺海地形模型。本研究成果不僅可應用於澎湖海岸地形監測與變遷分析，也為離島地區氣候變遷下的海岸管理與防災規劃提供技術支援與數據基礎。

中文關鍵詞：澎湖、氣候變遷、海岸環境變化、機器學習

地熱開發-地質調查與鑽探工程的協同作業與優化

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在全球邁向淨零碳排與能源轉型的趨勢下，地熱作為穩定且潔淨的基載能源，其開發潛力日益受到關注。然而，地熱資源的探勘與開發仰賴地質調查與鑽井工程相互驗證，整體過程不僅風險高，亦具高度技術門檻。

地質調查，泛指我們熟悉的地表地質調查（裂隙量測、地熱徵兆紀錄等）、地球化學分析（水樣、氣樣）、地球物理測勘（如重力、大地電磁法、震測等），描繪出地底下的熱源、儲集層構造、蓋層分布以及流體通道等。目的為建立地質概念模型，評估資源潛力，定出合適的鑽探點位，並預測鑽探過程中可能遭遇的地層特性，例如岩性變化、斷層破碎帶、潛在的高溫高壓區或漏失層。然而，地質模型終究只是基於間接證據的推斷，唯有透過鑽探工程的驗證，才能真正驗證地底的真實情況。鑽探工程師負責將地質學家設定的目標轉化為實際的井孔，他們需要根據地質預測來設計井體結構、選擇合適的鑽頭與泥漿、制定鑽進參數（如鑽壓、轉速），並規劃應對可能地質風險的應變措施。問題在於，若缺乏有效的溝通橋樑與協作機制，地質報告可能淪為束之高閣的參考文件，鑽探過程中的即時地質發現也可能無法迅速回饋給地質團隊進行模型修正。如何優化這兩者間的協同作業？我認為在探勘初期，地質與鑽探團隊就應共同參與，從選址、目標設定到初步的鑽探可行性評估，都應納入雙方的專業意見。並建立暢通的溝通管道，將地質概念如：預測的地層與岩石強度、可能遭遇破碎帶或高溫高壓帶等資訊；以及鑽探過程中得到的資料如隨鑽測井（LWD/MWD）數據、岩屑即時分析、泥漿錄井等資訊，應結合地質判斷與工程經驗，迅速做出最佳決策。鑽井完成後的測井、產能測試等資料，應由地質與鑽探團隊應共同分析這些數據，總結經驗教訓，為後續的井位部署或開發策略提供修正依據。

地熱開發的成功，不僅仰賴精確的地質調查，更需穩健的鑽井工程相輔相成。唯有促進地質與鑽井團隊的協同合作，方能有效提升鑽探成功率，降低開發成本與風險，加速實現政府與社會對地熱發展的期待。

中文關鍵詞：地熱資源、地質調查、鑽井工程、技術門檻、風險控管

量化工程地質模型不確定性對邊坡穩定分析之影響

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邊坡穩定分析中，地質模型的不確定性常源自地層分層、材料性質與弱層幾何參數之模糊描述。當現地調查已揭示潛在弱層存在，惟其幾何與力學特性難以準確掌握時，將嚴重影響安全係數估算與設計判斷。本文以國道沿線一處邊坡災害案例為例，導入地質模型數位化與三維視覺化技術，重建災前穩定分析所採用之地質剖面，並透過災後補充之鑽探資料建立地層層序，進行滑動面位態與層位對比。結果顯示，災前推估之潛在滑動面與實際破壞面在空間上存在顯著的幾何落差，導致安全係數被高估，反映出地質模型不確定性對風險評估之深遠影響。

本研究應用極限平衡法，將控制滑動面的幾何與材料參數進行分解，並透過蒙地卡羅法量化各項不確定性對安全係數之貢獻程度。結果顯示，弱層深度、傾角與力學參數為主導穩定性的高敏感度因子。

本研究建議，針對具弱層潛勢之邊坡，應於維護管理階段導入風險導向之調查策略，以地層層序對比結合歷史災害辨識出潛在關鍵弱層，補強對安全係數最具影響之關鍵參數，分階段更新地質模型，以提升監測預警與決策精度。此方法論可作為邊坡長期管理中地質調查優化與風險控管之參考依據。

中文關鍵詞：工程地質模型、邊坡穩定、不確定性

活動斷層地質敏感區劃定現況與展望

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地質法自100年12月1日公布施行，當時的中央地質調查所立即以資料最完整的車籠埔斷層為起始，開始進行活動斷層地質敏感區劃定作業，並逐步完善劃定原則，並於103年03月28日完成公告。同時也檢視與調查其餘32條活動斷層，是否有足夠地質資料可劃定地質敏感區，針對資料不足的活動斷層，規劃逐步進行補充地質調查，並依成果滾動式進行後續地質敏感區劃定作業。

在113年12月17日，地礦中心公告了口宵里斷層、利吉斷層與初鄉斷層的活動斷層地質敏感區，累計公告達25處。目前正依113年執行調查狀況，滾動研議114年劃定目標，預計進行大茅埔-雙冬斷層與木屐寮斷層的活動斷層地質敏感區劃定。

此外，除已公布的活動斷層，地礦中心也持續蒐集資料與學界提出建議，評估可能具活動性的斷層(暫簡稱潛在活動斷層)，著手調查，部分則委託產學界協助調查，並已獲得相當成果，如在110年新公布的活動斷層增至36條，預計於115年底也將公布更新版本的臺灣活動斷層分布圖。

基於地質法中規定的活動斷層地質敏感區劃定原則，須滿足明確的十萬年來曾活動證據，以及足夠完整的易受斷層影響範圍，因此，多數活動斷層都需經補充調查，方能獲得足夠證據進行劃設。但即便進行了補充調查，也不是每一條活動斷層都足以通過嚴格的審議程序以劃定地質敏感區。

尚未能劃設地質敏感區的活動斷層，地礦中心仍持續進行地表變形觀測、蒐集各項鑽探調查資料，更新其資訊，如山腳斷層條帶地質圖已於113年1月19日更新公布於官網，提供做為建築法規更新與耐震評估之依據；此外，對於地方政府在國土規劃及防災演練等方面，地礦中心亦協助及共同面對將地震與活動斷層對民眾生命財產造成威脅儘可能降至最低。

中文關鍵詞：活動斷層地質敏感區、劃定原則、劃設公告、活動斷層條帶地質圖

大屯火山群地熱儲量評估：從衛星熱影像時序資料估算熱通量與熱逸散

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台灣大屯火山群（TVG）是由構造擠壓區過渡到地殼伸展區的活躍構造區，是一個有利於地殼岩漿侵入的地殼薄化結構（即地塹）區域。此種地質環境為火山和地熱系統的發展提供了熱源，另外，由於存在大量與年輕火山岩相關的地表熱特徵，TVG因此為地熱勘探頗有前景的熱點。本研究根據衛星熱影像觀測量所衍算之地表溫度（Land surface temperature; LST）等參數計算地熱輻射熱逸散來評估TVG的地熱資源儲量。首先，輻射熱通量 (Radiative heat flux; RHF) 是根據 LST，地表發射率，大氣透射率及環境溫度(Emissivity, atmospheric transmittance, and ambient temperature)，以斯特凡-波茲曼定律（Stefan-Boltzmann law）加以演算。其次，透過對大油坑地熱區域的熱通量像素值求和來估算總輻射熱逸散(Radiative heat loss; RHL)。然後，計算基於大油坑地熱區附近類似大小的非地熱區域的背景輻射熱逸散，從而透過從總輻射熱逸散扣除背景輻射熱逸散來獲得地熱（淨）輻射熱逸散。根據上述過程，可以得到TVG地熱輻射熱逸散隨時間的變化趨勢。研究結果表明，TVG 四十年來(1984-2024)地熱輻射熱逸散的趨勢以每年 1 MW（兆瓦）的速率增加，平均值為 211 MW。此平均估算值與先前研究以地球化學方法研究所得結果處於同一數量級。然而，估算得出TVG熱逸散年增長率為首創成果。本研究是首次嘗試利用衛星熱影像評估 TVG 地熱儲量潛能之研究，得益於衛星遙測資料集之有效取得與運用，彰顯利用長期遙測資料進行地熱和火山研究的優勢。

中文關鍵詞：大屯火山群 (TVG)、陸地衛星(Landsat)、地表溫度 (LST)、輻射熱通量(RHF)、輻射熱逸散(RHL)

Mapping Fault Zone Attenuation Using MiDAS Downhole Optical Fiber and Borehole Seismic Arrays

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Fault zone architecture offers critical insights into earthquake dynamics. The structural components of a fault zone, including the fault core, damage zones, and surrounding host rocks, play pivotal roles in seismic behavior. The quality factor (Q), representing seismic attenuation (Q^{-1}), is inversely related to the degree of fracturing within these zones; higher fracture densities typically correspond to lower Q values, indicating greater energy dissipation. Moreover, the permeability of these fractured zones facilitates fluid migration, which can alter fault strength and affect earthquake nucleation processes. The Milun Fault, an active east-dipping, left-lateral reverse fault, is located in the northern section of Taiwan's Longitudinal Valley, near the boundary between the Eurasian Plate and the Philippine Sea Plate. This fault has been responsible for multiple major earthquakes, including the 1951 Longitudinal Valley Fault Earthquake and the 2018 Hualien Earthquake. The Milun Fault Drilling and All-inclusive Sensing Project (MiDAS) initiated a scientific drilling with two boreholes operation in 2021 integrated with optical fiber sensing and borehole seismometers in 2022. The MiDAS Hole-A intersects the recent slipped fault zone at 520-540m providing the unique opportunity to map fault zone attenuation architecture using high spatial resolution of distributed acoustic sensing (DAS) and borehole seismometer arrays. To characterize the detail attenuation structure, we estimate the attenuation factor Q along MiDAS Hole-A using DAS records, with borehole seismometer data for validation. Our analysis focuses on seismic events approximately 20 km from the borehole site between June and December 2023. Before exploring the high-resolution attenuation mapping within the fault zone using DAS (4m spatial resolution), we first examine two depth station pairs: borehole seismometers MDSA1 and MDSA5 (positioned at 94 m and 638 m, respectively) and optical fiber nodes 1257 and 1390 at corresponding depths. The datasets are in acceleration and strain-rate, which are subsequently integrated into velocity and strain, respectively. We applied the STA/LTA method to identify the seismic arrivals and use polarization analysis to select events with incidence angles below 45°. Arrival time and effective shaking duration (ESD) are used to define P-, S-wave, and noise windows for frequency-domain analysis. We compute the spectral ratios between stations to estimate the attenuation parameters, Q_p and Q_s , from Δt_p^* and Δt_s^* by applying least-squares fitting. Preliminary results indicate consistently low Q (with 10s of values) across the fault zone, with comparable estimates from DAS and borehole seismometers at depths of 94 m to 639 m. Further analysis will refine the attenuation character within fault zone and explore the potential of fiber-optic data for achieving high-resolution attenuation mapping along the fault zone.

Keywords:Milun Fault, Seismic attenuation, Fault-zone attenuation, Milun Fault Drilling and All-inclusive Sensing Project (MiDAS), Distributed Acoustic Sensing (DAS)

Reconstructing geothermal geological models by combining geophysical, geochemical and geological studies in Tatun volcanoes area, Northern Taiwan

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In this study, we conduct a multi-disciplinary study, including geophysics, geochemistry, and geology, with help of tens of previously drilled exploration wells, to reconstruct geothermal geological models at the shallow 3-5 km, for a geothermal exploration project in the Tatun volcano area, northern Taiwan. Our reconstructed geological profiles show that the Tatun volcanoes have a ~1-2-km thick of lava flows and pyroclastic deposits, erupted on top of the 6-8-km-thick fold-and-thrust belt of Miocene sedimentary rocks. The seismic velocity imaging indicates a likely main magma reservoir of high anomaly of Vp beneath the Tatun at the depths of 8-15, with an estimated volume of ~250-300 km^3.

Incorporating the regional geology with the newly acquired magnetotelluric (MT) results, we found three high-resistive areas at different depths, which we tend to interpret as possible “heat bodies”. Surrounding these three high-resistivity areas, there exists overlying low-resistive zones or layers, which we interpreted as “cap rocks” and the potential geothermal reservoirs in-between the “cap rocks” and “heat bodies”: 1) two shallow reservoirs, at the depth of 600-1200 m (downhole temperature of 150-250°C), and 2) a deeper reservoir, at the depth of ~ 2-3 km, seemingly in the uppermost basement of quartz-rich sandstone, underneath low-resistive lobs.

At least four high micro-seismicity zones have been observed. Two zones with cylinder shape are interpreted as conduits of hot fluid derived from deep over-pressured zones, beneath the Qixing Mt and Da-You-Keng (at the depth of 1~3 km). One zone is more dispersed beneath the Da-Jian-Hou shan at the depths of 1-4 km. The fourth zone occurred in the deeper part around the outer edge of the fluid saturated magma reservoir around 4-6 km depth. These hot-fluid related seismicity zones are considered of potential for “super-hot or super-critical geothermal” exploration.

Keywords:Tatun Volcano, Geothermal, Magnetotelluric, Seismicity, Structural Geology

Structural history and kinematic evolution during exhumation processes in the eastern Central Range, Taiwan

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Kinematic evolution of exhumation processes is an intriguing question for the mountain building. Analyses of meso-structures, strain distribution, and P-T-stress state during the exhumation processes in the eastern Central Range of Taiwan provide a unique opportunity to understanding the structural history and kinematic evolution in the retro-wedge of orogenic belts.

It is well known that sub-horizontally along-strike stretching lineation is noticeable on the NE-striking foliation with moderate dip at the eastern Central Range, contrast to the down-dip stretching lineation at the western Central Range. Magnetic fabrics consistent with petro-fabrics provides the strain pattern across the eastern Central Range. With shear-sense indicators, it illustrates that along-strike shearing associated with almost E-W compression took place during ductile and semi-ductile deformation under the strike-slip faulting stress regime, which is still active inferred from current earthquakes. Conversely, later shallow structures including the sub-horizontal crenulation cleavages, listric normal faults and NW-striking sub-vertical joints and quartz veins subparallel to the motion of the Philippine Sea Plate locally cut the foliation throughout the eastern Central Range, displaying that sub-vertical ductile thinning associated with N 20-30E extension was active during semi-brittle and brittle deformation under normal faulting stress regime with NE-extension. The results of fluid inclusions with CO_2-H_20 system display that these sub-vertical quartz veins were formed at the sub-supercritical conditions of CO_2 with 407°C trap temperature and 109MPa trap pressure at the depth of around 5km, where is almost overlapped the depth of earthquakes with strike-slip faulting stress regime.

Variation of kinematics at the brittle-ductile transition might indicate that dynamics changes dramatically in the orogenic exhumation system and might further suggest that the existence of a lid separated brittle behavior from overpressurized ductile deformation to facilitate the exhumation in the eastern Central Range, Taiwan.

Keywords:Exhumation, Eastern Central Range, Taiwan

Thermal Characteristics of the Milun Fault Using Borehole Optical Fiber Sensing

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Understanding the thermal characteristics of fault zones is crucial for gaining insights into earthquake dynamics, fluid transport processes, and fault mechanics. Temperature anomalies within fault zones are generally attributed to frictional heating during seismic slip, fluid migration, or lithological variations. The Milun Fault, an active east-dipping, left-lateral reverse fault, is located in the northern section of Taiwan's Longitudinal Valley, near the boundary between the Eurasian Plate and the Philippine Sea Plate. This fault has generated multiple major earthquakes, including the 1951 Longitudinal Valley Fault Earthquake and the 2018 Hualien Earthquake. Due to its frequent slip behavior and potential seismic hazard, the Milun Fault Drilling and All-inclusive Sensing Project (MiDAS) initiated a scientific drilling operation in 2021 to monitor the fault's thermal and mechanical properties. The MiDAS Hole-A observation site is situated on the northwestern edge of the Milun Terrace and directly intersects the fault zone at a depth of 520-540 m. The borehole is equipped with a Distributed Temperature Sensing (DTS) system, enabling high-resolution, continuous thermal monitoring along its depth.

Since December 2022, DTS measurements have been conducted to monitor long-term temperature profile along MiDAS Hole-A, from the surface to a depth of ~ 700 m. These measurements capture variations in the geothermal gradient in the subsurface, which might be influenced by environmental changes. In addition to that, a notable temperature anomaly (~ 0.04 ^{o}C) has been consistently observed at depths of 540-580 m, located below the fault zone, throughout the year. The absence of significant temperature changes within the fault zone suggests that this anomaly is unlikely to result from frictional heating associated with coseismic slip in 2018. Instead, this deviation in the regional temperature profile may be related to compositional variations in the fault or fluid movement.

Notably, a significant Mw 7.4 earthquake on April 3, 2024, occurred near the MiDAS site. Following the earthquake, DTS data revealed a subtle temperature variation in the previously identified anomaly at 540–580 m, located below the fault zone. The cause of this anomaly remains unclear. To further investigate this phenomenon, we continue to conduct a comprehensive analysis of long-term DTS data to assess the potential influence of external factors, such as fluid migration or seismic activity. These investigations will contribute to a better understanding of the mechanisms driving temperature variations near active fault zones and enhance our ability to interpret thermal signals in seismically active regions.

Keywords:Optical Fiber, Subsurface Temperature Anomalies, Distributed Temperature Sensing

Evolution of the Songshan complex from geomorphological mapping, 40Ar-39Ar dating, petrology and geochemistry

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The Tatun Volcanic Group is a cluster of young volcanic centers on the northern flank of Taiwan's capital, Taipei. It is too poorly understood to reliably and quantitatively evaluate the hazards it poses. Here we report initial results from a multi-disciplinary study of one of these volcanic centers, the Songshan complex. Analysis of high-resolution LiDAR-based topography reveals a ten-km long array of at least six overlapping lava flows that extends from Mt. Songshan northward to the coast. Several new ^{40}Ar-^{39}Ar dates reveal that these six flows erupted over about 35,000 years, between 279.8 ± 3.3 and 246.1 ± 1.3 ka. Ages of 329.7 ± 1.8 and 437.6 ± 1.8 ka on basaltic boulders within a set of older lahars on the western flank of the flows point to still older, highly eroded and buried flows in the headwaters of the Songshan drainage. Similar lahar deposits are also sparsely exposed on the eastern flank, possibly indicating the lateral extent of a basal unit underlying the Songshan complex. Whole-rock geochemical analyses show that the samples share the following features: (i) intermediate SiO_2 contents (53–60 wt.%), and (ii) all belong to the calc-alkaline series. Furthermore, geochemical and petrographic analyses suggest that the flows can be grouped into basaltic andesitic and andesitic categories, reflecting distinct compositional trends. Initial petrography and geochemistry evidence suggests a dual-magma-chamber, episodic model for the Songshan complex, with compositional diversity likely tied to separate magmatic sources or evolutionary pathways. We will test this model via further examination of volcanic stratigraphy, geomorphology, and geochronology. By placing the Songshan complex within a robust framework, we will be able to provide more reliable, quantitative assessments of the hazards posed by the Tatun Volcanic Group.

Keywords:Tatun Volcanic Group, Songshan Complex, Geomorphology, 40Ar-39Ar dating, Geochemistry

臺東霧鹿地區地熱地質探勘

謝佩珊[1]、董倫道[1]、ZamanSemih[2]、黃淞洋[1]、衣德成[3]、郭泰融[1]、溫心怡[1]、林朝彥[1]、張郁敬[1]、錢正明[1]、林錫宏[4]、陳棋炫[4]、鄭中崴[4]

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經濟部地質調查及礦業管理中心為探查東部變質岩區潛在地溫異常區塊之地質構造與溫度狀況，選擇於臺東霧鹿與龍過脈地區持續執行地熱地質鑽探工作，全程取岩心以及進行井下試驗與取樣分析研究，並於前期探測基礎上，針對重要地溫異常區域執行補充調查，以提高地下構造模型的準確度，作為地下資源之基礎及必要資訊。

本研究之鑽探工作，由工研院材化所團隊、土耳其 Ortadoğu 鑽探公司與世其工程有限公司共同執行。霧鹿地區於112-114年度共完成三口小口徑地質探勘深井，鑽深分為WL01 1000.4 m、WL02 2004 m、WL03 1886 m。新建置之WL03位於高程約870 m，歷時100天完井共鑽取岩心1883.07 m。約地下52 m處進入岩盤，判釋岩性以暗色雲母石英/石英雲母片岩為主，間夾淺綠色變質凝灰質火成岩，亦於1644.7 m以下出現花崗岩與片岩穿插出現，直到完井深度仍未鑽穿花崗岩體。選擇WL03井位時根據MT探測結果，推測應會鑽在花崗岩與片岩交界，鑽探結果證實與MT模型相符。鑽井完成後進行PT量測，由132-1398 m之地下溫度剖面估計WL03升溫梯度約為6.0°C/100m，估算井底可達128°C，與鑽探期間留點溫度計量測溫度(1804 m、 121°C)接近，此升溫梯度至鑽探結束深度仍為穩定，若以此估算到2500 m深度，地下溫度可達165°C。

整合調查區內大地電磁與空中磁力探測資料，並以三口深井作為控制，推測探測區內地下潛伏一體積龐大的火成岩體，主要分布在新武呂溪北岸，在下馬部落附近轉向南擴展至大崙溪一帶。完整的火成岩體具有高磁及高電阻特徵，而受熱水作用區域則具有低電阻、低磁及磁力反轉的特徵，此火成岩體非直接熱源，熱水移棲則是受破碎帶控制，區域地下溫度仍受控於造山運動所致之異常地溫梯度，地熱潛能評估與開發策略建議往非傳統型地熱，如closed-loops或EGS推進。

中文關鍵詞：霧鹿、小口徑地質探勘井、地熱地質模型

以基因演算法優化地下三維應力場模型

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隨著全球對地下資源開發、廢棄物處置及天然災害風險的關注日益升高，三維應力場評估在地質工程與災害預防等領域的重要性亦日益增加。陳冠豪（2020）雖成功以全域搜尋法建立地下應力場模型，推估三軸主應力規模與方向隨深度的變化，但其方法不僅耗費龐大運算資源，亦難以評估模型誤差範圍。

因此，本研究延續其模型設計，改以撰寫基因演算法進行模型優化，期能提升運算效能、評估模型誤差，並進一步提高模型精度。採用線性旋轉模型，以不同深度的縮減應力張量作為觀測資料，重建三軸主應力隨深度之變化，並設計兩種選擇策略——最佳保留法與隨機競爭法，進行測試與比較。

初步以合成資料進行測試，結果明顯優於網格搜尋法。模型獲得標準答案的機率由1.12×10^{-9}提升至1.59×10^{-4}，且運算時間由數日大幅縮短至約五分鐘，不僅顯著減少運算資源消耗，亦能有效評估模型誤差。測試過程中雖曾於極小誤差範圍內出現多重解，但透過固定鉛直方向參數可有效解決該問題。進一步使用花蓮和平地區非彈性應變恢復法所測得之現地應力資料進行測試，基因演算法模型所得最小誤差結果亦優於網格搜尋法。

本研究另參考 Herrera-Poyato 與 Herrera（2017）提出之 Genetic Algorithm with Diversity Equilibrium based on Greedy Diversification（GADEGD），以維持族群多樣性，提升空間探索能力，惟結果未見顯著改善。進一步於合成資料中加入誤差擾動，以模擬真實觀測資料之不確定性，模型仍展現穩定性與適應能力，顯示其應用潛力。

未來將持續強化模型對觀測資料誤差所造成之應力場不均勻分布的適應能力，並針對斷層、褶皺等地質構造所導致的異向性進行優化，以期能進一步提升三維應力場重建之準確性與工程應用價值。

中文關鍵詞：基因演算法、縮減應力張量、應力模型

Thermal Conductivity of Iron Under High Pressure and Temperature: Implications for Mercury's Core and Dynamo Evolution

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Mercury currently exhibits a weak dipolar magnetic field, likely generated by a dynamo within its core. Remnant crustal magnetization data suggest that this dynamo may have been active since approximately 3.8 billion years ago. Mercury's core is notably large, with an estimated radius of about 2000 km, and is believed to be at least partially molten, containing a solid inner core. It is primarily composed of iron (Fe), with additional light elements, potentially sulfur, silicon, and carbon. A key factor influencing the planet's thermal and dynamo evolution is the thermal budget in its core, which depends critically on its thermal conductivity. To better understand the long-term history of Mercury's dynamo, it is essential to investigate the thermal conductivity of candidate materials forming its core. Here we have directly measured the thermal conductivity of pure Fe—representing an end-member composition of Mercury's core—using time-domain thermoreflectance coupled with an externally-heated or laser-heated diamond anvil cell. The broad range of measurement temperature from 300 K to ~2000 K allows us to assess how the thermal conductivity of Fe changes with temperature under relevant high pressure conditions in Mercury's core. These results provide important constraints for modeling the thermal evolution and dynamo activity of Mercury's core.

Keywords:Mercury, Planetary dynamo, Thermal conductivity, Iron

Thermal Conductivity of Iron Under High Pressure and Temperature: Implications for Mercury's Core and Dynamo Evolution

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Keywords:Mercury, Planetary dynamo, Thermal conductivity, Iron

Racolyte：自行研發的礦物拉曼光譜比對系統

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現今拉曼光譜儀使用的資料庫與比對軟體大多由儀器開發商提供，儘管開發商會對其資料庫進行維護，但礙於商業利益考量，這些資料庫通常是開發商自行研發建置，資料的資訊透明度與軟體比對準確度缺乏學術專業上的驗證。本研究針對學術工作進行礦物資料庫建置與鑑定軟體的開發。為了建立具有公信力的比對來源，首先匯入美國亞歷桑納大學RRUFF計畫提供的開源資料庫，並可以增加使用者自行擴建資料庫之功能，追求更完善的比對系統。使用之開發平台為商業數學軟體MATLAB R2023a，該軟體擅於數值運算，提供訊號處理、資料分析、視覺化資料等多項套件。為了使用者友善與方便性，本研究彙整資料庫構建、樣本前處理、資料比對和資料輸入輸出等功能，設計軟體的圖形化使用者介面。現階段結果顯示該軟體能夠兼容大部分開源資料庫之數據格式，已輸入資料庫之有效的礦物資料共14004筆，實際測試單筆樣本比對所需時間，平均時間約為6.21秒，意謂每秒可掃描並比對2255筆資料。使用70個礦物樣本實測資料進行比對測試，比對正確率為98.57%。本研究開發之軟體不僅可用於礦物拉曼光譜，亦有潛力延伸應用至其他光譜比對模式，例如X光繞射光譜。未來會持續擴大樣本測試數量，縮減單次比對耗時以提高效率，強化濾波、基線處理與移除螢光訊號等功能。該軟體將免費提供給臺灣的學術界使用，國立臺灣海洋大學礦物與地球化學實驗室會繼續進行建置礦物拉曼資料庫的計畫。

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中文關鍵詞：礦物比對、拉曼光譜、MATLAB

Microtextures of Bi-Au melt inclusions and droplets in pyrrhotite-dominant chimney fragments from the Geolin Mounds hydrothermal field offshore NE Taiwan: Implications for gold scavenging by bismuth melts in hydrothermal systems

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Native bismuth inclusions hosted by pyrrhotite in sulfide chimney fragments from the Geolin Mounds hydrothermal field offshore NE Taiwan were characterized by SEM-EDS-EBSD and TEM with implications for gold enrichment by bismuth melts. The chimney fragments are characterized by alternating layers of perpendicularly aligned coarse-grained pyrrhotite platy crystals and fine-grained sphalerite, isocubanite, and galena associated with pyrrhotite, implying a formation temperature of ~400°Cwiththe isocubanite geothermometer. In the middle of the pyrrhotite layers, negative crystal-shaped micrometer inclusions of native bismuth line up along horizons perpendicular to the pyrrhotite platy crystals and enclose disseminated grains of twinned crystals of native gold 10–100 nm in size. Submicrometer gold grains occur within some of the bismuth inclusions. Such Bi-Au inclusions are associated with expansion microfissures filled by bismuth and gold and the native bismuth is extensively twinned throughout each inclusion possibly due to mechanical twinning. In addition, droplets of native bismuth containing gold crystals are locally attached to the surfaces of pyrrhotite crystals. The data imply a melt origin for the Geolin Mounds Bi-Au association which implies condensation of bismuth melt droplets and gold scavenging by bismuth melts from hydrothermal fluids. Varying gold crystal sizes among Bi-Au inclusions could be attributed to varied growth rates and degrees of recrystallization in hydrothermal venting processes. The Geolin Mounds chimney presents a rare occurrence of repeated trapping of Bi-Au melts during successive pulses of hydrothermal venting.

Keywords:melt inclusion, sulfide chimney, bismuth, gold, TEM

Examination of evolutionary development and ontogenic variation in the foraminifera Globigerinoidesella fistulousa during the Plio-Pleistocene transition interval using 3D morphometric analysis

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The early Pliocene (4.5 to 3.0 Ma) marks the most recent time with climate conditions warmer than the modern, culminating in dramatic shifts in global climatic and palaeoceanographic conditions during the Plio-Pleistocene transition. This interval provides an exceptionally opportunity to examine the controls of rearranging paleoenvironmental conditions on the evolutionary response of marine organisms, specifically foraminifera. Our study investigates the evolutionary divergence of *Globigerinoidesella fistulousa* from *Trilobatus sacculifer*, examining specimen within the First Appearance Datum interval of *G. fistulousa*, IODP Hole 1482B, Indian Ocean. The speciesis readily distinguished by distinctive "finger-like" protuberances. However, due to morphological disparity in *T. sacculifer* the exact timing and drivers of *G. fistulousa's* speciation is a matter of debate.

We apply a novel 3D geometric morphometric approach utilizing a data set of 3D images generated through μ-computed X-ray tomography. Foraminifera morphology, in particular the *T. sacculifer* lineage, is strongly influenced by 3D metrics including volume, surface area, and shape variation, this analysis attempts to elucidate morphological, developmental, and evolutionary trends that might otherwise be poorly captured with 2D methods. Specifically, this analysis attempts to quantify the expansion and spatial positioning of the distinctive protuberance features of *G. fstulousa*, as well the timing and shifts in the developmental ontogeny of these features. Using these insights we attempt to identify the driver(s) of *G. fistulousa's* speciation and the processes of evolution and speciation as a whole.

Keywords:Foraminifera, Plio-Pleistocene, μ-computed X-ray tomography, 3D geometric morphometrics, Speciation

隧道結構行為之水力互制分析

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在台灣山多平地少的環境條件下，隧道是不可或缺的交通建設之一。然而在遭遇多變地質時，隧道開挖得面臨多種嚴峻挑戰，施工困難程度提升，湧水即為隧道開挖期間可能遭遇的災變之一。施工期間曾發生湧水事件的隧道案例，經常以阻水或排水工法降低水壓與水量以順利通過。因湧水事件的處理大多仰賴設計階段建構於開挖前之地質模型的假設情境以及現場人員的經驗，湧水處理對隧道周邊以及隧道結構自身的影響，尚無足堪作為設計流程之系統性準則因此本研究針對隧道開挖階段在地下水滲流作用下之受力行為進行探討。

為了解隧道開挖對岩體與地下水之變化等問題，本研究以簡化水力邊界之隧道案例進行水力互制數值分析，探討隧道滲水之水力互制機制，並釐清隧道開挖湧水案例之水壓與應力分布，可做為湧水潛勢隧道案例設計的參考，以期減少湧水導致之結構短期與長期損傷。

本研究之模擬結果顯示側向壓力係數 k的變化將影響隧道開挖後之塑性區分布，進而改變水力傳導係數，最終將影響著孔隙水壓洩降的範圍及梯度，同時影響總應力的變化。而由不同大小的水壓p案例中的可發現有效應力、總應力與水壓p成正比，若於無水壓情況下，彎矩峰值為有水壓的1/8倍，週期也會有所不同。

灌漿一直被視為隧道施工中防止地下水湧入的最有效措施之一。隧道周圍所形成的灌漿環可構築一個低滲透性區域，不僅能減少地下水進入，亦有助於確保開挖作業的安全性。然而，灌漿環內的地下水壓可能會相較於原始值上升或下降，這取決於灌漿方式、排水設計以及隧道結構是否具備防水功能等因素。

本研究針對灌漿及其相關因素對隧道結構的影響，採用二維水力－力學耦合分析，考量不同的側向壓力係數、邊界水壓、灌漿範圍與襯砌是否防水等條件進行模擬。分析結果顯示，孔隙水壓易在灌漿區外緣產生積聚現象。此外，灌漿會使隧道襯砌的彎矩增加至無灌漿情況下的約113%至150%。

中文關鍵詞：隧道開挖湧水、水力互制、阻水灌漿

以卡爾曼濾波器即時修正地震動預估：導入破裂方向性於地震預警系統

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地震預警（Earthquake Early Warning, EEW）是減輕地震災害的主要手段之一，能在破壞性地震波到達前提供數秒至數十秒的預警時間。傳統使用的點震源演算法，在快速獲取震源規模與位置的條件下，可提供合理的地震動估計。然而，現有系統的預測精度仍受到多項因素限制。首先，破裂方向性（rupture directivity）會在特定方向放大地動，然而，此關鍵震源特性並未被考慮進地動預估中。其次，預警系統中所採用的地震動預估模型（Ground Motion Models, GMM）無法反映事件間變異性，容易導致預估誤差。此外，在地震發生時，使用P波資料預測規模時常會造成低估，此不確定性亦加劇了預估的誤差。因此，本研究引入Kalman Filter，利用即時近場測站的PGA資料動態修正GMM係數，用以修正事件間的變異性，並於模型中加入破裂方向性項，以即時捕捉方向性震動放大效應。應用於多起臺灣規模6以上的地震案例顯示，本方法具備提升預警系統準確度的潛力，並能有效因應規模低估問題。以2024年4月3日花蓮Mw 7.4地震為例，此事件因預警規模低估，導致包含臺北都會區在內的七縣市未觸發PWS預警通知。使用此方法進行逐秒近即時的修正後，可於震後25至30秒內達到正確地震動預估並辨識主要破裂方向，成功補足原系統的漏報。本研究所提出之方向性GMM結合Kalman Filter資料同化的架構，除有助於提升地震動預估精度，並能及時取得震源破裂資訊，有助於加強對地震災害快速的應變與決策。

中文關鍵詞：地震預警、破裂方向性、卡爾曼濾波器

2025年M6.4大埔地震野外調查及孕震構造特性

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2025年1月21日凌晨，臺灣西南部嘉義縣大埔鄉與臺南市楠西區交界發生芮氏規模6.4地震，震源深度約15公里，初步震源機制分析顯示為逆衝型孕震構造活動所致。此區為中央山脈西翼構造活動帶，斷層分布複雜且具潛在活動性，本次地震為理解臺灣西南部孕震構造特徵與地震地表效應提供重要契機。本研究整合多項資料來源進行分析，其中包括野外調查、38個GNSS測站的同震地表位移與Sentinel-1A升降軌之DInSAR等資料，並針對地表變形觀測結果進行斷層逆推模擬。野外調查顯示，震後六甲斷層附近出現噴沙堆積，顯示當地應有發生土壤液化現象；在口宵里斷層附近觀察到張裂性地表裂縫，亦有多處斜坡崩塌與側向擴張現象分布於地形陡峭或沖積層厚度變化明顯的區域，呈現明顯場址效應。GNSS觀測結果顯示，北向最大水平位移為+24.56 mm，東向為+9.7 mm，垂直方向最大抬升達+50.05 mm。DInSAR分析則顯示升軌與降軌方向的LOS位移分別達到約120 mm與80 mm，兩個軌道的變形場呈現連續且一致的空間分布。GNSS資料與DInSAR結果互相驗證，說明此次地震確實有造成明顯的地表變形，並受到淺層構造約束。整合觀測結果與斷層模擬分析，推測地底除了主要的向東傾逆衝孕震構造以外，深10~15KM處尚有一向西傾之孕震構造，顯示此區域孕震構造間存在應力傳遞與互相觸發的潛力。本研究後續將進一步整合地質、岩心、災情新聞與地形等資料，探討深淺孕震構造間之關聯性，以及構造活動對地表之影響。本研究展示遙測技術與地面觀測資料在震後快速分析與構造解釋中的應用潛力，對於理解臺灣西南部活動構造特性、地震災害潛勢評估及防災策略擬定，具有重要科學與實務面向的貢獻。

中文關鍵詞：GNSS、DInSAR、岩心、臺灣西南部孕震構造、數值地形

2022年關山池上地震誘發之同震山崩

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地震發生時，地震波的傳遞可能導致坡地不穩定，進而引發山崩，稱為同震山崩（Coseismic landslide），亦稱為地震型山崩（Earthquake-triggered landslide）。根據歷史地震案例的災害紀錄顯示，同震山崩是地震發生時最主要致使人員傷亡的一種災害。若能系統性地整理同震山崩的崩塌位置和崩塌面積等資訊，建立完整且準確的山崩目錄（Landslide inventory），將有助於理解同震山崩的分布特徵和發生機制。若進一步將山崩目錄與誘發山崩的因子進行相關性分析，即可掌握山崩潛勢地區，提升災害應變與預警能力，減低同震山崩所造成的傷亡以及經濟損失。

2022 年 9 月 17 日與 18 日，臺東縣關山鎮與臺東縣池上鄉接連發生了芮氏規模 6.4 和 6.8 的關山－池上地震序列，也造成臺灣東部縱谷南段一帶相當多的同震山崩。由於各個研究機構對於此次地震的同震山崩僅有部分的調查以及圈繪，因此本研究欲透過地震前後的衛星影像與航照資料，為此次地震建立完整的山崩目錄。本研究比較地震前後解析度 50 公分的 Pléiades 衛星影像，以及航測與遙測分署拍攝解析度 25 公分的正射航照資料，首先利用常態化差值植生指標（Normalized Difference Vegetation Index）快速尋找山崩區域，並使用視覺判讀圈繪山崩範圍。針對中央氣象署所公布關山－池上地震的前震與主震，震度達到 5 弱以上的區域，初步繪製 538 個山崩，總面積約為 90 萬平方公尺。後續將持續完善關山－池上地震的山崩目錄，並將山崩目錄與主要誘發因子（如岩性、坡度和與震央距離等）進行相關性分析。藉由深入探討關山－池上地震與山崩分布之間的關聯性，以期能作為後續山崩潛勢分析的參考。

中文關鍵詞：關山池上地震、同震山崩、山崩目錄、常態化差值植生指標、潛勢分析

台灣甲仙鹽水坑頁岩冷泉碳酸鹽岩中新發現之海蛄蝦

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海蛄蝦（Thalassinidea）或稱幽靈蝦(Ghost Shrimp)廣泛分布於西太平洋地區，是台灣現生常見的甲殼類生物。本研究於高雄市甲仙區楠梓仙溪的鹽水坑頁岩層中，發現大量海蛄蝦（*Neocallichirus sp.*）的化石，主要為身體部位的殘骸，沉積環境中也存在大量的生痕化石與化石相伴而出的現象。

甲仙地區早期上新世的冷泉碳酸鹽岩中，首次記錄到台灣海蛄蝦化石。化石主要包括海蛄蝦(*Neocallichirus sp.*)之大螯 (propodus)、部份腕節 (carpus) 和少量頭胸甲(carapace)，分布於塊狀頁岩和碳酸鹽岩中，並伴隨大量生痕化石，顯示海蛄蝦與洞穴結構的緊密關聯性。化石大多為原地保存，表明海蛄蝦在冷泉環境中具有高度的活動性。此物種為台灣首次報導，本研究著重於此物種之重要的外觀特徵(Diagnoses)、化石描述(Description)、埋藏學(Taphonomy)，此物種的化石鑑定主要以大螯 (propodus)之特徵為主，其propodus（腕節）為矩形，固定指（fixed finger）纖細且短，咬合面近端有鋸齒，活動指（movable finger）粗壯，咬合面有小鋸齒，尖端微微向下鉤曲為其特點，目前對照上新世之世界各國報導其他*Neocallichirus*之物種並無與其相對應物種，以此目前暫稱其*Neocallichirus sp.*。埋藏學部份，目前確認為現地保存，證據包括化石的高度集中性，以及發現化石出現在碳酸鹽生痕管當中，很可能是當時這個生物體在此處定居，而後死亡後直接於原地生成為化石。大螯化石因甲殼幾丁質高度鈣化易於保存，因此於該處可大量發現此部位化石，並且也發現數個罕見頭胸甲等部位化石。甲仙地區的大量海蛄蝦化石記錄側面證明了當時冷泉甲烷氣滲漏的除了常見的滿月蛤，此生態系還供給其他種群生物生存。

本研究的發現表明，海蛄蝦可能在特定情況下的古代冷泉系統中也是主要的組成成員，推測可能與現生依賴甲烷滲漏相關的細菌來維持生存情況相似。，本研究填補了台灣化石紀錄的空白，並為冷泉生態系研究提供了全新生物種群。

中文關鍵詞：甲殼類、海蛄蝦、Neocallichirus、上新世、鹽水坑頁岩

台北盆地工程地質分區建置

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因地質特性不同，不同區域其工程規劃、設計與施工考量即有所不同。工程地質分區旨在考慮工程地質特性均勻性，將一個大區域劃設成數個工程地質特性相似的小區域，並作為國土規劃、防災、與工程計畫推動之參考。台北盆地歷史上經過兩次湖陸循環，地質狀況較為複雜，建立工程地質分區有助於釐清地質背景，降低工程風險。前人建立第三代台北市工程地質分區，以松山六次層的沉積物為基礎，劃分台北市工程地質分區，以提供工程界分析和判斷地層的結構。本研究在此之上考慮了基盤的分布與砂、泥層的厚度變化，建立新一代的地質分區，並針對各分區予以解釋。

本研究整理工程地質探勘資料庫提供之資料，使用10,681孔工程地質鑽井、前人建立之景美層頂部以及第三系基盤的高程空間內插作為分區資料的參考。首先建立台北盆地礫石、砂與泥的分布比例三相圖，其次分別建立基盤分區、礫石層分區、火成岩再積物在地表下三十米內是否出露而設立之火成岩再積分區。剩餘台北盆地區域則依照砂、粉土與黏土沉積物在地表下十五米內比例變化劃分分區。最後針對不同分區，利用地表下第一層泥層的厚度空間變化，將各分區劃分為數個子分區，最終建立台北盆地工程地質分區。

研究結果考量不同分區的地層的差異，劃分不同地質條件的分區，並針對各分區的地層結構探討其可能地質背景。命名時考量沉積物主要受河川影響，分區以河流-主要地質條件-次要地質條件作為命名標準，最終將台北盆地分為十二區。

中文關鍵詞：台北盆地、工程地質分區、土壤分層、礫石

考慮隧道開挖對裂隙岩體滲透特性影響之近場水流模擬

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滲水為山岳隧道常見的現象，地下水作為影響山岳隧道安全性及服務性的重要環境因子之一，並且其影響可從施工階段至營運階段，對於隧道的結構穩定及功能性帶成挑戰。因此從設計乃至營運階段皆不易掌握隧道襯砌外的地下水水壓與匯集至隧道的流量。儘管現代隧道仍有設置排防水系統，但營運中隧道仍存在滲水、湧水的風險，相關營運中山岳隧道湧水的案例，如2022年臺灣中仁隧道發生營運中湧水事件，該事件導致設備機房淹水、路面抬升。2024年於日本鹿兒島的北薩隧道也發生營運中隧道湧水的案例，該事件甚至引起隧道壁面坍方。雖然這兩起湧水案例發生極為罕見，凸顯出當實際地下水量超出排防水設計時仍需考量背後衍伸的問題。

綜觀目前國內外的相關研究，許多文獻仍聚焦於施工階段時的流量及水壓預測，對於營運過後地下水造成的長期結構及功能性影響仍有待精進。因此本研究旨在研究地下水如何影響營運中隧道，將以標準隧道斷面及真實隧道排防水系統建立地下水滲流與山岳隧道互制關係的三維模擬數值技術。

然而裂隙水於同一地層中分布非常不均勻且具方向性，其作用受節理方向影響之大，故本研究採用等值節理岩體組成律模式，考慮隧道開挖後圍岩應力應變調整引致裂隙的剪動、閉合及剪脹現象，造成裂隙隙寬變化，進而改變岩體的等值滲透係數張量，據以評估山岳隧道開挖後圍岩塑性區以及滲透係數變化範圍。最後經由不同情境比對探討襯砌承受地下水壓力的差異，以及入流隧道地下水量。本研究方法可提供山岳隧道排水與防水系統設計及營運管理之參考，進而提升山岳隧道工程於全生命週期中的韌性與使用安全。

中文關鍵詞：山岳隧道、地下水、完整排防水系統、等值節理岩體、近場水流

應用寬頻地震儀探討山崩構造-以捷克山崩為例

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本研究的山崩案例位於捷克東部外西喀爾巴阡山區的Ondřejník山崩，以及波希米亞地區拉貝河右岸的Ceřenistě山崩。外西喀爾巴阡山的Ondřejník的基岩為白堊紀的複理岩(flysch)，Ceřenistě則是由火山岩(主要為玄武岩及橄欖玄武岩)組成。Ondřejník地勢陡峭，山脊與峽谷交錯，受構造運動影響明顯；Ceřenistě則是呈現高原與深切峽谷交錯特徵。Ondřejník的岩層風化嚴重，存在多層破碎帶與弱面；Ceřenistě則局部風化破碎，塑性泥岩與沉積層間接觸帶導致該區的山坡地不穩定。Ondřejník為複合型山崩，包括主要滑動塊體與次滑動面；Ceřenistě則以崩積層、側向支脊及塌陷區為特徵。

在前人研究中，在本研究案例使用了電阻率層析法（ERT）：藉由在地表安裝電極以測量地下岩土材料的電阻率分布。因為不同類型的地質材料（如砂岩、黏土、含水層）具有不同的電阻率，因此可以透過(ERT)重建地下構造的剖面。此外，樹輪地形學技術(dendrogeomorphology)亦被應用在滑動塊體的活動性分析中。其為利用導管腔面積（VLA）數值的變化，來判斷樹木生理狀況和環境反應，進一步做為山崩監測和災害風險評估。本研究為使用寬頻地震儀於山崩案例做現地的微地動(microtremor)測量，其為分析微地動訊號，比較不同地質材料的波速，以解析滑動塊體的構造。

研究成果顯示，Ondřejník案例的主要滑動面深度介於10至30公尺，次滑動面位於2至10公尺的地下深處。而長期觀測顯示，山崩活動與強降雨事件相關。在Ceřenistě案例中，受影響樹木的VLA分別平均下降約40%與37%，且事件反應指數顯著高於傳統年輪偏心法(tree-ring eccentricity)的結果，顯示滑動範圍更為廣泛。在本研究中，利用Geopsy軟體分析微地動訊號後，初步得知地下分為兩層，之後再分析單站法測量的頻散曲線，可得知地下分層深度。未來的工作為，將本研究微地動分析成果與前人研究使用的地電阻作為比對依據，分析是否存在更深的地下分層，以釐清滑動塊體的地下三維分布情形。

中文關鍵詞：山崩構造、微地動、外西喀爾巴阡山、波西米亞

單晶 CaSnO$_3$ 彈性模量之決定：整合布里淵散射與 DFT 模擬

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Megawite（Ca(Ti$_{.7}$Sn$_{.6}$Zr$_{.1}$)O$_3$）為發現於捕虜岩中的鈣鈦礦結構礦物，其端成分包括 CaTiO$_3$、CaSnO$_3$ 與 CaZrO$_3$，皆屬於 GdFeO$_3$ 型的 $A^{2+}B^{4+}O_3$ 鈣鈦礦結構。其中，CaSnO$_3$ 因其與地球深部穩定存在之鈣鈦礦型矽酸鹽（如 MgSiO$_3$、CaSiO$_3$）具有高度結構相似性，而常作為 CaSiO$_3$ 鈣鈦礦（毛氏石，Davemaoite）在常溫常壓下無法穩定存在時的結構類比物，以預測其物理性質。

儘管過去已有針對CaSnO$_3$多晶體的超聲波測量研究，但其單晶彈性常數（Cij）至今尚無實驗數據。本研究首次於常溫常壓下，利用布里淵散射技術(Brillouin scattering technique)量測高品質CaSnO$_3$單晶的完整彈性常數。我們以四顆高品質單晶樣品進行布里淵散射實驗，並透過聲速數據配合Christoffel方程進行最小平方迴歸分析，成功獲得完整的彈性模量，包括縱向模量（C$_{11}$、C$_{22}$、C$_{33}$）、剪切模量（C$_{44}$、C$_{55}$、C$_{66}$）與非對角模量（C$_{12}$、C$_{13}$、C$_{23}$）。由此計算出的體積模量(bulk modulus)、剪切模量(shear modulus)及聲波速度（V$_P$與V$_S$）與以往多晶測量結果（Kung et al., 2001；Schneider et al., 2008）一致。

在數據擬合過程中，建立良好的初始C_{ij}模型至關重要。對於如CaSnO$_3$等缺乏既有彈性性質數據的新材料，初始C_{ij}可藉由理論計算獲得。本研究採用CASTEP計算程式進行密度泛函理論（DFT）模擬，利用LDA、GGA與mGGA泛函，並搭配norm-conserving與ultrasoft贗勢以模擬電子與離子之間的交互作用，計算得到Cij數值，作為擬合分析的初始模型。經由逐步迭代優化擬合，使殘差最小化，最終獲得實驗與理論一致的最佳Cij參數組合。

本研究首次透過實驗手段確定單晶CaSnO$_3$之完整彈性常數，並結合理論計算驗證，建立一套可應用於新穎材料力學性質決定的整合研究流程。本成果對於深入理解鈣鈦礦材料的力學行為，並推進地球科學與高性能材料應用領域，具關鍵意義。

Ref.
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中文關鍵詞：鈣鈦礦、CaSnO3、彈性性質、布里淵散射、密度泛函理論（DFT）

利用密集陣列觀測探討玉里斷層之地震振幅空間分布

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本研究旨在探討2022年9月18日台東池上規模Mw 7.2地震所引發之玉里斷層錯動，是否存在地震波振幅的斷層放大效應，藉以評估玉里斷層帶的可能空間分佈及該區域地震災害之潛在風險。研究資料取自2022年11月至12月期間，在玉里斷層帶（玉里國小舊址）及其東西、南北向周邊共設置70台SmartSolo地震儀所記錄之地震波形。分析內容包括各測站所接收到的最大振幅及總能量（定義為震波時間序列振幅平方總和）。為降低遠震與小地震所造成的高雜訊干擾，本研究篩選震央距離陣列50公里內、芮氏規模4.0以上之地震事件進行分析。初步結果顯示，垂直分量振幅較大的區域主要分布於斷層帶西側，並呈現由西向東遞減的趨勢，此結果與地表錯動的空間分佈是否具有對應關係，仍待進一步探討。後續將擴大樣本數，納入規模3.5以上事件，並進一步分析水平分量與三向幾何平均結果，同時比較各測站總能量分佈，藉以釐清振幅異常是否主要源自場址效應，或與斷層放大作用有關。本研究期望釐清玉里斷層周邊地震動特性的空間分佈，作為未來地震災害潛勢評估之參考依據。

中文關鍵詞：斷層放大效應、玉里斷層、密集陣列觀測

利用同步輻射X射線吸收光譜探討礦化反應機制

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全球暖化的問題日趨嚴峻，因此減少大氣中二氧化碳濃度至關重要；二氧化碳的地質封存被認為是一門具有龐大發展潛力的一種封存技術，常見的地質封存包含構造封存、溶解封存等，將二氧化碳灌注到目標地層中並依地層壓力、溫度、礦物成分等形成不同封存型態；其中礦化封存會使岩石中的陽離子與二氧化碳溶於水形成的碳酸根離子產生反應，形成二次相礦物並沉澱，以達到其封存的目的。

本研究利用同步輻射X射線吸收光譜技術(X-ray absorption spectroscopy, XAS)探討二氧化碳與去離子水在不同環境條件下與富含鐵鎂質類岩石發生礦化反應時的化學行為。為模擬現地灌注中的不同壓力下的反應條件，研究中設計並建構一套可允許調控壓力的三相混合流動反應裝置，以模擬在現地情形下鐵鎂質岩石—二氧化碳-水三相共存的反應環境，並針對反應過程中水溶液中鐵離子的濃度與物質形態變化進行分析，藉以推測礦物溶解、離子置換及二次礦物生成等反應機制。

在原位(in-situ)實驗中透過XAS技術測量水中鐵離子的化學態，並使用感應耦合電漿光學發射光譜儀量測溶液中鐵離子濃度，結合化學計量分析與濃度計算等水化學方法，綜合探討不同壓力條件下鐵鎂質岩石與二氧化碳水溶液反應所引發之離子置換與二次礦物沉澱現象，並推算其在不同壓力下的封存潛力，將有助於評估礦化封存的穩定性與找到礦化封存的關鍵因子。

中文關鍵詞：礦化封存、原位反應、吸收光譜

恆春西台地的四溝層頂部礫岩來源探討

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恆春地區四溝層的成因及其沉積物來源，對理解南台灣的地質演化歷程具有關鍵意義。四溝層分布於恆春半島西側台地，主要由砂頁岩與礫岩組成。其中上部的礫岩層，由於礫石來源未明，限制了對該地區構造抬升與沉積環境變遷的重建。若能釐清其物源資訊，將有助於推測恆春西台地的抬升時序，並進一步釐清與鄰近地層之間的地質關係。

本研究旨在探討四溝層頂部礫岩的物源組成，透過岩石薄片觀察，對礫石的岩性進行分類與比對。研究樣本採集自恆春西台地四溝地區之露頭，樣品經切割製作成薄片後，以偏光顯微鏡觀察礫石的礦物組成與岩性特徵，並與鄰近地區石門礫岩、墾丁層及里龍山層的礫岩樣本進行初步對照。初步結果顯示，四溝層礫石主要為火成岩（輝綠岩）及沉積岩（石英砂岩），其中部分樣本與石門礫岩及墾丁層具有相似特徵，顯示其可能源自這些地層的再搬運沉積物。整體而言，本研究提供了恆春西台地礫岩初步的物源資訊，不僅有助於建立恆春地區地層間的時空關聯，也可作為未來探討造山帶邊緣沉積作用與構造演化的重要基礎資料。

中文關鍵詞：恆春西台地、四溝層、物源分析

氣候與人為活動因子對逕流變化之歸因分析：以雲林地區為例

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氣候變化及人類活動不僅改變了全球環境，還對水文環境與作為可用水量代表之逕流量造成影響。雲林地區需大量農業、畜牧業和工業用水，因此有必要探討該地區徑流變化的原因，這對評估水資源可用性和管理至關重要。本研究首先評估1960年至2023年間雲林地區逕流量時間序列的趨勢與轉折點，以區分前期與後期。另外，本研究基於Budyko理論方程式，評估逕流量對於降雨、潛勢蒸發散以及流域特徵參數的彈性係數，最後量化氣候因子與人類活動造成逕流變化相對貢獻。時間序列分析結果顯示，過去60年來，逕流量以2 mm/year的速率呈現上升趨勢，轉折點出現在2004年。後期(2005年至2023年)與前期(1960年至2003年)平均年逕流量分別為338 mm/year與530 mm/year，增加高達56%。彈性係數顯示，每增加1%降雨，逕流量就會增加4%；而每增加1%潛勢蒸發散，則會降低1.3%逕流量，代表人類活動因子的流域特徵參數，每增加1%特徵參數，則會降低0.9%逕流量，顯示逕流以降雨量變化的反應最大。最後，歸因分析結果顯示，氣候因子對逕流變化的相對貢獻為49.2%，而人為活動則相對貢獻50.8%，兩者對逕流變化均有重要影響。本研究通過分析雲林地區逕流變化的趨勢與原因，為該地區水資源的永續發展規劃提供了有價值的參考。

中文關鍵詞：逕流變化、轉折點、Budyko理論、雲林地區

2024年4月3日花蓮 Mw 7.32地震近場地震波特性

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本研究旨在探討2024年4月3日發生之規模Mw 7.32花蓮地震於花蓮區域及MiDAS（花蓮米崙斷層科學鑽探計畫）測站所觀測到的近場地震波特性，重點包括震源破裂歷程、地表永久位移以及旋轉運動的分析。該地震在MiDAS測站造成約30公分的垂直永久位移，並於旋轉地震儀中記錄到目前全球最大的永久旋轉量，為地震旋轉特性研究提供珍貴資料。地震產生旋轉運動的原因，長期以來存在爭議，可能源於場址效應或複雜震源機制。本研究結合中央氣象署地震測報中心、中央研究院地球科學研究所及MiDAS所設置之寬頻、強震與旋轉地震儀波形資料，並搭配台灣速度模型平台（TVM）提供的速度模型，運用頻率－波數（FK）法模擬震後60秒內的地震波場。震源模擬部分，參考李憲忠老師針對此次地震破裂區域與破裂時序的初步分析，進一步探討複雜斷層系統對地震動的影響。研究核心聚焦於MiDAS測站所設置於米崙臺地西北方之地表寬頻與旋轉地震儀，因其位於震央至最大破裂區域的破裂路徑上，提供研究此次地震近場六分量波形的重要觀測依據。

中文關鍵詞：0403花蓮地震、近場地震波、頻率－波數（FK）法、MiDAS

臺灣的岩礦標本之科學文化價值及保存

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臺灣自大航海時代即有許多礦物資源受到矚目，然而相關產業則到清末的煤業、砂金、硫磺等，才開始有規模的發展。並於日治時期的現代化工業發展需求下，大量地質調查及岩礦資源探勘，將地質資源開發及臺灣地質學推進至重要紀元。在這段歷程中有些礦物資源短暫出現，有些則發展成重要工業基石，造就經濟活動及城鎮，或成為重要的原物料、建築、及人文聚落發展基礎。如此歷史脈絡多量談述於臺灣歷史發展的文書中，然而相對於文字，身為「物證」或基石的岩礦標本則相對少見於各博物館或教育陳列中，與相對應的歷史、產業、以及人文一起保存，論述其基礎及重要性。開發過程中所發現的礦物及岩石標本，也往往疏漏於收藏或管理，最後於時間中消散甚至消失，也未見各界持續有系統採集保存，甚為可惜。如今除了礦物學研究之外，許多涉及礦物資源的地方歷史脈絡考究，甚至古蹟建物原物料修復的需求，缺乏有系統性考究或保存的許多臺灣岩礦標本，成為不容易取得的研究材料。礦物標本除了地質科學保存意義外，已然同時肩負了文化資產的背景。因此標本保存有限不僅於科學研究上，原始材料保存有了空窗之外，於相關的產業與文資考究產生諸多不便。

透過考究臺灣最早的礦物學紀錄清單「臺灣產鑛物雜說」，並論述其現況與標本出產狀態，建請學術或博物館單位持續有系統的保存重要岩礦資產，及討論許多臺灣重要礦物露頭產地的保育與未來面向。為地質科學、以及文化資產保存教育提供堅固的基石，並加強論述地質材料與人文歷史之間交互的關聯性。

中文關鍵詞：礦物科學、岩石礦物標本、文化資產、地質遺產、礦業遺產

從InSAR與GNSS觀測探討2016至2021年間黃石火山的地表變形

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黃石火山位於美國懷俄明州西北部，過去總共經歷三次大規模噴發，最近一次的噴發約為64萬年前，形成現今的黃石破火山口（Yellowstone caldera），及位於其內部東北方的Sour Creek resurgent dome（SC）和西南方的Mallard Lake resurgent dome（ML），此外還有火山口內部超過1萬個地熱特徵及500多個間歇泉。過去大地測量紀錄顯示caldera地表會因底下的岩漿及熱液活動造成抬升或沉降現象，例如首次透過InSAR技術發現1996年破火山口北邊外的Norris Geyser Basin（NGB）有抬升情形，並且該處的地表垂直變形與破火山口內部相反。變形模型結果顯示，當破火山口大部分區域正在下沉時，岩漿或熱液會在破火山口北方累積，導致NGB持續抬升，這種長期地表變化趨勢可能與底下岩漿活動有關，而短期暫態地表變化如2013年NGB的水熱爆炸事件，則與熱液流體運動有關，並有觸發群震的可能。本研究使用InSAR時間序列及GNSS觀測數據監測2016年至2021年黃石火山的地表變形，發現在這段期間破火山口年均下沉速率約2至3公分，NGB地區則於2016至2019年呈現抬升現象，年均抬升速率約2公分，然而 2019至2021年進入下沉階段，年均下沉速率約1公分。另外，我們首次發現NGB西側的P711測站於2016至2021年間觀測到地表在垂直方向有持續抬升，並伴隨向西的水平運動。InSAR時間序列結果顯示NGB抬升區域有沿著黃石公園內的斷層帶擴散趨勢，並且在2017至2018年Norris-Hebgen斷層帶發生群震。前人研究結果曾透過Vp/Vs的比值（約1.5）顯示群震發生與流體運動有關，而711測站附近的異常抬升區域位於凝灰岩層（Lava Creek Tuff, LCT），為高孔隙度及低地震波速度異常帶，當孔隙壓力增加可能導致地表隆起。因此，P711測站附近異常抬升，很可能是流體從NGB向西沿著斷層帶進入凝灰岩層所引發的地表變形。這些研究結果突顯了大地測量在理解流體遷移與地震活動中的重要性，為火山災害評估提供了寶貴的見解。

中文關鍵詞：黃石火山、地表變形、熱液活動、InSAR、GNSS

結合文史田野調查再探1935年新竹台中大地震的致災因素及地震文化資產保存

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1935年4月21日上午6時2分發生的新竹台中地震，迄今仍是台灣有史以來傷亡最慘重的單一地震事件。根據《昭和十年臺灣震災誌》調查報告顯示，台中州的「死亡人數/全倒戶數」為36%，新竹州則為11%，極大的差距被解釋為兩行政區居民的族群差異所致。然而，本研究進一步採用《昭和十年臺灣震災誌》調查報告中的大字行政區探究更細緻的災情分布，並運用田野調查方法深入1935年災情慘重各聚落重新調查，發現大字「死亡人數/全倒戶數」高低並不符合族群分布差異，而是斷層破裂位置、聚落型態、產業分布、宗教活動等多項因素的綜合結果，過往長期的認知需被修正。雖90年前的建築樣式（以不耐震的土角厝為主）與現代不可同日而語，然而若以更細緻的聚落（大字）分布重新分析傷亡與建築災損的極端差異分布，歸納出更接近真相的線索與詮釋，裨利社會大眾以更合理的認知面對下一場大地震。本研究也在文史田野調查過程中，與各地社區居民交流合作，彙整與1935年新竹台中地震相關、尚待保存的各類地震文化資產；並透過台中市文山社區大學舉辦「紀念1935年新竹台中大地震走讀工作坊」、牛罵頭文化協進會舉辦「1935年大地震清水數位走讀實境解謎」等多元具體行動，把現代地震防災認知落實到社會大眾。

中文關鍵詞：1935年新竹台中地震、地震防災、田野調查、地方文史、文化資產保存

利用福爾摩沙陣列探討臺北都會區之微震特性

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Microseism(一般譯為微震)泛指長週期、能量分佈集中於0.05 – 0.5 Hz的訊號，生成機制被認為與浪高，氣壓、風速、潮位和颱風等海洋學、氣象學資料有高度相關(Pradhan et al., 2022; Ferretti et al., 2013; Chen et al., 2011; Lin et al., 2022)。本研究利用114個福爾摩沙陣列（Formosa Array）的測站，分析2019整年微震的時空特徵，探討大台北都會區各測站高度相似的微震時間趨勢，並透過對比各項海洋氣象參數，了解微震之生成機制。大台北地區0.25 – 1 Hz頻段，微震在大多數的測站具同步特徵，並呈現9-15天的週期性。透過滑動窗口交相關係數分析和格蘭傑因果關係統計測試(Granger causality test)，我們發現與振幅之週期行為可能受控於當地氣溫、氣壓等參數。除此之外，北台灣西北海岸、蘭陽平原海岸具最高振幅，其空間對應較平緩的海底地形或相反方向的海流。這些結果說明大氣和海洋現象與海底地形的耦合在微震特性扮演重要角色。

中文關鍵詞：微震、噪聲地震學、福爾摩沙陣列、格蘭傑因果關係測試

A Comparative Analysis of the (ML 6.8; Mw 7.3) November 14, 1986, and (ML 7.1; Mw 7.4) April 2, 2024, Hualien, Taiwan earthquakes: Insights into Seismic Characteristics and Regional Impact

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The November 14, 1986 (ML 6.8; Mw 7.3) and April 2, 2024 (ML 7.1; Mw 7.4) Hualien earthquakes underscore the seismic hazards posed by offshore fault structures near northeastern Taiwan. Despite occurring nearly four decades apart, both events caused significant damage in Taipei, over 120 km from their epicenters. The 1986 earthquake, recorded with limited instrumental coverage, was attributed to an east-dipping fault in earlier study.However, due to the sparse seismic network at the time, uncertainties remained regarding its precise rupture characteristics. In contrast, the 2024 event (Mw 7.4)—Taiwan's largest earthquake since the 1999 Chi-Chi earthquake—was captured by a modern, high-density seismic network. This allowed for precise relocation and detailed rupture analysis. Advanced joint sourceinversion and strong-motion comparisons revealed that the 2024 earthquake involved a complex rupture on both east- and west-dipping fault planes, significantly influencing ground motion distribution and damage patterns. We leverage advanced analytical techniques from the 2024 earthquake to re-examine the 1986 event, aiming to better understand their source characteristics. While differences in location introduce uncertainties, primarily due to the sparse station coverage in 1986, these two earthquakes share similar focal mechanisms. Comparative analysis of GDSN (Global Digital Seismographic Network) in 1986 and IRIS (Incorporated Research Institutions for Seismology) in 2024 stations recordings for both earthquakes reveals high waveform similarity in long-period signals (>1 sec). Additionally, when comparing velocity records from local strong-motion stations, the 1986 earthquake's data from SMART1-C00 (16-bit, 0.1–50 Hz bandwidth) aligns closely with the modern 24-bit digital recordings (TSMIP-E026) from 2024. The similarity in teleseismiclong-period signals, and velocity records from local strong motion stations suggest that both events likely originated from similar seismogenic mechanisms. Further spectral analysis of the two earthquakes in Hualien and the Taipei Basin shows higher ground motion in the southwestern Taipei Basin, reached comparable spectral levels in both events, correlating with significant structural damage. The enhanced building codes implemented after 1999 helped mitigate the impact of the 2024 event, yet the persistence of strong shaking highlights ongoing vulnerabilities. The remarkable similarity in waveforms and spectral characteristics between the 1986 and 2024 Hualien earthquakes suggests that these events share not only comparable focal mechanisms and magnitudes but also a common seismogenic process. However, discrepancies in the hypocenter determination of the 1986 earthquake, compounded by limited instrumental responses during the 1986 event, underscore the challenges in accurately associating the rupture processes of the 1986 and 2024 Hualien earthquakes. Our study emphasize the necessity for in-depth insights into the seismogenic structures of Taiwan's offshore faults and their potential impacts on metropolitan regions. These findings highlight the critical need for enhanced offshore fault characterization and improved seismic hazard assessments to mitigate risks to urban centers like Taipei.

Keywords:1986 Hualien earthquake , Strong ground motion, Source model

沉積岩地熱場址地下溫度估算：以台南關子嶺溫泉為例

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台南關子嶺與嘉義中崙地區的地下地層主要由沉積岩構成，岩性多為泥質砂岩與泥岩。此區淺於三公里的地溫梯度可達40-50℃/km，具沉積岩型地熱系統的潛力。大地電磁法透過天然電磁場信號的測量與頻譜分析，推算出地層的三維電阻率，對溫度與液體含量具高度敏感性，常作為地熱探勘的重要工具。然而，過去地物資料的解釋著重探討熱源、水源和儲水裂隙等特性，地下溫度除了溫泉和油氣探勘井直接測量溫度外，對於廣泛的深部溫度場則了解有限。加上電阻率降低的成因主要來自高溫、鹽水或泥質含量影響，增加獨立區分溫度貢獻的難度。

本研究藉由分析關子嶺地區的井下溫度數據與大地電磁法（Magnetotellurics, MT）三維資料，初步探討地下溫度與電阻率之關係，並評估地層的溫度狀況。由於研究區域主要岩性為泥質砂岩，本研究使用探討泥質對電阻率貢獻的 Simandoux 模型與 Dual-water 模型（DW 模型）。前者廣泛應用於井測解釋，但缺乏詳細的物理機制基礎；後者基於黏土礦物之電雙層理論，建立更為完整的電阻率推算模型。本研究使用井下資料之孔隙率、地下水導電度、和水飽和度等資料，利用兩種方法推算地層的溫度分佈，並與井底溫度進行比對以比較其準確性。

研究結果顯示，Simandoux 模型在深層地層的模擬溫度與井底溫度相近，但於淺層表現不佳，地溫梯度結果顯示過高；而 DW 模型在深淺層的地溫梯度與井底地溫梯度相近，估算地溫梯度約每公里40-50攝氏。本研究初步推測兩模型的理論基礎Simandoux 模型視泥質為穩定導電體，與泥體積分率有關，對溫度變化反應有限；DW 模型則認為導電性主要來自附著於黏土礦物表面的結合水，與表面積有關且對溫度變化相對敏感。此外，研究區域以「分散型泥質」為主，相較於層狀分佈更不適用 Simandoux模型，可能也是導致模擬結果差異的主因之一。

中文關鍵詞：關子嶺地熱、地溫估算、Simandoux模型、Dual-water模型

非彈性應變回復法現地應力評估的統計分析與精進

蔡維倫[1]、葉恩肇[1]

(1)國立臺灣師範大學地球科學系

隨著科技日新月異且與時俱進、及經濟迅速發展的環境下，為了提升生活水平，天然資源與能源開採、工程開發和廢棄物處置等各項需求也日與俱增。對於這些發展的促使與推動下，地下開挖工程逐步普遍，也因此現地應力的量測及資訊趨於重要。現地應力量測有諸多方法，如套鑽法、水力破裂和非彈性應變回復法等。其中以非彈性應變回復法(Anelastic Strain Recovery，ASR)為目前成本耗費較低與效率較高的現地應力測量方法(孫東生等人，2014)。ASR法是以鑽井獲取地下深處岩石，藉由應力解壓後所產生的應變回復進以推算三維現地應力方向和規模的方法。

前人以非彈性應變回復法來進行應力場的規模回推，解析方式是使用18個黏貼於岩芯的應變計測量9個方向的回復正應變規模，以程式重建三維應變張量，進行三維主應變場的演算，轉換成主應力方向與規模。但得到的結果只有一組平均數值，且並未分析各方向與規模的偏差量，以致無法說明數據的可信度供工程單位參考使用。本研究進行原程式的改進，將原本9個方向應變數據改以6個獨立方向為一組單位，並於每個獨立方向使用4個應變計進行量測，再以數據利用最小平方法與奇異值分解法進行運算，之後以共變異數進行機率與統計的計算，以數值的變數變化程度來和期望值進行分析比較。

實驗樣本取於臺東南橫大崙溪，深度140米之片岩樣本。ASR實驗黏貼24隻應變計數據初步分析結果顯示為非典型安德森斷層應力場形式。最大、次大和最小主應變之位態分別為141.14°/45.79°E、36.22°/14.05°E和293.74°/40.81°W，水平最大應力的擠壓方向為西北-東南向，主應力由大到小分別為3.66、2.22和2.06 MPa。葉理傾向和傾角分別為296.18°和65.31°，葉理面的法向量與三軸主應變相距較遠，推測本樣本可能沒受到葉理面力學異相性的影響。

後續將得到的數據結果進行統計與總結，使ASR實驗應力精度的可信度增加。

中文關鍵詞：非彈性應變回復法、現地應力、地質工程

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中文關鍵詞：非彈性應變回復法、現地應力、地質工程

馬祖地區現代與熾坪隴遺址螺類殼體穩定同位素紀錄所反映之全新世中晚期古環境

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本研究分析馬祖地區南竿與東莒22個海水樣品、南竿及東莒各3個現生螺類樣本及東莒14件熾坪隴遺址（距今約6000~4000年前）遺址螺類殼體之穩定同位素成分，重建馬祖地區全新世中晚期古環境。

南竿地區海水樣品平均氫、氧同位素數值分別為-2.2 ± 2.5‰和-0.8 ± 0.3‰（平均值 ± 1σ；N=74；V-SMOW）；東莒地區水樣品平均氫、氧同位素數值分別為-1.7 ± 1.6‰和-0.8 ± 0.2‰（平均值 ± 1σ；N=2）。除了東莒水體的氫同位素數值比同一天(不同採樣時間)南竿水體的氫同位素數值分別大4.7‰及2.7‰，東莒水體的鹽度、溫度及氧同位素數值，與同一日南竿水體的相對應參數皆無顯著差異，且東莒水體的氫氧同位素數值與南竿水體之長期氫氧同位素數值無顯著差異，故可以南竿水體之長期現代觀測紀錄做為現代水體環境資料的參考。根據本研究分析之同位素數值和雨量、鹽度等數據，顯示水體氧同位素數值變化受到淡水與海水混合影響。

現生東莒螺類殼體平均碳、氧同位素數值，分別為-0.3 ± 0.8‰和-1.6 ± 0.6‰（± 1σ；N=233；V-PDB）；現生南竿螺類殼體平均碳、氧同位素數值，分別為-1.0 ± 1.1‰和-1.5 ± 0.5‰（± 1σ；N=119）。馬祖東莒熾坪隴遺址P1坑螺類殼體平均碳、氧同位素數值，分別為1.3 ± 0.4‰和-1.6 ± 0.5‰（± 1σ；N=770）；熾坪隴遺址P2坑螺類殼體平均碳、氧同位素數值分別為0.9 ± 0.7‰和-1.6 ± 0.5‰（± 1σ；N=714）。熾坪隴遺址P1坑與P2坑之遺址螺類殼體平均碳同位素數值有0.4‰的差異，氧同位素平均數值則無差異。遺址螺類殼體的平均氧同位素數值，與現生螺類殼體的平均氧同位素數值差距小於0.1‰，顯示當時海水溫度可能已跟現代相近。

遺址螺類殼體的平均碳同位素數值，比東莒現生螺類殼體的平均碳同位素數值大約1.4‰，比南竿現生螺類殼體平均碳同位素數值大約2.1‰，可能反映出6000~4000年前馬祖地區水體的基礎生產力較高，也可能是混和水體中溶解性無機碳之碳同位素成分的變化。

現生與遺址螺類殼體之氧同位素數值均呈現隨個體發生時之季節性振盪，根據最完整的12個遺址螺類樣本，距今約6000~4000年前熾坪隴遺址人類採收螺類季節之分布分別為春(N = 2)、夏（N = 3）、秋（N = 6）和冬（N = 1），採收季節可能較集中於秋季。

中文關鍵詞：穩定同位素、瘤岩螺、馬祖東莒熾坪隴遺址、古環境

結合地震波速與重力數據的順序反演法於台灣中部之地下構造研究

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台灣中部地質構造複雜且活動頻繁，涵蓋褶皺、多條斷層、構造盆地、高山變質帶與深部構造的不確定性，為造山作用與地殼變形的重要表現區。中央山脈與西部麓山帶之間的縫合帶在地體構造的接合與差異對地下物性分布造成顯著影響。為探討該區地殼構造與潛在構造活動，本研究針對台灣中部地區進行0至50公里深度範圍、5km網格的三維速度構造建模以探討地殼變化，將地震與重力資料經由各自獨立的反演算法的兩物理量採順序逆推法(Sequential Inversion)結合，首先藉由雙差分層析成像法(tomoDD)得一速度模型，再使用經驗公式(Brocher, 2005)將速度轉換為密度模型，將重力資料加入以進行重力逆推，即完成一次順序逆推，共計兩次逆推流程外加一次的走時反演。0.05°和0.1°網格的棋盤格測試結果皆顯示模型從7km至50km有良好解析；淺層深度段的解析較不足，結合重力逆推後能使模型更靠近重力觀測的結果，以彌補淺層地震波線交集過少的問題。從1至6公里的剩餘重力異常圖可看出，五條斷層的錯動在五個深度段各自反映其重力效應。從布蓋重力異常分布及淺層速度模型得知，在西部地區呈-50 ~ -60 mGal的負異常和明顯的低速特徵，對應的是濁水溪沖積扇和埔里盆地基盤以上的厚層積物，反映大範圍構造盆地之重力效應，東部高異常則是中央山脈變質岩基底；Vp、Vs速度構造在0至10公里的深度段呈西低東高，經15公里深的過渡帶後，在20公里深後呈現西高東西。從A-A'測線的垂直剖面在速度構造與速度擾動皆發現明顯的滑脫面直至中央山脈下方，莫荷面的深度隨著山根深度變深，並在東部的隱沒帶又再度變淺。往南的數條測線的速度構造和擾動有類似的趨勢與地震分布，在埔里盆地下方10至30公里深有明顯強烈的構造活動，使得7.5(km/s)等值線開始不連續。為更了解造山帶內部構造變化、期望在中部地區能建構更具高解析度、精細且結合多重物理特性的三維速度模型，為後續地震災害評估與地體構造研究提供重要參考依據。

中文關鍵詞：順序反演法、三維速度模型、地體構造、滑脫面

Extending the Reach of Marine Geophysics: Nearshore Ocean Monitoring and Active Source Applications with Distributed Acoustic Sensing

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Distributed Acoustic Sensing (DAS) offers a transformative approach to nearshore ocean monitoring by converting existing fiber-optic cables into dense seismic arrays. In this study, we demonstrate the effectiveness of DAS in capturing ocean wave dynamics and current velocities using a 20-km submarine dark fiber. By applying frequency–wavenumber (FK) analysis, we transform DAS recordings into high-resolution spatiotemporal observations, enabling in-situ estimation of current velocity and water depth through dispersion curve fitting with theoretical ocean wave propagation models. The DAS-derived velocities show strong agreement with co-located tide gauge records, underscoring the method's reliability in resolving dynamic oceanographic processes. We further present a comparative analysis between a 1-km self-deployed DAS array and Ocean Bottom Node (OBN) recordings in response to both natural and controlled underwater acoustic sources. The DAS arrays not only reproduce wavefield characteristics consistent with OBN results but also provide superior spatial resolution, particularly beneficial in shallow water regions inaccessible to survey vessels. This success demonstrates the feasibility of DAS arrays for marine active source experiments in nearshore settings. In both cable configurations, DAS recordings clearly delineate the transition from land to ocean environments. These results collectively establish DAS as a powerful tool for investigating coastal interfaces, tracking wave-induced motions, and extending the capabilities of marine geophysical studies into previously inaccessible environments.

Keywords:Distributed Acoustic Sensing, ocean wave dynamics, frequency–wavenumber analysis, active source experiments

生物炭的環境穩定性有利於增匯減排對碳封存及氣候變遷有積極影響

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生物炭（Black Carbon or Biochar, BC）是生物質或者石化燃料不完全燃燒產生的顆粒有機碳。生物炭最終可沉降至土壤與水體及沉積物，進入長期碳循環，其環境穩定性與降解機制亟需機理性的理解及研究，以便更準確的評估其對碳循環及封存的貢獻及效能。

本研究透過X射線吸收近邊緣光譜（XANES）與高分辨飛行時間質譜（TOF-MS）等先進分析技術，探討不同生物質來源在不同熱裂解條件下形成的生物炭，其分子結構變化、降解產物與環境穩定性。**結果發現生物炭熱解後表面的半揮發性有機物（SVOCs）**，其中V型木質素衍生物（MW166＆168、$C_9H_{10}O_3$＆$C_8H_8O_4$）可作為關鍵生物標記，用以追蹤生物炭的分解途徑及在環境中的化學性質改變。此外，研究顯示高溫（700°C）形成的生物炭比低溫（300–500°C）生物炭更具有化學穩定性，在厭氧條件降解能維持較長時間的碳封存。

另一方面，結果揭示在土壤中，生物炭表面隨著埋藏時間，其表面官能基會增加，並且可與礦物質產生化學鍵結，加上物理性的保護，將極大增強其環境長期穩定性，及其長期碳封存潛力。這項研究從機理上理解生物炭的長期穩定性，對運用生物炭及其管理增進碳封存及土壤碳匯具有重要意義，顯示生物炭管理可成為增匯減排的重要策略。

中文關鍵詞：生物炭、生物質、氣候變遷、碳封存、半揮發性有機物

陣列分析近震源地動紀錄探討2023年9月屏東化學品爆炸事件

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本研究綜整台灣即時地震網資料，以地震學陣列分析方法確認2023年9月22日屏東工廠化學品爆炸發生的地點、時間與當量並用以追蹤、核實後續之再爆事件。研究顯示台灣地震監測網資料適用於探究屏東爆炸歷程，所獲事證提供朔源事件發展過程並可為爆炸事件爭議的鑑識調查提供重要佐證。為達成通報與快速反應台灣重大爆炸事件之目標，本研究建議簡易升級地震網功能，透過增建少量次聲波測站及優化地震網資料的處理流程，台灣地震網或可對未來再發生的重大爆炸事件提供即時、精確的訊息，支援救災並緩解目前災害爆炸事件尚無明確公部門進行監測、科學數據收集及快速回應大眾的需求。

中文關鍵詞：陣列分析、化學品爆炸、當量預估、次聲波、屏東

Aseismic slip and seismic swarms leading up to the 2024 M7.3 Hualien earthquake

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Understanding the role of aseismic slip in earthquake cycles is essential for assessing seismic hazards and short-term forecasting. Eastern Taiwan's double-vergence suture zone, where the Philippine Sea Plate subducts beneath the Eurasian Plate, experiences frequent M ≥ 6 earthquakes and widespread aseismic slip, making it an ideal natural setting to study earthquake triggering processes. Using a 24-year catalog of repeating earthquake sequences (RESs) and earthquake swarms, we investigated aseismic deformation leading up to the April 3, 2024 Mw7.3 Hualien earthquake. We find that nine out of ten swarms in the epicentral area, northern Longitudinal Valley, were accompanied by increasing aseismic slip rates, as revealed by RESs on the west-dipping Central Range Fault (CRF). A notable aseismic slip episode in 2021, indicated by GNSS signals, the accelerated RES-derived slip rate, and a four-month-long swarm sequence with high diffusivity (~5.2 m^2/s), suggests joint contributions from over-pressured fluids and deep fault creep. This episode was followed by a cluster of M6+ events and a later phase of slightly accelerating seismic and aseismic activity beginning in 2023. Coulomb stress modeling indicates that these aseismic slip events and transient fluid flow increased stress on the CRF, potentially promoting the 2024 mainshock. Our results provide rare evidence for aseismic-slip-induced stress triggering of a major earthquake and highlight the importance of integrating aseismic processes into earthquake hazard models for collisional fault systems.

Keywords:swarm, repeating earthquake, slow slip, GNSS, precursory

Imaging the Upper Mantle Beneath the Oldest Pacific Seafloor With Finite-Frequency Tomography: Insights From Oldest-1 and Oldest-2

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The oldest seafloor on Earth preserves the birth record of the Pacific Plate, making it key to understanding oceanic lithosphere evolution. Its remote location, however, has hindered detailed seismic investigations. The **Oldest-1** experiment, part of the Pacific Array project, deployed **ocean-bottom seismometers (OBSs)** in the region from 2018 to 2019, revealing features of Pacific Plate evolution. Building on these results, the **Oldest-2** experiment extended coverage to a younger section of the seafloor (160–170 Ma) farther west, with OBS deployments from 2022 to 2023. We combine teleseismic P-wave data from both experiments to develop an expanded 3D P-wave velocity model of the upper mantle beneath this region.

Teleseismic earthquakes with magnitudes > 5.5 and epicentral distances between 30° and 90° are selected for relative P-wave travel-time analysis. Vertical-component seismograms are pre-processed by removing trend, mean, tilt noise, and instrument response, then band-pass filtered into three frequency bands: 8–16 s, 12–24 s, and 16–32 s. Manual inspection identified over 200 events with high signal-to-noise ratios for further analysis. We employ *Aimbat*, an interactive Python package, to measure relative travel-time residuals between stations using iterative cross-correlation and stack (**ICCS**) and multi-channel cross-correlation (**MCCC**) algorithms. The residuals and their finite-frequency sensitivity kernels are integrated into a multi-scale tomographic inversion. This approach improves both lateral and vertical resolution of the upper mantle beneath the oldest seafloor, offering new insights into the dynamic evolution of the Pacific oceanic lithosphere.

Keywords:Pacific Plate, Oceanic Lithosphere, Ocean-Bottom Seismometers, Finite-Frequency Tomography, Teleseismic P-wave Travel Times

Construction of Horizontal Strain Array from DAS sensor

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Distributed Acoustic Sensing (DAS) technology offers a cost-effective means of deploying thousands of linear strain meters along a fiber-optic cable. To fully capture the strain field, at least three linear strain measurements with different orientations are required at a single site to resolve the horizontal strain tensor. Taking advantage of the surface fiber cable redeployment in the MiDAS (Milun fault Drilling and All-inclusive Sensing) project at the end of 2022, three segments of fiber-optic cable, each 20 meters in length and oriented at 0°, 45°, and 90°, were installed on the surface. This configuration enables the reconstruction of the complete horizontal strain tensor and allows for the transformation of the strain components into a radial-transverse coordinate system. In addition to the DAS array, a co-located 3-component seismometer and a 3-component rotational sensor were installed, yielding a total of 10 independent measurements of the elastic wavefield. In this study, we combine the strain, rotation, and seismic measurements at the same station to evaluate the performance of wave propagation direction and phase velocity of specific wave types.

Keywords:Distributed Acoustic Sensing, Strain tensor, MiDAS , rotation, strain

Investigating the Northern Segment of the Chiayi Blind Fault Using the Seismic Reflection Survey

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The Chiayi blind fault is hypothesized to be north-south-trending, east-dipping thrust at the front of the orogenic belt in the Chiayi region, southwestern Taiwan. Previous studies, based on the seismic profiles south of the Meishan fault and the geomorphic characteristics of the lateritic terrace, suggest that the Chiayi blind fault is truncated by the Meishan fault, resulting in its division into northern and southern segments. Additionally, some researchers propose that the westward thrusting of the Chiayi blind fault contributed to the structure of the Hsiaomei anticline. However, most seismic studies have focused on the southern segment of the Chiayi blind fault, leaving the geometry of the northern segment poorly understood. To address this question, a northwest-southeast reflection seismic survey was conducted in May 2023. The survey site, located north of the Meishan interchange, was conducted based on previous fault interpretations. Seismic data were acquired using a MiniVib source, with signals recorded by 240 geophones (Smartsolo). The total length of the seismic survey line is 4.2km, with a receiver interval of 5m and a shot interval of 15m. As a result, the depth resolution of the seismic profile can extend down to approximately 2.2 seconds (~2.5km), enabling detailed subsurface analysis. The results indicate that the strata tilting westward could be related to the Hsiaomei anticline and the reflection signals between layers remain continuous, with minimal variation in amplitude and frequency. No significant faulting can be identified from the profile, suggesting that the displacement of the northern segment of the Chiayi blind fault may be below a depth of 2.5km.

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Keywords:Chiayi blind fault, Seismic reflection survey, Hsiaomei anticline, Meishan fault

南墨西哥灣 Macuspana 次盆地新生代地層元素分析及其物源意義

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南墨西哥灣東南盆地（Sureste Basin）具有豐富的油氣資源潛力，在其最東緣的 Macuspana 次盆地為典型前陸盆地。在中中新世（約13-11 Ma）發生的恰帕斯造山運動（Chiapaneca Orogeny）導致山脈抬升與剝蝕，大量陸源碎屑物自南向北輸入盆地，構成了次盆地內新生代地層的重要物源之一。其東側邊界的猶加敦平台（Yucatán Platform）為侏羅紀至白堊紀時期所形成的碳酸鹽岩平台，曾受到希克蘇魯伯隕石撞擊事件（Chicxulub impact）影響，形成該區石油系統重要儲集岩的角礫岩層。

本研究聚焦於 Macuspana 次盆地北部一口深度約5750公尺的鑽井，取得6個不同深度的岩屑樣品，並採用微區X射線螢光光譜分析儀（μXRF）與能量散射X射線光譜儀（EDS）進行元素分析。預期藉由主要元素（如 Si、Al、Fe、Ca、K、Na、Mg 等）含量的變化，可探討沉積物的來源與搬運歷程，例如Si與K含量升高可能反應造山帶陸源物質的增加，而Ca含量則可能與猶加敦平台的碳酸鹽岩侵蝕有關。另外透過元素含量的垂直分布變化，可建立不同地層單元的地球化學特徵，以作為地層的區分依據進而改善地層劃分與對比研究的依據，進而提升對區域地層架構與石油系統的認識。

中文關鍵詞：南墨西哥灣、Macuspana次盆地、元素分析、沉積物來源

天然氣資產投資價值條件分析-以澳洲西北海域為例

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澳洲西北海域為澳洲主要的油氣產區，且多以生產天然氣為主，亦為目前我國油氣探勘的核心地區。西北海域主要包含五大盆地，包含Bonaparte Basin、Browse Basin、Roebuck Basin、North Carnarvon Basin與South Carnarvon Basin。過去十多年，台灣中油對於澳洲西北海域的主要盆地的油氣潛能皆曾有相關研究，並有成功生產的經驗，例如：生產中的Ichthys與Prelude礦區。此研究希望根據澳洲西北海域氣田之大數據資料進行分析，並評分及排序，提供未來在此區域礦區投資之參考。

本計畫蒐集國際能源顧問公司提供之五個主要盆地的各天然氣資產相關資料，並參考各大能源相關組織開放資料與世界各大油公司投資油氣探勘所評估之資料建立一評分機制，最後，從五大盆地中篩選出適合投資之天然氣資產。本研究與我國的探勘核心地區緊密連結，同時配合政府的新南向政策，成果可提供為後續研究之基礎資訊，更可作為未來在澳洲西北海域在投標、讓入，以及氣田併購時的參考依據。

中文關鍵詞：澳洲西北海域、天然氣資產、投資價值分析

地熱探勘階段地質調查作業項目實務探討

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臺灣自1966年於大屯山區開始地熱探勘起，迄今將近60載。因地質背景與地體構造特性之故，臺灣有諸多地區足具地熱能源開發潛勢，目前政府與民間單位皆在不同地區案場執行地熱地質調查工作，瞭解各案場詳細地熱條件，作為後續地熱發電之評估。

美國能源資訊管理局(U.S. Energy Information Administration, EIA)在GeoRePORT(Geothermal Resource Portfolio Optimization and Reporting Technique, 地熱資源評估報告系統)中，依據地熱探勘成熟度，從未探勘階段到生產井試驗階段，分為G1至G5五個階段。臺灣目前之地熱案場，從G1至G5皆有。

本研究透過訪談產業界與學術界，在地熱案場執行過調查工作之專業人士，瞭解實務面上，地熱地質調查階段工作之重點、常遇到的問題或困難，以及試圖解決問題的各種處理方式。

G1階段需就不同地熱源或地熱特性，規劃調查方式，例如火山型地熱或構造型地熱，適用不同調查方式。G2階段執行各調查方法(例如MT、微震、地化等)，並對結果進行數據反演與整合，瞭解地熱儲集層、熱通道、流體狀況等，作為後續鑽井之選址評估。G3階段著重於地熱井之鑽探，包括鑽井規格與設計、鑽探過程各種問題與困難排除、所提取之岩心判釋。並由鑽探結果，瞭解地下地熱地質特性。G4階段著重產能測試之各項井測結果與分析。G5階段著重生產運轉前之各項模擬測試及規劃。

本研究希望藉由收集與彙整各項地熱探勘工作常見之討論與分析，得以協助國內地熱探勘工作常遇到之技術性問題，找到改善的關鍵與方式。

中文關鍵詞：地熱探勘、地質調查、地熱鑽探、產能測試

運用渺子成像術完成高解析度之地層密度剖面圖－桃園石門水庫（24°49’27.5"N, 121°17’9.8"E）

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本研究於桃園石門水庫地區（24°49’27.5"N, 121°17’9.8"E），設置一座主要結構由閃爍體及矽光電倍增管（SiPM）組成的渺子探測器，運用渺子成像術成功製作出台灣首幅高解析度之地層剖面圖。探測器在主要架構上可分為四層，每層由64個切割成5 × 5 × 1.2cm的閃爍體組成，當渺子（muon）通過閃爍體時，渺子的能量使閃爍體產生光子，光子再藉由矽光電倍增管（SiPM）轉換為電信號，最後通過電路將此信號傳送至電腦並記錄下來，最後將統計出的渺子數量除以時間、有效面積、立體角等即可得到渺子通量（flux）。本研究利用上述探測器得到的渺子通量，計算出觀測山體位於探測器探測範圍之密度分佈，成功地製作出一幅涵蓋水平方向約60公尺、深度約10公尺的地層密度剖面圖，並區分出探測區域（桃園石門水庫地區南港層）內砂岩與頁岩段的密度（砂岩段地層密度約為2.5869 g/cm^3；頁岩段地層密度約為1.9284 g/cm^3）。此項成果不僅利用探測結果成功還原真實地層密度構造，更證實了渺子成像術在地質岩層密度掃描上具有高度解析能力。

中文關鍵詞：渺子成像術、密度、桃園石門水庫阿姆坪

大屯火山地質製圖原則探討

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火山產物複雜多變，對比困難，實務上難以建立區域尺度的分層標準。火山地區容易辨識的不連續面對於野外工作者進行地層層序調查或岩體單位劃分來說，具有直觀且實用的價值。然而，火山不整合面多缺乏良好延續性，較難用於遠地層位對比。相較於過去以岩性成分劃分非正式火山岩體單位，現代火山地層學著重火山作用地形演育概念（宋聖榮等，2009、2010、2021；陳文山等，2003、2007），適度應用不整合概念定義火山地層界限（Martí et al., 2018），以搭配火山噴發產物岩相與成分界定岩體單元與層序，如何對應現行地層命名原則規範之合適地層位階（小段-段-層），是火山地層學家或地質製圖工作者的重要課題。本報告以大屯火山群西半部範圍為例，說明地表與地下地質對比對於火山地質製圖之重要性，以及製圖實務上須克服地質紀錄缺失之困難，將影響產製地質圖資之精度與可靠性。

中文關鍵詞：大屯火山、地質製圖、不整合、地形演育

利用井下數據解析Bedout次盆地Caley儲集層沉積環境與地層特徵

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澳洲西北海域長期以來為該國主要油氣產區，近年來仍持續有新發現，顯示該區域具顯著勘探潛力。為進一步理解其地質背景與盆地演化，本研究選取Bedout次盆地為案例，綜合井下電測資料（包含伽馬射線、電阻率及聲波阻抗）、岩屑描述及化學地層學分析（重礦物、主要元素、微量元素及稀土元素），以探討研究區域中主要儲集層的沉積環境及地層特徵。

初步結果顯示，該區主要儲集層Caley砂岩具有特定的礦物組成特徵，例如鋯石和二氧化矽含量顯著增加，而石榴子石和大部分的主要元素及微量元素含量則相對減少。此一現象顯示Hove-Caley不整合面以下的礦物相較穩定，可能代表Caley砂岩曾經歷較長時間的風化與搬運作用，使砂岩成分更為成熟，故足以成為品質優良的儲集層。

本研究透過電測資料、岩屑描述與化學地層數據，嘗試重建目標區域中重要儲集層的沉積環境與地層特徵。後續將整合其他井的資料以獲得更全面的認識。預計此成果可增進對Bedout次盆地演化的理解，並對未來的勘探及開發策略提供重要參考依據。

中文關鍵詞：Bedout次盆地、化學地層、儲集層成熟度、電測

Topographically Informed Regression for InSAR Tropospheric Correction: Taiwan Tropospheric Delay Model

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The differential interferometry synthetic aperture radar (DInSAR) technique is widely applied to geodetic analyses. However, the accuracy of DInSAR measurement is often affected by tropospheric delay of microwaves due to spatial-temporal changes of weather variability. Although they are commonly corrected by using external datasets, such as global numerical weather models (NWMs), these models tend to be less reliable in tropical regions like Taiwan owing to inaccuracies in water vapor estimation.

Taiwan's dense GNSS network enables the development of a localized tropospheric correction model to improve DInSAR applications. To achieve this goal, we compute zenith total delay (ZTD) from over 400 GNSS stations. To address uneven GNSS coverage, we apply the Topographically InformEd Regression (TIER) model, which considers topographic features to interpolate ZTD across the island. The final Taiwan Tropospheric Delay (TTD) model has a 900 m spatial and 5-minute temporal resolution.

We then correct tropospheric effects in 184 DInSAR phase maps from ALOS-2/PALSAR-2 ScanSAR images acquired between January 2016 and April 2022. The results are compared with the corrections made by using ECMWF ERA-5 re-analysis datasets. Our results indicate that after applying the TTD model to tropospheric delays correction, there’s a significant reduction in root mean square error (RMSE) in most cases, showing TTD model's effectiveness. We expect further improvement of the TTD model by incorporating a quadratic or power-law relationship between tropospheric delay and elevation. The operational TTD model will then be made available to all InSAR users working on Taiwan-related geodetic studies.

Keywords:Taiwan Tropospheric Delay Model, Tropospheric Delay Correction, Differential Interferometric Synthetic Aperture Radar (DInSAR)

好景區的機率性油氣可採資源量評估與排序

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國際石油公司除了標購正在生產中的開發油氣田外，面對處於探勘階段的礦區，亦需要評估該礦區各好景區的油氣資源量或蘊藏量，此資源量或蘊藏量數值多寡會直接影響投資活動是否進行，優先挑選哪個好景區進行探勘活動，未來是否繼續探勘、開發或生產等決策。通常在不同探勘階段所能蒐集到的資料類別、特性及資料量也不盡相同。本研究的目標礦區已有清楚的震測解釋成果，但研究區內尚未有一口鑽井，僅在礦區外有探勘井，故本研究以原始埋藏資源量（Original Gas in Place, OGIP）乘以採收率的計算公式為基礎，由地質概念與類比法假設主觀參數，利用震測解釋成果分析客觀參數，結合蒙地卡羅模擬（Monte Carlo Simulation）的模擬統計法，完成各好景區機率性天然氣可採資源量的計算與排序。初步篩選後，續加入雙儲集層的現地因素，及石油探勘成功率分析，提出多重分析角度的好景區可採資源量排序，完成本礦區的綜合彙整分析。本研究所提出的分析與排序方法可做為處於類似探勘階段的好景區資源量評估方法參考。

中文關鍵詞：油氣資源量評估、不確定性分析、好景區

Application of PSInSAR for Landslide Monitoring with Corner Reflector

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The low density of Persistent Scatterers (PS) presents a major challenge in applying Persistent Scatterers Interferometric Synthetic Aperture Radar (PSInSAR) techniques to vegetated areas. This issue not only limits deformation monitoring capabilities but also leads to phase unwrapping errors due to discontinuous coherent pixels in the spatial domain. To address this limitation, corner reflectors have been introduced as effective artificial targets that consistently provide strong, stable radar backscatter. A corner reflector typically consists of three mutually perpendicular flat surfaces, enabling efficient reflection of radar signals back to the satellite. This geometry produces a high-intensity response in SAR imagery and reliable interferometric phase data for precise deformation measurements. Designing an effective corner reflector network requires careful consideration of reflector size, which significantly influences phase quality. Field experiments show that reflectors with inner leg dimensions of 1 to 2 meters are optimal for real-world applications using X- and C-band SAR sensors, delivering millimeter-level deformation accuracy. In this study, a landslide site adjacent to the road to Alishan in Chiayi County was selected as the target for the corner reflector experiment. Four corner reflectors were built and deployed to enhance PSInSAR performance. As a result, these objects perform reliably as artificial PS points, which enable enhanced deformation monitoring in areas where natural PS are insufficient. Seasonal activities in the landslide area are observed from 2020 to 2023, total of 50 mm deformation in the SAR line of sight direction can be confirmed. This result indicates the critical role of corner reflectors in extending PSInSAR capabilities, particularly in vegetation-dense or low-coherence environments.

Keywords:PSInSAR, Landslide, Corner reflector

Stress Test: Earthquake Cycles Under Different Loading Conditions

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The various fault slipping behavior is now observable in nature with high precision. This lead to progress in new physical models. Numerical simulation is the only way to experiment with different physics involved in a full earthquake cycle. And the primary method is boundary-element models that only simulate evolution on the fault plane. The faults are contained in a purely elastic bulk. This greatly simplifies calculations but also creates two main issues. The first one is the ambiguity in applying the stressing rate boundary condition. In this research, we show that different ways of applying stressing on the fault create very different rupture behavior and cycle length, even if the long-term slip rate is comparable. Recognizing this is crucial when interpreting earthquake recurrence using such simulations. The choice of stressing method arises from the second issue: without special treatments, stress accumulate indefinitely in an elastic medium, when in reality the material will yield or crack. The "backslip" method that uses a fixed slip rate was created in this light to cancel the accumulating stress. However, it creates an unnatural stressing history and slip profile. Therefore, we propose that we should instead apply a fixed stressing rate that reflects the tectonic stressing rate. We use a simple viscoelastic relaxation to reduce stress concentration, allowing simulations of many earthquake cycles on non-planar faults. With the relaxation, we analytically obtain the steady-state stress anomaly. We use the relation to estimate the viscosity needed to create a persistent stress barrier that produces partial ruptures and complex sequences in a simple fault system.

Keywords:SEAS, earthquake cycle, simulation, fault system, fault interaction

Kinematic and Dynamic Source Rupture Scenarios of a Potential Megathrust Earthquake along the Southernmost Ryukyu Subduction Zone

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The kinematic source model is widely used for earthquake simulations due to its simplicity and ease of implementation. In contrast, dynamic source modeling provides a more physically grounded framework for understanding earthquake nucleation, rupture propagation, and arrest. This study focuses on the southernmost Ryukyu subduction zone near northern Taiwan. Interseismic GPS data from northeastern Taiwan indicate a pattern of strain accumulation, suggesting that a future megathrust earthquake in this region could reach magnitude 8.7. We develop dynamic rupture models to assess the seismic hazard of such a potential event, using kinematic rupture scenarios derived from GPS-based inversion. Multiple kinematic scenarios with varying slip distributions are also considered to better constrain the dynamic rupture process. Initial stress conditions and fault friction are explored through trial and error, guided by regional plate coupling and tectonic settings. Dynamic stress fields from the prescribed kinematic slips are analyzed to check consistency with fault mechanics. Ground motion simulations use a 3D spectral-element method, incorporating both dynamic and kinematic models. ShakeMaps and ShakeMovies from these simulations evaluate the spatial impact of ground shaking across Taiwan. Additionally, dispersive tsunami simulations estimate maximum wave heights along the coast based on seafloor displacements from different models. This study provides physically grounded earthquake scenarios that can inform emergency response planning and disaster preparedness in Taiwan.

Keywords:southernmost Ryukyu subduction zone, megathrust earthquake, kinematic source model, dynamic source model, tsunami and shaking simulations

Rayleigh wave phase velocity maps in Eastern Indonesia

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This study investigates Rayleigh wave phase velocity variations beneath East Indonesia over a period of 15-150 s. Using the two-station method, we measured interstation dispersion curves from vertical-component waveforms recorded at 212 stations. We analysed 6458 paths from 3450 teleseismic earthquakes ($M \geq 5.5$, depth ≤ 50 km, epicentral distance 20°-170°). We selected interstation paths and epicenter lying along the same great circle path, with an azimuthal tolerance of 5°. These dispersion curves were then inverted to obtain high-resolution isotropic phase velocity maps.

At short periods (15–50 s), high-velocity anomalies in the Banda Sea and north of the Bird's Head region of Papua, reflect thin oceanic crust, while fast velocities across the Australian Shelf suggest stable cratonic lithosphere. Low velocity anomalies beneath Papua's Central Range, Sulawesi, the Banda Arc, and western Timor indicate thicker crust, active deformation, or mantle wedge melting. The weakening anomaly in East Timor marks a transition from subduction to arc-continent collision. A pronounced low-velocity zone in the Molucca Sea suggests sediment accumulation or slab dehydration in its unique double subduction system. At longer periods (75–150 s), high velocities dominate the southeast, corresponding to subducted slabs beneath Nusa Tenggara and the Banda Arc, while low velocities persist in the northwest, indicating high temperatures or tectonics activity. These variations reflect the region complex tectonics, including subduction, arc-continent collisions, and lithospheric deformation. Future work will include seismic anisotropy and develop a 3-D shear-wave velocity maps

Keywords:lithospheric structure, rayleigh wave, phase velocity, dispersion curve, East Indonesia

Reconstruction of northern Taiwan hydroclimate conditions over last 13.3 cal kyr BP using multiproxy analysis in Tsui-Tsui Valley sediment cores

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To address the climatic data gap in northern Taiwan prior to the late Holocene, a study has been conducted by analyzing two sediment cores from Tsui Tsui Valley, TTV-11 and TTV-17. Radiocarbon dating of these cores provided a robust chronology, covering the period from 13.3 cal kyr BP to the present. To investigate the climatic changes over this time frame, analyses were conducted on diatoms, micro-XRF, carbon isotopes, and carbon (C) and nitrogen (N) concentrations from the sediment cores. The diatom data indicated that water levels were high from 11.1 to 8.8 cal kyr BP, suggesting the lacustrine conditions, which likely outburst due to increased runoff conditions during 8.8 cal kyr BP. Principal Component (PC) Analysis of the micro-XRF records from both cores showed a strong positive correlation between detrital proxy elements (Ti, Fe, K, and Si) and PC2 (PC2 TTV-11 and PC2 TTV-17), indicating higher/ lower runoff and wet/dry climate conditions. The TTV-11 core depicted a transition from wet to dry conditions from 13.3 to 11.0 cal kyr BP, aligning with the Younger Dryas event, and showed a shift to wetter conditions after 11.7 cal kyr BP, with intermittent dry events at 11.0, 10.3, and 8.2 cal kyr BP. In addition, the TTV-17 core indicated wet conditions at 4.5–3.0, 2.0–1.7, 1.2–0.8, and 0.4–0.2 cal kyr BP, with dry periods at 3.0–2.0, 1.7–1.2, and 0.8–0.4 cal kyr BP. The Mn/Fe ratios, inc/coh ratios, C and N contents, and PC2 suggested that organic matter dilution by inorganic (detrital) material during wetter climate conditions. The drier climate conditions occurred between 13.3 and 8.0 cal kyr BP were largely coincided with strong East Asian Winter Monsoon (EAWM) and weak East Asian Summer Monsoon (EASM), which driven by Arctic ice sea expansion and low winter insolation, and dry climate conditions which occurred between 4.5 cal kyr BP to present, were response of negative Atlantic Meridional Overturning Circulation (AMOC) and El Niño-Southern Oscillation. On the other hand, wet climate conditions observed in the current study were the response to strong EASM, a response to La-Niña conditions in the Pacific Ocean, and weak EAWM due to positive AMOC.

Keywords:Taiwan, Climate, EASM-EAWM, Stable Isotopes, Holocene

透地雷達應用於建築基地之地下環境調查

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大樓興建施工前，若能掌握興建場址周圍地下環境狀況，將有利於工程設計與開挖工作之進行，透地雷達為一種非破壞性探測技術，無須破壞目標物與周圍環境即可描繪目標物內部構造，且其應用於地下構造調查之高可靠性，已被列為臺北市建築物施工中維護公共設施管理要點之施工前基地調查方法之一。本公司辦理大樓興建工程，為提高施工效率與安全性，故以透地雷達進行地下環境探測，本次調查作業使用美國Geophysical Survey Systems, Inc.（GSSI）之SIR 4000主機搭配350 MHz單頻天線（350 HS Antenna）進行施測，針對待測區域共佈設85條網格狀分布之測線。透地雷達資料經時深轉換、零點修正、濾波處理、訊號增益與移位等資料處理後，進行地下管線與異常反射特徵之判釋和分析，共發現18處未知管線(群)與疑似箱涵之特殊結構物，其中5處平行道路方向之未知管線與民間工程顧問公司管線調查成果之光纖電纜、天然氣管線與自來水管線分布相吻合，剩餘13處未知管線將作為潛在管線位置參考。

中文關鍵詞：Ground Penetrating Radar、Pipeline、Geophysics

Late Holocene Decoupling of East Asian and Indian Summer Monsoons Linked to Tropical Ocean-Atmosphere Forcing

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The Asian Summer Monsoon (ASM), a major component of the global hydrological cycle, profoundly shapes the environment, ecosystems, and human societies across Asia. Comprising two distinct subsystems—the Indian Summer Monsoon (ISM) and East Asian Summer Monsoon (EASM)—its evolution during the late Holocene is critical to understanding regional climate dynamics and past societal transformations. Yet, the question of whether these monsoons varied synchronously or independently remains contested. In this study, we present a 3,200-year-long high-resolution $\delta^{18}O$ record from two precisely dated stalagmites (Kadapa composite) from the Deccan region of India, consisting of 2,913 $\delta^{18}O$ data points and 60 U/Th ages. The data reveal a major hydroclimate shift in ISM intensity around the end of the Roman Warm Period (~1.7–2.0 kyr BP), marking a sharp departure from the long-term, solar insolation-driven drying trend. In contrast, EASM records continued to decline gradually, though with localized monsoon excursions in its southern and central domains. This asynchronous behavior highlights a decoupling between ISM and EASM. The ISM shift coincides with a dramatic increase in positive Indian Ocean Dipole events, intensified ENSO variability, and shifts in North Atlantic temperatures and westerly patterns. These findings suggest that tropical Indo-Pacific ocean-atmospheric interactions may have triggered a mean monsoon climate shift during the middle Late Holocene. While solar forcing governs orbital-to-millennial-scale variability, sub-millennial ISM changes appear increasingly controlled by tropical ocean-atmospheric dynamics. EASM variability, meanwhile, remains tightly linked to North Atlantic influences. Additional high-resolution paleoclimate data and model simulations are crucial to understanding and preparing for future abrupt monsoon changes.

Keywords:Indian summer monsoon, East Asian summer monsoon, Late Holocene climate, Monsoon decoupling, Tropical Ocean-Atmospheric interaction

High-Frequency Seismic Waves Analysis and Slab-Guided Wave Observations in the Southeastern Solomon Islands

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Seismic guided waves are a form of seismic energy that propagate along subsurface structures, such as faults, sedimentary layers, or subducting slabs, where wave energy is trapped and guided along specific pathways. These waves can retain high-frequency components over long distances due to low attenuation within the waveguide, offering valuable insight into structural geometry and heterogeneity. In this study, we analyze seismic waveforms recorded by a new regional seismic network in the southeastern Solomon Islands to investigate wave propagation characteristics and potential slab-guided wave phenomena associated with the subducting Australian Plate. Through comparative waveform and spectral analyses of selected shallow and deeper earthquakes, distinct differences are observed at the forearc station. Deeper events (>60 km) exhibit stronger high-frequency energy and more pronounced P-wave onsets compared to shallow events. These patterns suggest that seismic waves from deeper events may travel along a waveguide within the subducting slab, amplifying high-frequency components. Averaged spectral results further confirm that deeper events consistently show elevated spectral amplitudes, particularly between 4-7 Hz. Based on these observations, we propose that the seismogenic structure of the subduction zone in the southeastern Solomon Islands can be divided into shallow and deeper regions. The inferred boundary at 50-60 km depth, along with the seismic gap (25-50 km) identified in a previous study, may provide further evidence for a structural transition within the subduction zone at these depths.

Keywords:southeastern Solomon Islands, high-frequency seismic waves, slab-guided waves

大屯火山地下速度構造的時空間變化

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大屯火山群是臺灣北部最受關注的火山群，原因不外乎是其緊鄰大臺北都會區。近期已有許多研究指出這個火山仍具有活動性的特徵，其中，最主要的活動地區被認為在大油坑地區，當地的地表存在許多火山噴氣孔與硫磺柱，其下方有著十分密集的線形火山地震通道，在線形地震通道的下方則發現流體儲存槽的存在，這個儲存槽內可能處於高壓狀態，並同時影響著周邊地震的活動。在大屯火山觀測站長年的努力下，目前在大屯火山地區已設置十分密集的地震觀測網，配合當地有著頻繁的地震活動，因此紀錄了十分大量的地震資訊。本研究將利用此觀測網2014至2021年間的地震資料，針對大屯火山地區進行四維速度構造的反演。在經過一連串的測試與評估後，本研究發現，在2018年前後，大油坑地區地下淺層，波傳速度出現十分明顯的變化。這個速度變化顯著且呈現柱狀分布，推測這個速度變化的地區可能是先前研究指出的火山地震通道，而柱狀的波傳速度變化則可能反應著地震通道中，火山流體壓力的增減。

中文關鍵詞：大屯火山、時空間變化、速度構造、地震通道

Anisotropic Structures Beneath Sulawesi, Indonesia, Inferred from Shear-Wave Splitting of Local and Teleseismic Events

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Sulawesi is located at the triple junction of the Indian-Australian, Sunda, and Philippine Sea plates. The interaction between these plates over geological time has shaped Sulawesi as a K-shaped island, surrounded by several subduction zones. Cao et al. (2024) used shear-wave splitting of teleseismic SK(K)S and local S-waves to study anisotropy beneath northern Sulawesi. They found a generally trench-parallel pattern of fast polarizations, with some trench-normal orientations, which they attributed to lithosphere-scale deformation and local stresses. We conduct a similar analysis for the entire Sulawesi Island using data from 69 stations in the Indonesian network. The event selection criteria are: (1) local S-waves from earthquakes at depths ≥ 100 km, filtered at 0.1–1 Hz; and (2) teleseismic SK(K)S phases from events with Mw ≥ 6.0, filtered at 0.02–0.2 Hz. After analyzing events from 2021 to 2024, we retained only those that exhibited consistency across moving-window results, defined as a polarization angle variation within ±30°, a delay time variation within ±1 s, and a Wüstefeld quality factor ≤ 0.5. The results reveal predominantly trench-parallel fast polarization directions throughout most subduction zones surrounding Sulawesi. In contrast, Gorontalo Bay and the area near Colo Volcano display trench-normal orientations, suggesting the influence of complex local features due to extensional rifting and volcanic activity. Stations located near major faults display polarization patterns parallel to the faults, whereas stations located between parallel strike-slip faults exhibit cross patterns. This study provides valuable insights into the geodynamics of Sulawesi.

Keywords:anisotropy, shear-wave, splitting, geodynamics, Sulawesi

竹苗外海離岸風場地質特性初探

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離岸風電為政府達成2025年非核家園的重要綠能政策，地礦中心自111年起逐步建置離岸風場區域尺度的基礎地質資料，　113年完成竹苗外海離岸風場完成多項地質調查工作，包括786公里多頻道反射震測探測、10站沉積物岩心採集、564平方公里多音束水深探測、317公里底拖式高解析聲納探測、503公里電火花震測探測、565公里表拖式磁力探測及11.82小時海床影像觀測，並完成北部潛能風場近岸水深地形測繪9.8平方公里。調查涵蓋D1-D6風場區域，特別加強D2-D5大水深風場的調查。

綜合各項調查結果，發現竹苗外海南側沉積物較為均質，北側則多為混合底質，沉積物主要由砂質組成，深度160公分以下則為粉砂質，反映水流強度的變化。地球物理資料則顯示竹苗外海淺部斷層多為逆斷層，與中彰外海擁有大量切穿至近地表之正斷層構造相異，竹苗外海的斷層可分為兩個主要斷層擴展褶皺系統，靠近海岸線的逆斷層和褶皺構造具活動性。堅硬地層分為淺層及深層兩類型，淺層可能為礫石層或生物礁體，主要影響D2風場；深層為玄武岩或基盤岩，深度超過250公尺，對風場影響較小，與澎湖群島周邊存在大量淺部堅硬地層源於火成岩塊體崩落堆積的形式不同。海床具新月形沙波，主要分布於D2風場及D4、D5風場東側。流體特徵則分布於苗栗外海。此外，竹苗地區的東北西南走向背斜與逆斷層分布趨勢一致，顯示兩者發育的關聯性。。

藉由整合特項調查資料，我們編製了竹苗外海地質風險評估並繪製地質環境影響因子分布圖，建立標準化的海域地質資料庫確保資料有效管理與利用，為風場選址、開發、設計、施工及營運風險管控提供科學依據，支持臺灣離岸風電產業發展，為國家能源轉型提供關鍵的地質安全保障。相關資訊皆可於「離岸風場開發地質與環境感知系統暨資訊供應服務平台」查詢，並下載高解析度圖檔應用。

中文關鍵詞：離岸風場、海域地質、竹苗外海

Tectonic Significance of Ultra-Slowly Uplifted Seychelles Granites: Insights from Argon Geochronology

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The granitic Seychelles islands, located between Madagascar and the Indian subcontinent, are composed mostly of Precambrian granitic basement (ca. 750–760 Ma) that represents remnants of the Gondwana supercontinent. This continental fragment first rifted from Madagascar during the breakup of Gondwana and later separated from western India during the Early Paleocene (~62 Ma). These granites have experienced minimal post-emplacement deformation, making them an exceptional archive of exhumation, and uplift processes. To investigate the thermal history of the Seychelles crust, in-situ single-grain laser ablation $^{40}Ar/^{39}Ar$ dating was performed on PL1, a K-feldspar and biotite-bearing granite from the island of Praslin. A total of 21 biotite grains yielded ages ranging from 414 to 598 Ma, with two KDE-weighted mean ages at approximately 565 Ma and 430 Ma. Two inverse isochron (intercept) ages were obtained: 538.0 ± 8.8 Ma (initial $^{40}Ar/^{36}Ar$ = 299.5 ± 4.3, MSWD = 1.8) and 420.2 ± 9.6 Ma (initial $^{40}Ar/^{36}Ar$ = 301.0 ± 9.2, MSWD = 2.8), suggesting the presence of two biotite crystal domains—likely magmatic and metamorphic in origin. Meanwhile, 23 K-feldspar grains yielded ages ranging from 345 to 403 Ma, with a KDE-weighted mean age of ~373 Ma and an intercept age of 368.2 ± 7.0 Ma (initial $^{40}Ar/^{36}Ar$ = 299.2 ± 9.3, MSWD = 7.2). Estimated closure temperatures for biotite and K-feldspar range between 265–304°C and 226–264°C, respectively. With estimated crystallization pressure of 1-2 kbar and our new thermal-chronological results, the PL1 granite body was emplaced at a relatively shallow crustal level (4~5 km). It was subsequently buried to 8–9 km during the late Cambrian to Silurian. The granite body remained at similar but slightly shallower level (7-8 km) till the Late Devonian possibly due to the glacial coverage of the Ordovician-Silurian Glaciation, which may have influenced thermal gradients and exhumation rates.This ultra-slow uplift history reveals a close interlink between crustal dynamics, tectonic evolution, and climate systems, underscoring the importance of integrating geochronological, structural, and climatic records to reconstruct long-term continental behavior.

Keywords:Tectonic Significance, Ultra-Slow Uplift, Seychelles Granites, Argon Geochronology

Pore Structure Characterization and Transport Property Estimation under Multiscale X-ray Computed Tomography

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X-ray computed tomography (CT) provides a rapid, non-destructive and high-resolution approach for acquiring reliable digital images of reservoir samples. It relates macroscopic transport properties to microscopic pore geometries. This relationship is crucial for improving the assessment of reservoir capacity and simulating fluid migration in Carbon Capture and Storage (CCS). However, the resolution of CT imaging is inherently limited by sample size. High-resolution imaging typically requires small core plugs, which may compromise representativeness. In contrast, low-resolution imaging allows scanning of full-core samples but loses pore details, which may cause property estimation errors. In this study, we selected four samples from the Kueichoulin, Nanchuang, and Cholan formations, each with distinct pore structures. We compared a set of digital rock properties derived from CT images at voxel sizes of 5, 22 and 69 μm with experimental ground truth, including porosity (direct measurement), pore size and permeability (via Pore Network Model). The results show that permeability estimated at 22 μm resolution and coarser are unreliable, due to pore disconnection and the mixture of pores and matrix. To bridge the resolution gap, we propose an image-derived parameter based on grayscale topography. In comparison with simulation results, this parameter effectively captures pore size characteristics and improves permeability estimates even under 69 μm conditions. This study demonstrates a multi-scale approach for CT-based pore structure characterization, offering new opportunities for assessing transport properties at the full-core scale.

Keywords:X-ray Computed Tomography (CT), Porosity, Permeability, Pore Structure

Slow slip event detection from deep to shallow

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The discovery of slow slip event provides insights into fault slip dynamics over the past two decades. However, how those episodic and continuous deformation contribute to the earthquake cycle is crucial. In this study, we developed a comprehensive slow slip event detection scheme across different depths in Taiwan. By integrating multiple seismic signatures of slow earthquakes, including deep tectonic tremors, earthquake swarms, and repeating earthquakes, we systematically identified and characterized slow slip events. This approach involved decomposing GNSS data by stacking offsets during tremor and inter-tremor period near tremor sources. For events associated with earthquake swarms, we focused on detecting slow slip signals using nearby station data and correlating them with aseismic slip history derived from repeating earthquake. Our analysis revealed distinct slow slip event characteristics across different tectonic environments. Tremor-associated slow slip events showed clear deformation patterns through GNSS offset stacking and were distingue from inter tremor periods, while swarm-related events demonstrated localized continuous deformation coinciding with aseismic slip acceleration. By combining detected slow earthquake information and GNSS time series, we aim to elucidate how stress accumulation resulting from aseismic slip impacts the earthquake cycle.

Keywords:slow slip, tremor, repeating earthquake, earthquake swarm

Improving X-Ray Computer Tomography Image Alignment for Detecting Injection-Induced Changes in Core Flooding Studies

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Core-scale flooding experiments are essential for understanding fluid migration and mechanical behavior changes in geological formations, as seen in applications such as Carbon Capture and Storage (CCS). X-ray Computed Tomography (XCT) offers a non-destructive means to examine changes before and after fluid injection, including fluid migration, mineral dissolution and precipitation, as well as microstructural evolution. Accurate alignment of pre- and post-injection images is critical for such analyses. However, the registration process is often challenged by contrast variations from fluid saturation differences, and structural deformation caused by mineral reactions and mechanical changes. To address these, this study applied the Structural Similarity Index Measure (SSIM), with manual assistance, for preliminary alignment, followed by fine-tuning using the Enhanced Correlation Coefficient (ECC) algorithm and Particle Swarm Optimization (PSO). ECC is a gradient-based method with fast convergence, suitable for moderate changes, while PSO, a global optimization algorithm, is more robust under large deformations or in cases where gradient-based methods are less effective. The performance of this approach was evaluated under post-injection image variations. Tests on basalt and sandstone cores—representing lithologies with contrasting pore structures and geochemical behavior—demonstrated improved registration accuracy and robustness. These results highlight the method's reliability and generalizability for XCT-based analyses across a wide range of geological settings.

Keywords:X-ray Computed Tomography, Image Alignment, Core Flooding, Carbon Capture and Storage (CCS)

Exploring the Impact of Subducted Sediment Properties, Shear Heating, and Dehydration on Seismicity in Subduction Zones Using MEFISTO

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This study utilizes a 2D spring-slider model, MEFISTO, incorporating cementation processes and a fluid flow model to investigate how multiple factors at the subduction interface influence the spatiotemporal distribution of megathrust earthquakes. We introduce a combination of pressure solution creep and dislocation creep flow laws to calculate inelastic slip within plate interface. Additionally, shear heating from both coseismic rupture and interseismic creep is introduced, alongside a thermal diffusion model. We then apply the updated version of MEFISTO to the Kodiak, Semidi, and Shumagin sections of Alaska subduction zone and validate them by comparing their coupling coefficients, extent of seismogenic zone, recurrence interval of great earthquakes () and b-value with observations. We conducted a series of simulations varying friction coefficient, shear zone thickness, grain size and deep-sourced fluid production rate. The results show that the b-value is positively correlated with shear zone thickness and deep-sourced fluid production rate but negatively correlated with grain size. Shear heating is most intense in the lower seismogenic zone, indicating coseismic slip as its primary thermal source. Shear heating is amplified by coarser grain sizes and thinner shear zones. The Kodiak section model with km shear zone thickness, μm average grain size and deep sourced fluid production rate exhibits average coupling coefficient close to 1, km locking depth and years recurrence interval for earthquakes. Semidi section model with km shear zone thickness, μm average grain size and deep sourced fluid production rate results in medium average coupling coefficient, km locking depth and years recurrence interval for earthquakes. Shumagin section model with km shear zone thickness, μm average grain size and deep sourced fluid production rate leads to a lower average coupling coefficient, km locking depth and years recurrence interval for earthquakes. The locking depth and recurrence interval of great earthquakes of these models are consistent with the geodetic observations. These findings provide insights into the interplay of multiple physical factors controlling seismicity along megathrust, offering a more comprehensive understanding of along-strike variations in subduction zones.

Keywords:spring-slider, subduction zone, pressure solution, shear heating, b-value

Stress transfer cycle from slow to fast earthquakes across the southernmost Ryukyu subduction thrust during deep slow slip

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Spatiotemporal linkages between slow and fast earthquakes have been observed in global subduction zones, indicating mechanisms involving elevated fluid pressure and static stress transfer. Recent megathrust events preceded by slow slip events highlight stress transfer as a key triggering mechanism, although previous observations have provided limited insights into this process. This study presents direct evidence for the stress transfer cycle in the southernmost Ryukyu subduction zone, connecting deep interplate slow slips to earthquake swarms occurring in the overriding plate. This region has experienced recurrent earthquake swarms approximately every one to two years over the last two decades. Notably, three significant swarms occurred in 2005, 2009, and 2015, each preceded by deep slow slip events at depths ranging from 15 to 45 km. We investigated the temporal variations in *b*-value, principal stress axes, and Coulomb failure stress during periods of increased seismic activities from interplate slow slips. We found that the *b*-value dropped below 0.7 during all slow slip periods before their peak slip rates. The lowest *b*-value, compared to the long-term background average, occurred during the 2009 slow slip event along with a 30º rotation in the σ_1 axis orientation. A high spatiotemporal correlation was observed between increased seismic activity and positive Coulomb stress loads at the front of slow slip patches, raising concerns about potential megathrust event. These findings underscore the stress transfer process in advance of elevated fluid pressure and fracture development, and the need for ongoing monitoring in this seismically active subduction zone.

Keywords:stress transfer, slow slip, earthquake swarm, b-value, Ryukyu subduction zone

Revisiting the turbulent torque of a precession-driven flow

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Precession drives fluid motion within the liquid layers deep inside planets and moons. A boundary layer forms at the solid–liquid interface. It is now believed that this boundary layer is marginally turbulent in Earth's core and fully turbulent in the Moon's core. Several laboratory experiments have produced results on precession-driven flow that cannot be explained by existing theories of turbulent torque, highlighting the need for improved theoretical approaches.

In this work, we review the theoretical framework for calculating viscous torque and demonstrate an alternative approach based on analysis of the localized boundary layer. This method offers a pathway for investigating turbulent torque, both theoretically and numerically. For experimental applications, we revisit the classical solution for precession-driven flow by incorporating the effect of turbulence. We identify a parameter regime in which this effect should be sufficiently pronounced to be detected in laboratory settings, providing a foundation for future experiments on turbulence in precessing flows.

Keywords:Precession, Turbulence, Theory

應用地動訊號解析深層滑坡潛勢與滑動特徵之研究

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過去深層滑坡的監測多仰賴鑽井配合傾斜管、伸縮計等孔內監測儀器，並結合地表大地測量進行長期觀測，雖能提供精確的變形資料，但因其布設成本高、覆蓋範圍有限，難以快速掌握大範圍潛在滑動區的分布與活動特性。為達快速評估之目的，本研究首先以密集式且大範圍之微地動量測，進行短期（數小時至一天）地動訊號收錄，藉由單站頻譜比、陣列分析與極化分析方法，可得知滑動特徵（滑動深度、方向與潛勢）與潛在活動區分布。進一步選定高潛勢區域進行較長時間之連續監測，探討強降雨與強地動事件影響下，滑動特徵之變化情形。觀測區域涵蓋台灣三處具代表性的深層滑動潛勢地，包括：新北市石碇區大崙山順向坡、新竹縣尖石鄉梅花地滑區，以及嘉義縣梅山鄉幼葉林地滑區。這些地區在歷次強降雨事件後皆曾出現明顯坡體滑動現象，顯示其具高度活動性與潛在災害風險。部分地區雖經整治，但仍存在再滑動的疑慮，顯示持續監測之必要性。極化分析結果顯示，大崙山順向坡在坡腹區仍具有較高之滑動潛能，而梅花與幼葉林地滑區經整治後，目前整體塊體趨於穩定。根據單站頻譜比結果，滑動潛勢區域普遍呈現明顯之共振主頻，顯示淺層鬆軟崩積土層與下伏砂頁岩互層間具有顯著之剪力波速度對比。經與井測資料及傾斜管變形深度比對後，推測此一速度界面可能對滑動行為具有關鍵控制作用，並可作為辨識潛在不穩定區之依據。長期觀測結果指出，於大地震發生期間，共振主頻與對應之放大倍率皆出現明顯下降，並於數日後逐漸回復至原始狀態，顯示大應變條件下土層非線性效應顯著。此外，在強降雨期間，地下水位上升亦伴隨共振主頻所對應之放大倍率降低的現象，推測為地下水飽和程度提升導致剪力波速度降低所致，顯示孔隙水壓變化可能影響場址動態反應特性。本研究證實微地動訊號可用於快速辨識深層滑動活動，並可作為後續長期監測與災害潛勢評估之依據，具高度應用潛力。

中文關鍵詞：深層滑坡、微地動量測、大崙山順向坡、梅花地滑區、幼葉林地滑區

Pliocene otoliths from NW India reveal first fossil Osphronemid and structure of a Himalayan freshwater ecosystem

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The Neogene Siwalik deposits have long been recognized for their rich terrestrial fossil record, yet their freshwater ichthyofauna remains virtually unknown. This gap limits our understanding of past aquatic ecosystems and the biogeographic history of South Asian freshwater fishes. In this study, we report the first fossil record of freshwater fish otoliths from the Upper Siwalik Pliocene deposits of Mohand, Saharanpur district, in the northwestern Himalaya, India. Three taxa*Channa* (Channidae), *Trichogaster fasciata* (Osphronemidae), and Gobiidae indet were discovered through our extensive bulk sampling. Among these, *T. fasciata* represents the second known fossil record of Osphronemidae globally and the first based on otoliths. The assemblage reflects a structured trophic composition composed of mid-level preys and apex predators. These faunal components suggest a calm, possibly lentic freshwater habitat with dense vegetation, consistent with the spawning and hunting behavior of labyrinth fishes and snakeheads. Despite the limited number of otoliths, this collection provides rare but significant insights into Pliocene freshwater biodiversity in the Himalayan region.

Keywords:Upper Siwalik, labyrinth fishes, diversity, paleoichthyology, predator-prey composition

Investigating Velocity Pulse Generation through 3-D Ground Motion Modeling Case Studies of the 2016 Meinong and 2018 Hualien Earthquakes in Taiwan

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Recent studies have frequently observed velocity pulse during earthquakes, often attributed to rupture directivity effects and linked to severe structural damage. Notably, the 2016 Meinong and 2018 Hualien earthquakes exhibited pulse-like ground motions and significant building damage. In this study, we investigate the mechanisms of velocity pulse generation by conducting 3-D numerical simulations of these two events, comparing synthetic ground motions with observational data. The simulations incorporate finite-fault models and characteristic source models based on the Recipe method. Synthetic full waveforms are computed using the 3-D traction-image finite-difference method, accounting for 3-D velocity and surface topography. Velocity pulses are identified using a standardized pulse indicator and compared with the CH20 ground motion model. Among the tested source parameters, asperity geometry and rupture velocity emerge as the most sensitive in pulse generation. Results show that the characteristic source models tend to generate fewer pulse-like ground motions in the KC velocity model compared to the HH velocity model. In addition, a shallow low-velocity surface layer appears to significantly affect pulse generation, a phenomenon particularly evident in the HH_surface velocity model. Furthermore, pulse periods of the synthetic results are observed to range from 1 to 2 seconds, shorter than those seen in observations from 2 to 5 seconds. The study enhances our understanding of the factors influencing velocity pulse generation and proposes a simulation framework for source model construction using the Recipe method, to improve the accuracy of ground motion prediction.

Keywords:Velocity Pulse, Ground Motion Simulation, Finite-Difference Method, Recipe

Microearthquake monitoring in northern Hualien, Taiwan with a borehole seismometer array

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Northern Hualien area, located at the collision boundary between the Eurasian and Philippine Sea plates, has a complex tectonic environment that remains debated. The region shows high seismicity with magnitudes ranging from M1 to M8 and at depths from near the surface to 150 km. Due to the lack of seismic stations in this area, we deployed a station near Heping Village since 2020 to enhance earthquake detection and identify more small events not listed in the Central Weather Administration (CWA) catalog in the study area. The seismic station includes a 100-meter-deep borehole, an acceleration seismometer, and a velocity seismometer on the surface. We corrected the instrument response and examined the probabilistic power spectral density (PPSD) for the noise evaluation. Instrument background noise ranges from -80 dB to -120 dB. In addition, we calibrate the orientation of the borehole sensor using long-period waveforms from the 2021 Qinghai earthquake in China. The corrected angle is 339.11° counterclockwise. Moreover, we manually identified 11,076 events from continuous records of the borehole seismometer during October 2022 and December 2023 and found 2,956 events that are not listed in the CWA catalog. Using the Taiwan 3D velocity model and the P-wave arrival times from three nearby CWA operated borehole seismometers, we located 496 events, mostly north of our station. Finally, we estimate the source parameters of these events using a spectral fitting approach and conclude that no significant relation between stress drop and seismic moment in a magnitude range from 0 to 3. Our results suggest that microearthquakes in the research region are self-similar pattern.

Keywords:Microearthquake, Borehole seismometer, Probabilistic power spectral density, Earthquake source parameters

A Comprehensive Review of the Environmental and Hydrological Consequences of Large H.E.P Dam Projects in Taiwan

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Embankment dam failures are most commonly attributed to spillway-related issues such as overtopping, erosion, and internal piping, which account for approximately 44% of global incidents. In Taiwan, these risks are amplified by frequent typhoons, steep terrain, and intense seismic activity. Notable events—including the 1999 Chi-Chi earthquake, which ruptured the Shih Kang Dam spillway gates, the 2008 Wenchuan earthquake, and the catastrophic Banqiao Dam failure during Typhoon Nina in 1975 that triggered cascading failures in 61 other dams, underscore the urgent need for integrated, hazard-resilient design.

This study presents a critical review of four major Taiwanese hydroelectric power (H.E.P) dams; Zengwen, Wushantou, Feitsui, and Shimen, focusing on spillway vulnerabilities under flood and seismic stress. Utilizing Gumbel and Log-Pearson Type III statistical distributions, in accordance with ICOLD guidelines, the study models flood return periods and seismic magnitude scenarios to evaluate design thresholds. Findings indicate that aging infrastructure (some exceeding 50 years), coupled with intensified hydrological extremes from climate change, has significantly reduced spillway capacity, elevating failure risks.

The results advocate for urgent infrastructure upgrades aligned with ICOLD (International Commission on Large Dams) standards, emphasizing inflow flood data over rainfall for superior hydrological modelling. Strengthening these critical structures is essential not only for maintaining energy security and protecting downstream communities, but also for enhancing Taiwan's resilience to future multi-hazard events in a changing climate.

Keywords:Flood frequency analysis, ICOLD guidelines, Spillway failure risk, Gumbel distribution, Log-Pearson Type III distributions

High-Resolution Shear-Wave Velocity Imaging for Geothermal Exploration in the Ilan Plain Using Dense-Array Microtremor Analysis

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The Ilan Plain, located at the southwestern tip of the Okinawa Trough in northeastern Taiwan, is a region of active back-arc extension with significant geothermal potential. To investigate its subsurface structure, we deployed a seismic array of 81 stations across the plain and a dense array of 186 sensors in the Hongchailin area from July 2022 to January 2023. Using the Horizontal-to-Vertical Spectral Ratio (HVSR) method, we analyzed ambient seismic noise to estimate resonance frequencies and delineate the geometry of the sediment-bedrock interface. Results show a northeastward thickening of alluvial deposits over a tilting Miocene basement, consistent with prior studies. We further applied the Degree-of-Polarization (DOP-E) method to extract Rayleigh wave ellipticity and inverted these curves using the neighborhood algorithm to derive high-resolution 1-D shear-wave velocity models at each station. The models reveal prominent low-velocity zones beneath Yuanshan Township—site of Taiwan's first deep geothermal well—and southeast Hongchailin. Another strong anomaly beneath Lize suggests high geothermal potential. A significant velocity contrast along the Lanyang River, suggesting that it may serve as the boundary between the Hsuehshan Range to the north and the Central Range to the south. Our results demonstrate that dense-array microtremor analysis is an effective, non-invasive tool for imaging geothermal and basin structures in tectonically active rifted regions.

Keywords:Microtremor analysis, HVSR, Basin structure, Geothermal energy, Dense seismic array

Moist Static Energy Budget and Madden–Julian Oscillation-Induced Extreme Precipitation: Land–Ocean Contrast in the Maritime Continent

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Extreme precipitation (EP) over the Maritime Continent (MC) exhibits strong intraseasonal modulation by the Madden–Julian Oscillation (MJO), particularly during the boreal winter season (November–April). This study investigates the moist static energy (MSE) budget associated with MJO-induced EP using the fifth-generation European Center for Medium-Range Weather Forecasts (ERA5) reanalysis data, focusing on the contrast between land and ocean regions. Although the temporal evolution of regions. regions. precipitation appears broadly similar across surface types, the underlying energy pathways differ notably. Over the land, horizontal MSE advection, primarily driven by the dynamic component, acts as the dominant mechanism for atmospheric energy recharge. In contrast, over the ocean, net flux heating contributes a more substantial role in recharging the MSE. dynamical processes in regulating both horizontal and vertical MSE transport during MJO-induced EP. These results underscore the spatial heterogeneity of recharge–discharge mechanisms across the MC and emphasize the critical role of surface type in shaping the intensity and vertical structure of intraseasonal precipitation extremes.

Keywords:Madden–Julian Oscillation, Moist static energy, Maritime continent, Extreme precipitation

Lipid biomarker and palynology data from Shenmihu Lake, Taiwan

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Paleoclimatic studies in Taiwan can be challenging due to the limited number of well-preserved natural archives. Lake sediment is one of the few, if not the only, that can be utilized to understand Taiwan's terrestrial climate in the past. Among the lakes in Taiwan, Shenmihu Lake is one of the most promising in that the radiocarbon dating indicates continuous sedimentation covering the entire Holocene. In this study, we apply lipid biomarkers and palynological data to disentangle lake succession from climate change. The P_{aq} ratio is used to indicate lake water level, while the Carbon Preference Index (CPI) is used to indicate organic material freshness/degradation. Pollen assemblages are used to reveal the lake catchment ecosystem dynamic and lake evolution.

The results show that the climate proxy values in Shenmihu Lake display distinct variations. Paq ratio ranges from 0.09 to 0.58 while the CPI ranges from 2.31 to 8.73. Pollen data also show that trees and shrubs vary over time, with algae only showing up in the early stage, indicating the high water level. The dynamics of lipid biomarkers and palynological data indicates that lake evolution excerted a major control on the variability of the proxies. Therefore, the lake's evolution must be properly understood before any paleoclimate reconstruction are attempted.

Keywords:Paleoclimate, Shenmihu Lake, lipid biomarkers, palynology, lake evolution

建立二維震波測勘區內的地質異常體模型流程 -以Petrel震測解釋軟體為例

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震測資料中之地質異常體(geological anomalies)係指在震測反射特徵上與周圍反射訊號的振幅、連續性、傾角有顯著差異的區域。這些地質異常體在震測剖面上呈現的形貌可能是水道(channel)、波卡點(polka-dot)、急劇的振幅截止(sharp amplitude cutoff)、管狀(pipe)…等。在垂向與橫向解析度較高的三維震測資料中，可藉由不同的震測資料切片方式，如: 時間切片(time slice)、層面切片(horizon slice)與地層切片(stratal slice)觀察地質異常體的特徵並確認類型，且能結合適當的震波屬性計算方式強調異常體邊緣並刻劃出形貌。基於三維震測資料所描繪出的地質異常體因周圍解釋較為完整，易於整併至網格化構造模型中。但在部分僅有二維震測資料覆蓋的區域中，若震波測勘施測路徑截切地質異常體，則此些地質異常體亦能見於二維震測剖面內。受限於二維震波測勘的施測密度，測勘範圍內的地下異常體描繪較三維震測解釋更為困難且具不確定性。

中油公司近年來主要使用Petrel一體式震測解釋軟體進行震測解釋、構造建模與屬性模型建立工作，該軟體之震測解釋優點為可於三維空間與二維剖面中互動式的進行解釋工作。但軟體內各項功能模組，對於二維震測資料內的地質異常體之解釋和建模，仍有所侷限且無既有的工作流程。為使網格化模型盡可能地符合地下地質狀況以利相關研究進行，本研究以Petrel震測解釋軟體內既有功能，針對單一且具獨立性的地質異常體，測試並建立一系列基於二維震測資料的地質異常體解釋、補強描繪及轉換流程，可將描繪出的地質異常體結合至網格化構造模型內，並已實際應用於本公司自有研究場址，成功建立內含多個地質異常體的網格化構造模型。

中文關鍵詞：地質異常體、構造建模、屬性建模

A New Deinotherium levius (Deinotheriidae, Proboscidea) Finding from Thrace, Türkiye: Implications for Anatolian Paleobiogeography

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Deinotherium levius was a strict browser, primarily consuming soft, leafy vegetation from forested habitats. Its distribution during the Middle to Late Miocene encompassed Europe and the southern part of Türkiye. Previously, four deinothere discoveries were documented from Miocene localities in Thrace, Türkiye. *D. giganteum* was identified at the (MN9) Küçükçekmece, (MN10) Yulaflı, and (MN10–12) Domuzdere localities, while a single specimen from the Middle Miocene (MN7+8) Pişmanköy locality was classified as *Deinotherium* indet. Although an additional eight deinothere findings are known from the rest of Türkiye, our study reports the first occurrence of *D. levius* in Thrace and only the second documented record for the entire country. This new discovery from Thrace further suggests a paleobiogeographic connection between Anatolia and Europe for *D. levius*. Deinotheres are known from over 100 localities across Eurasia, with the westernmost being La Cistérniga, Spain, and the easternmost Khorat, Thailand. Our new Thracian finding comprises a single hemimandible preserving the m1–m3 (first to third lower molar) series. The second and third molars are well-preserved, while the first molar is broken, with its anterior portion missing. Biometric analysis of this specimen from Çerkezköy indicates that it is larger than all known *Prodeinotherium bavaricum* specimens but smaller than all *Deinotherium giganteum* specimens. These results confidently place the Çerkezköy specimen within the size range of *D. levius*.

Keywords:Deinothere, Miocene, Türkiye, paleogeography

How reactive is permafrost after thawing? Changes in permafrost organic matter reactivities across the land-to-shelf transect in the Laptev Sea, Arctic

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Circumarctic permafrost is one of the major terrestrial carbon stocks. Due to the ongoing rapid warming in the Arctic, a significant amount of carbon previously freeze-locked in permafrost may be released back into the atmosphere. The extent of carbon release strictly depends on the reactivity of the organic matter in thawing permafrost. However, our understanding of how organic matter reactivity varies across terrestrial permafrost types and how it changes during transport from land to marine shelves remains limited. In this study, we analyzed the thermogravimetric properties of bulk deposits to quantify changes in organic matter reactivity among terrestrial Holocene and Pleistocene permafrost, surface sediments from the Laptev Sea, and sediment cores from the western Laptev Sea. We found that terrestrial Pleistocene permafrost exhibited lower reactivity compared to Holocene permafrost. Similarly, reduced organic matter reactivities were observed in surface sediments from the eastern Laptev Sea shelf. This region receives a higher terrestrial input from Pleistocene permafrost compared to the central and western Laptev Sea. A cross-shelf gradient in organic matter reactivity was observed in the central and western Laptev Sea. Downcore analyses revealed that the reduction in organic matter reactivity is primarily due to degradation during cross-shelf transport rather than post-depositional processes. Our findings advance the understanding of organic matter reactivity differences between Pleistocene and Holocene permafrost, as well as the transformations that occur during transport and deposition.

Keywords:organic matter reactivity, permafrost thawing, Arctic Ocean, thermogravimetric analysis, labile organic matter

台灣西南海域濁流扇之震波反射特徵與沉積模式

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濁流為海水中富含懸浮顆粒的高密度流體，受重力的驅使順著斜坡向下流動，過程中能侵蝕海床表面沉積物混和入流體中，並會在坡度平緩處沉積成扇體，沉積物搬運距離可達數百公里。在深水沉積環境中，濁流扇是一含砂量高且規模較大之沉積單元，在油氣探勘中被視為具有較高之油氣儲集潛力。

近十幾年來世界上不同盆地的深水區開始有許多具經濟規模的油氣田被發現，深水探勘及相關研究逐漸受到重視，台灣中油公司也與多方國際石油公司合作，取得台灣西南海域深水區的二維與三維震測資料，本研究使用這些震測資料，在台灣西南海域深水區晚中新世地層中發現存在具規模的濁流扇強振幅反射訊號，並觀察到此強振幅訊號有垂直濁流流向之側向堆積的現象。深水濁流岩沉積後會受到高能底流作用後再次搬運堆積形成不同形式之混和型沉積系統，根據本研究觀察之結果，推測該濁流系統受到由東北往西南方向之底流作用而改造，顯示於晚中新世時期台灣西南海域深水區之濁流沉積作用曾受到底流作用影響。

中文關鍵詞：台灣西南海域、濁流扇、油氣探勘

Effect of intrinsic thermal conductivities on a conductive Martian basal magma ocean : Insights from simulations of mantle convection

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A basal magma ocean (BMO) has been suggested to exist below the Martian mantle, above the core (Samuel et al., 2023; Khan et al., 2023). Such a BMO largely affects interior thermal evolution in multiple ways, through the redistribution of heat producing elements (HPE) between the BMO and the mantle, and the likely suppression of both mantle and core convection. The mode of heat transport from and across the BMO itself is also crucial to the thermal evolution. This is, however, dependent on the convective state of the BMO, which is yet to be determined and confirmed. While the large amount of heat generated within the HPE-enriched BMO can be conducted to the mantle above and the core below, possible vigorous convection of the liquid-state BMO (compared to the timescale of solid-state mantle convection) allows additional heat loss from this layer.

Here, we consider the scenario where the BMO is the product of an end-member fractional crystallisation of the initial global magma ocean, followed by the subsequent overturn of the iron- and HPE-enriched component. This single overturn (as described by e.g. Elkins-Tanton et al., 2003) results in a very strong density stratification, such that the BMO is strictly unable to convect (Samuel et al., 2021, 2023). Using the mantle convection code StagYY, we therefore assume in our models that conduction is the only mode of heat transport across the BMO; as such, the intrinsic thermal conductivities of the BMO and of the mantle are key parameters that may impact the long-term thermal evolution of Mars. Varying the intrinsic thermal conductivity as a function of depth, temperature and composition, we report on its effect on observation diagnostics, including but not limited to mantle temperature and crustal growth history. We further investigate the thermal exchange and feedback between the BMO and the core, considering different thermal structures within the core. Our model results assuming a conductive BMO and adiabatic core temperature profile are compared with those obtained in Samuel et al. (2023).

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Keywords:Mars, Mantle convection, Basal magma ocean, Numerical modelling, Planetary interior

What causes rapid terrestrial permafrost mobilization—and how? Tracing sources with compound-specific radiocarbon analysis of biomarker

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Arctic permafrost stores vast amounts of terrestrial organic matter. Under a warming climate, permafrost thaws and releases aged carbon on land that can severely impact the modern carbon cycle once remineralized during transport towards the Arctic Ocean. Identifying the sources of mobilized terrigenous material is essential for understanding the potential climatic feedbacks associated with permafrost thaw, as permafrost of different ages varies in its potential to release greenhouse gases upon thawing. In this study, we examined the characteristics of terrestrial biomarkers, including *n*-alkanes, fatty acids, and lignin phenols in marine sediment cores from the Laptev Sea, a marginal sea of the Arctic Ocean. Our objective was to assess how the sources of terrestrial organic matter transported to the ocean responded to varying environmental conditions such as sea-level rise, sea-ice coverage, inland climate warming, and freshwater input. To further explore the permafrost source during periods of rapid terrestrial permafrost mobilization we analyzed variations in the radiocarbon ages of deposited terrestrial biomarkers, including high molecular weight fatty acids, high molecular weight *n*-alkanes, and mid-chain *n*-alkanes. Our findings underscore the influence of regional environmental conditions alongside global drivers, which can either promote or preclude regional terrestrial organic carbon fluxes. Moreover, compound-specific radiocarbon data from terrestrial biomarkers reveal the complexity of permafrost mobilization pathways, as reflected in the differing signals among lipid classes.

Keywords:fatty acids, n-alkanes, compound-specific radiocarbon analysis, pre-depositional age, Arctic Ocean

Comparing Metabolic Rates Between Seagrass Monocultures and Coral-Seagrass Systems: A Winter Assessment from Dongsha Island

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Tropical seagrass ecosystems exhibit strong diel fluctuations in dissolved oxygen (DO) driven by daytime photosynthesis and community respiration. As climate change intensifies, understanding DO dynamics in these systems becomes increasingly important. We investigated dissolved oxygen (DO) dynamics at two distinct seagrass habitats on Dongsha Island: a semi-enclosed lagoon dominated by *Halodule uninervis* and an open coastal area where *Thalassia hemprichii* coexists with scleractinian corals. In situ benthic chamber incubations were conducted during winter to quantify metabolic rates. Hourly and daily DO changes were used to estimate gross primary production (GPP), community respiration (R), and net ecosystem metabolism (NEM). At the open coast, daily GPP averaged 93.39 mmol O_2 m^{-2} d^{-1} and R was -118.65 mmol O_2 m^{-2} d^{-1}, yielding an NEM of -25.25 mmol O_2 m^{-2} d^{-1}. At the same site with coral-seagrass cohabitation, average GPP and R were 58.86 and -95.08 mmol O_2 m^{-2} d^{-1}, respectively, with a more negative NEM of -36.21 mmol O_2 m^{-2} d^{-1}. In the semi-closed lagoon, GPP and R were 61.00 and -96.60 mmol O_2 m^{-2} d^{-1}, with a similar NEM of -35.60 mmol O_2 m^{-2} d^{-1}. All sites maintained heterotrophic status during winter, with R ratios consistently exceeding 1.0, suggesting significant allochthonous carbon subsidies or utilization of stored organic matter. These findings reveal species-specific and habitat-dependent variations in seagrass community metabolism, highlighting the complex interplay between community composition, environmental factors, and ecosystem functioning in tropical seagrass systems under seasonal constraints.

Keywords:Seagrass, Microbial activity, Primary productivity

利用地震與重力資料序列逆推台灣東北部三維速度與密度構造

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台灣位於歐亞板塊與菲律賓海板塊的聚合邊界，於台灣東北部的琉球隱沒帶，菲律賓海板塊向北隱沒至歐亞板塊之下，形成琉球隱沒帶，產生了一系列的構造，包括琉球海溝、琉球島弧與張裂的沖繩海槽。本研究區位於台灣島的東北部，因受到海槽擴張及板塊隱沒影響，有許多火成活動，例如龜山島與大屯火山。也有與板塊的張裂活動，例如宜蘭平原。

本研究採用序列逆推法(Sequential Inversion)，使用中央氣象署地震資料並利用雙差分層析法(Double difference)進行反演算得到研究區域內之三維速度模型。由於地震波於淺層區域之解析度有限，我們加入重力資料增加淺層構造的解析能力。透過速度—密度轉換式，將速度模型轉換成相對應的密度模型，進行重力逆推，最後將得到的密度模型透過轉換式轉回速度，完成第一次的序列逆推。

結果顯示，淺層（<2 km）宜蘭平原呈現低Vp，並在平原北邊呈現高Vp/Vs異常，推測此未固結沉積層與高孔隙流體壓力有關；而中層（4–15 km）則於龜山島下方辨識出垂向延伸的高Vp/Vs通道，對應已知之部分熔融與脫水流體上升構造。深層（>20 km）高Vp/Vs、低Vs異常體則延伸至地函楔區域，可能為隱沒板塊脫水引致之熔融體根部，與先前文獻所述的「香腸狀」熔融體構造結果一致。整體而言，地震與重力資料的聯合反演有效提升模型的淺層解析力，並提供宜蘭盆地構造、地熱系統及岩漿通道的整合性解釋。

中文關鍵詞：速度構造、重力異常、台灣東北部

Seismicity Migration along the Deformation Front Offshore Southwest Taiwan

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Based on high-resolution relocated seismicity data, we identified a sequence of energetic seismic activity that initiated following the Mw 5.3 near-shore Tainan earthquake on February 10, 2017. This activity subsequently migrated northeastward along the western flank of the deformation front, progressing toward the southwestern coast of Taiwan. To investigate the mechanisms driving this seismicity migration, we first calculated Coulomb stress changes induced by the Tainan earthquake using an elastic half-space model. Our results indicate that most aftershocks occurred in regions experiencing negative Coulomb stress change, suggesting that stress transfer from the mainshock played a limited role in triggering these subsequent events. In addition, we identified a cluster of repeating earthquakes near the source region of the Tainan earthquake. These events exhibit high waveform similarity, overlapping rupture areas, and short recurrence intervals, consistent with the presence of a localized asperity or persistent source area. Analysis of the spatiotemporal evolution of the seismic sequence reveals a two-stage migration pattern. During the early stages, seismicity migrated away from the Tainan earthquake hypocenter in a logarithmic time-dependent manner, characteristic of afterslip-driven processes. In contrast, later events exhibited a migration pattern proportional to the square root of time from the hypocenter of the largest event in the sequence, indicative of fluid diffusion. Collectively, these observations suggest a two-stage process governing the seismicity migration: an initial phase dominated by afterslip immediately following the Tainan mainshock, succeeded by a secondary phase driven by pore fluid diffusion.

Keywords:deformation front, seismicity migration, repeating earthquake, Coulomb stress change, pore fluid

EGS: A Solution for Taiwan Geothermal Energy

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Geothermal exploration conducted by the Geological Survey and Mining Management Agency (GSMMA) of Taiwan has estimated the region's geothermal potential to reach up to 40 gigawatts (GW). The national strategic plan aims for an installed capacity of approximately 3 to 6 GW by 2050. However, the potential for shallow geothermal energy is currently assessed at less than 1 GW. To achieve the ambitious target of 3 to 6 GW of geothermal capacity, Taiwan must prioritize the development of deep geothermal resources through the utilization of Enhanced Geothermal System (EGS) or Advanced Geothermal System (AGS) technologies. Taiwan's geographical location within an arc-continent collision zone results in a high geothermal gradient, although significant land constraints present challenges. The geothermal reservoir beneath Taiwan is relatively small and limited by the availability of fractured spaces to store thermal water, a consequence of the region's compressed tectonic activity. Consequently, the deployment of EGS or AGS technologies is critical for the construction of large-scale geothermal power facilities, thereby facilitating the achievement of Taiwan's geothermal energy goals. However, the AGS remains prohibitively expensive and lacks commercial applications globally. As such, EGS presents a more viable solution for the development of geothermal energy in Taiwan.

Keywords:Enhanced Geothermal System (EGS), Geothermal , Taiwan

應用機器學習法自動分辨及圈繪高準確率礫石遮罩：以台灣東部河流礫石粒徑分布為例

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台灣位於歐亞板塊與菲律賓海板塊的弧陸碰撞邊界，因此具有強烈的造山作用及地表侵蝕活動。過去研究常藉由河流地形，應用水力下切模型（stream power model）評估河流侵蝕速率（erosion rate），計算河流陡峭度（channel steepness），進而獲取構造抬升率（uplift rate）或是岩石易侵蝕性（rock erodibility）的空間分布。但水力下切模型缺乏考慮河道寬度（channel width）及沈積物變動（sediment dynamics）等重要因素，可能導致錯誤的估算。河流礫石粒徑分布反應了水力的大小，與河流陡峭度、河寬及沈積物搬運息息相關，而過去藉由野外量測礫石粒徑需耗時多日，因此本研究採用機器學習法（machine learning），以提供可快速估算礫石粒徑與空間分布的方法。

本研究針對台灣東部河流使用無人機拍攝河床照片及製作高解析度正射影像，並採用機器學習方法訓練礫石辨識模型，以自動圈繪正射影像中之礫石並進一步計算其長、短軸資訊及各河流之粒徑中位數（D50）與河道剖面礫石粒徑變化。此外自動圈繪之資料也與現地量測之數據進行比對，以評估其與實際測量之誤差值。其中機器學習法應用了為細胞分析發展的Cellpose機器學習模型，其採用監督式學習法，並利用U-net及residual block等架構，使其具備訓練快速與對特定大小物體具有高準確率等特性。但其缺點為圈繪極端物體（與預期目標物體大小相差數十倍）時，因模型架構設計的限制，使圈繪效果不佳。所以，本研究調整每次訓練所使用之原始影像礫石大小，以及將影像隨機縮放及旋轉等方法，使模型可用於礫石粒徑變化大較大之影像，並透過調整正射影像解析度，將不同解析度圈繪的礫石資料結合，可使其圈繪所有不同大小的礫石，並具有高準確率。後續透過經濟部水利署水文年報上載之東部水文站年平均流量，結合河床寬度與經驗公式推算研究河段理論流量，比較不同河流之流量、河流陡峭度及沈積物粒徑分布結果，探討台灣東部河流沈積物粒徑分布的特性，與其搬運的控制因素。

中文關鍵詞：機器學習、沈積物粒徑分析、河流、台灣東部

以同位素地球化學方法進行濁水溪流域地表與地下水文循環評估

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濁水溪流域是台灣最早開發利用地下水的區域之一，為了滿足經濟與產業需求，當地長期大量抽取地下水。然而，地下水屬於有限資源，其永續利用仰賴於降雨、岩層水等來源的補注。透過水量平衡的計算，有助於評估潛在的水資源。目前已有研究透過演算法與降雨-逕流模型等方法，估算濁水溪中上游跨集水區的地下水流動情形，但仍缺乏化學性證據。本研究在濁水溪中、上游地區採集河水、淺層地下水與深層地下水樣本，探討水體的溶質來源，釐清其在縱向與側向上的互動關係，並與現有數值模型對比，期望提供未來地下水資源調查與管理的依據。本研究透過感應耦合電漿發射光譜儀（ICP-OES）進行主要元素的定量分析，結合溶解性離子與陰陽離子比例，推估水體溶質來源及風化路徑對水化學的影響；同時採用多接收器感應耦合電漿質譜儀（MC-ICP-MS）進行$^{87}Sr/^{86}Sr$比值測定，評估水體交換情形。觀測結果顯示：縱向上，在同一子集水區的地表河水、淺層及深層地下水的鍶同位素比值相近。深層地下水具有較高的矽酸鹽風化比例，而河水與淺層地下水多以碳酸鹽礦物風化為主導，並在Ca/Na與Mg/Na比值上相似，顯示兩者溶質來源較為接近。側向分布方面$^{87}Sr/^{86}Sr$比值在陳有蘭溪東西側有顯著的差異，在東側較高，西側則較低；在同側多個子集水區的地表及地下水水體經變異數分析後，顯示幾乎無差別。推測陳有蘭溪東西兩側的水流皆有往中間方向移動的情況，與現有數值模型中，清水溪流域為失水集水區、陳有蘭溪流域為得水集水區的結論相符，亦可反映陳有蘭溪在構造上作為西部麓山帶與變質帶交界的狀況。綜合結果討論，在濁水溪流域上游，河水和淺層地下水的溶質來源主要為碳酸鹽礦物，深層地下水則含有較多矽酸鹽礦物。地表與地底的水體存在一定程度的水體交換，並以陳有蘭溪為東、西分界，存在跨集水區的地下水流動。

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中文關鍵詞：濁水溪、地下水、鍶同位素、風化路徑

MYSTERY OF THE KUTCH TERRANE, BIOGEOGRAPHIC EVIDENCE FROM THE MIOCENE SAND DOLLARS

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During the final stage, the Tethys was separated into the Indian Ocean and Mediterranean Sea during the Miocene. The timing and exact process of this disconnection, however, remain unclear. The Kutch region, India, is now interpreted as an isolated terrane that later collided and merged into the Indian subcontinent after India had already collided with the Eurasian plate. By comparing fossil echinoids from Kutch with echinoid faunas from Taiwan and the Mediterranean, this study tests hypotheses on the final episode of the Tethys based on echinoid biogeography.

Specimen images from three regions – Europe, India (Kutch terrane), and Taiwan – were used for landmark analysis to understand evolutionary relationships within the superfamily Astriclypeoidea Lin in Lee et al., 2023. Traditional and geometric morphometric landmark analyses, along with Principal Component Analysis (PCA), were employed. This study shows Kutch echinoids share closer affinities with Indo-West Pacific (IWP) faunas, based on their similarities to Taiwan fossils, thus challenging established theories on their origins and migration directions. This correlation underscores the importance of combining traditional and geometric analyses, reinforcing conclusions and prompting a reevaluation of echinoid evolutionary paradigms.

Keywords:Morphometrics, PCA, Astriclypeoidea, Miocene biogeography, Tethys

Mitigating Ionospheric Effects in DInSAR Using TRIM TEC Map: A Case Study of the September 17, 2022 Earthquake

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On September 17 and 18, 2022, shallow earthquakes struck Guanshan and Chihshang, respectively, causing significant surface ruptures and noticeable ground deformation. We used Differential Interferometric Synthetic Aperture Radar (DInSAR) technology to analyze the deformation pattern. This study employed ALOS-2 satellite images captured in the descending track before (April 3, 2022) and after (September 18, 2022) the earthquake, covering the September 17 event, which had a magnitude of M6.6 and a focal depth of 7.8 km.

Ground displacements can be detected by performing differential interferometry on two radar satellite images. However, besides surface deformation, the measurements also contain errors caused by ionospheric effects, and topographic variations etc. The ionospheric errors result from delays as the satellite signal traverses the ionosphere. Taiwan is located in the Equatorial Ionization Anomaly (EIA) region, where the Total Electron Content (TEC) varies over time due to EIA fluctuations. If there is a difference in TEC between the two images, additional phase fringes appear in the interferograms.

To mitigate the ionospheric effects in DInSAR results, this study utilizes the Taiwan Regional Ionospheric Map (TRIM) TEC data provided by the Taiwan Analysis Center for COSMIC (TACC). Given that Taiwan is near the northern boundary of the EIA, ionospheric correction is typically performed using the peak electron density altitude (hmF2) distribution as a penetration window. A weighting matrix is applied during correction since the signal path may be oblique and curved. After ionospheric correction, the accurate coseismic surface deformation can be accurately obtained.

Keywords:DInSAR, Ionospheric effects, Total electron content, Taiwan Regional Ionospheric Map, Generic Mapping Tools

濁水溪沖積扇中部層序地層與水文地質架構

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在濁水溪沖積扇海拔15－35公尺的中部區域，抽取地下水使得局部沈降快速。到目前，地下水管理仰賴深度300公尺以內的水文地質架構：4個阻水層—富水層組合，大致對應第四紀晚期萬年尺度的海進—海退循環。海退時，上扇礫石堆積向下發散，在中扇形成富水層；海進時，下扇與近海泥質堆積向上淹漫，在中扇形成阻水層。然而以往發現濁水溪兩岸有顯著的差異，層序對比尚有疑義，另外還有來自更深處的沈降量。本次調查利用5孔深達400公尺的新舊鑽井岩心，擴大檢視中扇的層序特性與對比，作為強化水文地質架構的參考。

本區岩心的岩相特徵變異大，易辨識、統整為3礫石、3砂層與3泥層相，並組成3沉積相：代表上—中扇的辮狀河礫砂層、中—下扇外洗平原的泛濫平原砂泥層、與沿海的潮汐灘台與遠濱貝殼質泥砂層。各井岩心最多分出5個堆積層序，界限是嚴重斑駁、厚達數公尺的土壤層頂面，代表海平面持續下降、中扇區出現堆積間斷與不整合面。界限之上是辮狀河與氾濫平原的礫砂層，代表海平面不再下降，處於穩定的低水位時期，中扇區堆積重新啟動。爾後出現的是沈積相更深、顆粒度更細的潮汐灘台—遠濱泥砂層，代表海平面大幅回升，海岸線入侵中扇區。層序最上部沈積相再度變淺為氾濫平原與辮狀河礫砂層，代表海平面達到最高水位並緩慢下降，海岸線逐漸退出中扇的過程。在地表以下的第一個層序中，碳十四年代指出低水位堆積晚於30千年前才開始，並持續到16千年前，海進堆積約發生於16—6千年前的期間，高水位堆積為最近6千年。

各層序海進階段的潮汐灘台—遠濱泥砂層側向延伸良好，貫穿南北兩岸，據此建立的地層架構成功地擴展到400公尺深度，阻水層—富水層組合增加到5個。另外剖面也顯示，北岸各層序的陸相礫砂層佔比高、厚度大，顯示長期處於中扇略上游的堆積環境，儲水潛能、粒間支撐性良好；南岸則反之，礫石層也以極細礫居多，屬於中扇略下游的堆積環境，儲水潛能、粒間支撐性稍遜一籌。

中文關鍵詞：濁水溪、沖積扇、層序地層、水文地質、中扇

Waveform Polarity Determination via Deep Learning and It Application in Focal Mechanism Inversion

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We propose a novel concept of waveform polarity and develop the corresponding deep learning approach to achieve rapid focal mechanism solutions that are close to the Global Centroid Moment Tensor (GCMT) catalog. Based on 12 independent median-to-large earthquakes in Taiwan, the results demonstrate that most focal mechanisms are close to GCMT, with Kagan angles less than 35 degrees. Also, the proposed approach shows performance robustness under a 0.2-second random time shift of the arrival time. Similar robustness is difficult to meet for the traditional first-motion polarity approach.

Keywords:focal mechanism, deep learning, polarity

關仔嶺地區不同流體對邊坡穩定之影響

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摘要:

(1)邊坡的穩定性受到環境氣候、岩層岩性、地形構造及地震活動等因素所影響，由複雜的滑移機制所調控。目前已知當流體滲透岩石時，短時間內將提高孔隙水壓，造成有效正應力降低，減少摩擦力，進而促使邊坡滑移，而長時間的水-岩反應則可能造成黏土礦物增生，進而使岩石強度減弱。關仔嶺地區具備三種不同流體特性，分別為溫泉水、地下水及河水，其流體的化學成分有所差異，在長時間進行水岩反應後，可能造成礦物比例或微觀組構分布差異而造成不同的物理特性，進而影響岩石孔隙率及摩擦係數，本研究利用礦物學與微觀技術分析不同流體對現地岩石的影響，進而提供邊坡穩定性更深入的微觀資訊。

(2)關子嶺溫泉區之岩層呈現東北-西南走向，出露地層包括上新世的鳥嘴層(泥質砂岩、砂質頁岩及厚砂岩)、澐水溪層(頁岩)、六重溪層(泥質砂岩、砂質頁岩及粉砂岩)及部分階地堆積層。本研究於鳥嘴層及澐水溪層分別採集露頭，分別為G2和G4，根據地層位態搭配合適的水樣溫泉水(GZL3)、地下水(GZL6)以及河水(GZL8)，分別進行常溫25℃下60天與180天的水-岩反應，也進行150℃30天之水岩反應模擬反應前後之變化趨勢。以感應耦合電漿光學發射光譜儀（Inductively coupled plasma optical emission spectrometry,ICP-OES）比較反應前後之流體離子濃度變化，並量測PH值、導電度及總溶解固體量，利用掃描電子顯微鏡搭配能量發散光譜儀(Scanning electron microscope-Energy dispersive spectrometer,SEM-EDS)觀察其微觀組構之特性，並透過X光繞射儀（X-ray diffractometer,XRD）分析礦物相佔比。

(3)首先在水質檢測的結果中觀察到，所有流體都在水-岩反應後PH值有明顯上升的趨勢，此外，溫泉水顯著提升流體中Ca^{2+}及Mg^{2+}濃度，不同於地下水提升K^{+}濃度，以及河水造成流體中Si^{4+}和K^{+}濃度提升。由XRD結果中發現三種流體進行水-岩反應後，皆造成黏土礦物增生的現象，尤其在長時間反應後結果更為顯著。並在SEM影像觀察到部分石英及長石溶解的情況，尤其以河水反應後有最明顯的侵蝕痕跡。

(4)綜合以上結果，由水質資料結果證實流體與岩石之間發生交互作用，進而使流體趨向鹼性，並發現三種流體進行水-岩反應後，造成流體中離子濃度變化趨勢明顯不同，由SEM結果可以看出不同流體在水-岩反應速率增加的情況下可能造成特定礦物的侵蝕行為，降低邊坡岩石之機械強度，進而對邊坡穩定性造成不同的風險層級，本篇研究提供微觀證據，比較不同流體對邊坡穩定性之影響，為工程端提供新的見解，以助於邊坡安全之防護更完善。

中文關鍵詞：邊坡穩定性、水岩反應、黏土礦物

Spatial Correlations Between Land Subsidence and Population Density: A Case Study from Jakarta, Indonesia

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Land subsidence has emerged as a growing global issue, specifically in urban areas, which is dominantly driven by both sediment consolidation and groundwater withdrawal. Numerous earlier studies indicated a high relationship between driving factors and population density, inducing larger subsidence zones across the spatial domain. However, the empirical relationship is not yet clearly accounted for. Therefore, this study integrates population density as a predictive factor for land subsidence rates across areas with varying population levels, using an empirical model based on a land subsidence case in Jakarta, Indonesia. The deformation results from 1275 pairs of images in SBAS-InSAR were incorporated with Moran's I algorithm to estimate the spatial heterogeneity of each variable. To validate the spatial heterogeneity result, Ordinary Least Squares (OLS), Geographically Weighted Regression (GWR), Multiscale GWR (MGWR), and Semi-parametric MGWR (SM-GWR)—all spatially explicit regression models—were employed to identify the most suitable model for capturing geographical heterogeneity. Moran's I values of land subsidence rate and population density are 0.93 and 0.96, respectively. The performance of OLS, GWR, MGWR, and SM-GWR was evaluated using the coefficient of determination (R^2) and the corrected Akaike Information Criterion (AICc). The respective R^2 values were 0.025, 0.960, 0.978, and 0.979, while the corresponding AICc values were 19,838, 1,150, –716, and –615. These findings indicate a clear presence of spatial heterogeneity in Jakarta and its surrounding regions. The annual deformation rate within the study area, measured along the Line of Sight (LOS) direction, ranges from -60 mm/year to +20 mm/year. The increasing subsidence rates in most affected areas demonstrate a predominantly positive correlation with high population density. However, two distinct zones reveal a contrasting trend, where the impact of population density on subsidence is either diminished or inversely related. Furthermore, the derived empirical equation was applied to predict land subsidence rates in Bandung City, West Java, Indonesia. The prediction strongly agreed with InSAR observations, validated by an R^2 value of 0.8298. This empirical model underscores the high accuracy of spatial heterogeneity estimation achieved in Jakarta and its surrounding regions. It offers valuable insights into subsidence potential in areas where ground deformation has yet to be identified.

Keywords:Land subsidence, Population density, S-BAS InSAR, SM-GWR

Classification of the April 3rd, 2024 Mw 7.4 Hualien, Taiwan, Aftershock Sequence Using Waveform Cross-Correlation

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A destructive M_w 7.4 earthquake struck Hualien, Taiwan, on April 3, 2024, followed by hundreds of felt aftershocks. Understanding the fault geometry of this sequence is crucial for comprehending its seismogenic structure and enhancing future preparedness. In addition to the common Centroid Moment Tensor (CMT) solution for the aftershocks, we utilized the cross-correlation of seismic waveforms to classify the characteristics of the aftershocks sequence.

We firstly analyze M >4 aftershocks that occurred within one week after the mainshock (April 3–10, 2024) from the relocated catalog using double-difference method by Hsin-Hua Huang. Waveform data were collected from all 41 stations of the Broadband Array in Taiwan for Seismology (BATS). We define an earthquake pair as two events separated by a distance of less than 3 km. This threshold is chosen not only to ensure proximity of the sources but also to maintain similar Green's functions, allowing for more reliable cross-correlation analysis. We considered the time window spanning 0.5 seconds before to 5 seconds after the estimated P-wave arrival, applying a 1–8 Hz bandpass filter. For event classification, we compute cross-correlation coefficients for each earthquake pair using waveforms recorded across all channels of the BATS stations. This analysis aims to categorize aftershocks based on their waveform similarities, providing insight into their characteristics, and helping to map the major seismogenic structures through their spatial distribution.

By examing aftershocks patterns and the seismogenic structures in which they occurred, we seek to gain a deeper understanding of the faulting processes involved in the 2024 Hualien earthquake sequence. Additionally, this study explores the possible complexity of the offshore seismogenic structure associated with Ryukyu subduction zone.

Keywords: Aftershock classification, Waveform cross-correlation, Fault geometry, Faulting complexity, Offshore seismogenic structure

利用歷史地震探討臺灣的孕震構造-臺灣地震帶專書發表

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位處於板塊交界的臺灣地震頻繁，然而許多地震的孕震構造解釋，亦或是地震與活動斷層的連結仍不明朗，成為長久以來的研究課題。國家災害防救科技中心為了提升對活動構造的認知，並支援與強化地震應變作業，自2018年起與學界合作，透過系統性的分析臺灣陸域與鄰近海域1990至2020年的歷史地震，搭配震源機制與地下速度構造，將臺灣八大地質構造區劃分出38個地震帶與2個無震帶，並藉由歷史地震性質與區域地質特性來探討各個地震帶的地震類型與分布範圍，嘗試給予各個地震帶的地質解釋，以串聯地震與活動構造，並將成果於2024年9月出版為「臺灣地震帶」一書。

除了進行地震的分類，本書也對於各個地震帶在地下速度構造展現的物理特性進行探討，並分析31年的歷史地震中，各個地震帶是否存在重複出現的地震現象，以獲取中型地震（規模M_L6.0-7.0）的活動特性。本研究亦藉由GOCAD軟體建構每個地震帶的三維數值模型，用以計算各地震帶的體積與單位體積的地震數量，進行跨地震帶的活躍程度評估。

中文關鍵詞：歷史地震、活動斷層、孕震構造、地震帶

An X-ray Computed Tomography-Based Approach for Enhancing Visual Core Description

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Identifying sedimentary features—such as grain-size variations and sedimentary structures— is crucial for understanding depositional processes and reconstructing paleo-environments. Conventional methods like visual core description remain fundamental in sedimentology but are limited by internal visibility and subjective interpretation. X-ray Computed Tomography (CT), a non-invasive imaging technique with high spatial resolution, offers a complementary approach for visualizing three-dimensional internal features and enabling quantitative analyses of sedimentary characteristics. This study evaluates the potential of CT to enhance visual core description by analyzing two sedimentary cores from the Dapeng Bay region in southwestern Taiwan. In addition to revealing internal structures that are imperceptible to the naked eye, CT-derived parameters—such as mean CT intensity, coefficient of variation, intensity range ratios, and morphological attributes—were used to characterize textures and structures quantitatively. Through this approach, fourteen CT-based sedimentary units were delineated and grouped into three broader facies: lagoonal, channel, and tidal flat. These results support the reconstruction of a 500-year depositional history and highlight how subtle variations in CT imagery and associated metrics can reveal high-energy depositional signatures. By integrating qualitative CT imaging with quantitative descriptors, this study proposes a systematic and reproducible framework for enhancing visual core description, capturing subtle sedimentary heterogeneities and ensuring interpretive consistency across cores. This work underscores the potential of CT-based approaches to improve sedimentological interpretation through reproducible, quantitative analysis applicable across diverse depositional systems.

Keywords:Computed Tomography, Core Description, Dapeng Bay

基於LSPIV之微型電腦流量監測系統-以金崙溪流域為例

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本研究旨在開發一套基於大尺度粒子影像測速技術（Large-Scale Particle Image Velocimetry, LSPIV）的河川水流監測系統，用於獲取河川表面流速，進而估算流量變化，並於台東縣金崙溪進行實地安裝與應用。該系統採用低成本的樹莓派單板電腦及鏡頭模組，設置於金崙溪虹橋附近右岸，每小時自動拍攝10秒連續水流影像，影格率為30 FPS。所拍攝之影像後續透過開源程式 pyOpenRiverCam 進行正射校正，並應用 LSPIV 技術估算觀測河段之表面流速場。結合人工測繪之河道剖面與水深資料，可進一步運用速度－面積法進行流量推估。本研究針對2025年2月至5月期間所拍攝之河道影像進行分析，透過比較 LSPIV 所估算之表面流速與現地實測流速，探討流量估算之潛在誤差來源，以提升LSPIV在流速估算上的可靠性。綜合不同水深條件下所推估之流量資料，可建立該河段之水位－流量率定曲線（rating curve），進而於洪水等劇烈水位變化事件期間，透過此監測系統進行即時流量估算，補足傳統水文觀測方法之不足。建立一套可於目標河段快速架設、低成本且具高可靠性的河川監測系統，將有助於蒐集山區河川之水文資訊，提升洪水災害之觀測與應變能力。

中文關鍵詞：大尺度粒子影像測速技術(LSPIV)、流速估算、水位-流量率定曲線、金崙溪

大屯山高溫中性流體酸化探討

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大屯火山擁有龐大的地熱資源，除了現有的結元四磺坪地熱電廠利用淺處的乾蒸氣發電外，若能開發深部的高溫中性流體，則可為台灣地熱開發帶來極大躍進。回顧大屯山過去的鑽井紀錄，資料顯示大屯山高溫的地熱井往往無法自噴或以噴氣為主。地熱井之流體地球化學又隨著時間有極大跳動：如有完整紀錄的E205號井最早流體pH值約5左右，而後蒸氣乾度提升且pH值上升至5.6，然而三個月後　pH值降至2。對於pH值的降低前人提出的解釋包含：原本的出水層因為流量與壓力洩降，由乾蒸氣轉為濕蒸氣，火山氣體中的硫化氫得以溶入液滴形成硫酸根降低pH值、高濃度滷水因為閃發造成鹽類析出沉澱，堵住裂隙通道導，致使其他通道的酸性流體入侵…等。

這幾年的地熱探勘計畫，我們有機會取得大屯山多口地熱深井流體，與過去研究類似，我們亦觀察到深部流體在完井初期為弱酸至中性，而後產測之pH值、各項離子濃度呈現大幅跳動。除了地下儲集層流體熱焓與成分本身的變動外、冷凝器汽水分離的程度都會影響地化量測的數值。再者，現場量測之中性流體由於含高濃度的鐵離子與硫化鐵，至地表後的氧化亦會釋放氫根與硫酸根使pH值下降(其中一口井甚至由pH值6.1降至3.2)。這些顯著的變化隱示硫化鐵與熱液中高濃度的鐵離子在大屯火山氧化帶亦在酸化扮演重要角色、深部流體若流量減弱且暴露於連通大氣的條件下，不僅蒸氣濕度提升會造成硫化氫溶於水變成硫酸根之酸化、鐵氧化亦會加劇pH值降低。將地表水注入儲集層亦須考量鐵氧化之酸化問題。

中文關鍵詞：大屯山、地熱、中性流體、鐵氧化、酸化

鈣鈦礦結構鹼土金屬錫酸鹽之熱膨脹與結晶化學關聯性分析
Analysis of the Correlation Between Thermal Expansion and Crystal Chemistry in Perovskite-Structured Alkaline Earth Stannates

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鈣鈦礦（ABO_3）結晶結構可視為由共頂點的BO_6八面體構成之三維結構，A位離子則填充在八面體間形成的8至12配位空隙中。Goldschmidt tolerance factor[1]用以衡量A、B離子半徑的匹配程度，其值接近1時，形成理想的鈣鈦礦（cubic）結構。隨著其值逐漸偏離1，導致BO_6八面體扭曲程度增加，形成$GdFeO_3$型（orthorhombic）鈣鈦礦，進而影響結構穩定性與物理性質。

在鹼土金屬錫酸鹽$(Ca,Sr,Ba)SnO_3$序列中，隨A位離子半徑由Ba^{2+}（1.61Å）、Sr^{2+}（1.44Å）遞減至Ca^{2+}（1.34Å），tolerance factor依序從1.06降至0.88。$BaSnO_3$維持立方結構，而$SrSnO_3$與$CaSnO_3$因八面體傾斜，皆屬$GdFeO_3$型斜方對稱[1,2]。由於此系列錫酸鹽在高溫仍保持鈣鈦礦結構 故視為探討地球深處鈣鈦礦結構矽酸鹽$((Mg,Ca)SiO_3)$礦物物理性質的良好類比材料。本研究以固相反應法[3]合成$CaSnO_3$、$SrSnO_3$與$BaSnO_3$粉末樣品。為獲得高解析數據，於國家同步輻射研究中心（NSRRC）進行高溫高解析X光繞射實驗（HT-XRD），於298至1173K範圍內觀察樣品熱膨脹行為。

除$BaSnO_3$外，其餘樣品成功利用高解析粉末繞射數據觀察到高溫下氧原子位置變化及錫氧八面體（SnO_6）之振動。觀察結構中三軸方向膨脹行為，$BaSnO_3$呈現均向線形膨脹；在$CaSnO_3$之a軸則出現非線性膨脹；$SrSnO_3$在三軸膨脹行為不同且皆非線性。而從體積熱膨脹率來看，儘管Ca^{2+}、Sr^{2+}與Ba^{2+}之離子半徑差異顯著，但以$BaSnO_3$為基準計算，$CaSnO_3$與$SrSnO_3$的體積熱膨脹係數與$BaSnO_3$相比，差異均小於7%，且三者皆呈現良好的線性膨脹行為，顯示體積膨脹係數未明顯受陽離子半徑影響。此外，$SrSnO_3$為本系列在高溫下唯一發生相變的材料，其自斜方晶系轉變為四方晶系，體積在相變過程中呈現連續變化，從熱力學觀點認$SrSnO_3$在此溫度區間之相變屬性屬於二階相變。綜合高解析粉末繞射實驗結果，本研究呈現鈣鈦礦結構材料在高溫下受結晶化學控制的結構演化行為，一系列的熱膨脹率數據可針對地球科學領域鈣鈦礦結構材料在熱性質研究提供協助。

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中文關鍵詞：鈣鈦礦結構、結晶化學、熱膨脹係數、高溫X光繞射、鹼土金屬錫酸鹽

High-Resolution 3D Imaging of the Thrust System East of Chiayi Using Dense Array Ambient Noise and Eikonal Tomography

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Southwestern Taiwan lies within a zone of intense structural deformation resulting from the arc-continent collision between the Luzon Arc and the southeast Eurasian continental margin. East of Chiayi, a thrust system composed of imbricated faults and associated folds accommodates substantial crustal shortening and uplift driven by this ongoing tectonic convergence. In such areas, high-resolution seismic imaging can be useful for delineating crustal structures and understanding active deformation; however, this is often limited by sparse station coverage and topographic constraints. This study integrates ambient noise tomography (ANT) with eikonal tomography to investigate the shallow-to-mid crustal structure of the thrust system east of Chiayi using data from a dense nodal seismic array. Rayleigh wave and Love wave phase travel times were extracted from empirical Green's functions obtained through cross-correlation of ambient seismic noise. Spatial gradients of the travel-time fields were then used to construct detailed phase velocity maps. The dense array improves azimuthal sampling and enhances the resolution of lateral velocity variations, allowing the identification of subsurface discontinuities, low-velocity zones, and fault-related features. The results provide new constraints on the structure of the thrust system.

Keywords:ambient noise tomography, Eikonal tomography, thrust fault system

地質樣本用高解析Micro-CT成像系統開發與性能評估

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為實現2050年淨零碳排放之目標，台灣已將碳捕捉、利用與封存（Carbon Capture, Utilization and Storage,CCUS） 技術列為十二項關鍵戰略之一。其中，「碳封存」的關鍵在於選擇具備良好儲碳潛力與長期封存穩定性的地下儲層。此評估通常需透過岩心鑽取與其微觀孔隙結構分析，以確認儲層容量與封存安全性。

近年來，微型電腦斷層掃描（Micro-computed Tomography, Micro-CT）技術逐漸應用於地質樣本的三維結構分析。相較於傳統的岩石切片觀察與汞滲透法，Micro-CT具有非破壞性，並可提供高解析度三維影像數據等優勢，不僅可完整保存珍貴樣本，亦能清楚呈現孔隙空間分布並提供可視化影像，進而加速孔隙特性參數（如孔隙率與連通性）之量化分析。此技術有助於提升潛勢封存場址的篩選效率與定量評估能力，為碳封存技術發展提供關鍵支援。

本研究由國家原子能科技研究院建置一套高解析度微型電腦斷層掃描系統（Micro-CT），支援傳統斷層掃描（CT）與斷層合成（Tomosynthesis）模式。系統配置五軸自由度高精密掃描機構與大面積平板式偵測器，可因應不同形狀與尺寸樣本，提供靈活掃描條件及最大280×240 mm^2的成像視野。為驗證系統性能，本研究首先以QRM公司製標準線對假體（Micro-CT bar pattern phantom）進行空間解析度測試，後續並針對實際碳封存場址之砂岩岩心樣本進行掃描。結果顯示，系統影像空間解析度可達5 μm，並能清晰呈現砂粒排列與孔隙分布特徵，驗證本系統具備高精度岩心掃描能力，未來可應用於三維結構建模及孔隙率等地質特性參數之量化分析，對於強化國內碳封存場址之評估與研究工作具實質助益。

中文關鍵詞：微型電腦斷層掃描、二氧化碳地質封存、砂岩、孔隙尺度

臺灣中部橫貫公路變質泥岩磁黃鐵礦顯微組織對其生成及轉變之啟示

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本研究以電子及光學顯微鏡分析中部橫貫公路變質泥岩剖面之礦物學變化，以增加瞭解磁黃鐵礦生成及轉變之現象與分布。雪山山脈西側達見砂岩板岩未見黃鐵礦，但普遍見有約略平行劈理之半自形嵌晶狀鈦鐵礦($Fe_{0.95}Mn_{0.05}TiO_3$)板晶，包裹石英或片狀矽酸鹽礦物，偶見包裹細粒不規則狀金紅石、方鉛礦和殘存磁黃鐵礦。綠簾石－褐簾石局部包裹磁黃鐵礦、輝砷鈷礦或黃銅礦，石英則局部包裹閃鋅礦、黃銅礦、磁黃鐵礦、輝砷鈷礦或方鉛礦等硫化物；達見砂岩含黑雲母板岩具有沿劈理發育之磁黃鐵礦。達見砂岩東側之佳陽層未見鈦鐵礦，由西而東分別見有沿劈理延伸之不規則狀多晶磁黃鐵礦集合體、再結晶自形黃鐵礦和黃鐵礦莓狀體。脊梁山脈關原斷層以西板岩含有黃鐵礦莓狀體或莓狀體集合體，局部伴生閃鋅礦、黃銅礦、輝砷鈷礦或方鉛礦。關原斷層附近初現沿劈理發育之不規則狀多晶磁黃鐵礦集合體，局部見有黃鐵礦莓狀體部分為磁黃鐵礦單晶假像取代，另有部分磁黃鐵礦集合體局部保有莓狀體微晶假像組織，相對粗粒黃銅礦、含鐵閃鋅礦、方鉛礦及輝砷鈷礦常鄰近磁黃鐵礦生長。關原斷層以東，僅見沿劈理發育之磁黃鐵礦，缺乏黃鐵礦莓狀體，部分樣品同時出現再結晶粗粒自形黃鐵礦。關原斷層附近磁黃鐵礦成分為$Fe_{0.85}Ni_{0.01}S$，關原斷層以東及雪山山脈磁黃鐵礦則分別具有$Fe_{0.88}S$和$Fe_{0.88}Ni_{0.01}S$成分。金紅石普遍存在於脊梁山脈變質泥岩，但多數板岩未見鈦鐵礦。脊梁山脈變質泥岩同構造期磁黃鐵礦生成與成岩黃鐵礦密切相關，初期乃透過假像取代黃鐵礦生成，局部伴隨黃鐵礦及其他硫化物之再結晶。雪山山脈達見砂岩變質泥岩證實亦曾存在磁黃鐵礦，但多數已透過與金紅石氧化反應脫硫，為鈦鐵礦所取代。佳陽層變質泥岩則呈現與脊梁山脈變質泥岩相似之黃鐵礦－磁黃鐵礦轉變反應。本研究結果顯示中橫公路變質泥岩磁黃鐵礦之分布曾較目前所知為廣。

中文關鍵詞：磁黃鐵礦、黃鐵礦、鈦鐵礦、顯微組織、變質泥岩

臺南玉井地質調查-鏡面砂岩的層位探討

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鏡面砂岩出露於臺南麓山帶，向南傾沒的玉井向斜構造內，以灰色或黃灰色細粒至中粒砂岩及泥岩為主。在過往文獻中，此砂岩呈透鏡狀，在向斜樞紐帶厚達數百公尺，翼部變薄，並可延伸至牛牧嶺與坑內一帶，作為區分北寮頁岩與玉井頁岩的依據。

野外調查與光達（LiDAR）地形資料顯示，鏡面砂岩在向斜樞紐帶可由兩套向上變細的厚砂岩，間夾中層至薄層的砂泥互層組成，厚砂岩底部多以水道沉積物為主，間夾具生物擾動的砂泥岩，此與翼部出露的砂岩產狀不同。超微化石生物地層分析成果，顯示鏡面砂岩位於Backman (2012)所示CNPL8生物帶內，進一步參考Large *Gephyrocapsa* (>5.5μm) 分布，樞紐帶出露的鏡面砂岩屬CNPL8生物帶下部，西翼的鏡面砂岩在CNPL8生物帶上部，推測樞紐帶與翼部出露的砂岩分屬不同的層位。

中文關鍵詞：鏡面砂岩、鈣質超微化石生物地層、玉井向斜構造

Relocated Seismicity near the Chaochou Fault from the SALUTE Array

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SALUTE (Southern Array for the Lithosphere and Uplift of Taiwan Experiment) is a seismic array composed of broadband stations deployed both on land and offshore. The land-based stations are primarily arranged in a cross-shaped configuration, consisting of an east-west line that spans southern Taiwan from Kaohsiung to Taitung, and a north–south line that is distributed laterally along the Chaochou Fault. Deployment of the array began in October 2021 and was completed in August 2024 with 32 stations. With an average interstation spacing of approximately 7 km, the SALUTE array provides dense coverage across south-central Taiwan, enabling the detection of small-magnitude earthquakes. The Chaochou Fault is a left-lateral fault with a minor thrust component. However, recent significant earthquakes near its northern segment, including the 2010 Jiashian, 2012 Wutai, and 2016 Meinong events, occurred at depths exceeding ~20 km. Shallow seismic activity near the Chaochou Fault is still unclear.

To enhance spatial coverage, we integrate eight additional stations from the BATS (Broadband Array in Taiwan for Seismology) network. We combine several tools for seismic detection and location. EQTransformer, a deep learning-based earthquake detector and phase picker (Mousavi et al., 2020), is used to identify P and S arrivals. Detected events are then located using scanloc, a module from SeisComP, which incorporates DBSCAN-based clustering for local earthquakes. For high-precision relocation, we apply the double-difference algorithm using HypoDD (Waldhauser and Ellsworth, 2000). With this configuration, earthquakes as small as ML0.5 are reliably detected. The purpose of this study is to identify and characterize potential structures that may correlate with known surface fault traces.

Keywords:SALUTE, Chaochou Fault, SeisComP, HypoDD

Towards resolving phase wrapping artefacts in strong motion DAS recordings

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Distributed Acoustic Sensing (DAS) has the potential to bring many new opportunities to the field of seismology, but it suffers from the issue of phase wrapping during strong ground shaking.
We investigate the possibility of repairing wrapping in data collected from the MiDAS (Milun Fault Drilling and All-inclusive Sensing project) borehole installation in Hualien, Taiwan.
In our case, unwrapping of this data by conventional techniques is hampered by the high DAS noise floor which, when combined with the automatic decimation performed by the interrogator, has the effect of smoothing the exact transition when wrapping, making it more difficult to detect wrapped signal segments.
We present a method for 2D phase unwrapping based on image processing techniques and assess the performance on locally recorded earthquakes with magnitudes up to 7.4 by comparing the integrated unwrapped DAS records and collocated borehole seismometer records.
Suggestions as well as practical considerations and limitations are given with regards to implementation of phase unwrapping for strong-motion recordings.

Keywords:DAS, Milun Fault, Earthquake

水岩反應模擬宜蘭員山EGS之儲集層地化變化

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地熱因其可以做為基載電力來源而為國家重點發展對象，傳統型地熱發電須包含三大條件:充沛的水源、足夠的熱源與良好的儲集層(如裂隙系統、蓋層等)，這些嚴苛的條件使得開發時經常不如預期，增強型地熱系統(Enhanced Geothermal System，EGS) 由於可人為製造裂隙及注水循環取熱，被視為未來極具潛力的發電方式。

中央研究院與台灣中油公司於宜蘭縣員山鄉進行EGS地熱電廠前研究除了鑽鑿4000公尺探勘井外，EGS注水後牽涉到氧化態的地表水灌入還原態的地下汲取熱源，水與圍岩交互作用下礦物的溶解與沉澱是後續儲集層管理重要的一環。

本研究以員山一號井的岩屑為材料，，觀察岩屑與超純水高溫水岩反應之變化，將岩屑與超純水放入水岩反應裝置進行高溫水岩反應，透過改變水岩比、溫度與時間來模擬EGS後可能的水岩礦物化學反應。以多功能水質計觀察水岩反應前後水之性質變化、以離子層析（IC）、感應耦合電漿光學發射光譜儀(ICP-OES) 、滴定儀探討離子濃度變化。並將反應前後的岩屑樣本進行掃描電子顯微鏡（SEM）與X光繞射分析（XRD）分析觀察礦物的溶解與生長。

初步結果顯示，四稜砂岩地層富含黃鐵礦，若注入水與黃鐵礦進行水岩反應，會改變熱液性質。高溫且氧化環境會使黃鐵礦溶解、進而造成水樣pH值下降、水樣中硫酸根離子的上升，在進行水岩反應的坩鍋中，也可以看見明顯的鐵染狀況，反應後的岩屑樣本也有紅褐色鐵氧化物出現，此結果暗示在員山之EGS可能因為循環的流體酸化而能溶解碳酸鈣結垢，然而氧化鐵沉澱是否影響流體循環則需更多的評估。

中文關鍵詞：黃鐵礦、加強型地熱系統EGS、宜蘭員山、水岩反應、氧化還原

Characterization of carbon storage systems in central Taiwan and its offshore area

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Geological carbon storage is a key strategy for mitigating atmospheric CO_2 emissions. This study evaluates the carbon storage potential of up to 8 km-thick Cenozoic rock strata in central Taiwan and adjacent offshore regions, where major CO_2 emission sources are located. The target formations consist primarily of interbedded sandstone and shale layers. Using data from 22 boreholes and several seismic profiles, four potential carbon storage systems are characterized in terms of their lithological distribution, formation thickness, burial depth, permeability, and porosity. Three priority sites—Taichung Power Plant (TPP), Changhua Coastal Industrial Park (CCIP), and Mailiao Taisu Industrial Park (MTIP)—are selected for detailed analysis. The identified storage systems, each comprising a reservoir-caprock pair, include: (1) R1 system of the lower Cholan Formation (Fm); (2) R2 system from the Chinshui Shale (Sh), Kueichulin Fm, to Nanchuang Fm, and Kuanyinshan Sandstone (Ss); (3) R3 system from the Talu Sh to Peiliao Fm and Shihti Fm; and (4) R4 system from the Piling Sh to Mushan Fm and Wuchishan Fm. Spatial variations in depth and lateral facies changes among these systems result in distinct storage characteristics across different sites. Our results indicate that central Taiwan and offshore areas are ideal for the geological sequestration of CO_2 and that their capacity to host CO_2 requires further investigation.

Keywords:Geological carbon storage, caprock and reservoir, porosity and permeability, central Taiwan

Active tectonics of the Yuli fault in the central Longitudinal Valley area, eastern Taiwan

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The Yuli Fault, which was firstly recognized from the surface rupture of the November 1951 Chihshang-Yuli earthquake sequence, lies in the middle of the Longitudinal Valley, eastern Taiwan. The complete trace of the Yuli Fault was difficult to identify due to the lack of prominent geomorphic expression prior to the September 2022 Guanshan-Chihshang earthquakes and thus its long-term activity is yet characterized. To understand its long-term active behaviors, we use historical topographic maps, digital elevation models (DEMs) and field survey to map active tectonic features associated with the Yuli Fault along the recent surface rupture. Our analysis shows the Yuli fault has deformed a series of young alluvial fans, producing features including deflected streams, springs, and sag ponds. These features indicate that the Yuli fault is a highly active west-dipping oblique fault. Based on the offset of deflected streams in Lingzi alluvial fan and its age inferred from nearby alluvial surfaces, the millennial left-lateral slip rate of the Yuli fault is likely greater than 8-13 mm/yr. Given an average coseismic slip of ~0.8 m on the fault plane from recent earthquake, we suggest the recurrence interval of the Yuli fault is likely shorter than 100 years.

Keywords:Yuli fault, tectonic geomorphology, geomorphic features, digital elevation models, Longitudinal Valley

Unraveling the Climate and Human Impact on Surface and Subsurface Runoff Elasticity in Diverse Ethiopian Sub-basins

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Climate and landscape (n) changes significantly influence runoff, making it essential to understand water availability. However, the impact of climate and landscape characteristics on surface and subsurface runoff is less discussed. In this study, we quantified the changes in runoff components due to climate and landscape characteristics using the Choudhury–Yang equation (a modified Budyko equation) across six Ethiopian sub-basins. Trend and breakpoint analyses (1964–2023) using Mann–Kendall and Pettitt tests divided runoff data into pre- and post-breakpoint periods. The results revealed precipitation decreased (-1.33 mm/year) while potential evapotranspiration increased (1.72 mm/year) over the past 60 years. Total, surface, and subsurface runoff decreased by -19.7, -7.6, and -12.4 mm, respectively, between period 1 and period 2. Surface runoff elasticity was mainly driven by precipitation (49.3%), followed by potential evapotranspiration (26.2%) and landscape (24.5%). With a higher dryness index, the sensitivity of surface runoff elasticity to changes in precipitation increased. Subsurface runoff elasticity was dominated by potential evapotranspiration (33.6%) and landscape characteristics (39.7%). Climatic variables (precipitation and PET) dominated runoff elasticity, accounting for 66.7%. Notably, while total runoff elasticity reflects a combined response, our result showed that surface and subsurface runoff elasticity respond differently to catchment and landscape characteristics. Decomposing runoff elasticity into surface and subsurface components provides a novel approach for analyzing hydrological changes and offers new insights for managing water resources in complex catchments.

Keywords:Budyko framework, Runoff elasticity, Subsurface runoff, Surface runoff

Utilizing pig urine as a sustainable urea substitute in Microbial Induced Calcite Precipitation (MICP) for soil stabilization

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Microbial Induced Calcite Precipitation (MICP) is a sustainable technique for soil improvement, enhancing stiffness and reducing permeability through biologically mediated calcium carbonate ($CaCO_3$) precipitation. This study investigates the use of pig urine (PU), a urea-rich agricultural waste, as a sustainable substitute for commercial urea in MICP by evaluating its calcification potential and geotechnical performance using *Sporosarcina pasteurii* (DSM 33). Quartz-sand and soil columns were exposed to PU with calcium chloride (1.1 M), and key parameters including, bacterial concentration, injection intervals (4-12 h), retention time, solution concentration (0.25–1.0 M), and back pressure (0–100 kPa), were systematically examined under a constant effective stress of 50 kPa. Results showed that PU can effectively replace industrial urea, leading to significant $CaCO_3$ precipitation and improved engineering properties. Results indicate that shorter injection intervals (4 h) enhanced calcite precipitation by up to 43% compared to the untreated control, accompanied by significant reductions in porosity and permeability. Simultaneously, increasing treatment concentrations improved stiffness but caused premature pore clogging at higher levels, affecting uniformity of calcification. Continuous monitoring using s-wave bender elements confirmed that stiffness development correlated with calcite content rather than pore water pressure. Moreover, XRD and SEM analyses confirmed the mineralogical formation of calcite in PU-treated specimens, validating the microstructural transformations. These findings demonstrating advancing bio-based soil stabilization using agricultural by-products, and offers guidance for optimizing field-scale applications of MICP.

Keywords:Microbial Induced Calcite Precipitation (MICP), Sporosarcina pasteurii, Pig Urine, Bio-cementation, Sustainable Geotechnics

Volcanic history of Shamao complex: One of the youngest volcanic events in the late Pleistocene of Tatun Volcano Group, northern Taiwan.

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The Shamao complex is one of the youngest volcanoes in the Tatun Volcanic Group (TVG), resulting from a Quaternary andesitic magmatic event. It borders the northern flank of Taiwan's capital, Taipei City (population: 7 million), which raises significant concerns regarding the potential consequences of future volcanic activity, including the possibility of fatalities and substantial economic losses. Here, we present high-resolution geomorphological mapping and high-precision $^{40}Ar/^{39}Ar$ radiometric dating combined with petrology to constrain the volcano's eruption characterization and history of the latest scenario in TVG. Our results show that the Shamao complex comprises three principal landforms: The East and West Domes and the West Flow. The West Flow extends ~500 m westward from the southwestern base of Mt. Shamao, and the mountain itself consists of the East and West domes. The West dome growth that overlies the northwest corner of the East dome, which is composed of Hypersthene-hornblende andesite, occurred at 28.1 ± 7.89 ka, and the East dome growth at 24.2 ± 1.77 ka, composed of Augite-hypersthene-hornblende andesite. The West flow, an effusive lava flow event domain by two-pyroxene andesite, forms at 196.4 ± 2.3 ka.

Keywords:Dome morphology, 40Ar/39Ar Geochronology, Petrographic, Shamao complex, Tatun Volcano Group

Numerical Modeling of Overriding Plate Deformation and Pore Fluid Dynamics in Subduction Zones

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The slip behavior of subduction megathrusts is strongly associated with the properties of the plate interface and the deformation within the overriding plate. Viscosity, stress state, permeability, and pore fluid pressure within the overriding plate are important factors, because the accumulated elastic strain in the overriding plate applies tectonic stresses to the plate interface. While numerous studies have extensively investigated how individual factors affect plate interface coupling, numerical studies that simultaneously consider overriding plate deformation, the drainage effect of faults, and fully coupled hydro-mechanical modeling remain scarce. This study builds upon the i2elvisHTM model, a hydro-thermo-mechanical model using incompressible poro-visco-elasto-plastic rheology and combining finite difference (FD) and marker-in-cell (MIC) methods. We implement power-law viscosity to simulate the brittle-ductile transition zone and introduce strain weakening to represent the strength reduction in ruptured faults. Additionally, we incorporate the shear dilation effect, which accounts for rock yielding under high strain rates and overpressured conditions. This mechanism allows faults to act as fluid conduits during brittle fracturing at high pore pressure factors. Consequently, we can examine how fault drainage influences the distribution of pore fluid pressure and the coupling at the plate interface. The outcomes of this enhanced modeling framework provide deeper insights into the interplay between overriding plate deformation and fluid dynamics in controlling megathrust slip behavior.

Keywords:hydro-mechanical modeling, permeability, subduction zone, megathrust, coupling coefficient

二氧化碳封存數值模擬工具之計算效率評估

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隨著全球氣候變遷議題日益嚴峻，碳捕捉與封存（Carbon Capture and Storage, CCS）被視為達成淨零碳排目標的重要途徑之一。其中，地質封存技術利用深層鹽水含水層作為二氧化碳（ ）的儲存介質，具備封存潛力大與地層條件穩定等優勢。然而，CCS 實務應用中面臨的挑戰之一即為需對複雜地質構造中的　　遷移行為進行模擬，以確保封存效率與長期安全性。因此，模擬工具的選擇與效率評估，成為封存場址設計與風險評估過程中的關鍵議題。

目前在地熱開發與二氧化碳封存等地下流體模擬領域，TOUGH3 與 OpenGeoSys（OGS）為兩款廣泛應用的開源數值模擬工具。TOUGH3　　由美國勞倫斯柏克萊國家實驗室（Lawrence Berkeley National Laboratory, LBNL）開發，具備強大的模擬能力，能在孔隙介質（porous medium）或裂隙介質（fractured medium）中，處理多相流（multi-phase）、多成分（multi-component）及多維系統下的非等溫（non-isothermal）流體和熱流的質量與能量守恆方程式；OGS 則由德國地學研究中心開發，除了具備相似於TOUGH3的模擬功能外，亦強調高度模組化架構與彈性的物理、化學耦合能力。儘管兩者皆已廣泛應用於二氧化碳地質封存模擬，然而在模擬準確性、計算效率與應用彈性等層面上，仍缺乏系統性的比較與量化分析。

本研究旨在針對 TOUGH3 與 OpenGeoSys 兩套模擬工具進行性能比較與效率評估，透過基準案例解析解進行驗證與三維地質案例模擬，探討其於二氧化碳地質封存（CCS）應用中的表現與潛力。研究首先參考 Nordbotten et al.（2005）所提出之 CO 羽狀體解析解模型，模擬注入過程中羽狀體的橫向擴展與前緣推進行為，藉以驗證兩工具對基本物理機制的模擬準確性。接著，選用北海挪威 Sleipner 封存場之三維地質案例，建構具代表性之 CCS 模型，進一步比較兩工具於不同 CPU 數量下之平行計算效率與擴展性表現。

本研究預期透過理論驗證與模擬規劃，系統性分析 TOUGH3 與 OGS 在 CCS 模擬應用中的功能差異與資源需求，提供使用者在選擇模擬工具的參考依據。研究結果將可應用於 CCS 項目的前期可行性評估、封存場址建模與運算資源配置，並可作為未來開發高效率、大尺度地質模擬架構之基礎。

中文關鍵詞：二氧化碳封存、OpenGeoSys(OGS)、TOUGH3

Tracing GDGT and n-Alkane distribution patterns in the Central Arctic Ocean During the Last Glacial Cycle

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Arctic sea ice plays a vital role in regulating the Earth's energy budget, influencing Arctic marine productivity and the global thermohaline circulation. Its seasonal and long-term distribution patterns strongly affect sediment and organic matter (OM) transport and deposition across the Arctic Ocean basin. Lipid biomarkers are important proxies for tracing OM origin and transport pathways in the central Arctic. However, the sources of these biomarkers and their spatial and temporal variability over the last glacial cycle remain poorly constrained. To address these gaps in understanding, we conducted a multiproxy geochemical analysis—including total organic carbon (TOC), long-chain *n*-alkanes, and glycerol dialkyl glycerol tetraethers (GDGTs) on nine sediment cores collected from the central Arctic Ocean. Our GDGT results reveal that branched GDGTs (brGDGTs) in this region are likely of predominantly marine origin, thereby challenging the long-standing assumption that they are exclusively derived from terrestrial sources. To assess the origin of these compounds more accurately, we applied two indices, which yielded contrasting interpretations. Elevated IIIa/IIa values during MIS 3–1 suggest a marine source, while $\#rings_{tetra}$ ratios point toward a terrestrial origin. However, the $\#rings_{tetra}$ index is likely less reliable in this setting due to its sensitivity to pH fluctuations, which are difficult to constrain in Arctic marine sediments. Therefore, the IIIa/IIa ratio is considered a more robust indicator of in situ brGDGT production in the central Arctic. TOC, terrestrial biomarkers (e.g., long-chain *n*-alkanes), and marine biomarkers (isoprenoid and branched GDGTs) all show the highest concentrations in the Central Lomonosov Ridge (CLR) cores, which lie closer to the Siberian shelves. These concentrations progressively decrease in the Lomonosov Ridge Offshore (LRG) and Morris Jesup Rise (MJR) cores, which are located further away from the shelves. This spatial gradient, combined with the evidence for persistently low primary productivity in the central Arctic, suggests that both marine- and land-derived biomarkers were largely transported via sea ice drift originating from the Siberian shelves. This mechanism remained active throughout MIS 3–1, although transport intensity was likely reduced during glacial periods. Additionally, elevated Branched Isoprenoid Tetraether (BIT) index values observed during glacial intervals may reflect changes in GDGT production dynamics on the shelves and/or selective degradation of crenarchaeol during long-range transport. These findings underscore the complex interplay between production, transport, and preservation processes shaping the biomarker records in the central Arctic.

Keywords:GDGT, n-alkanes, organic matter provenance, sea ice drift, central Arctic ocean

評估高精確度Na/Li地質溫度計作為熱水儲集層溫度指標：以中崙與關子嶺地熱系統為例

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在地熱場域中，透過地質溫度計從地表露頭水預測熱水儲集層的溫度，已被廣泛的運用，如SiO_2、Na/K地質溫度計等。然而，運用在不同岩性的地熱系統，地質溫度計往往獲得不一致或是偏差大的預測值，使得可信度面臨重大的挑戰，也強調多重地質溫度計互相驗證的重要性。本研究針對Na-Li元素在熱水系統相對穩定的化學特性，系統性地分析文獻資料、數據收集及討論影響Na/Li地質溫度計的因素。我們的結果顯示：岩性與熱液來源為影響流體Na/Li比值最顯著的因素。因此，本研究針對台灣的地質岩性、熱水來源，發展出適用的Na-Li地質溫度計：

T(℃)=1000/((0.50±0.02)log(Na/Li)+1.26±0.04))-273.15。

其中，Na/Li單位為莫耳濃度，適用溫度範圍從33至300℃。新的Na-Li溫度計，透過清水地熱實測溫度的驗證，偏差值為±5 %內；相比於文獻所提出Na-Li溫度計偏差可高達±20%，預測精確度大幅提升。經過模型回歸後，也證實岩性以及水起源是一個重要的影響。本研究進一步將新的Na-Li溫度計用於預測中崙與關子嶺的儲集層溫度；結果顯示中崙與關子嶺溫度為120-140℃及140℃，誤差為±4℃。此外，Na-Li溫度計受到天水混染導致偏差的程度較Na-K溫度計輕微，僅最濕季樣品表現出異常值。根據Mg/Na、Ca/Na、Na/K及Na/Li進行水化學特徵分析，僅最濕季樣品化學特徵為天水，其餘Na/Li比值保持恆定，證明Na-Li地質溫度計較不會受到乾、濕季的影響。本研究成果指出， Na-Li地質溫度計為可靠的地質溫度計，可作為SiO_2、Na-K地質溫度計交互驗證的工具，以提升從地表露頭水預測儲集層溫度的精確度與可信度。

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中文關鍵詞：Na-Li地質溫度計、熱水儲集層溫度、岩性、熱液來源

土壤液化調查與風險評估計畫

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行政院於109年正式核定推動「土壤液化調查與風險評估計畫」，由經濟部主責執行，作為內政部「安家固園計畫」的延續與深化。此計畫不僅承襲過往累積之基礎資料與調查成果，更著眼於全國性防災整備與永續發展之需求，針對地質環境脆弱區域進行系統性盤點與風險重估，並建立更完整且具前瞻性的調查策略。透過與地方政府協力，本計畫期能整合資源、提升地質資料的精確度與實用性。

自110年起，經濟部地質調查及礦業管理中心與18個縣市政府密切合作，推動都會區地質調查工作。目前已完成階段性作業，針對補充鑽探部分，區分為岩心全取樣之地質井（用以判視地層）及工程井（進行標準貫入試驗與劈管取樣分析）。至今累計完成鑽孔數約4,000孔，並設置自記式水位監測井約400孔、人工地下水位監測井約3,600孔，所獲得的龐大資料均已彙入地質資料庫。此外，為提升成果應用層面，計畫亦完成超過21處老舊建築物與地下管線的風險評估，並於地方辦理相關教育與宣導活動，增進民眾對土壤液化風險的認知。

展望未來，計畫將持續精進鑽探品質，並提升鑽孔密度，目標涵蓋8,000平方公里之國土防災圖資建置，同時完善三維地質資料庫，開放供各界查詢應用。此一資料庫將成為工程開發的重要參考基礎，有效降低探勘成本與時間，更能支援政府重大政策決策之需求。

中文關鍵詞：土壤液化、風險評估、三維地質資料庫

土壤液化圖資創新與防治技術發展計畫

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近年隨著土壤液化風險之課題備受關注，政府為提升國土安全與基礎設施韌性，持續推動多項土壤液化相關研究計畫，地質調查及礦業管理中心從理論模型、現地試驗、資料系統建構到實務工法應用，全面強化對液化現象的掌握與應變能力。本計畫分別從試驗技術優化、水位動態監測、建築對策評估及圖資整合精進等多面向，構築出更完整且科學化的土壤液化風險評估與防治體系。

本計畫分四項關鍵計畫進行：1.在應用動態循環三軸試驗精進之部分，建立適合臺灣之抗液化強度曲線，改善傳統依賴SPT-N值的簡易法之準確性。迄今已建置逾百組試驗資料庫，並優化薄管取樣冰凍技術，有效降低土壤擾動誤差15~18%，提升評估信度。試驗成果顯示臺灣土壤動態強度普遍優於日本JRA法，對國內液化評估具高度適用性。2.在淺層地下水位動態模式評估方面，嘗試採用機器學習方法，整合173口水井與水文、地質數據資料，建立小時尺度之水位預測系統，供後續加值應用。成果不僅顯示降雨為主要地下水位變動控制因子，更推估出蘭陽平原地區高解析三維USCS統一土壤分布，提供液化評估與水資源管理重要依據。3.在低樓層建築物抗液化地質改善工法評估部分，針對民宅等低樓層建築，評估微型樁抗液化策略之成效與成本。模擬結果顯示，微型樁貫入非液化層6倍樁徑即可將沉陷由20cm降至5cm以下。設計費用佔總建築成本約4~6%，具實務可行性，並已完成示範案例與應用指引編制，利於未來推廣。4.在圖資製作與防治技術精進部分，整合全台1萬餘筆鑽孔資料，建立高精度三維地質圖資。並蒐集68例相關平原區地質災害案例及致災原因，並套匯最新軟弱地質圖層，評估地質環境與災害潛勢之關係。

中文關鍵詞：土壤液化、動態循環三軸試驗、水位預測、微型樁、三維地質圖資

Micro-earthquakes Induce Fumarole CO_2 Emissions: A Case Study from Taiwan Tatun Volcano Group

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Monitoring volcanic hazards is crucial, particularly in densely populated areas, to mitigate potential risks. Carbon dioxide (CO_2) emissions serve as key indicators of subsurface processes, with variations in their concentration and isotopic composition providing critical insights into volcanic activity. Seismic activity can influence CO_2 dynamics by creating pathways through rock fractures, facilitating the migration of deep-seated CO_2. Therefore, integrating seismic and CO_2 monitoring is essential for a comprehensive understanding of volcanic hazards. The Tatun Volcano Group (TVG) in northern Taiwan, located near the highly populated Taipei area, presents an ideal site for such investigations. Between 2019 and 2022, we monitored CO_2 concentrations and isotopic compositions ($\delta^{13}C$ and $\delta^{18}O$) to assess the sources and behaviour of CO_2 emissions at TVG. Our results indicate three primary CO_2 sources: mantle-derived, organic matter, and carbonate. The mantle-derived CO_2 remained a persistent contributor (percentage contribution ~40 %), whereas fluctuations in CO_2 levels were associated with varying contributions from organic matter (percentage contribution ~20 %) and carbonate (percentage contribution ~40 %). Two primary processes contributed to carbonate-derived CO_2: (1) dissolution via interaction with acidic hydrothermal fluids, which provided a steady CO_2 source similar to mantle contributions, and (2) thermal decomposition of carbonate induced by fracturing. The latter process, occurring sporadically, was linked to elevated $\delta^{13}C$ values. This carbonate decomposition was further supported by its strong correlation with periods of increased gamma-ray radiation, suggesting subsurface fracturing that likely generated frictional heat, leading to carbonate breakdown. These observations indicate that seismicity did not significantly influence magma-related CO_2 dynamics, suggesting stable magmatic conditions throughout the study period. Although no new magmatic activity was detected, the persistent presence of mantle-derived CO_2 confirms the existence of a magmatic body beneath TVG and highlights the potential for future volcanic activity. Periodic fluctuations in CO_2 emissions may pose localized environmental risks, including gas accumulation in confined spaces and alterations in groundwater chemistry. These findings emphasize the necessity of sustained geochemical and geophysical monitoring to detect early signs of volcanic unrest, refine hazard models, and enhance risk mitigation strategies for the TVG region.

Keywords:Carbon and oxygen isotopes, fumarole, CO2

Establishment of a Plastic-Free Laboratory

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Plastic products are among the most widely used materials in the world today. However, the substantial increase in plastic production has led to a significant threat to the environment, biodiversity, and even human health, in the form of plastic waste. Plastics can be degraded into smaller plastic particles, known as microplastics. Microplastics are now ubiquitous found in urban areas, water bodies, and even remote forests. Microplastic material embedded in coral skeletons offers a potential means of reconstructing oceanic plastic pollution over past decades. Many experiments conducted in previous studies, particularly those in conventional laboratories, risk contamination from the ambient environment. To accurately study coral-inferred plastic history, a plastic-free laboratory environment is essential. Here, we established a plastic-free laboratory at the Biodiversity Research Center, Academia Sinica. In the initial stage, we examine the air conditioning system, deionized water and chemicals used in the laboratory to test for the presence of microplastics, show no microplastic in these procedure blank tests. In the second stage, we examined subsamples of a coral fossil from Vanuatu around 16.5 ka (natural sample without microplastics), which had been collected underwater at around 14m depth and has been delivered and stored at a non-plastic-free environment. We discovered that most particles in the blank test are likely natural fibers, while others may originate from lab coats and clothing, and after three rounds of ultrasonic clean, only fibers originating from lab coats and clothing remained. This confirms the effectiveness of our plastic-free laboratory setup. Our developed protocol will be applied to coral samples collected from southern Taiwan to reveal that porous rocks including uplift carbonate rocks may be affected by fluids carrying microplastics into their pores that may be one of the pathways for plastic sinks.

Keywords:Plastic sink, Microplastic, Coral

Eruptive histories of the Eastern Tatun Volcano Group, Taiwan, resolved by 40Ar-39Ar and zircon double-dating (ZDD) of lava flows

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The Tatun Volcano Group (TVG) in northern Taiwan is part of the Northern Taiwan Volcanic Zone (NTVZ), formed in an extensional back-arc setting at the western end of the Ryukyu subduction system. Recent studies have shown that the TVG is much younger than previously thought, though reliable eruption ages are still scarce, complicating the reconstruction of its eruptive history. In this study, we used high-precision 40Ar/39Ar dating of plagioclase and groundmass, along with U-Th disequilibrium and U-Th/He dating of zircons (Zircon Double Dating, or ZDD), from andesitic lava flows to constrain eruption ages at Mt. Huangzuei in the eastern TVG. Our results, combined with previous data, propose five eruptive phases at Mt. Huangzuei: Stage I (~380 ka), Stage II (~141ka), Stage III (~107 ka), Stage IV (~90 ka), and Stage V (less than ~70 ka). Additionally, zircon U-Th crystallization age populations that overlap with eruption stages suggest a common magma source and reveal possible undocumented stages. These findings provide new insights into the volcanic history of the TVG, refining the eruptive timeline and offering constraints for future volcanic models in the region.

Keywords:Tatun Volcanic Group, Taiwan, Mt. Huangzuei, Ar-Ar dating, Zircon double dating (ZDD)

多頻道反射震測與重力整合分析探討南海太平島海域的地殼構造

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南海被動大陸邊緣位於臺灣西南方海域，與台灣碰撞帶西半部的歐亞板塊相連，有類似的地殼性質。南海張裂歷史始於早古近紀，海洋地殼在漸新世時以南北向擴張形成西北次海盆與東次海盆。早中新世時期古中洋脊向西南延伸，在洋脊跳躍（Ridge Jump）後擴張方向轉為西北-東南向，形成西南次海盆。同時臺灣島西北部、西南部海域皆發現同年代的公館期火成岩，顯示具有廣泛分佈的岩漿活動。多數過去的研究主要討論大陸岩石圈的異質性對中洋脊擴展方向的影響，岩漿作用導致的岩石圈弱化現象則未詳細分析。本研究遂希望研究南沙群島周圍的陸-洋地殼交界帶（COT）的岩漿分布，探討西南次海盆海底擴張初期的岩漿活動，如何影響南沙群島周圍海域的地殼構造。本研究欲使用多頻道反射震測(MCS)和重力資料，挑選五條經過疊前時間移位（PSTM）的長、短支距震測剖面，提供了淺部盆地主要的地層邊界。另外利用全球布蓋重力異常反演和長支距震測剖面得到的莫荷面深度結果，建立二維重力模型，比較模擬與重力異常觀測值的差異推測地殼構造。震測剖面顯示太平島東邊測線在陸-洋交界帶中高振幅且高傾角的反射訊號且形成於同張裂時期，對應重力模擬的高密度體結果，顯示為盆地底部之岩漿作用。然而位於此測線西側約40公里的剖面則未見此特徵，顯示岩漿噴發的範圍有限。南沙群島全區域的重力模擬顯示均質的大陸地殼密度獲得比觀測值低的重力值，暗示此區域大陸地殼不均質，可能存在岩漿作用形成的高密度體。而模擬在COT靠近海洋地殼側被高估，推測與海洋地殼形成初期的地殼構造異質性有關。本研究推測地殼中的高密度體為下部地殼底侵作用，可連接到盆地底部噴發之火成岩體，視為西南次海盆擴張時的岩漿入侵系統。由於位置靠近西南次海盆東界之中南斷層，可能提供岩漿入侵的通道，可對洋脊跳躍的機制提供更進一步的線索。

中文關鍵詞：南中國海、南沙群島、反射震測、重力模擬、中南斷層

由米崙礫岩變質礫石碳物質拉曼光譜分析建構台灣造山帶近期演化

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南中國海洋殼在約 15 Ma開始由馬尼拉海溝隱沒至菲律賓海板塊之下，形成呂宋火山島弧。隨著板塊持續擠壓，變形與變質的中國大陸邊緣隨之俯衝進入隱沒帶，根據蛇綠岩套中藍片岩的白雲母$^{40}Ar/^{39}Ar$定年，約在 9 Ma隱沒深度達藍片岩相。此後在 6.5 Ma前陸盆地形成，揭示了火山島弧與大陸邊緣斜向碰撞造山的起點，經一段遲滯期，山脈在約 2.5 Ma隨劇烈的弧陸碰撞迅速掘升並出露於地表，伴隨風化與剝蝕作用，掘升而出的變質岩屑迅速進入鄰近的盆地。因此，在台灣東部可見沉積記錄自呂宋島弧相關的都蘭山層火山序列，逐漸轉變為弧陸碰撞相關的變質碎屑沉積。

在約 0.7 Ma更新世中期，中央山脈東翼變質岩剝蝕而下的變質礫石堆積於淺海並成岩，米崙礫岩就此形成，隨後抬升成為米崙臺地。由於米崙礫岩中所含變質礫石於變質前為富含碳物質的中國大陸邊緣沉積物，本研究前往位於花蓮縣台東縱谷北延之米崙臺地採集米崙礫岩中此富含碳物質的變質礫石，並利用碳物質拉曼光譜（Raman spectroscopy of carbonaceous material, RSCM）地質溫度計，測定這些變質岩屑曾深埋在地殼時所經歷的最高變質峰值溫度，得出共 38筆數據。

前人亦曾以 RSCM方法測定水璉礫岩中變質礫石的變質峰值溫度，水璉礫岩與米崙礫岩相似，為約 1.5 Ma前中央山脈東翼變質岩剝蝕而下的變質礫石堆積於深海並成岩的產物。此外，前人亦沿中橫公路採樣並由RSCM方法測定現今中央山脈東翼出露變質岩的變質峰值溫度。

以本研究測得約 0.7 Ma前沉積形成的米崙礫岩中礫石變質峰值溫度，結合前人研究中對約 1.5 Ma前成岩之水璉礫岩中變質礫石與現今中央山脈東側變質岩測得的變質峰值溫度，並將三者結果進行對照與比較，顯示自約 1.5 Ma 至今，中央山脈東側掘升出露的變質岩變質峰值溫度，呈隨時間逐漸上升之連續變化，揭示從中央山脈掘升出之變質岩變質度的動態遞進，由此推論台灣造山帶掘升尚未達掘升穩態。

中文關鍵詞：台灣造山帶、掘升作用、米崙礫岩、從源到匯

從觀測到預警：以震度分布、強度與持續時間訓練生成式AI預警模型

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傳統的地震預警系統可分為區域型與現地型兩大類。區域型系統仰賴震央附近數個測站所接收到的P波，先進行震源定位與規模估算，並透過地震動衰減公式推估遠地的震度，再決定是否發布預警以及預警範圍。然而，其準確度受限於P波挑選與地震定位的精度，當短時間內有多個地震同時發生或大震後接連出現餘震時，偵測能力將大幅下降。現地型系統則依賴單一或少數測站的P波資訊，利用經驗公式快速推估當地震度並判斷是否發布預警。雖然反應速度快，但應用範圍有限，亦面臨與區域型系統類似的挑戰。為克服上述限制，近年來興起一種不依賴震源參數的新型區域型預警策略，稱為基於「觀測場」的地震預警方法。該方法透過觀測所有測站所記錄的實時震度資訊，根據地動強度、持續時間與空間分布特徵，動態決定是否發布警報及其範圍。此方法無需震源定位與規模計算，不僅能即時掌握地震波傳遞趨勢，亦能隨時間累積更多觀測資訊，在犧牲部分預警時效的同時提升預警準確性與可靠度。本研究蒐集中央氣象署605個地表加速度測站的即時最大地動加速度資料，針對2020年至2024年間的歷史地震建立訓練資料集，並以2025年地震資料作為測試集。資料格式為地震發生後每秒的最大震度，觀測長度自震源時間起持續至120秒，分別以10秒至60秒為單位建立不同長度的輸入模型。研究採用 Hugging Face 的 Transformer 架構進行大語言模型訓練，模型輸出為是否應發布預警及預警範圍，並以中央氣象署預警標準（規模 ≥ 5.0 且最大震度 ≥ 4級，或規模 ≥ 6.5 且最大震度 ≥ 3級）作為評估依據。結果顯示，輸入觀測長度達60秒時，模型幾乎無誤報與漏報，顯示本方法具備高度準確性與實用潛力，可作為地震預警系統的重要補充與未來發展方向。

中文關鍵詞：地震預警、觀測震度、大語言模型

廬山地區三維熱-水耦合數值模擬

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為能達到能源轉型的願景，台灣2050淨零轉型十二項關鍵戰略中，第三項的前瞻能源即包括了地熱能源。全球同位處於火環帶的國家包含印尼、菲律賓、紐西蘭，以上各國之地熱電廠裝置容量皆已達1GW。雖然經濟部能源署推估台灣淺層地熱(<3km)可開發量為400MW；深層地熱(3~6km)為8GW，但截至2024年10月為止，台灣地熱電廠累計裝置容量僅為7.49MW，顯示台灣地熱發電尚處於萌芽階段，仍有相當大的發展空間。

本研究選擇台灣10大地熱潛能區之一的廬山地熱區作為研究對象，並以建立符合廬山地熱區現地溫度分布情況的地熱數值模型為目的。廬山地熱區已存在地質、地物、地化等探勘調查的資料，並有三口中油廬山地熱井，其井深介於七百至一千兩百米之間，且已擁有初步地熱概念模型，但仍需進一步使用數值模擬工具來驗證地下水流與熱傳輸機制。

本研究使用數值模擬軟體COMSOL建立三維地熱數值模型，並進行熱、水耦合數值模擬。廬山地區地質為廬山層板岩帶，一段東北-西南走向的變質砂岩段夾在板岩之中，並穿過廬山溫泉，變質砂岩被數條左移斷層切割成數段，其中斷層破碎帶由於其滲透性高，往往是地下水主要的流動通道，使得天水可以流向深層岩石經加熱後流向地表。本研究根據現有資料建立三維地熱傳輸數值模型，以情境模擬方法分析廬山地區可能的熱液傳輸機制。目前的模擬結果顯示，結合地溫梯度、地熱井內熱流、高溫低電阻區熱流以及來自走向滑移斷層底部的熱流，可以使中油廬山一號地熱井井內12個點位的模擬與觀測溫度間的RMSE為3.31°C。

基於目前的結果，未來將使用Morris one at a time(MOAT)全局敏感度方法，找出廬山地熱數值模型中關鍵的水文地質參數，後續結合參數最佳化，使模型能自動尋找參數最優解，建立一個符合現地地熱井溫度分布的地熱數值模型。

中文關鍵詞：廬山地熱區、三維熱-水耦合數值模型、COMSOL

活動斷層地質敏感區（F0026利吉斷層）之劃設

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利吉斷層為臺灣東部重要的活動斷層之一，野外調查顯示，榕山西方卑南溪東岸，利吉斷層西側卑南山礫岩向西北傾斜，東側礫岩向東傾斜，兩者之間為斷層接觸而非呈背斜構造，主要原因在於斷層東側礫岩層中夾有約10公尺厚的砂質泥岩，泥質岩層以低角度逆衝於礫岩層之上，與西北側礫岩層在岩層層序、岩性組合明顯不同。由鑽探所得之岩心，經碳十四定年（年代經樹輪校正），其資料顯示斷層在距今10,234至10,120年後曾經活動，且2022年關山-池上系列地震後在臺東瑞隆新良附近沿利吉斷層產生地表破裂現象與同震地表變形現象。地質露頭與鑽探資料顯示斷層分隔利吉層與卑南山礫岩，已造成卑南山礫岩東側礫石傾向呈鉛直，甚至反轉，同時截切全新世地層。若再次發生活動，恐威脅人民生命財產安全，並造成重大經濟損失，故在綜合考量下，將利吉斷層列為地質敏感區劃定的標的斷層，並劃設為活動斷層地質敏感區。

中文關鍵詞：活動斷層地質敏感區、利吉斷層、全新世

Late quaternary eruption history of the Tatun Volcano Group (Taiwan) – new constraints from zircon double-dating and 40Ar/39Ar dating of lava flows in Mt. Shamao

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Growing evidence for an active magmatic system in the Tatun Volcano Group (TVG), northern Taiwan, has intensified efforts to understand its eruption history. Determining the timing of past eruptions is essential for assessing volcanic hazards, particularly given TVG's close proximity to the Taipei metropolis. However, limited studies have often reported conflicting results, highlighting the need for reliable dating methods to establish a robust geochronology. This study focuses on the Shamao lava dome, considered the youngest eruptive product in the TVG, using a combination of zircon U-Th disequilibrium and (U-Th)/He dating (also known as zircon double-dating) alongside high-precision $^{40}Ar/^{39}Ar$ groundmass dating. Zircon U-Th disequilibrium data constrain the maximum eruption age of Mt. Shamao to 16.3 ± 1.2 ka and reveal both continuity in zircon crystallization ages spanning ~200 ka and distinct age clusters at ~23, 60, and 117 ka, with some grains in secular equilibrium (>300 ka). These older populations coincide with other magmatic events in the TVG, suggesting zircon inheritance or the tapping of a long-lived, interconnected magma reservoir with episodic pulses. Zircon (U-Th)/He dating provides a late Pleistocene eruption age of 16.3 ± 4.9 ka, in agreement with the new groundmass $^{40}Ar/^{39}Ar$ plateau age of 15.0 ± 6.3 ka and previously reported radiocarbon ages documenting eruptions from 23 to 13 ka. These findings contrast with earlier interpretations of Holocene (1.3 ka) volcanism in Mt. Shamao and emphasize the reliability of combined geochronological approaches for dating young volcanic rocks. While additional data are needed to refine eruption recurrence models, these results provide a critical foundation for improving hazard assessments and risk evaluations in northern Taiwan.

Keywords:Tatun Volcano Group (TVG), Eruption chronology, Zircon double-dating, 40Ar/39Ar dating

大屯火山群的長期地球化學監測：來自連續土壤氣體、火山噴氣與溫泉觀測的解析

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大屯火山群位於台灣北部，目前雖然處於相對穩定狀態，但由於地下岩漿庫的存在，仍被認定為活火山。考量其鄰近台北都會區，任何火山活動皆可能對社會與環境產生重大影響。為了更全面評估未來可能的活動變化，已進行長期地球化學監測，包括火山氣體與溫泉水的採樣與分析，並於區域內建立兩座連續性土壤氣體二氧化碳觀測站，累積了大量高解析度的長期數據。

自 2018 年以來，監測結果顯示多項地球化學指標發生顯著變化。火山噴氣觀測結果顯示氯化氫（HCl）與氦氣（He）濃度上升，隨後溫泉水中的陽離子濃度亦急遽增加。同時，土壤氣體中的二氧化碳濃度也出現變化，但同時間內變化模式與其他地球化學指標並不完全吻合，顯示可能存在岩漿-熱液系統的複雜交互作用。

與此同時，大屯火山群地區的地震活動亦顯著增加，並發生多起深源與大規模地震。而地表環境亦出現異常變化，包括多次且大範圍的泥漿噴發。另外，地表變形的監測結果顯示，2021年在主要地熱區(大油坑地區)觀測到顯著的垂直位移變化，可能反映地下動力過程的變化。這些觀測結果顯示，大屯火山群在特定時期內可能經歷了短暫的不穩定活動階段，然後續發展仍需透過持續監測進一步評估。

中文關鍵詞：大屯火山群、地化監測、火山噴氣、土壤氣體監測、溫泉

2018年9月28 Mw 7.5印尼帕魯地震的應變能評估

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本研究利用表面波與遠場SH波來評估2018年M_W 7.5印尼帕魯地震的破裂特徵及應變能(W)。首先以雷利波與洛夫波週期100秒相速延遲與頻譜節點來進行破裂方向性分析，得到此地震為單向超剪力破裂事件(unilateral supershear)，其最佳破裂方向為北偏東179°、破裂長度(L)為118.9 km、平均破裂速度3.84 km/s、平均歷時31 s及上揚時間(rise time)為6.06 s。接著以遠場SH波進行非負解時間域解迴旋得到帕魯地震的震源時間函數，其地震矩(M_0)為1.59 x 10^{20} Nm，震源輻射能量(E_S)為2.49 x 10^{15} Nm。由於大規模走向滑移地震的破裂寬度平均約為20-30km，藉由$M_0 = \mu DA$可以進一步估算其平均滑移量(D)，由$\Delta\sigma_d = \mu(dD/dt)/\beta$得到平均動應力降(dynamic stress drop)(μ為剛性係數，β為S波速度，t為時間)，再結合實驗室岩石摩擦試驗的結果來評估帕魯地震的正向應力(σ_n :normal stress)及動摩擦應力(σ_f :dynamic stress)，最後可以評估其摩擦能$E_F = \sigma_f M_0/\mu$，此時的應變能為$W = E_F + E_S$，經過計算後得2018年M_W 7.5印尼帕魯地震的應變能為1.8 - 2.7 x 10^{17} Nm，其地震效益(η : seismic efficiency)為0.009-0.014，符合$\eta \leqq 0.06$。

中文關鍵詞：帕魯地震、破裂方向性分析、超剪力破裂、應變能、地震效益

臺灣周圍海域離岸風場海域洋流及地質環境分析-不連續雙黏性流模式於離岸風機沖刷模擬之應用探討

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隨著再生能源需求日增，離岸風電於台灣近年迅速發展。然而，台灣近海具高能量環境特性，風機不僅須承受強烈洋流與颱風浪襲，更面臨基樁周圍海床淘刷所帶來之穩定性挑戰。因此，建立一套能準確模擬波浪、洋流與結構交互作用之計算流體力學模式，實為風場設計之關鍵。為此，本研究基於三維不可壓縮流模式 Splash3D，發展一套可模擬非牛頓流體之數值模式—不連續雙黏性流模式 (Discontinuous Bi-viscous Model, DBM)。Splash3D以三維不可壓縮流求解Navier-Stokes方程式，並採用流體體積法 (Volume of Fluid Method)處理自由液面，紊流行為則以大渦模擬法(Large Eddy Simulation)進行描述，模式因此具備處理碎波、渦流與液面重建之能力。啟用DBM後，模式透過流變參數重新計算控制方程式中之黏滯項，進而捕捉海床泥砂運動與海床沖刷等複雜流變特性。為驗證模式準確性，本研究進行數項驗證案例，包括賓漢流體於平行板間之壓力驅動流、傾斜坡面上之流體擴散行為、高嶺土坍度實驗對比以及德州石膏尾礦潰壩模擬，無論與解析解或實驗成果比對，模擬結果皆呈現高度之一致性，展示出DBM模式應用於泥石流、山崩及局部沖刷之潛力，未來可配合特定風場選址，整合海象、氣象與地形等資料，以DBM進行離岸風機結構周圍之三維流場與局部沖刷模擬分析。

中文關鍵詞：離岸風電、Splash3D、不連續雙黏性流模式、DBM、局部沖刷

不連續面位態引致滲透係數異向性與應力致使強度異向性對順向岩石邊坡之影響

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岩體中的不連續面（如節理、裂隙等）不僅會影響岩石邊坡的穩定性，也常為地下水流通的主要通道。不連續面的幾何特性，如密度、長度、內寬與位態，會導致岩體的滲透係數呈現異向性，進一步影響邊坡穩定。根據前人研究（Oda, 1986）指出，不連續面之位態分布會造成岩體滲透係數的異向性，Kanatani（1984）則以二階第三類偏差張量（Deviatoric Tensor）描述不連續面幾何排列的特性。本研究採用Dzz值（0 ~ 5）代表不連續面在Z方向法線向量的空間分布異向性程度，Dzz值愈大表示異向性愈明顯，並以此推導出相應的滲透係數張量（Permeability Tensor），並使用遍佈節理模式(Ubiquitous-Joint Model)探討應力對不連續面強度異向性的影響。

本研究利用數值分析軟體 FLAC3D 建立岩石邊坡模型，並將前人推導的異向性滲透係數公式與總水頭計算式，轉換為 FLAC3D 內建的 Fish 語言，以求得異向性滲透係數並納入模型進行分析，並針對不連續面之強度異向性使用FLAC3D本身具備的遍佈節理模式分析，探討等向性與不同異向性程度下的差異。透過數值分析，可取得不同深度與位置的孔隙水壓及總水頭變化情形，再以剪力強度折減法（Strength Reduction Factor, SRF），逐步降低岩體強度參數（摩擦角與內聚力），模擬岩石邊坡的極限穩定狀態，進而求得邊坡安全係數。此外，本研究亦藉由最大剪應變增量（maximum shear strain increment）的分佈，探討由不連續面引起的滲透係數異向性與不連續面強度的異向性對邊坡穩定性的影響。

研究結果顯示，當岩體內不連續面滲透係數異向性與不連續面強度的異向性程度越高，邊坡安全係數明顯降低，且不連續面強度的異向性的影響會比滲透係數異向性高，顯示異向性對岩石邊坡穩定性具有顯著影響。因此，在岩石邊坡穩定性評估中，充分考慮不連續面引起的異向性特性，具有重要的實務意義。

中文關鍵詞：偏差張量、滲透係數異向性、FLAC3D、遍佈節理模式、邊坡穩定分析

Seismic Modulation of CO_2 Degassing in the Fault Zone: Insights from Two Major Earthquakes in Adjacent Fault Systems

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Understanding how seismic activity modulates crustal degassing is crucial for evaluating fluid-fault interactions in tectonically active regions. In eastern Taiwan, the Chihshang Fault (CSF), located along the eastern margin of the Longitudinal Valley (LV), serves as a natural laboratory for such studies. After the 2022 M6.8 Chihshang earthquake, soil gas surveys revealed that surface CO_2 flux nearly doubled, from ~70 to 140 t/d, likely due to microfracturing that enabled the ascent of shallow and deep-sourced gases. Heavier $\delta^{13}C$ values supported increased deep carbon input. Elevated CO_2 degassing lasted over 3 to 6 months, highlighting the CSF's role as a transient fluid conduit.

In March 2025, prior to the occurrence of a M5.7 earthquake in a nearby region, a soil CO_2 flux survey was conducted two days before the event along the Central Range Fault (CRF) on the western side of the LV. This survey captured a rare pre-seismic CO_2 anomaly. CO_2 flux rose from 32 to 59 t/d, with a broader spatial extent than in previous surveys. A follow-up two weeks later showed flux levels increasing to 66 tons/day. Isotopic data revealed two gas sources: heavier $\delta^{13}C$ from deep crustal origins, and lighter $\delta^{13}C$ from atmospheric mixing, suggesting enhanced near-surface permeability after rupture.

This study provides the first field-based documentation of a pre-seismic CO_2 anomaly, indicating early development of vertical migration pathways. The 2025 results support the hypothesis that structural weakening and fluid migration are linked during earthquake preparation. Compared to 2022 post-seismic data, the 2025 findings emphasize the value of gas geochemistry in identifying potential seismic precursors. Continued monitoring is essential for understanding fault zone permeability evolution and fluid roles in earthquake recurrence.

Keywords:CO_2 degassing, deep carbon input, pre-seismic CO_2 anomaly, earthquake preparation

Near-Surface Geological Structures of the Southern Longitudinal Valley Fault in Taiwan

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The southern segment of the Longitudinal Valley Fault is known as the Lichi Fault, which connects to the Chishang Fault further north. This study conducted three electrical resistivity surveys totaling 2,100 meters and eight geological drilling boreholes with a combined depth of 600 meters. Additionally, existing shallow well data were compiled and analyzed to better understand the near-surface distribution and activity of the Lichi Fault. We compiled the aforementioned geological data and constructed seven geological cross-sections. Radiocarbon dating (C-14) revealed that the fault's most recent activity occurred after 8,980 ± 30 years BP (10,234 - 10,120 cal BP). By integrating previous research with the results of this study, we propose that the Lichi Fault system has likely been active throughout the Holocene, classifying it as an "active" fault. By combining electrical resistivity profiles and borehole data, we have delineated the extent and characteristics of the Lichi Fault. Our findings suggest that the fault traverses the eastern side of Mount Pinan and the eastern side of Liyu Hill, passing through Taitung's most densely populated areas. Although the region has experienced low seismic activity over the past 30 years, this suggests significant accumulation of tectonic energy. Consequently, urgent mitigation measures are necessary to reduce potential loss of life and property in future earthquakes.

中文關鍵詞：Near-Surface Geological Structures、Longitudinal Valley Fault、Holocene

利用高密度地震陣列觀測七星山微地震活動之研究

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七星山是位於台灣北部大屯火山群中最高的火山峰，為一重要的活火山研究區域。該山區具有一系列活躍的地表特徵，包括噴氣孔（fumaroles）、溫泉（hot springs）以及古老水蒸氣爆發（phreatic eruptions）的遺跡。根據長期的觀測結果，此區域內時常發生規模較小的群震事件，為了更全面且精確地掌握七星山區域的微地震活動特性，本研究七星山鄰近區域內部署了高密度地震觀測陣列。該陣列由24個Fairfield Nodal ZLand 3C可攜式地震儀組成，每個監測站點間距設計為100-200公尺，此配置顯著提升了地震觀測的精確度與解析度。透過此密集陣列所收集的數據，我們能夠更精確地定位微地震震源位置、判別地震類型、分析震源機制，以及評估地下熱液活動與構造應力的關聯性。初步研究結果顯示，七星山區域的微地震活動呈現明顯的時空聚集特性，主要集中於特定深度範圍及構造帶。透過波形分析與震源定位，我們識別出數個可能與岩漿活動相關的地震訊號特徵。這些微地震活動模式與地表熱液活動區域具有顯著的空間相關性，進一步證實了大屯火山群的地熱系統仍相當活躍。

中文關鍵詞：大屯火山群、七星山、地震

River sediment observatory in the mountainous catchment: Long-term and high spatiotemporal monitoring with distributed acoustic sensing (DAS), large-N geophone array, hydrophone, smart rock, AI-based grain-size scanner, and photogrammetric survey

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The big challenge addressed in this study involves understanding Earth surface processes, such as landslides, sediment transport, and bedrock incision, which shape landscapes and link climate, tectonics, and erosion. These processes require long-term monitoring of experimental catchments to capture the full range of timescales involved in their evolution. Hydrophones deployed in stream can record fluvial soundscapes over frequencies from Hz to tens of kHz, which are possibly corresponding to sediment transport. Large-N array geophone deployed along riverbank can also provide additional constraints on bedload flux and turbulent flow using seismic physical models. However, high-frequency (> 100 Hz) of fluvial-related seismic signals are rapidly attenuated before arrival riverine geophones. Discrepancies in frequency contents and sensing space resulted that is difficult to fully connect passive seismo-acoustic signals to fluvial processes. In this study, distributed Acoustic Sensing (DAS) is proposed as possible solution to advance in understanding of sediment transport. DAS not only records strain-rate at meter scales, similar to large-N geophone array, but also monitors frequencies from mHz to kHz, similar to hydrophone. This study aims to establish a river sediment observatory in a mountainous catchment in Taiwan. This observatory will serve as a research and educational hub for long-term monitoring, providing valuable data for sediment transport studies and environmental conservation. The goals in this study include developing new monitoring instruments, validating seismic models, and exploring the impact of extreme events on sediment dynamics.

Keywords:Sediment Observatory, Distributed Acoustic Sensing (DAS), Hydrophone, Smart Rocks, Dense Geophone Array

南呂宋中源地震的震源特性與孕震潛能分析

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本研究以菲律賓南呂宋地區的中源地震（深度約落在80–180公里）為對象，利用二階段逆推（遠場 P 波逆推與非負解時間域解迴旋），探討其破裂過程之震源特性與潛能分析。首先，自美國地質調查局（USGS）目錄篩選 1990 年以來震源深度 50–300 公里、規模 M_W 6.0 以上的地震，最終取得 7 起符合本研究目標的地震事件。第一階段以遠場 P 波逆推估算各地震之地震矩、矩心深度、平均歷時與震源機制；第二階段逆推則使用非負解時間域解迴旋結合多重破裂分析，重建震源時間函數，並得到地震的輻射能量釋放、靜應力降（static stress drop）與應變降（strain drop）等參數。分析結果顯示這些中源地震皆呈逆衝機制（thrust fault），同時，這些地震雖然展現了中深部地震常見的低輻射能量比(E_S/M_0)，但其應力降卻明顯高於一般中深部地震。此外，震源歷時（T）與地震矩（M_0）之關係呈現 $M_0 \propto T^3$ 的趨勢，但是否符合地震自相似性的假說仍有待更多觀測資料加以驗證。另外，2020–2023 年間四個密集的地震事件顯示其應變降（strain drop）相當一致，表示此區地震較符合「滑移可預測模型」（slip-predictable model），而非「時間可預測」或「完全可預測」模型；同時，這些地震的重複發生需要一個平均滑移率約33 cm/yr，明顯大於地表的8–9cm/yr聚合速率，暗示可能存在拉伸(stretching)或頸縮（necking）等板塊變形現象。

中文關鍵詞：中源地震、遠場 P 波逆推、非負解時間域解迴旋、應變降、滑移可預測模型

Natural CO2 diffuse degassing from the Tatun Volcano Group, Northern Taiwan

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The Tatun Volcano Group (TVG), situated in northern Taiwan, constitutes a region characterized by notable volcanic and geothermal activity. This study systematically examines the spatial distribution and sources of diffuse carbon dioxide (CO_2) emissions, with the dual objectives of quantifying degassing processes and evaluating their correlation with volcanic activity. The primary aim is to enhance the understanding of gas migration pathways and assess the potential volcanic hazards associated with the TVG. A total of 448 soil gas flux measurements were conducted across a 10 km² area using a closed-chamber method. The findings revealed significant CO_2 emissions from both hydrothermal zones and non-hydrothermal regions. Notably, the presence of well-developed fractures and degassing structures in non-hydrothermal areas was identified, facilitating the migration of deep-seated gases to the surface. Isotopic analyses of carbon and helium unequivocally confirmed the mantle-derived origin of the emitted CO_2. The $\delta^{13}C_{CO2}$ values and helium isotope ratios indicated a mixture of magmatic and crustal sources. Moreover, interactions between high-CO_2 flux zones and shallow hydrothermal systems were observed, resulting in carbonate precipitation and modified isotopic signatures. These processes suggest the existence of shallow aquifers, which may elevate the risk of phreatic explosions under conditions of intensified magmatic activity.

Temporal variation of soil CO_2 flux in the Dayoukeng (DYK) hydrothermal area from 2009 to 2024 revealed a significant expansion of degassing zones, with a 210% increase in area. Elevated soil temperatures and water vapor anomalies were closely associated with high-CO_2 flux regions, corroborating the hypothesis of hydrothermal gases rising and condensing near the surface. This study provides critical insights into the diffuse CO_2 degassing mechanisms within the TVG and their connection to underlying magmatic processes. The results underscore the importance of continuous monitoring, particularly in high-risk non-hydrothermal areas, to improve volcanic hazard assessment.

Keywords:Tatun Volcano Group (TVG), carbon dioxide emission, volcanic hazard assessment

New Web Services of Broadband Array in Taiwan for Seismology (BATS)

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In accordance with the FAIR principles, we have developed a new web service platform to support the research community by providing access to data collected through the Broadband Array in Taiwan for Seismology (BATS). This seismic array has been operated by the Institute of Earth Sciences (IES), Academia Sinica, since 1996. The Data Management Center of the Institute of Earth Sciences (IESDMC), Academia Sinica, is responsible for the systematic archiving, quality assurance, and distribution of the data.

To commemorate the 30-year development of BATS, the homepage of the platform features a comprehensive overview of its history and instrumentation. Researchers can access detailed station information through the online platform, which includes a newly developed event waveform data viewing system to facilitate the assessment of data status prior to usage. Additionally, the platform allows users to request both waveform data and AutoBATS Moment Tensor solutions. Furthermore, several data-derived results obtained from BATS waveform data are curated under the Data Products option for extended applications.

In celebration of the 30th anniversary of BATS, the Institute of Earth Sciences is revising its data policy to enable real-time access to all BATS waveform data channels. This platform serves as a preliminary initiative to mark this significant milestone.

Keywords: Broadband Array in Taiwan for Seismology, BATS, waveform data, regional seismic network, IESDMC

Trigger and Mechanism for the Late Ordovician Glaciation and Mass Extinction

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The first of the "Big Five" Phanerozoic mass extinctions- the Late Ordovician Mass Extinction (LOME)—occurred in association with episodic glaciation during the Hirnantian Age (~445 million years ago) of the Late Ordovician. The mechanisms underlying this event, particularly the role of carbon cycle perturbations in initiating Hirnantian glaciation and driving extinction, remain the subject of ongoing debate. Complicating this picture is a growing body of geochemical evidence indicating the expansion of marine anoxia and euxinia during the Late Ordovician, which further obscures efforts to identify the primary driver (s) of the LOME. However, the lack of a continuous, high-resolution global redox record has recently led to increased scrutiny of the hypothesis that widespread anoxia was a principal cause of the extinction. Consequently, the role of oxygen deficiency in the LOME remains contentious and poorly constrained.

To address these uncertainties, we conduct new multi-isotope (Li-Mg-Ca) analyses of bulk carbonates from the well-characterized Copenhagen Canyon (COK) carbonate succession, representing a shallow marine to shelf-proximal depositional setting. Our objective is to elucidate the interplay between glaciation, continental weathering, and disruptions to the marine carbon cycle, and to assess whether determine whether global cooling, expanded anoxia, or a combination of both were the dominant mechanisms driving the LOME. By integrating a suite of novel geochemical proxies- including Li isotopes to reconstruct silicate weathering intensity, and redox-sensitive trace metals (e.g., I/Ca) to infer variations in marine redox conditions- we aim to develop a more comprehensive and mechanistic understanding of environmental changes in Late Ordovician oceans. These insights will advance our understanding of Earth system responses to major climatic and biogeochemical perturbations, as well as the processes governing the recovery and stability of the long-term environmental changes.

Keywords:Late Ordovician Mass Extinction, Hirnantian Glaciation, Continental Weathering, Oceanic Anoxic Event, Climatic and biogeochemical perturbations

大油坑噴泥事件之地震訊號分析

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大油坑位於大屯火山群內，是區域內噴氣活動最活躍的地帶之一，尤其地震活動相當頻繁。為釐清大油坑的地震特徵，於大油坑放置Zland進行密集觀測，期能紀錄大油坑噴氣活動異常的訊號，並透過分析地震訊號來探討其時序與可能機制。該短週期密集監測網佈放期間，曾於2021 年底至 2022 年初期間，在大油坑主噴口附近觀察到大範圍的泥狀堆積物，同時，地球化學分析也顯示 2021 年底溫泉水中陽離子濃度異常升高。而即時影像監測亦顯示，2021 年 12 月 12 日至 2022 年 1 月 2 日之間，在主噴口上方發生額外的噴氣活動。綜合上述現象推測，此時期的大油坑區可能發生了氣體釋放大量釋放，甚至為小規模的熱液活動事件。藉由鄰近大油坑詳細記錄並解析整段異常活動的時序與特徵。根據鄰近主噴口的短週期地震資料，訊號演化可分為下列階段：(1)活動初期：12 月 8 日開始，觀測到微震活動增加，顯示區域活動開始產生初步擾動。(2)顯著增強期：12 月 10–11 日期間，觀測到明顯加強且複雜的震波與高頻聲波的混合訊號，每一階段持續數小時，顯示可能有強烈的流體活動。(3)低頻微地動：12 月 12 日觀測到顯著的低頻微地動訊號，推測可能對應到泥狀物質的噴出。(4)重複活動：持續至 12 月 16 日，先前觀測到的震波-聲波複合訊號再度反覆出現，並持續數小時，顯示持續的流體活動。(5)活動趨緩：至2022 年 1 月時，訊號強度已明顯降低，顯示此次事件的活動序列逐漸減緩。本研究透過密集且短週期的地震網資料，分析大油坑此次異常活動的時序與地震特徵，對於未來建立大屯火山群的活動模式，以及建立相關監測與防災模型具參考意義。

中文關鍵詞：噴泥事件、大油坑、微地動、聲波

台灣海峽海域玄武岩層盆底尺度之空間分布

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台灣海峽與南海被動大陸邊緣相連，盆地演化從古近紀之張裂盆地系統，和上覆新近紀開始發育之前陸盆地組成。在兩時期之間的陸域和海域，曾報導廣泛分布的晚中新世玄武岩層，透過鉀氬定年法等顯示其形成介於約1600萬年至800萬年前。然而整體的空間分布及盆地尺度之岩漿輸送系統，仍缺乏完整的了解。因此本研究收集數千公里之海域多頻道反射震測（MCS）資料，紀錄深度到雙程走時1-1.5秒深，進行台灣海峽海域淺層盆地中火成岩層的測繪與火山特徵分析。

研究結果顯示，海峽中之玄武岩體沿著東北—西南走向分布，並集中於新竹苗栗外海與台中彰化外海兩區。深度於海峽中線最淺約數十公尺，沿著前陸盆地往台灣島變深至一千五百公尺。震測剖面中辨識強振幅之反射面，與海域鑽井的玄武岩層深度相似，推測為間夾於沉積層中的玄武岩層。玄武岩層於震測剖面中呈良好連續性的平板狀反射層，可區分出為四至五層不同深度的玄武岩層。此外，其中一層玄武岩層辨識出大規模隆升構造，隆升直徑達約70公里，顯示後期的岩漿入侵導致盆地內地層變形抬升，其垂直抬升量可達雙程走時0.1至0.2秒，估計約數百公尺。

對比陸域和海域鑽井的玄武岩層深度相近，可推測震測剖面中火成岩之岩性與最晚年代與澎湖玄武岩和陸域角板山期岩漿活動相近，為南海北部後張裂時期的岩漿活動面積分布最廣的區域之一。空間分佈上鄰近北港高區和觀音高區，與鹿港高區指示的高磁化強度區域重疊，可能為提供磁性礦物的來源之一。另外盆地中玄武岩層分布的區域，鮮少淺層0-5公里深的地震，與台灣桃園台地無震帶和北港高區無震帶區域重疊。因此台灣海峽晚中新世的岩漿活動，於造山前造成盆地內部岩性不均質，與後續發育之褶皺逆衝構造有深遠的影響。

中文關鍵詞：台灣海峽、多頻道反射震測、海域玄武岩

臺灣周圍海域離岸風場海域洋流及地質環境分析-離岸風電風力機對於水文影響分析

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離岸風能發電在近年來快速發展，對於風機與海水間之流體交互作用已具更為深入的研究。針對臺灣特殊的海象條件，離岸風機須承受強勁洋流與颱風所引發的巨浪威脅，因此建立一套完整且高精度之計算流體力學模式，以模擬風機與波流之間的複雜互制行為，為研究人員持續關注之重點。本研究透過三維數值模擬，分析離岸風機設置後對海域流況的情形，並探討風機基樁周圍流場分布與底床動力條件之變化，以量化風場設置後對區域水動力分布與流場結構所造成之影響。

本研究針對桃園至苗栗外海風場潛勢區，以苗栗中港溪外海為代表場址，採用三維數值模擬探討風機基樁對流場與海床沖刷的影響。模擬採用Splash3D模式，結合體積分率法（VOF）與大渦模擬（LES）紊流模型，來模擬波浪、海流與結構物之交互作用。模擬情境涵蓋夏季、冬季與50年重現期颱風條件，波高分別設定為2.88、3.91與6.12公尺，以保守波浪條件代表各季節海況。於基樁周圍採局部加密之數值網格，以提升紊流與沖刷解析能力。

中文關鍵詞：離岸風電、數值模擬、Splash3D、紊流模擬

Generating Slow to Fast Earthquakes in the Lab: An Update to Fault Zone Geology Lab

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Earthquake faults exhibit a wide range of frictional behaviors, ranging from slow deformation to rapid rupture. This variability introduces complexity into the processes of nucleation, rupture dynamics, and the distribution of slip and energy release. A fundamental question is about the interplay between slow and fast earthquakes, including their connection to large seismic events. In this study, we introduce an improvement to the Fault-Zone Geology Lab at NCU. This improvement involves developing innovative laboratory experiments to generate slow to fast earthquakes and investigating earthquake scaling properties. Two novel instruments have been developed/upgraded: a direct shear configuration on a triaxial apparatus and a hydrothermal pressure vessel on a low-to-high-velocity apparatus. The direct shear configuration on a triaxial apparatus has been mainly utilized for investigating friction constitutive law worldwide for decades (e.g., friction instability and healing). Currently the relevant experiments under shallow crustal depth conditions (~ 8-10 km) can be conducted in Taiwan. On the other hand, the hydrothermal pressure vessel on a low-to-high-velocity apparatus can reach similar pressure conditions to the triaxial apparatus but is equipped with a more advanced heating system (~500˚C). The cutting-edge experimental conditions can achieve the brittle-to-ductile transition and will be applied to unravel fault deformation in tectonic settings with ultra-high geothermal gradient (i.e. super-hot or supercritical conditions). These developments may deepen our understanding of slow-to-fast earthquake processes and improve our knowledge of earthquake source physics.

Keywords:triaxial apparatus, rotary shear apparatus, frictional law, super hot , fault zone geology lab

An Investigation into The Relationship between Avian Bone Structure and Flight Ability

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Changes in skeletal morphology and structure have played a crucial role in the evolution of vertebrate flight. Furthermore, recent studies of mammalian osteocytes have shown that osteocytes can act as mechanoreceptors that respond to mechanical loads on the skeleton, suggesting that the morphology of osteocytes is related to vertebrate locomotion patterns. However, most previous studies have relied on two-dimensional cross-sections of bones to estimate osteocyte size, which cannot faithfully represent the three-dimensional structure of bone tissue or accurately calculate the volume of osteocytes. In this study, we have collected data from several extant birds and small theropod dinosaurs. We reconstructed 3D models of their humeral osteocyte lacunae using the transmission X-ray microscope at the Taiwan Light Source, National Synchrotron Radiation Research Center. Our tomographic results provide accurate osteocyte morphological parameters and volumetric sizes, providing a significantly improved model and a basis for interspecies comparisons. The study found that the volume of bird osteocyte lacunae was significantly positively correlated with their body mass. The height/width ratio of osteocyte lacunae was negatively correlated with the hand-wing index of birds, which is related to the dispersal ability and aerial lifestyle of birds. Updated data from small therapod dinosaurs and correlation analyses will generate insight into the evolution of flight ability in paraves. We hope these results will bring new insights into the study of the evolution of bird flight ability.

Keywords:osteocyte lacunae, transmission X-ray microscope, extant bird, theropod dinosaur

測繪孿生結合數值模型精進山岳隧道施工監測探討

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施工監測為現代化隧道工法確保地質不確定性造成不利影響重要防線，考慮設備與成本，常採隧道數倍開挖直徑佈置監測斷面，難免疏漏。隨著雷射掃描技術(LiDAR又稱光達)發展成熟，地面光達已可以快速、精準且全面性地蒐集隧道三維空間資訊，透過不同時期點雲差異量分析方法可求得隧道周壁變位，作為監測隧道變位的依據，然隧道掃描結果能補足傳統隧道控制點監測資料不足之現象，其隧道監測變位結果充滿不確定性。

本研究使用地面光達測繪技術應用於山岳隧道蒐集施工階段定期重複掃描之隧道三維空間資訊建立動態隧道數位孿生模型，並透過點雲差異分析建置施工測繪孿生模型，為掌握測繪孿生模型之精度，再透過現地全尺度試驗評估其測繪孿生模型精度。此外，本研究蒐集隧道施工前地質鑽探資料建置隧道區域工程地質模型，最後建立整合測繪孿生模型、工程地質模型與施工開挖數值模擬模型，迅速比較周壁變位以評估施工反應的監測流程。同時選定一案例隧道，透過重複掃描產製測繪孿生模型，建置隧道區域工程地質模型與數值模擬模型，透過實驗確定測繪模型精度，最後整合工程地質模型、數值模型與測繪模型進行隧道開挖周壁變位評估測試，完善其整合模型應用於隧道工程之流程。

本研究透過將不同資料來源之模型整合至同一平台上，讓使用者更直觀地檢視隧道施工資訊，並透過整合模型提供施工反應之參考，有助於其施工決策並減少施工時間成本，並可以利用本研究建立之數位孿生模型進行後續隧道驗收、維護、營運管理。

中文關鍵詞：山岳隧道施工監測、雷射掃描技術、孿生模型、數值模擬、模型整合應用

臺灣新竹馬武督的鋯石巨晶：U-Pb 地質年代學、原位 Hf-O 同位素特徵及其地質意義

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台灣西北部新竹關西至橫山晚中新世南庄層中，出露狹長狀東北-西南走向鹼性玄武岩體，在鄰近切穿鹼性玄武岩體河流的沖積層中，採集到2-5釐米鋯石巨晶及藍色剛玉、橄欖石、頑火輝石、鉻透輝石等礦物。鋯石晶體呈透明至半透明；顆粒的顏色範圍從無色到淺棕色、到暗棕色；大多數鋯石晶體表現出複雜的表面發育，另一些鋯石巨晶顆粒形狀約略呈圓形；陰極射線發光影像顯示鋯石內部扇形分帶結構（sector zoning）及振盪環帶（oscillatory zoning），具岩漿鋯石的特徵。

藉由二次離子源質譜儀(SIMS)及鐳射剝蝕-感應耦合電漿質譜儀(LA-ICP-MS)分別進行U-Pb定年、O同位素及Hf同位素分析。首先以鋯石陰極射線發光影像為基礎，在18顆鋯石巨晶進行23個U-Pb定年測點，明顯獲得兩群鋯石U-Pb平均年齡: 12.9±0.2 Ma (~13 Ma, Th/U=0.77-1.42)及10.0±0.3 Ma (~10 Ma, Th/U=0.75-1.41)，兩群鋯石的Th/U比值明顯大於0.5，具岩漿鋯石的特徵；氧同位素$\delta^{18}O$=5.47-5.92(~13 Ma, n=12), $\delta^{18}O$=5.14-5.93(~10 Ma, n=11)。並在原位測點測得鉿同位素值ε_{Hf}(~13 Ma)=-1.73-2.61 (n=12), ε_{Hf}(~10 Ma)=0.39-5.91 (n=11)，顯示鋯石兩期岩漿物質來源略有不同。

經由野外地質調查鋯石巨晶分布、鹼性玄武岩體找獲鋯石、鋯石巨晶的年代與鹼性玄武岩體年代極為接近等原因，推測鋯石巨晶成因與鹼性玄武岩極為相關；並經由Hf-O同位素數據推測兩期鋯石巨晶物質來源為地函與地殼物質混染，~13 Ma鋯石巨晶物質來源地殼物質混染較多，地函岩漿較少；~10 Ma鋯石巨晶物質來源地殼物質混染較少，地函岩漿較多，表明~10 Ma的張裂環境岩漿作用較~13 Ma 岩漿作用較為激烈。暗示在馬武督地區晚中新世角板山火山活動期，~13 Ma為地殼張裂作用初始，至~10 Ma轉為地殼張裂作用強烈時期。

中文關鍵詞：馬武督鋯石巨晶、U-Pb年齡、原位Hf-O同位素、二次離子源質譜儀、鐳射剝蝕-感應耦合電漿質譜

以台西盆地進行二氧化碳地質封存模擬之案例研究

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摘 要

本研究以台灣西部沿海之台西盆地為模擬場址，結合數值模擬與風險分析技術，應用開源高效能模擬工具PFLOTRAN與美國風險評估平台NRAP-Open-IAM，考量不確定性假設不同地質參數與井況情境，進行二氧化碳遷移與洩漏行為分析，建立一套符合國際發展且具第三方驗證潛力之安全評估流程。

參考台西盆地井下鑽探的地質特徵文獻，利用PFLOTRAN進行地層建模與反應傳輸模擬，假設不同的孔隙度及滲透性等條件，探討二氧化碳注入儲集層後的遷移行為。PFLOTRAN具備優異的並行計算能力，並為美國環境保護署列為認可之二氧化碳地質封存模擬工具，具有開源透明、計算穩定與高可信度等優勢，並且應用範圍涵蓋事前調查到灌注後場址管理的CCS生命週期。

由於井是CCS主要潛在洩漏途徑之一，本研究假設不同井況情境：(1)水泥完井（基本情境）與(2)開放井（保守情境）等，並以PFLOTRAN模擬結果作為NRAP-Open-IAM之輸入參數，量化二氧化碳經由井路徑洩漏的風險分析。NRAP-Open-IAM由美國能源部（Department of Energy, DOE）的國家風險評估夥伴計畫（NRAP, National Risk Assessment Partnership）開發，其具有開源、降階及串接模組等特性，可快速調整井或受體模組，針對多種風險情境進行量化分析。

參考國內CCS安全評估文獻，採用PFLOTRAN與NRAP-Open-IAM為分析工具，建構二氧化碳封存安全評估流程，透過NRAP-Open-IAM生成之審查區域（Area of Review, AoR）、領結圖及敏感性分析，探討洩漏風險的主要參數與影響，能系統性地呈現洩漏事故發生風險，可作為場址監測範圍規劃參考，並能提升風險管理與民眾溝通的效益，為國內推動CCS提供第三方驗證的科學技術支持。

中文關鍵詞：碳封存、台西盆地、PFLOTRAN、NRAP-Open-IAM、風險評估

Feeling Taiwan's Seismic Rhythm by Heart

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We provide a new method for predicting earthquakes by integrating topological data analysis with deep neural networks to capture the intrinsic geometric and dynamic features embedded in Taiwan's seismic time-series data. By applying Takens' theorem, the original time series is transformed into a high-dimensional point cloud where key topological features, such as persistence barcodes, are extracted to quantify the evolution of n-dimensional holes.

In the first forecasting approach, a graph convolutional network converts spatial information into a vector representation, which is merged with a 12-dimensional topological feature vector to form the input of a long short-term memory (LSTM) network. Weighting factors for time, location, and magnitude are incorporated to correct subtle discrepancies. An alternative method constructs a persistence diagram that tracks the birth and death of topological features. Finally, we can conclude: "**An earthquake at time t occurs if and only if the value at times t–2 and t–1 remain stable, followed by a significant increase or decrease at time t when using the bottleneck distance.**" This rule is evidenced by the pre-shock patterns observed before the 921 event.

In conclusion, by fusing TDA with deep learning, the proposed method offers a robust framework for earthquake anomaly detection and prediction, holding significant promise for early warning systems and improved disaster mitigation measures.

Keywords:Topological Data Analysis, Deep Learning, Anomaly Detection, Graph Embedding

二氧化碳地質封存儲集層之斷層掃描影像分析初探

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二氧化碳地質封存潛在場址之儲集層水力特性將影響二氧化碳超臨界流體的移棲，係構造與地層封存(structural and stratigraphic trapping)機制之重要因素，其中，孔隙率(porosity)及滲透率(permeability)為封存潛能評估及流體移棲數值模擬的關鍵參數，通常藉由現地試驗及實驗室試驗獲得巨觀的數值。殘餘封存(residual trapping)、溶解封存(solubility trapping)及礦化封存(mineral trapping)亦為重要的封存機制，鑑於儲集層的微觀構造不易取得，目前針對相關封存機制的研究較少，並常直接使用巨觀的條件比擬微觀分析的所需參數。

國家原子能科技研究院使用自行開發之斷層掃描儀器，最精細解析度可達5微米的條件下，進行二氧化碳地質封存潛在場址儲集層試體(取自魚藤坪砂岩及觀音山砂岩)之斷層掃描。本研究依據斷層掃描影像並使用影像分析軟體Avizo，藉由二值化(banalization)執行地質材料之顆粒與孔隙的區分，並進一步針對各自的幾何(如尺寸、體積、球度等)與分布(顆粒的接觸、孔隙的連通等)進行判釋，最終推得顆粒的粒徑分布、孔隙率等統計結果，其中，配合Kozeny-Carman方程式(KC方程式)可快速推求滲透率，作為試驗室量測滲透率之對比依據；此外，顆粒與孔隙的微觀尺度三維空間分布亦可匯出成物件檔案，供殘餘封存、溶解封存及礦化封存的數值模型建構與分析使用。

初步的顆粒分析結果顯示，推算後之魚藤坪砂岩試體顆粒粒徑介於37.1 μm至0.28 mm，中徑(D_{50})為0.13 mm；觀音山砂岩試體的顆粒粒徑介於28.4 μm至0.27 mm，中徑為0.14 mm。初步的孔隙分析結果則顯示魚藤坪砂岩試體的全孔隙率為37.01%；觀音山砂岩試體的全孔隙率為41.96%。依據Bear(1972)之KC方程式進行推估可獲得魚藤坪砂岩試體的滲透率約為1.2E-11 m^2；觀音山砂岩試體的滲透率為2.2E-11 m^2。

配合後續潛在的大量二氧化碳地質封存潛在場址調查需求，將引入人工智慧自行自動化顆粒與孔隙的判釋；同步匯出顆粒與孔隙的三維空間分布供微觀尺度的數值模型建構使用。

中文關鍵詞：二氧化碳地質封存、Avizo影像分析、孔隙率、滲透率、Kozeny-Carman方程式

台灣國際地熱論壇對地熱能源政策的影響

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自2018年至今，能源轉型、淨零碳排2050、能源轉型2.0等能源政策持續關注地熱能源的發展，陸續調整不合理的環評限制、開放過去探勘資料、修訂地熱發電程序法規，終於著手建立對於地熱能源開發有利的投資環境，因此雖然地熱發電裝置容量(capacity)不足全國能源會議2025年目標的1/20，但國際地熱產業更越來越重視台灣的地熱開發市場，從連續三年舉辦的台灣國際地熱論壇(Taiwan International Geothermal Conference, TIGC)可觀察到政策及產業的熱度(degree of attention)持續提升。

台灣地熱資源發展協會(Taiwan Geothermal Association, TGA)是2019年成立的非政府組織(NGO)，成立以來積極與荒野保護協會(SOW)、生態關懷者協會(TESA)、台灣再生能源聯盟(TRENA)、野薑花公民協會(CAPPT)、綠色和平(Greenpeace)、綠色公民行動聯盟(GCAA)、台灣環保聯盟(TEPU)、環境權保障基金會(ERF)等能源環保倡議NGO合作，2021年開始倡議TIGC，2022年與經濟部合作籌辦TIGC並落實擴散資訊的策略，例如演講口譯直播、會後簡報分享、促進實體交流，將國內地熱推動政策及國際地熱能源科技在一天內重點呈現，逐步解決各領域對地熱議題的資訊落差(Access to information inequality)。

從2023年至2025年TIGC一躍成為國際重要的地熱盛事，也同時促進政府大幅調整地熱能源政策。主要展現在三個層面上：

1、地熱能源目標調整：經濟部提出能源轉型2.0的地熱發電目標，短期內在2030年達到1.2GW；長期在2050年達到6GW。

2、國際合作與技術引進：台電公司、中油公司、各大學地熱相關研究中心、地熱協會陸續與國際地熱團隊簽訂MOU，特別是在技術創新和產業鏈整合方面。

3、政策與資金支持：政府提供更多地熱計畫合作機會與政策支持，以吸引國內外投資者參與地熱能源開發，全力向目標衝刺。

中文關鍵詞：台灣國際地熱論壇、地熱推動政策、地熱能源科技

Finite-Fault Rupture Characteristics of the 2025 Mw 7.7 Myanmar Earthquake Along the Sagaing Fault

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Myanmar lies in a tectonically complex region shaped by the oblique convergence of the Indian, and Eurasian plates. The Sagaing Fault, a major right-lateral strike-slip fault over 1200 km long, accommodates ~23–24 mm/yr of dextral motion and marks the boundary between the Burma microplate and the Sunda plate. While its northern and southern segments have ruptured historically, the Meiktila segment in central Myanmar had remained a seismic gap. On 28 March 2025, a Mw 7.7 earthquake near this region and may have ruptured part of this gap. To study the rupture characteristics of this earthquake, we performed a joint finite-fault inversion of teleseismic (body and surface waves) and regional strong-motion waves. The initial hypocenter and moment tensor parameters were adopted from the GCMT catalog. The fault plane was divided into four sections matching Sagaing Fault geometry. We used 56 P, 43 SH, 67 Rayleigh, 61 Love waves, and 6 strong-motion records, selected based on misfit < 0.5 and azimuthal coverage. The final model yielded an average misfit of ~0.2. The resulting rupture propagated asymmetrically southward, spanning ~410 km along strike and ~22.5 km down-dip. It initiated near the hypocenter at ~10 km depth, with southward propagation over 350 km and limited northward extension (~60 km). Peak slip (~6 m) was centered around the hypocenter, with moderate slip (~1–3 m) extending southward and coherent low slip (~0.5–1.1 m) in the southernmost segment. The moment rate function showed two peaks (~20 s and ~77 s), and the total rupture lasted ~90 s. This event highlights the hazard of seismic gaps and the importance of ongoing earthquake monitoring in Myanmar.

Keywords:Myanmar earthquake, Rupture characteristics, Finite-fault inversion, Sagaing Fault, Seismic gap

臺灣西南部即時地震活動觀測與潛在孕震構造

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臺灣西南部多次發生嚴重災害的歷史地震，有複雜的斷層系統與孕震構造，顯示具有較高的地震活動潛勢。除了在西部麓山帶與平原交界有南北走向的逆衝斷層之外，還存在東西走向的橫移斷層系統，盲斷層則潛伏在沖積平原底下。三種不同類型的斷層，地表破裂型態與災害特性各不相同，需要評估每條斷層的活動程度及關聯性。位於平原的都會區人口密集，並持續增設科學園區與精密機械園區提供就業機會，但地震時沖積層會造成震波放大，並伴隨土壤液化等災害。因此減少地震導致的經濟損失，強化災後復原能力，降低地震所帶來的衝擊是相當重要的議題。

為了即時掌握地震資訊與了解地震活動特性，根據地震活動與斷層分布，設置6個即時傳輸的短周期地震觀測站。同時，整合中研院地球所及中正大學地環系即時寬頻地震站資料，增加測站密度並提升地震偵測能力。並與中央氣象署地震測報中心合作，以SeisComP軟體進行即時資料接收，與地震定位及震源機制解算等分析工作，獲得更高解析度的背景地震活動資訊。從2023年至今，臺灣西南部發生了多次有感地震序列，包括新港-民雄、朴子-太保、布袋-義竹、中埔、佳里-麻豆、大埔-楠西及官田-六甲等，且有些地震序列至今仍持續活躍，逐一說明每個地震序列的特色。綜合這些觀測結果，深入了解嘉南平原的地震活動特性，與孕震構造之間的關聯性。評估各斷層的活動程度與建立相關參數，以進行地震動潛勢與伴隨的複合災害分析。期望助於減輕未來地震可能帶來的災害，提升嘉南地區的防災能力。相關研究成果，已逐步發表於國內外學術研討會，及撰寫於國科會計畫報告與國震中心相關刊物等。

中文關鍵詞：臺灣西南部、地震活動、孕震構造

南沖繩海槽棉花、土龍海底火山之地層構造與火成活動特徵

鍾承峻[1]、王明[2]、許鶴瀚[1,2]、謝獻祥[2]、劉家瑄[2]、林依蓉[3]、陳松春[3]

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中文關鍵詞：南沖繩海槽、海底火山、多頻道反射震測、地球物理資料

南沖繩海槽棉花、土龍海底火山之地層構造與火成活動特徵

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Unraveling fault slip dynamics in northern Longitudinal Valley: insights from coseismic ruptures, aseismic slip, and seismicity

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The 2024 M_w 7.3 Hualien earthquake caused widespread deformation across northern Taiwan, with horizontal displacements from ~2 cm in the west to ~18 cm in the east and vertical uplift up to 44 cm near Hualien. Using GNSS coseismic displacements and the Okada model, we inverted for fault geometry and slip distribution. The rupture involved the west-dipping Central Range Fault (CRF, ~30° dip) and the east-dipping Longitudinal Valley Fault (LVF, ~70° dip), with maximum slips of 1.5 m (CRF) and 1.0 m (LVF). Major slip occurred north of the hypocenter in a low aftershock zone. Given the overlapping rupture zones of the 2018 M_w 6.4 and 2024 M_w 7.3 events, we applied the 2024 fault model to invert the 2018 slip distribution. The 2018 rupture mainly involved shallow slip on the LVF and CRF, complementary to the 2024 pattern, consistent with expected stress redistribution following sequential earthquakes. Both rupture areas have experienced frequent seismic swarms. Following the 2019 M_w 6.1 earthquake, aseismic slip accelerated on the CRF, coinciding with increased repeating earthquakes and two swarm episodes in 2019 and 2021. By removing long-term trends, annual signals, and coseismic offsets from the GNSS position time series, we identified transient deformation that aligns with the swarm periods, suggesting deep fault creep likely driven by overpressured fluids. This transient slip likely occurred on fault segments distinct from those ruptured during the 2024 event. Integrated seismic and geodetic analysis is needed to better understand the interactions among earthquakes, swarms, and aseismic slip.

Keywords:2024 Mw 7.3 Hualien earthquake, GNSS, coseismic slip distribution, aseismic slip, seismicity

以卡爾曼濾波與主成分分析探討GPS時間序列中的暫態變形訊號

詹鎧齊[1]、張午龍[1]

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GPS 位移時間序列中所含的暫態訊號可以反映地表諸多變形，如震後位移、火山作用及地下水位變化等，讓我們能夠以此研究地殼變形的性質並洞察災害發生的可能性。但在此連續位移紀錄中，存在著非常多的雜訊，導致較微弱的暫態訊號因低訊噪比而較難被觀察到。本研究參考Ji and Herring (2013a)所提出的方法，將FOGM (first order Gauss-Markov)隨機過程置入原始時間序列的狀態函數中，並以卡爾曼濾波器(Kalman filter)去除序列中固定振幅的趨勢(trend)、年週期、半年週期等狀態訊號以及白雜訊(white noise)，其所得的FOGM過程即包含了序列中各狀態分量的動態變化以及色雜訊(color noise)。最後將各站各分量的FOGM進行主成份分析(principal component analysis, or PCA)，以萃取其在時間與空間中的主要共同分量。相較於色雜訊，GPS測網中顯著的共同暫態地殼變形多來自位移趨勢中低頻且振幅較高的變化，因此將預期出現在PCA前面的幾項主成份。此方法可同時降低雜訊在時間域及空間域的影響，使微弱的暫態訊號能夠更容易被檢測。我們將以位於美國西部Utah州Wasatch 斷層帶的GPS 測網資料作為範例(觀測時間>10年)，分析此區域可能出現的暫態地表變形以及它們與此斷層的關聯。

中文關鍵詞：卡曼濾波、主成分分析、暫態訊號

Evaluation of wildfires and rockfall assessment in Alishan region through rainfall and granite analysis

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Alishan mountain region in Taiwan faces the increasingly unpredictable weather and wildfire events, raising concerns about rockfall risks. This study combines rainfall data, mineral analysis, and thermomechanical testing of granite to assess wildfire-driven impacts on slope stability. Dry-season rainfall has grown more varied with a March-2016 spike over 230mm pointing to extreme climate shifts. X-ray diffraction analysis reveals that feldspar and illite dominate mineral composition of Alishan granitic rocks, both are susceptible to thermal stress. Controlled heating experiments demonstrate that porosity increases markedly >400°C, reaching over 2.5% at 800°C, indicating structural weakening. Stress-strain curves from uniaxial compression tests reveal consistent decline in peak stress with increasing temperature, indicating that rocks lose strength and show significantly more fragile post-wildfire. Microcrack analysis further confirms increased inter-crystalline and grain boundary fracturing beyond 500°C with sharp rise in microcrack width. These internal changes coincide with mass-loss and volume-expansion, reduce rock cohesion. Findings suggest that post-wildfire rock masses weakened by heat-induced porosity and cracking are more vulnerable to rainfall-triggered failures, especially under fluctuating seasonal precipitation. This research highlights the importance of using comprehensive hazard assessment models, which incorporate both climate and geological data to improve the prediction and prevention of rockfall incidents in wildfire-affected mountain regions such as Alishan.

Keywords:Alishan mountains, Wildfire impact, Rockfall hazard, Granite thermal behavior, Rainfall variability

Ground Subsidence and Hydrological Properties in Yangon, Myanmar

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Yangon is the former capital city of Myanmar, home to approximately 2.75% of the country's total population (~55 million people). The city is bounded by the Yangon River to the south and the Bago River to the east, with the Shwegondaing-Mingalardon anticline sandwiched in between. Over the past century, Yangon has gradually expanded from its core area atop the anticlinal crest to the adjacent low-lying floodplain. Due to rapid population and economic growth in the past decade, the public water supply system has failed to cover the entire metropolitan area, leaving a large proportion of residents dependent on groundwater from private wells. The lack of proper groundwater regulation and the increased extraction from the floodplain have raised the risk of land subsidence and flood hazards in Yangon. This study derives long-term ground deformation in Yangon using Multi-temporal Interferometric Synthetic Aperture Radar (MTInSAR) techniques. We obtained displacement time series from the L-band ALOS data (2007–2009), C-band RADARSAT-2 data (2012–2014), and C-band Sentinel-1 data (2015–2022). Our results indicate subsidence of up to 2.8 cm/yr in the eastern floodplain during 2007–2009, which increased to more than 4–5 cm/yr during 2012–2014, while lower rates were observed to the west of Yangon. The highest subsidence rate of 6–7 cm/yr occurred between 2015 and 2022, particularly in the eastern part of the city, while rates of about 2 cm/yr were observed in the west and only a few millimeters in the south. In the downtown area, ground subsidence is less prominent due to the presence of exposed Pleistocene formations along the anticline. The subsidence observed in the eastern part of the city aligns with the long-term trend of the only available groundwater head record in the area. Combined with data from hydrological wells, we estimate the first geodesy-based hydrogeological model for the Yangon area.

Keywords: Land subsidence, MTInSAR, Groundwater extraction, Yangon, Hydrogeological model

臺灣本業敷瓦的文化資產價值及材料特性分析

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「本業敷瓦」（ほんぎょうしきがわら）作為愛知縣瀨戶地區生產的地磚，是日本國產磁磚的先驅，是一種以製陶技術製作的內裝磁磚，在日本磁磚發展史具有重要意義，短暫出現於1880s-1900s之間。本業敷瓦為濕式製法後來被引自西方的乾式製法生產的日製馬約利卡磚（Majolica Tile）所取代，其生產約集中於1910s-1940s之間。本業敷瓦做為臺灣最早在明治時代被引入的國產磁磚，卻因史料缺乏而導致建築史意涵及文化資產價值鮮少被討論。

本研究調查發現目前臺灣之本業敷瓦的案例僅7例，且多數主要分布於嘉義、臺南及屏東。本業敷瓦素坯為白色，為日本瀨戶一帶地質條件所產的黏土之主要特徵。史料紀載其所使用的釉藥隨著時代的變遷由天然的吳須土轉變為人工合成吳須。大多數的本業敷瓦皆使用銅版轉寫技術進行施釉，為一種將轉寫紙上的含鈷釉藥轉印在素坯化妝土上再上一層透明釉燒製的技術。轉寫紙的製作開始盛行可能與明治時期引進的氧化鈷有關，自此本業敷瓦得以大量製造。

臺灣本業敷瓦素胚的礦物相表明，原臺南廳長官邸所使用的本業敷瓦燒製溫度皆低於嘉義時敏堂及臺南大塭寮郭宅。暗示明治時期生產的本業敷瓦燒製溫度較低而大正時期以降可能因為窯業技術的提升而使本業敷瓦可以在更高溫穩定的窯內燒製。釉藥的化學成分表明，臺南廳長官邸的本業敷瓦之釉藥可能為天然的吳須土。其他案例的本業敷瓦則顯示為合成的氧化鈷。此外，現代本業敷瓦及所使用之轉寫紙上之釉藥分析結果顯示不含錳並含有鉻及鎂等特徵。研究結果顯示，臺灣現存本業敷瓦的素坯材料及釉藥成分在時代的對應上似乎存在成分差異，後續或許可由礦物相及化學成分作為指紋對未知來源的本業敷瓦進行時代推測及了解材料與技術的演變。

中文關鍵詞：磁磚、本業敷瓦、瀨戶窯業、吳須、銅版轉寫

Unraveling Heavy Metal Contamination in Mangrove Ecosystem: Risk Assessment, Phytoremediation Potential, and Rhizospheric Microbial Roles

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Mangrove ecosystems, critical for coastal resilience and biodiversity, face escalating threats from anthropogenic pollution, particularly Heavy metals (HMs). This study presents a comprehensive evaluation of HMs distribution, ecological risks, phytoremediation potential of mangrove vegetation, and rhizospheric microbial communities in the Xinfeng Mangrove Reserve, Taiwan, through hydrochemical assessment, sediment geochemistry, bioaccumulation analysis in mangrove species, and metagenomics profiling of microbial assemblages. Physicochemical analyses of adjacent water bodies (river, estuary, coastal sea, and overlying water) revealed moderate contamination levels, with mobility of Bi, Pb, Co, and Sr at the sediment-water interface. Sediment geochemical indices indicated high contamination by Bi and Pb, and moderate contamination by Zn, Sr, Cu, and Cd. Ecological risk assessment highlighted Cd as posing a moderate risk. Two native mangrove species, *Kandelia obovata* and *Avicennia marina*, demonstrated significant phytoremediation capacity, accumulating and translocating HMs such as Bi, Cd, Mn, Sr, and Co. Metagenomics profiling of rhizosphere sediments uncovered diverse plant growth-promoting microbes (PGPMs) with genes linked to nitrogen fixation, phosphate solubilization, IAA synthesis, and metal resistance. These findings emphasize the synergistic roles of mangrove vegetation and associated microbiota in mitigating HMs, offering insights into sustainable management and conservation of these vulnerable coastal ecosystems under rising pollution pressures.

Keywords:Mangrove Ecosystem, Heavy Metal Contamination, Ecological Risk Assessment, Phytoremediation, Rhizospheric Microbial Community

Topographic Reconstruction of Dahan River Terraces by Using Historical Aerial Images

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Terrain analysis is a method used to explain the formation and evolution of landforms. In our study area, the Dahanxi River Terrace is located in Taoyuan, which is the largest river terrace group in northern Taiwan, extending from the Jiaobanshan area to the Yingge area. The Dahan River has experienced significant incision and formed widespread river terraces due to the orogenic activity in northern Taiwan and the subsidence of the Taipei Basin. However, because of the construction of the Shimen Reservoir in 1964, a portion of the Jiaobanshan River Terrace submerged. Consequently, the current digital terrain models and images cannot fully present the terrain of the Dahan River Terrace. Historical aerial images become valuable resources for recording the topography of the Dahan River Terrace. In this research, we used historical aerial images of the Dahanxi River from 1957 and combined them with the Structure from Motion (SfM) technique to reconstruct a three-dimensional topographic model. Initial outputs include a digital surface model (DEM) and orthoimage with an error range of 6 to 8 meters. From the SfM-generated DSM, the original topography of the Jiaobanshan area is visible and reveals the additional river terrace.

Keywords:Structure from Motion (SfM), river terrace, Historical Aerial Images

Geochemical Characteristics of Pyrite: Implications for Genesis of gold deposits in Tatun volcanic area, Taipei

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Pyrite is the most abundant sulfide mineral on Earth's surface, widely distributed in various hydrothermal deposits and diagenetic environments. Its mineralogical and geochemical characteristics serve as important indicators for gold exploration. This study focuses on the Sihuangziping area within the Tatun volcanic region, located near the historically mined Sanchungchiao gold deposit (Ba-yan), reportedly exploited by the Spanish. Mineralogical similarities between the Sihuangziping and Chinkuashih deposits suggest a potential connection and a shared hydrothermal background. However, the precise mechanisms governing pyrite formation and their implications for gold enrichment in the Tatun volcanic area remain unclear.

The aim of this study is to establish the first comprehensive trace-element database of pyrite from the Tatun volcanic area, thereby elucidating the metallogenic processes and providing reliable indicators for geochemical exploration. Pyrite samples from drill cores (maximum depth of 775 meters) were analyzed using Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Spectroscopy (EDS), Electron Probe Microanalysis (EPMA), and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS).

Analytical results reveal enrichments in cobalt (Co; up to 815 ppm), nickel (Ni; up to 2601 ppm), and arsenic (As; up to 2.97 wt%), along with minor copper (Cu; up to 36 ppm). These enrichments, combined with observed oscillatory zoning, suggest episodic influxes of metal-rich hydrothermal fluids in the Tatun volcanic area. Pyrite morphologies predominantly include euhedral cubic and octahedral forms, as well as irregular aggregates exhibiting compositional zoning and structural disorder. Approximately 70% of the samples have Co/Ni ratios greater than 1 and S/Fe atomic ratios ranging from 1.88 to 2.11, supporting a dominantly hydrothermal origin characterized by localized medium- to high-temperature fluid conditions. A zoned pyrite grain with notably high Co, Ni, and As concentrations further indicates multiple episodes of fluid overprinting and subsequent late-stage recrystallization.

In contrast, pyrite from the Chinkuashih deposit consistently exhibits low Co/Ni ratios (<1) and elevated Cu concentrations (up to 7878 ppm), indicative of low-temperature, late-stage hydrothermal precipitation. Despite sharing a similar high-sulfidation hydrothermal background, these distinct geochemical signatures between the two areas reflect different metallogenic stages. The Tatun system likely represents an early phase of hydrothermal evolution, with ongoing fluid activity suggesting potential for future mineralization. Conversely, Chinkuashih documents a more mature system, having completed its mineralization processes.

Keywords:Pyrite, Epithermal gold deposits, Invisible Gold, Tatun volcanic area

Clustering Analysis of the BMKG Catalog of Sumatra Using the DBSCAN Algorithm

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Sumatra located along the convergent boundary, where the Indo-Australian Plate is subducting northeastward beneath the Eurasian Plate. The oblique subduction beneath Sumatra results in a trench-parallel shear component, which is accommodated by the Great Sumatran Fault (GSF), a trench-parallel strike-slip that extends approximately 1,900 km along Sumatra. Consequently, this region is active seismically and complex tectonically. In this study, we aim to identify earthquake clusters in Sumatra and investigate the associated mechanisms. We employ the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm to the BMKG catalog (2009-2022), with M_{LV} converted to M_w and M_c=4.2.

DBSCAN identifies high-density regions as clusters and low-density regions as noise or outliers based on the concept of connected dense components, established when a point has at least minimum number of objects within a specified radius. We separately examine the trade-off curves of the radius and the minimum number of points against their respective sum of squared errors, and determine the corresponding optimal parameters at the corner of each curve. The results demonstrate 24 earthquake clusters in Sumatra, each spatially well-separated. Notably, the clustering reveals a depth-dependent seismic pattern, distinguishing shallow events from intermediate-depth earthquakes, thus highlighting the distinct tectonic settings associated with each cluster.

Keywords:Clustering, DBSCAN, Earthquake, Sumatra

利用荷重-克來勞方程式估計LLVP造成之CMB非自轉扁率

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克來勞定理(Clairaut's theory)是描述受牛頓古典重力與相對小的自轉離心力之天體達靜力平衡時，自轉離心力與天體內部扁率兩者關係之理論，為大地測量學(geodesy)中歷久不衰之經典定理。本文中，我們以Chao & Shih (2024)與Poisson & Will (2014)為基礎(i)將經典的克來勞定理擴張成荷重-克來勞定理(Load-Clairaut's theory)，使其能夠計算天體於不連續面以上擁有微小的側向密度變化且達靜力平衡時，天體內部之扁率或形變係數隨半徑的變化，並嘗試使用此理論計算地球內部LLVP對於CMB扁率、地表扁率、地球J_2參數之影響；(ii) 利用相同的方法計算克來勞定理於球諧函數(Spherical Harmonics)任何一次之形狀變化，並討論潮汐鎖定即自轉與公轉同步之天體，受重力與相對微小之引潮力的二次項後達靜力平衡時的形變大小；(iii) 證明經典的克來勞定理於n層密度模型有解析解，並嘗試將PREM換算成n層密度模型(n-layer density model)，避開數值積分直接計算地球內部扁率分布之強近似值。透過荷重-克來勞定理即可以相對精簡的方式計算天體內部之不連續面，包括天體表面有額外荷重時天體內部的形變係數隨半徑的變化，並且此方法能夠同時計算側向密度變化之荷重造成的形變與其重力位造成的形變，可於計算長波長的球體形變時，避免誤套用平面靜力平衡之算式，只計算荷重造成的形變，或使用於球體表面方成立之近似式等錯誤。

中文關鍵詞：重力位理論、重力異常與地球結構、行星大地測量與重力

Thermobarometric Constraints on the Formation of Major Eruptive Phases of the Tatun Volcanic Group

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A mineral chemical study was conducted on basaltic to andesitic rocks from seven eruptive centers of the Tatun Volcanic Group (TVG). We aim to constrain the temperature and pressure of the magma reservoir(s) and track their evolution of the lifetime of the volcanic field, which spans several hundred thousand years. Temperature estimates vary based on the thermobarometric methods used, in the order of clinopyroxene-liquid (~1100-1200 °C), two-pyroxene (~930-1070 °C) > amphibole (~820-950 °C). Crystal chemistry of pyroxenes and amphibole reveals a broad equilibrium pressure range (0.1-0.9 GPa, corresponding to 3-27 km depth) with pressure data clustering at distinct crustal levels, even within a given eruptive center (e.g., Shamao and Qixing). Other centers give relatively restricted pressure estimates (e.g., Hunglu and Songshan). Overall, the data appear to be consistent with the presence of a vertically extensive, partially molten magma plumbing system over the Late Pleistocene in the crust where the TVG formed. Ongoing work is set to address factors affecting the estimated temperature and pressure including sampling bias, decompression-driven crystallization, and antecryst entrainment, before comprehensive information can be gleaned about magma storage conditions.

Keywords:Crystallization, volcanic rocks, 40Ar/39Ar dating, mineral chemistry

Spinel and phosphate mineral chemistry as potential markers for the formation of the Southampton Pallasite

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The Southampton pallasite is classified within the pallasites' main group, resulting from its relatively uniform forsterite content in olivine (Fo88±1). Chromian spinel, as an accessory mineral, occurs either as inclusions enclosed in olivine and as massive crystals. The composition of chromian spinel crystals exhibits significant variability in terms of Cr#=Cr/(Al+Cr) (93-99) and Fe#=Fe/(Mg+Fe) (50-77). All spinel crystals show a compositional zonation from core to rims, characterized by enrichment in Cr# and Fe#, and Al# depletion, which may be caused by re-equilibration reactions. Nevertheless, chromian-spinel cores may have preserved primary magmatic composition from which it crystallized. The phosphate-bearing minerals identified are Ca-merrillite and stanfieldite, both occurring as interstitial crystals between olivine. Texturally, both Ca-merrillite and stanfieldite crystals present Fe-filled fractures and alteration features, which indicates a possible secondary origin. However, two Ca-merrillite crystals texture suggests a potential igneous origin. Ca-merrillite show a slight compositional variability in terms of CaO (46-49 wt%), P_2O_5 (44-46 wt%), FeO (0.8-4.1 wt%) and MgO (3.4-3.7 wt%). Conversely, stanfieldite exhibits higher variability of CaO (20-26 wt%), P_2O_5 (41-47 wt%), FeO (4-15 wt%) and MgO (14-20 wt%). In Ca-merrillite and stanfieldite CaO and FeO show a strict substitution, in which an increase in FeO results in an equal decrease in CaO. Similarly, MgO and P_2O_5 show a negative correlation with FeO. The Ca-Fe^{2+} exchange, along with the decrease in MgO and P_2O_5, may result from a late-stage reaction between phosphate crystals and liquid Fe-Ni metal alloy.

Keywords:Southampton pallasite , planetary science , meteoritic Ca-phosphates, chromian spinel

不同斷層傾角對二氧化碳地質封存注儲效應之案例研究

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二氧化碳地質封存可能引起的誘發地震事件為碳封存風險的主要議題之一。透過事先模擬評估已知斷層誘發地震的可能性，可以協助選址與開發階段的規劃。本研究以台灣中部濱海工業區的深部鹽水層碳封存候選場址為案例，進行每年百萬噸大規模注入模擬，評估其對離場址最近的主要斷層所誘發地震的潛在風險。為進一步探討斷層傾角所造成的不確定性，本研究模擬數種不同斷層傾角對於大規模二氧化碳注儲之反應，以獲得該斷層處之壓力累積與應力變化的可能範圍，以供後續開發規劃參考。

本研究使用加拿大公司的CMG-GEM模擬器，結合二氧化碳注儲反應模擬與岩石力學耦合模組的計算，去評估大規模二氧化碳注入地層後，對於不同斷層傾角的壓力與應力反應。參考前期研究，案例模擬範圍為60公里見方，在注入地層中設計5種不同的岩石特性與24層不同孔隙率與滲透率的地質分層。在斷層傾角上設計30度、40度、50度與60度四種情境。在注儲設計上，以單口井假設其注儲率為每年1百萬噸二氧化碳進行注儲模擬，注儲期間為50年，並於關井後觀察500年。主要觀察為注儲後在不同斷層傾角下之壓力與應力場變化行為，並與前期無傾角的模擬比較。模擬結果顯示，在注儲期間，由於孔隙內之流體壓力變化，導致有效應力開始減少，在注入井處會發生相應的最大壓力與應力變化，並且壓力與有效應力的反應會進一步向遠離注入井的方向擴散；在停止注入後，由於二氧化碳會往高處移棲，移棲所導致的孔隙壓力變化，也會進一步影響應力場的分布。本案例於斷層處因二氧化碳注儲所引起的壓力與應力變化相當微小，無論情境為何都不會引起該斷層的再活動。然而不同傾角改變了應力分布，在傾角60度情境下所造成的應力變化為最大。因此，斷層傾角在誘發地震風險評估模擬上確實具有顯著的影響。

中文關鍵詞：二氧化碳地質封存、數值模擬、斷層、誘發地震、風險

甲烷煙囪源著底棲性海底生物洞穴形成流體通道的直接證據—來自台灣中部的化石紀錄

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在台灣中部一處上新世的甲烷滲漏點（methane seep），大量管狀碳酸鹽構造（甲烷煙囪；carbonate tubes）與雙殼貝化石被發現，顯示此處曾是活躍的冷泉環境。其中，一顆長約半米的白雲質碳酸鹽結核（dolomitic concretion）保存了一枚殼頂朝上的滿月蛤（*Anodontia goliath*），並提供了化學共生雙殼貝如何影響淺層流體遷移的直接證據。

該結核由外部的白雲石皮層（cortex）與內部中空的中央管道組成，管道中填有來自管壁剝落的亮晶方解石（sparite）與角礫岩碎塊。此研究發現，當復原滿月蛤的生前原位姿態後，有一個中央管道是連接至滿月蛤的前緣（anterior），而在下方較長的管道段則連接到滿月蛤的後緣（posterior）。此兩管道分別代表吸水與開採甲烷過渡帶（sulfate-methane transition zone, SMTZ）中硫化物的通道。

白雲石皮層的碳同位素組成顯示 $\delta^{13}C$ 值低至 -29‰（VPDB），反映管道周圍曾經歷活躍的厭氧甲烷氧化（anaerobic oxidation of methane）。中央管道底部的沉積結構向上變形，顯示流體自沉積物逸出時產生的拖曳效應；而管壁角礫化現象則指出，早期的甲烷滲漏具脈動性（即週期性的活化與停滯）。

綜合以上觀察，該生物洞穴在碳酸鹽膠結作用早期即成為一條高滲透性的垂向通道，長期引導甲烷與伴隨流體向上運動。這項研究提供了生物洞穴可作為流體通道的直接證據，顯示底棲生物的活動可能在冷泉系統的形成初期即預設了流體遷移路徑，並對成岩反應 (diagenetic reaction) 的速率、沉積物中的流體混合作用 (fluid mixing)，以及最終釋放的甲烷量產生深遠影響。

中文關鍵詞：甲烷煙囪 carbonate tubes、冷泉 cold seep、滿月蛤 Anodontia goliath、厭氧甲烷氧化 AOM、沉積物 sediment

Surface Deformation Induced by Active Faults and Mobile Shale: Implications for Infrastructure Planning in Southwestern Taiwan

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Road design frequently encounters uncertainties and challenges posed by geological conditions, particularly in regions with active tectonic activities. Southwestern Taiwan exemplifies such an area, where interactions between mobile shale and active faults present significant challenges to infrastructure stability. Rapid deformation observed at the Chungliao Tunnel underscores the necessity for an improved understanding of deformation mechanisms, particularly relevant to the planned eastward extension of Provincial Highway 86. To address these challenges, we utilized precise leveling data from the Geological Survey and Mining Management Agency (GSMMA), continuous and campaign-mode GNSS data collected by GSMMA, Central Weather Administration (CWA), and National Land Surveying and Mapping Center (NLSC), and Interferometric Synthetic Aperture Radar (InSAR) data derived from ALOS-2 and Sentinel-1A imagery processed using the Small Baseline Subset technique. Observations from GNSS stations in southwestern Taiwan indicate that the 2016 M_w 6.6 Meinong earthquake exerted postseismic influences for nearly two years. The velocity fields derived in this study are all relative to the S01R station in the Taiwan Strait. Additionally, precise leveling and D-InSAR analyses reveal an anomalous uplift of about 10–40 mm around the Lungchuan Fault (LCNF) between May 2021 and May 2022. To avoid overestimating postseismic deformation rates following the Meinong event, this study restricts its data collection period to May 2018 through May 2021. The vertical velocities indicate that the western block (footwall) of LCNF exhibits uplift rates of approximately 2.4–6.5 mm/year; whereas the eastern block (hanging wall) shows subsidence of –3 to –10 mm/year, revealing a pronounced velocity gradient across the fault. The horizontal velocities represent around 30–50 mm/year toward the southwest. To improve the reliability of the InSAR line-of-sight (LOS) velocity field, the InSAR LOS velocity field was constrained by GNSS LOS velocities. The ALOS-2 ascending LOS velocities show up to ~38 mm/year on the footwall side of LCNF, then decreasing eastward to around 18 mm/year across the fault. Meanwhile, Sentinel-1A data represent poor temporal coherence and radar shadowing over the mountainous region east of the fault due to the dense vegetation. A three-dimensional joint inversion was then conducted to quantify crustal deformation and strain rate distributions. During the interseismic period following the 2016 Mw 6.6 Meinong earthquake (2018–2021), results indicated that the Lungchuan Fault (LCNF) exhibits creeping behavior with right-lateral motion. Specifically, uplift of 5–8 mm/year was observed on the western block (footwall of the LCNF), while subsidence of –1 to –3 mm/year occurred on the eastern block (hanging wall of the LCNF). The integrated three-dimensional velocity field revealed clear alignment between velocity gradients and the mapped LCNF. Furthermore, localized uplift west of the fault corresponded well with the distribution of suspected mobile shale, suggesting a combined influence of active faults and mobile shale on surface deformation. Geological observations validated these geodetic results by confirming the alignment of fault locations with velocity gradients and the consistency between mobile shale distributions and observed deformation patterns. Ultimately, this study provided crucial insights for infrastructure planning by quantifying surface deformation patterns and strain rate distributions. Identifying low-risk corridors help planners avoid high-strain and high-deformation areas, significantly enhancing the long-term resilience and safety of infrastructure projects in tectonically active mudstone areas.

Keywords:Crustal deformation, Mobile shale, Geodetic data, Strain rate, Lungchuan Fault

利用岩石三軸壓縮實驗探討斷層帶的粉碎岩石

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粉碎作用是地震發生時的一種變形機制，會造成位於斷層破壞帶(damage zone)當中的岩石破碎成微米或更細微尺度的碎片，透過微構造分析發現：(1)儘管發展大量開口型微裂隙，礦物顆粒外型仍相當完整；(2)發展出的微裂隙幾乎或是完全沒有特定方向性，呈現拼圖狀的相互嵌合碎片；(3)微裂隙的發展不會造成原生構造產生偏移；(4)裂隙的發展幾乎或是完全不會造成碎片旋轉。

在MiDAS鑽井的米崙斷層帶發現疑似粉碎化的石英岩塊，為了探討此斷層岩石的成因，故以人工合成石英為試體進行單壓、三軸實驗。選用由希華的人工合成石英為試體進行室內實驗。將加工的圓柱試體透過GCTS RTX-1000進行無圍壓與有圍壓的實驗，加載速率以及數據收集頻率均分別以8.333×10^{-6}/s壓縮至試體破壞以及10 Hz的方式進行。破壞過後的試體將進一步製備成岩石薄片透過光學顯微鏡觀察破裂型態並透過Matlab的FracPaQ繪製成玫瑰圖分析方向性以及裂隙長度分析。

結果顯示無圍壓與有圍壓條件下的試體壓縮強度以及破壞瞬間的軸向應變速率分別是531.506 MPa、11.67 % / sec與585.576 MPa、23.99 % / sec，可以得知低於文獻粉碎作用所需最低應變速率。根據分析發現實驗室破壞後試體碎片相較於鑽井樣品破碎的更不均勻，但在鑽井樣品觀察到如同實驗室中的晶體旋轉以及貫穿式裂隙微觀特徵。玫瑰圖分析得出實驗室破壞後試體的裂隙方向性更加明顯。本次實驗的應變速率受到限制仍無法完全排除是粉碎作用的所導致的產物，故未來將會透過能提供更快加載速率的動態壓縮儀器進行實驗，並且將其微觀構造與此次研究結果進行比對分析。

中文關鍵詞：三軸壓縮實驗、斷層帶、粉碎狀石英、微構造分析

Reconstructing 10,000 Years of Climate Change in Northern Africa, Tunisia Using Stalagmite Isotope Data

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Holocene climate variations in key regions like the Mediterranean and North Africa offer insight into long-term North Atlantic and global climate linkages. A high-resolution $\delta^{13}C$ and $\delta^{18}O$ record from a stalagmite in La Mine Cave (36.03°N, 9.68°E, 975 m asl), Tunisia, captures hydroclimatic changes from 10.07 ± 0.05 to 2.13 ± 0.03 ka (relative to 1950 CE), reflecting contrasting Mediterranean precipitation and North African monsoonal influences on decadal-to-millennial timescales. Stable isotope measurements were obtained using GasBench II linked to an IRMS, and the age model was constructed from U-Th dates using MC-ICPMS (Thermo NEPTUNE). $\delta^{13}C$ values peak at –5.6‰ with a sharp drop at 10–9.7 ka, followed by evolving trends until 2.1 ka, where values reach –9.7‰ with a peak at –6.3‰ around 1.9 ka. $\delta^{18}O$ shows a distinct negative trend (–5.2 to –6.8‰) from 10–8.6 ka, followed by sharp fluctuations, then a stable positive trend from 8–4.5 ka, and slight variations from 4–2 ka. The $\delta^{18}O$ record reveals long-term aridification and sub-millennial variability, aligning with decreasing summer insolation. Concurrent $\delta^{13}C$ shifts suggest a vegetation/soil response to drying. These results capture the African Humid Period and its termination with high detail, offering new insights into Holocene climate evolution in central North Africa and complementing marine and lacustrine records.

Keywords:Stalagmite, Tunisia, Isotope, Paleoclimate

從臺灣東部交通路廊探討三維地質模型建構之策略與應用

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清代晚期蘇澳至花蓮初步修築可供人與馬車通行的便道，稱為北路，為東部陸路交通之起源。現代為有效強化了運輸效率與交通安全，將台灣東部陸運交通分為公路與鐵路兩大系統，其中公路部分，其雛形為日治時期修築的臨海道路，直至1932年完成單線通行，包含有14座短隧道，民國後改稱為蘇花公路，於1980年陸續進行拓寬工程，至1990年後實現雙線通車，目前共設有15座隧道。現今為提升蘇花公路之路網韌性，包含2020年完工的蘇花改善工程，並積極推動蘇花安。至於鐵路方面，北迴鐵路完工於1980年，為臺灣十大建設之一，全線新建16座單線鐵路隧道，隨後於東部鐵路改善計畫中新建14座隧道，於2003年通車使全線為雙軌運輸。

綜合以上，臺灣東部交通路廊經過多年持續性的基礎建設，特別是在隧道工程方面，已累積大量寶貴的工程地質資料，為地質研判提供了更深入的依據。過去地質評估多侷限於區域尺度的地表地質特徵，如今則可結合文獻、地質調查報告與隧道竣工紀錄等紀實資料，沿著實際開挖方向進行研判。同時，配合光達數值地形、無人機（UAV）空載影像等先進測繪技術，可有效精進地表地質特徵的比例尺，進一步掌握岩性界線與地質弱帶位置。不僅將傳統地質圖提升至更具應用價值的工程地質尺度，亦可透過三維視覺化技術進行呈現，有助於後續設計與施工階段之地質風險評估。

本研究將以蘇花改的和中-大清水段的山岳隧道為例，透過整合遙測地表地質、隧道開挖地質紀錄與TSP等地質資料，建構三維的岩體以及地質弱帶分布模型，討論不同地質比例尺資料對空間分布的不確定性、位態資料與TSP研判弱帶的不確定性，以及由既有地下資料推估鄰近隧道工程之可能地質條件。最終建立之三維地質模型，可依據不同階段與精度所獲取的地質資料進行更新與研判，可應用於規劃階段、設計階段、新建工程地質災害預警及運營中隧道管理等，為新一代工程地質發展之趨勢。

中文關鍵詞：三維地質模型、工程地質、地質不確定性

Microstructural and mineralogical characteristics of natural and experimental fault gouges and its implication for the Chegualin creeping fault, Taiwan

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Studies of active faults are fundamental scientific topics to improve geohazard assessment. Active faults are distributed and evolve by combining deformation processes on different microscales and timescales. We focus on the creeping Chegualin Fault located in the Chianan alluvial plain of southwestern Taiwan. The fault exhibits dominant dextral strike-slip at a rate of about 1 cm/yr and a reverse dip-slip component with minimal seismic activity. To better understand the frictional behavior and the associated deformation mechanisms, we characterize both the natural borehole fault gouge sample collected at 38.8 m depth and experimentally deformed samples sheared at slip rates of 10-4 to 1 m/s-1 (low to high velocities). The natural samples are analyzed by optical microscopy, scanning electron microscopy, and X-ray diffraction analysis. The natural samples are composed of quartz, feldspar, and clay, mainly illite, and show C-S structures, which are consistent with dextral transpression in the field. Further analyses of experimental samples will be conducted to investigate the deformation mechanisms, such as cataclasis, frictional sliding, or pressure solution. This work may improve our understanding of the frictional behavior of clay-rich creeping faults and its implications for seismic hazards in rapidly deforming regions.

Keywords:Creeping, Mineralogy, Microstructures, Rotary Shear, Mechanisms

以熱-水-力-損傷耦合數值方法模擬水力破裂中裂隙擴展行為

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台灣位處歐亞與菲律賓海板塊交界，地質構造活躍，擁有豐富的地熱資源，為再生能源開發的重要潛力區。然而，高溫、低滲透岩體中裂隙生成與擴展行為複雜，對熱流與熱交換效率具關鍵影響，特別是在深部地熱開發中，水力破裂行為的不確定性亦可能引發誘發性地震等風險。因此，建立可耦合多物理場變化之數值模型，對提升地熱開發的效率與安全性極具意義。

本研究旨在探討高溫高壓環境下裂隙岩體之水力破裂行為，透過數值模擬與實驗比對，分析裂隙啟裂與演化機制。研究中建立二維熱-水力-力學-損傷(Thermo-Hydro-Mechanical-Damage, THMD)耦合效應之數值模型，採用不規則三角形網格進行空間離散，以精細描述裂隙變形與孔隙滲透率變化。

本模型結合COMSOL Multiphysics多物理場模擬平台，考慮冷水注入引發之熱應力與水壓共同作用對裂隙擴展的影響。模擬參考Zhou et al. (2020)高溫真三軸壓裂實驗作為驗證基礎。模擬結果顯示，裂隙主要沿最大主應力方向擴展。當冷水注入高溫岩體時，將產生顯著的熱應力，造成水冷衝擊效應，進而削弱岩體的力學性質，有效促進裂縫啟裂與擴展。此外，此過程亦改變岩體的初始孔隙率、滲透性與熱傳導率，進一步提供流體通道，有效提升裂隙區域的流導性（Flow Conductivity）與熱交換能力。

本研究成果有助於強化對高溫低滲岩體中裂隙演化與導流特性的理解，提升地熱井場設計與注水策略擬定之精確性。未來可應用於地熱開發外，亦具備應用於深層二氧化碳封存、放射性廢棄物處置及地下儲能等工程領域之潛力，作為多物理場耦合破裂行為模擬與風險評估的重要依據。

中文關鍵詞：熱-水力-力學-損傷耦合數值模擬、水力破裂、裂隙岩體

Integrating LiDAR and InSAR technologies for post-earthquake surface analysis and disaster assessment in mining areas

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On 3 April 2024, a magnitude 7.2 earthquake struck Hualien County, Taiwan, causing significant terrain changes in mining areas and their surroundings. This study uses Light Detection and Ranging (LiDAR) technology as the primary methodology, integrating pre-earthquake airborne LiDAR imagery with post-earthquake UAV-based LiDAR imagery to analyse terrain changes and collapse mechanisms. High-resolution 2.5cm Digital Surface Models (DSM) and 5cm Digital Elevation Models (DEM) were generated using the RIEGL miniVUX-3UAV laser scanner. In addition, orthoimagery from Sony RX1RII and a6000 cameras provided comprehensive visualisations of post-earthquake terrain features. DSM of Difference (DoD) was used to compare pre- and post-earthquake LiDAR imagery, revealing that earthquake-induced collapse was primarily concentrated in forested areas outside the mine boundaries. Mining slopes designed with pre-stripping safety measures had minimal residual debris and posed no threat to protected targets. These findings highlight the accuracy and efficiency of LiDAR technology in quantifying terrain change and interpreting disaster characteristics. This study highlights the broad application potential of LiDAR and InSAR technologies in geological hazard assessment. To complement the LiDAR analysis, InSAR technology will be used to monitor post-earthquake surface deformation and slope displacement trends. By integrating LiDAR data with radar interferometry, this study aims to provide mining rights holders with advanced geological investigation and disaster warning solutions. The preliminary results demonstrate the effectiveness of combining LiDAR and InSAR technologies for post-disaster terrain analysis, providing technical support for sustainable mining operations. The study also highlights the importance of implementing robust mine safety measures and promoting sustainable mining practices to mitigate risks and ensure long-term operational stability. This integrated approach highlights the broad application potential of LiDAR and InSAR technologies in geological disaster assessment and sustainable mining development.

Keywords:LiDAR scanning technology, DSM of Difference (DoD), Post-earthquake terrain analysis, Interferometric Synthetic Aperture Radar (InSAR), Sustainable mining operations

DAS 與寬頻地震儀資料整合於即時觀測系統之應用

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光纖地震學的應用中，分散式聲學感測（DAS）技術成為近年地球科學研究的一個新興領域。這項技術透過測量光纖內雷射光的雷利散射相位變化，來獲取與雷射傳播方向平行的應變或應變率。MAGIC（Multidimensional Active Fault of Geo-Inclusive Observatory Chihshang）計畫專注於監測池上斷層周邊的微震活動，並結合地球化學和地球物理觀測來探討地震的可能孕震過程。在這其中，DAS 技術因其能在空間與時間上提供高精度的觀測資料而扮演了關鍵角色。MAGIC 計畫在池上地區鑽探了八口井，深度範圍從 40 公尺到 230 公尺不等，並在八口井中都安裝了井下光纖。這些光纖透過地表光纖相互連接，總長約為 2.95 公里，並在光纖的一端連接了光電儀器（AP Sensing N5225B DAS）進行監測。除了 DAS 資料，自 2021 年 11 月至 2024 年底，MAGIC 計畫在研究區域陸續安裝了 9 個寬頻地震站，並與台灣寬頻地震網（BATS）中的其他 10 個寬頻測站結合，形成了一個研究區域的寬頻地震儀陣列。本研究提出了一種創新的 DAS 資料處理流程，旨在促進近即時 DAS 資料流的傳輸，並將這些資料整合進 SeisComP 系統中，從而能快速結合寬頻地震儀陣列的即時資料，未來將能為區域內的微震活動監測提供更即時的資訊。

中文關鍵詞：MAGIC、DAS、SeisComP

應用UAV-LiDAR與MT-InSAR技術於大規模崩塌潛勢區之熱區監測與工程治理效益評估

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本研究聚焦於臺灣嘉義縣八寶寮地區的大規模崩塌潛勢區，應用多元多尺度遙測技術，包括高精度無人機光達（UAV-LiDAR）及合成孔徑雷達干涉技術（InSAR），以評估其構造地形特徵及地表活動性。由於該地區地質條件不良且發育多條侵蝕溝，自2011年起崩塌裸露範圍持續擴大。光學衛星影像在茂密森林區域的解釋能力有限，難以有效掌握真實地表特徵及崩塌線型。本研究因此採用0.5米精度的UAV-LiDAR技術，精確捕捉崩塌特徵、不連續面及裂隙分布，並結合日本宇航局ALOS-2雷達衛星影像進行InSAR分析，解算2022至2023年間的廣域地表變形速率，數據顯示平均年地表變形達6毫米/年。這些技術的整合為深入了解崩塌潛勢區的地表活動性提供了高精度的數據支持。

為進一步釐清大規模崩塌潛勢區的關鍵熱區，本研究透過三維地質模型的建置，整合UAV-LiDAR及InSAR技術所獲得的高精度地形及地表變形數據。三維地質模型能有效呈現崩塌區域的地形特徵及裂隙分布，並協助辨識高活動性區域及潛在崩塌熱區。裂隙分析結果顯示，該地區水系及侵蝕溝密度高，且地層面均呈現高角度位態發育，進一步加劇了崩塌的潛勢。此外，本研究採用多時序合成孔徑雷達干涉技術（Multi-Temporal InSAR, MT-InSAR），以更精確地監測地表變形特徵及動態變化。MT-InSAR技術能有效捕捉崩塌區域的微小變形，並提供高時間解析度的地表活動數據，進一步支持蝕溝工程治理的效益評估。

初步成果顯示，整合UAV-LiDAR及MT-InSAR技術，配合三維地質模型能提供動態地表變形特徵及地下地層分布，不僅能有效辨識崩塌潛勢區的關鍵熱區，還能提升工程治理的精準性及效益。透過多尺度遙測技術的應用，本研究成功驗證了其在大規模崩塌潛勢區監測中的適用性，並為蝕溝治理提供了科學依據。上述分析成果可回饋政府部門用於坡地災害防治及後續工程治理，並為其他高風險地區的災害監測提供技術參考，進一步提升災害應變能力及減災效益。

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中文關鍵詞：多元多尺度遙測技術、崩塌活動熱區辨識、三維地質模型、坡地災害工程治理

利用三維地質建模與InSAR技術解析滾水坪泥火山地下泥漿分布與地表變形特徵

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滾水坪泥火山位於臺灣高雄橋頭地區，自日據時期即被發現並受到關注。然而，隨著人為活動的增加，泥火山的面積與噴發活動逐漸減少。近年來，為推動科技產業發展，臺灣政府計畫於該地設立橋頭科學園區。然而，泥火山的長期活動可能引發地質災害，例如泥貫入體的貫入導致隧道結構抬升位移，以及泥漿流出造成周邊農田毀損，進一步影響農業發展與基礎設施建設。因此，南部科學園區管理局針對滾水坪泥火山進行了一系列詳細的地表地形與地質特徵研究，除了重點調查車瓜林斷層分布以外，更聚焦於淺層泥漿的分布，以確保區段徵收工程及提供未來廠房工程建設之參據。

為深入了解滾水坪泥火山地下泥漿的分布範圍及地質概況，本研究整合了多項地下地質資料，包括總長約14公里的地電阻測線數據、深度超過6500公尺的鑽井資料等，並利用Leapfrog Geo地質建模軟體進行三維建模。透過隱式建模技術（Implicit Modeling），將地電阻及鑽井數據進行插值，建構地下三維表面。此外，研究採用了徑向基函數（Radial Basis Function, RBF）內插法，將109至113年間的31條測線數據賦予XYZ三軸座標，建置地下電阻率三維模型。相比傳統的二維地電阻柵狀圖，三維模型能更準確地匹配電阻率與地下岩性之相關性，並有效分析近地表泥火山地下通道及泥漿的分布位置。

為進一步提升模型精度，本研究結合了110年產製的0.1米數值高程模型（Digital Elevation Model, DEM），進行地形修正。研究成果顯示，滾水坪泥火山的活動主要集中於橋頭科學園區的中軸位置及南部區域。透過地下0至30公尺的地電阻成果，建置了二維平面等深圖，清晰呈現泥火山地下泥漿的分布特徵及活動熱區。然而，本研究在建模過程中未考量地表水等其他因素，可能影響模型的精確性。此外，滾水坪泥火山的地表變動仍需進一步探討。為此，研究後續計畫採用合成孔徑雷達干涉技術（Interferometric Synthetic Aperture Radar, InSAR），分析橋頭科學園區及滾水坪泥火山的地表地形地貌。藉由InSAR技術，可解析多期影像間的地表變位情形，進一步探討地表變形活動熱區，並揭示泥火山地下分布樣態與地表變動的相互關係。

本研究透過高精度的地下三維模型建構，成功揭示了滾水坪泥火山地下泥漿的分布範圍及地層性質，為橋頭科學園區的工程規劃提供了重要的科學依據。同時，研究成果也為未來泥火山相關地質災害的預防與管理提供了參考，具有重要的學術價值與實際應用意義。

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中文關鍵詞：滾水坪泥火山、三維地電阻建模、地下泥漿分布、合成孔徑雷達干涉技術（InSAR)、地表變形監測

The Improvement of Tsunami Source Model for the 2024 Mw 7.4 Hualien Earthquake: Insight from USGS Moment Tensor, GCMT Moment Tensor, and USGS Finite Fault

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This study evaluates the performance of different seismic source models in simulating tsunami wave propagation generated by the 2024 Mw 7.4 Hualien Earthquake. Numerical simulations were carried out using source parameters derived from the Global Centroid Moment Tensor (GCMT) solutions, the United States Geological Survey (USGS) Moment Tensor solutions , and the USGS Finite Fault model. For the moment tensor-based scenarios (GCMT and USGS), initial sea surface displacements were estimated using empirical Scaling Law to approximate the slip dislocation. Observational data were obtained from the submarine cable seismic and tsunami observation system operated by Taiwan's Central Weather Bureau, which provides high-resolution ocean bottom pressure records used to estimate tsunami wave heights for model validation. Comparative analysis reveals that simulations based on moment tensor solutions predict earlier tsunami arrival times compared to the ocean bottom pressure. In contrast, the simulation utilizing the USGS Finite Fault model exhibits significantly improved agreement with the observed arrival times. Nevertheless, analysis of the waveform amplitudes reveals notable discrepancies between simulated and observed tsunami heights across all scenarios, highlighting limitations in the models ability to capture the complex source dynamics and emphasizing the need for further refinement in source parameterization and model resolution.

Keywords:Tsunami Source Model, Finite Fault, Moment Tensor, Ocean Bottom Pressure

西部雲林地區之淺層S波速度構造探討

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雲林地區位於沖積平原上，主要由鬆軟的沖積層組成，當地震發生時，容易受場址效應的影響，使地震帶來的災害更為嚴重。近幾年來，雲林的工業區也發展迅速，例如麥寮六輕工業區、雲林科技工業區等，已經成為工業重鎮。因此雲林地區的場址效應及淺層S波速度構造的探討即顯得相當重要。

本研究為探討西部雲林地區的淺層S波速度構造，於西部雲林地區(介於東經120.1度及120.4度之間，即崙背鄉、土庫鎮、元長鄉以西)選擇30個場址，進行微地動陣列量測，其中，每個場址皆量測S和L兩個尺寸的陣列，每個陣列都使用10台微震儀，以3個同心圓的方式佈設儀器，半徑分別為25、50、100公尺，以及100、200、400公尺。在資料分析方面，首先利用頻率-波數法(F-K method; Capon, 1969)分析由陣列量測所獲得的資料，可獲得不同場址之相速度頻散曲線，接著利用Herrmann (1991)之表面波逆推方法，估算淺層S波速度構造。

根據這些測點之頻散曲線結果，位於本研究區域東邊的測點，其相速度都高於其他測點。再者，根據逆推所得的淺層S波速度構造(約0-2000公尺)，若假設此地區第三紀岩盤之S波速度為1500 m/sec，可發現位於研究區域東邊的岩盤深度最淺(約800公尺)，位於西北邊最深(約1800公尺)，整體而言，此地區之第四紀沖積層厚度約為800~1800公尺。再者，於深度50公尺處，位於東邊測點之S波速度最高，且速度大致由東向西遞減。

中文關鍵詞：微地動陣列量測、頻率-波數法、相速度頻散曲線、表面波逆推方法、淺層S波速度構造

Duration-Amplitude Distribution of Non-Volcanic Tremor in Taiwan

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Previous studies of volcanic tremor have shown that the amplitude–duration relationship often follows an exponential law, suggesting that tremor size may be constrained by the geometry of the source conduit. Motivated by these findings, we investigate whether non-volcanic tremors in Taiwan exhibit similar behavior. Using a tremor catalog compiled by Ide (2023), which includes approximately 6,700 events recorded between 2012 and 2022 by the Broadband Array in Taiwan for Seismology (BATS), we analyze amplitude–duration characteristics across five regions distributed from northern to southern Taiwan.

These five tremor clusters form a nearly 200 km north–south alignment within the mountainous belt of eastern Taiwan. They are located at depths greater than typical crustal earthquakes (which are mostly shallower than 15 km) but shallower than the Moho. The most active tremor zone lies in the southern Central Range, a region previously documented by Chuang et al. (2014), Idehara et al. (2014), Ide et al. (2015), Chao et al. (2017), and Chen et al. (2018). This activity has been linked to fluids transported by exhumed metamorphic rocks from the mantle, which likely formed a localized shear zone conducive to tremor generation. Additional tremor zones are found at the northern end of the Hsuehshan Range and within the central Central Range.

Our analysis reveals that, for most events, the amplitude–duration relationship is better described by an exponential function than by a power law. Furthermore, the inverse decay slope ($1/\lambda$) shows periodic temporal variations in the northernmost and southernmost clusters, whereas the central regions display more stable behavior. These findings point to regional variability in tremor-generating processes and highlight the need for further research into the underlying physical mechanisms.

Keywords:Tremor, Non-Volcanic, Scaling

坡趾受河道下切與加積影響邊坡變形模擬探討

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邊坡潛變（creep）是指材料在長時間內，在持續低於瞬時破壞強度的應力作用下，產生緩慢、累積的變形。然而，此類邊坡變形速率不一致，現有大地材料組成律難以有效描述其運動特性，造成邊坡穩定分析評估困難，仍無法具體描述與模擬量化。

本研究針對南部橫貫公路某案例隧道附近正在潛變之重力變形邊坡，探討其運動特性與失穩觸發機制，修正既有的黏彈塑組成律，描述邊坡運動特性的變化並導入潛變應力閾值的概念以探討邊坡運動過程的變化。透過三維數值模擬，考量不同力學模式、材料特性、地下水位變化及河道下切等因素，初步評估各影響因子的角色及作用機制。模擬結果顯示，地下水位高低對滑動面發育具有關鍵影響，且河道下切加速坡趾區位變位現象。

中文關鍵詞：重力變形、黏彈塑組成律、河道下切、河道加積

Spatiotemporal distribution of seismicity and perturbation by moderate/large earthquakes in a tectonically active area and implications on seismic hazards mitigation: a case study in SW Taiwan

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We investigated seismicity rate changes in southwestern Taiwan where three M6 earthquakes occurred within a short time span of 6 years during 2010-2016, which caused some serious damage in the area and had similar source parameters of focal mechanisms. We compute seismicity rates distributed in a 2-D space for different periods, including 1) the background or "interseismic" seismicity (1994-2009) prior to the 3-earthquake sequence; 2) the "aftershock periods" following each of mainshock until the next large earthquake; 3) the "new background" seismicity post the 3-earthquake sequence (2019-2024). Based on background seismicity, we find four zones with relatively high rates in the study area of SW Taiwan, whereas the three M6 earthquakes occurred around the "edge" of one high-rate zone, we called the Meinong-Maolin high-rate zone. We also obtained perturbations of regional seismicity induced by moderate/large earthquakes in all four high-rate zones, but more significant in Meinong-Maolin zone. Following the timeline (1994-2024) for seismicity changing within the area and the high-rate zones, the seismicity changed differently after these three notable M6 earthquakes. Following the 2010 M6.4 Jiashian as well as the 2012 M6.0 Wutai earthquakes, aftershock activity declined sharply, with the number of events in the second day or week dropping to one-sixth of that in the preceding period. In contrast, aftershocks following the 2016 M6.4 Meinong earthquake decreased at much slower rate and behaved more gradually, with counts on the second day reducing to approximately one-third of those on the first. According to our results of annual seismicity rates, the overall study area and particularly the Meinong-Maolin high-rate zone exhibited abnormally low or near to the interseismic background seismicity for approximately 3 years prior to the earthquakes.

Following the three-earthquake sequence, the "new background" seismicity appeared to be in a higher rate compared to that prior to the 3-earthquake sequence. Particularly in one of the four high-rate zones, the Yujing high-rate zone, it rose from 9-18 events/year per 100 km^2 (prior to the 3-earthquake sequence) to a moderate rate (15–30 events/year per 100 km^2) post 3-earthquake sequence, which is similar to those in the Meinong–Maolin zone prior to the 3-earthquake sequence. We argue that this elevated activity likely represented a "precursor" of the Mw 6.0 Dapu earthquake that occurred in 2025, whose epicenter is located near the northeastern margin of the Yujing high-rate zone. Notably, a similar seismicity pattern - characterized by an anomalously low rate followed by a return to average levels in about 3 years prior to the large earthquake - was observed for both the 2025 Dapu and 2010 Jiashian earthquakes, suggesting potential utility for mainshock forecasting in the high-rate zones.

Furthermore, to better understand seismic rate behaviors in the Meinong-Maolin high-rate zone, where occurred the three M6 earthquakes, we calculated the annual frequency-magnitude distribution of seismicity within this high-rate zone from 1994 to 2024. We found abnormally low seismicity rates (mostly smaller magnitudes of M 2 - 4) in 1 - 3 years following each of the "large earthquakes" of M >5), for instance, the earthquakes of M5.1 in 2008, M6.4 in 2010 and M6.0 in 2012. Moreover, an anomalously low annual peak magnitude (Mp = 3.5) was observed during these "accumulation periods", indicating a notable absence of earthquakes exceeding this threshold. This suggests that substantial energy may have accumulated within the high-rate zone, potentially serving as an additional precursor signal for impending large earthquakes.

Keywords:Seismicity evolution, earthquake triggering, the 2010 Jiashian earthquake, the 2016 Meinong earthquake, the 2025 Dapu earthquake

Mangrove Root Microbiomes Respond to Microplastic Stress with Functional Plastic Degradation Potential

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Mangroves serve as natural filters and ecological buffers, yet their rhizospheric microbial systems are under increasing environmental stress due to the intensifying problem of microplastic pollution. This study investigates the rhizospheric sediments of two dominant mangrove species in Taiwan, assessing the extent of microplastic contamination and the microbial community's responses. The predominant microplastic types were films and fragments, mostly composed of small, transparent particles indicative of initial degradation. Microbial analysis revealed a significant upregulation of plastic-degrading genes in contaminated areas, suggesting that rhizospheric microorganisms possess functional potential to cope with plastic stress. These findings highlight the vital role of mangrove root-associated microbiomes in natural degradation processes and open new avenues for their application in environmental remediation strategies.

Keywords:Microplastic Pollution, Mangrove Rhizosphere, Plastic-Degrading Genes, Microbial Community, Bioremediation Potential

Advancing Deep-Seated Landslide Monitoring Using Borehole Distributed Acoustic Sensing Technology

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Deep-seated landslides are complex geological hazards that pose serious risks to infrastructure and human safety. Effective monitoring of their internal dynamics is essential for early warning and hazard mitigation. In this study, we utilize Distributed Acoustic Sensing (DAS) technology to monitor a deep-seated landslide in Lantai, northern Taiwan, using a borehole-deployed fiber-optic cable that crosses multiple slip zones. DAS converts fiber-optic cables into dense seismic arrays capable of detecting ground motion along their length, allowing high-resolution tracking of subsurface displacements and slip behaviors. Our results reveal that DAS successfully captures accelerated movements and recurring stick-slip events near the sliding interface between soil and bedrock at approximately 20 meters depth. These events, which are undetectable by surface geophones, recur at intervals modulated by typhoon-driven rainfall, suggesting velocity-weakening friction behavior likely related to transient pore pressure buildup along the sliding interface. Our findings provide new insight into the physical processes controlling landslide motion and demonstrate the potential of borehole DAS as a powerful tool for real-time monitoring of deep-seated landslides.

Keywords:Deep-seated landslides, borehole distributed acoustic sensin, stick-slip events, velocity weakening

區域地質構造對場址地質模型的影響：以陽明交大為例

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陽明交通大學陽明校區為順向坡地形，過去曾發生多次崩塌案例。本研究目的在透過地質特徵調查與分析，建立地質模型，提供更詳細的資訊，可用於評估場址若發生順向坡滑動的危害度。主要分析方法為地表地質調查、岩心描述、X光繞射分析(XRD)、岩象分析。根據野外地表地質調查結果，顯示此區域坡面與層面(bedding plane)之走向(strike)大致平行，且與過去資料與野外測量之構造位態進行對比也高度一致。透過岩心觀察與描述揭示各岩層厚度、岩性組成、沉積特徵及構造特徵，建立地下的二維地質模型並與地表地質調查比較。此外，本研究藉由XRD分析了解礦物組成隨深度的變化，試圖建立XRD分析結果的二維分布。其中一口井(BH6)的岩心存有破裂帶(fracture zone)，藉由XRD分析與微構造觀察，探討此破裂帶對於場址邊坡穩定性的影響。

中文關鍵詞：順向坡、Ｘ光繞射分析、地質模型、邊坡穩定性、破裂帶

台灣西南部鹽水溪重金屬汙染季節性探究與分析

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水對於我們的生活而言是相當重要的一部分，然而人類的活動勢必會對自然水體造成汙染。鹽水溪的中下游分別有著不同的土地利用，出海口處卻有著鹽水溪口濕地與四草濕地兩大濕地，為台灣最重要的國際級濕地與國家級濕地。過往的資料顯示該河川汙染指數達中度汙染至嚴重汙染的程度；但是對於重金屬汙染的數據卻不齊全。因此本研究希望深入探究鹽水溪的汙染並推測其汙染來源。此外，水質監測網的密度是水質監測的一大關鍵，然而廣設監測站卻不是經濟上實際的方法。本研究希望可以找到矽藻種屬分析與水質參數的相關性，使用特定矽藻群作為汙染代用指標。本研究分別會在乾季與濕季在鹽水溪進行採樣各五次，樣品數據包含水質參數、元素濃度與矽藻種屬分析。pH、導電度等水質參數於採樣現場使用Hanna HI9829 多參數儀測量，元素濃度使用光譜儀與感應耦合電漿四極柱質譜儀進行分析。矽藻種屬的分析與中正大學進行合作，將種屬分類為耐汙性種和清水性種，進一步計算矽藻汙染指標(DAIpo)。最後利用主成分分析求得水質參數、元素濃度與矽藻種屬之間的相關性。從濃度分析結果可得知鹽水溪中銅、錳、釩在河水中的元素濃度過高，推測可能為電鍍工業或金屬加工等工業活動所產生。矽藻分析的結果表示鹽水溪上游(南北寮橋、千鳥橋)至下游出海口皆為汙染的狀態。主成分分析的結果中，第一主成分主要由鹽度所影響，包含主要元素與鹽水矽藻種屬。釩和銅與第一主成分相關性高，推測與工廠位於鹽水溪的上下游有關。而矽藻種屬與金屬濃度和水質參數的相關性不明顯。本研究使我們更加了解鹽水溪的汙染狀況，並為汙染源的追蹤與治理提供了參考依據。

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中文關鍵詞：水化學、矽藻、汙染、主要和微量元素

氣候變化與病蟲害：清代蝗災的氣候驅動因素分析

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自古以來，蝗蟲一直被視為具有毀滅性的病蟲害，對人類社會與農業生產構成嚴重威脅。過去許多研究指出，蝗災的成因與氣候及環境條件密切相關，然而其機制仍未被充分探討。中國歷代王朝，特別是在清代（1644–1911）期間，保存了大量豐富的歷史文獻，從正史到地方誌，皆詳實記錄各類自然災害的情形，包括蝗災的發生情形、對農業社會的影響，以及所引發的社會現象。因此這些史料對於探討歷史氣候與蝗災之間的長期關係具有重要價值。

本研究從氣候系統的視角出發，旨在探討蝗災的驅動因素，並分析氣候條件與蝗災之間的互動關係。我們蒐集來自 REACHES 資料庫中清朝的蝗災記錄與氣候指數（Wang et al., 2018）。為了同時掌握蝗災的發生頻率與嚴重程度，我們建立了蝗災指數，並進行敏感度測試，以確保該指數的穩定性。接著，我們將所有資料的經緯度轉換為 1° × 1° 的解析度大小，並進行迴歸與相關性分析，以辨識氣候因子在各網格中的影響效果，並分析其空間分布特徵。最終，我們希望透過長期歷史資料的分析，有助於釐清蝗災與氣候驅動因素之間的關聯性，以理解氣候變化與病蟲害間的關係。

中文關鍵詞：蝗災、歷史氣候學、清代

放射性核種於裂隙水流與母岩基質擴散之行為探討

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依據臺灣用過核子燃料最終處置計畫，目前深地層處置概念是將用過核子燃料深埋在地下300 至 1000公尺的地層中，建立處置設施，並由工程障壁與天然障壁所組合的多重障壁系統與人類及生物圈隔絕，工程障壁系統的組成包含廢棄物罐(Canister)、緩衝材料(Buffer)、回填材料(Backfill)，天然障壁則為包覆工程障壁系統的天然母岩材質，而國際上用過核子燃料的處置母岩材質大致分為兩種，擁有高吸附性及孔隙介質為主的泥岩與滲透率較低的結晶岩體，而深層的地質環境中水流與溶質的遷移管道會以岩體裂隙為主，溶質在裂隙的遷移過程中部分會以擴散行為進入到母岩基質中，此行為稱之為母岩基質擴散機制，為瞭解此行為的複雜機制，本研究使用COMSOL Multiphysics多重物理量耦合軟體模擬放射性核種在母岩中的移流及基質擴散行為，研究中使用之概念模型包含裂隙及母岩基質，使用移流延散方程式描述核種在裂隙中的傳輸行為，再使用擴散模型模擬核種在母岩中的基質擴散，考慮核種在所有介面上的衰變行為，母岩對核種的吸附作用採表面錯合反應推算特定地下水水質及溫度之吸附係數，並測試不同注入端邊界對溶質傳輸的影響。本研究評估在不同情境下的傳輸行為，深入探討母岩擴散對放射性核種傳輸的影響，再量化及視覺化核種在衰變與傳輸過程中的各種作用，提供用過核子燃料於地質處置安全評估中的相關依據。

中文關鍵詞：裂隙岩體、耦合模型、母岩基質擴散、放射性核種、衰變

花東縱谷南段池上斷層之震測影像與構造解析

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花東縱谷為台灣東部的主要板塊縫合帶，過去百年來曾多次發生規模大於6的地震。經過屢次震後的地質、地物與地震調查，使我們對該區域的地震構造有了更深入的認識，卻也帶來更多未解的地質問題。2022年池上—關山地震序列，再次喚起國內對中央山脈斷層與縱谷斷層的關注。然而，兩個斷層系統之間的關聯性，至今仍缺乏明確的地表證據。

為探究縱谷南段池上斷層附近的地體構造，本研究於池上鄉伯朗大道、錦園與萬安地區，從秀姑巒溪東側延伸至海岸山脈西側，佈設約4公里長的反射震測測線，使用雙震盪震源車與無線地震儀進行資料收集，探測深度約達1.5公里。結果顯示，池上斷層西側的平原地區，淺部具有連續性良好、微向東傾的近地表沖積層，與現代沉積物流向一致，並以交角關係覆蓋於一向西傾斜的地層上，顯示深部（約1公里以下）地層可能源自海岸山脈方向。東段測線則受到池上斷層活動影響，近地表地層變形劇烈，且多呈西傾特徵。

本研究成功獲得池上斷層近地表的高解析震測影像，有助於釐清臺灣造山運動過程中的構造特徵，並深化對縱谷南段地震地體構造的認識，進一步可應用於地震防災與減災規劃。

中文關鍵詞：淺層反射震測、花東縱谷、池上斷層、海岸山脈

地質資訊智慧匯流系統之數位身分驗證應用服務

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經濟部地質調查及礦業管理中心為配合推動智慧政府目標辦理「地質資訊智慧匯流及圖資建置計畫」，致力發展創新數位化服務，建構完善的地質資料管理及供應體系，提升地質資料提交與查詢之智慧化流程，進而優化政府行政效能與便民服務品質。地質資料蒐集填報系統為因應「地質法」第十七條第五項以及「地質資料蒐集管理辦法」之規定，政府機關或公營事業機構自行、委託或獎勵補助辦理地質調查，以及目的事業主管機關審查後之相關地質調查資料，提供以線上方式填報地質調查報告資料之公開資訊系統。系統導入多元數位憑證認證機制，有效簡化人工填報流程，降低輸入錯誤與耗時情形，同時減輕客服諮詢需求，強化地質資訊服務便利性並提升系統服務品質，落實智慧政府之核心價值。

本文主要說明系統導入工商憑證、自然人憑證及行動自然人憑證（TW FidO）等數位身分驗證機制，使用者線上提交地質調查資料時，經由憑證認證後自動填入填表人的聯絡資訊，節省輸入填寫時間並提升資料正確性與完整性。透過工商憑證可查詢該公司歷年填報紀錄及提交證明單多筆查詢服務；使用自然人憑證及行動自然人憑證則可有效管理個人提交地質資料進度並追蹤歷年提交案件，節省傳統人工客服協助查詢所需時間成本；此外，行動自然人憑證（TW FidO）更提供免攜實體卡片和讀卡機的便利性。除導入數位身分驗證機制外，本計畫亦強化地質資料庫蒐集與管理機制，優化地質圖資系統網站功能，推動地質資訊數位化與整合應用服務，健全地質資料提交與共享機制，確保國家地質資料永續保存，並直接支援國家工程建設、國土規劃與地質災害防治等重要業務需求。

中文關鍵詞：地質資料蒐集管理辦法、工商憑證、自然人憑證、行動自然人憑證

「膽」識過人還是「膽」大妄為？埋藏學偏誤對古生物形態學的影響

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埋藏學是一門研究生物自死亡至形成化石之間過程的科學。在這「化石化」過程中，化石常受到不同程度的變形、換質與重結晶作用，進而可能對其形態與組成造成潛在改變，導致以形態為基礎的古生物學研究產生偏誤。儘管如此，埋藏學因素在臺灣古生物學界迄今仍少有深入考慮與討論。本研究描述七件新發現於曾文水庫地區、母岩為中至粗粒黃棕色塊狀砂岩的心形海膽化石，其中六件為內模，一件為外模。根據瓣帶特徵判斷，五件標本可明確歸入拉文海膽科（Loveniidae）。然而，進一步的形態分析顯示，這些標本的特徵與該科所有現生屬均不完全吻合：其大疣分布、口面骨板排列與整體輪廓雖與布萊恩海膽屬（*Breynia*）最為接近，但卻缺乏該屬最具辨識性的內帶線；此外，靠近頂系的步帶孔對亦明顯發達，與布萊恩海膽屬的診斷特徵不符。然而對產自澎湖海域的現生布萊恩海膽標本進行形態比對後顯示，由於該屬體殼之內表面與外表面形態存在顯著差異，因此本研究中的化石特徵與現生屬不一致，可能為其為內模化石所致的形態特徵改變結果。有趣的是，拉文海膽科內曾記載一地位未定的化石屬 *Spatangomorpha*，其形態特徵與本研究標本幾乎完全一致，因此本研究標本暗示*Spatangomorpha*有可能是因埋藏作用導致形態偏差下，錯誤建立的布萊恩海膽屬之異名。所有化石標本均歷經複雜的化石化過程，因此在進行任何化石形態學分析前，均應審慎考量埋藏學所可能造成的偏誤後再進行解釋與分類。

中文關鍵詞：化石、海膽、臺灣、分類學

Unveiling Tectonic Complexity of the April 3, 2024 Mw 7.4 Hualien Earthquake Using an AI-based Workflow

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The Mw 7.4 Hualien earthquake struck the northern Longitudinal Valley in eastern Taiwan on April 3, 2024, causing considerable damage in Hualien City and widespread strong shaking across Taiwan. Over the following month, intense and prolonged aftershock activity occurred, revealing a complex spatial geometry that reflects the intricate tectonic structures in the northern Longitudinal Valley. The dense aftershock sequence posed serious challenges to manual picking routines and delayed further analysis. To this end, we developed an automated workflow, AutoQuake, capable of handling large volumes of continuous waveform data using fine-tuned AI algorithms. AutoQuake integrates phase picking, phase association, 3-D double-difference relocation, local magnitude estimation, and focal mechanism determination, generating a high-resolution, more complete catalog. This AI-based catalog demonstrates exceptional performance in detecting small earthquakes and is more than five times larger than the routine catalog produced by the local agency. The new dataset reveals the intersection of Central Range Fault (CRF) and the Longitudinal Valley Fault (LVF) systems, as proposed by previous studies, and also illuminate a fault-to-fault, multi-stage rupture process between the northern LVF and structures near the Milun Fault. The resulting high-resolution catalog provides new insights into fault architecture and interactions within the northern Longitudinal Valley and contributes to future seismic hazard assessments in the region. This study highlights the potential of AI-based workflows for managing large seismic datasets and enabling more timely responses to major earthquake sequences.

Keywords:Hualien earthquake, Longitudinal Valley, machine learning, seismogenic structures

Path to SDGs: Cases in balancing geological resources and environmental protection

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Taiwan, surrounded by seas with limited geological resources on land, faces challenges in balancing economic development and environmental preservation. Since the late 20th century, global efforts like the **United Nations Framework Convention on Climate Change** and **Paris Agreement** have set clear targets for controlling global warming, alongside the **17 Sustainable Development Goals (SDGs)** While Taiwan pledged to cut greenhouse gas emissions by 2050 through its **Net-Zero Transition Strategy**, achieving this requires practical, phased steps.

Environmental protection and economic growth are often seen as opposites, but sustainable development calls for harmonizing both. Geothermal energy exemplifies this synergy: it's a clean energy source with minimal ecological impact. Nevertheless, conflicts, like those between geothermal development and conservation in Yangmingshan National Park, do exist and require renewed perspectives and added efforts to achieve multiple SDGs.

In Taiwan, precious geological resources underpin its economy and clean energy ambitions. Appropriate adjustments in ecological resilience can support specific economic development while upholding overall environmental sustainability, creating a win-win balance. These principles can be illustrated through the following situations, including geothermal under the Datun Volcanic Group, natural disaster and tourism in Taroko National Park, and Green Island's zero-carbon initiatives. By recognizing the complementary relationship between environmental protection and economic needs in sustainability, we can manage a balanced approach and pave the way for a better future.

Keywords:SDGs, Geothermal development, Economic growth, Environmental protection, Taiwan

高階室內岩石試驗分析於碳封存技術之應用

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財團法人中興工程顧問社大地工程研究中心擁有先進之室內與現地地工試驗設備，並於2006年經財團法人全國認證基金會(Taiwan Accreditation Foundation, TAF)審核通過，獲得土壤(物性、靜態、動態力學試驗)及岩石等多項試驗認證，為國內商轉中具有最完整土壤及岩石力學試驗設備之試驗室。

高階岩石試驗受台電公司碳封存先導試驗計畫支持，中興社於2010年建置我國第一座岩心二相流試驗設備，以超臨界態二氧化碳進行岩石滲透試驗，並採用非定常法量測岩石樣本之絕對滲透率與相對滲透率。今年進一步升級二相流試驗設備，可採用定常法，混合不同比例之二氧化碳與鹵水進行岩石滲透試驗。

新增購岩心核磁共振分析儀，以核磁共振法(Nuclear Magnetic Resonance, NMR)技術，搭配岩心測量軟體進行絕對孔隙率測定。國際上量測絕對孔隙率普遍採用壓汞法及NMR法，然國內因環保法規因素已限制汞材料進口，故不再適合測定使用。NMR法是一種快速且非破壞性的檢測技術，除了實驗過程較傳統壓汞法具有安全性外，樣品前處理增加真空及加壓飽水步驟，亦可強化數據可信度。

中文關鍵詞：高階室內岩石試驗分析、二相流試驗、滲透率、岩心核磁共振、絕對孔隙率

Characteristics of Acid Hydrothermal Alteration in the Northeastern Part of Tatun Volcano Group

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Hydrothermal alteration mapping at steaming grounds and related fields in the Tatun Volcano Group have been conducted since 2018 to reveal the characteristics of acidic fluid activities in TVG. The investigated fields are Shihuangping(SHP), Huangshan(HS), Huangshan East(HSE), Matsao(MT), Dayoukeng(DYK)、Lengshueikeng(LSK)、Zimingzi(ZM)、and Siaoyoukeng(SYK). Especially detail mappings were done at HS and SHP. Collected samples are altered rocks and hot spring water. Moreover, cores samples from the wells drilled in the TVG were also collected.

Alteration minerals observed at surface are silica minerals (amorphous silica, cristobalite, tridymite, and quartz), alunite minerals (alunite, Na-alunite, minamiite), kaolinite, pyrophyllite, smectite, pyrite, native sulfur. Altered products which formed under the strongest acid fluid with pH pH<2 is silicified rocks. The silicified rocks were basically identified from most of the investigated fields. Silicified rocks at HS are distributed along NE and NS directions; the former is arranging along NE trending fractures without active thermal activities, and the latter along the presently active fumaroles. Lineally arranged silicified rocks are also observed at HSE and ZM; both fields are lack of steaming ground at present. In other fields, silicified rocks are sporadically distributed. Theδ^{34}S of alunite developed around silicified rocks at HS is higher than 8 ‰ indicating volcanic water origin. Such occurrences of lineally arranged silicified rocks and alunite suggest that activity of acid volcanic fluid is controlled by fractures.

Alunite zone is developing widely at DYK, distributing almost 1km from the center of fumarolic activity to the north, and associated silica mineral is quartz. Moreover, pyrophyllite is observed at the northern area indicating higher temperature than 250°C in the past. These mineral paragenesis suggest that the area has been suffered by large amount of erosion probably due to lifting.

We will refer to the subsurface hydrothermal alteration of some boring cores and also consider a mechanism of hydrothermal alteration in TVG based on alteration mineralogy and fluid chemistry.

Keywords:Hydrothermal alteration, Silicified rocks, Alunite, Volcanic fluids, TVG

全監督式深度學習模型於山崩判釋之應用

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臺灣地形陡峻、山高谷深，且位於地震、颱風或豪雨等天然山崩災害頻發，藉由蒐集各種遙測空間資訊建立臺灣山崩發生資訊，有助於災害防救工作，保障民眾生命財產。近年深度學習崛起，已於影像辨識領域有諸多應用，可直接助益於山崩辨識。透過深度學習仰賴調整模型參數、架構及演算法，自行找出目標物特徵，可減少建立樣本特徵等數據準備時間與成本。本研究採用近年由Google開發較為成熟之deeplab v3+模型，其屬於CNN架構，並透過卷積層顯化影像的特徵，該模型之主要特色在於使用空間金字塔池化模組(spatial pyramid pooling module)以及編碼-解碼架構(encoder-decoder structure)。空間金字塔池化模組可疊加不同尺度特徵資訊，保留因層層卷積而消失的特徵，增加判別小面積山崩之能力；編碼-解碼的架構，在解碼時因與編碼過程中的低階特徵圖(low-level feature map)作連接，補足深層卷積所造成的資訊遺失，對邊緣、邊界的描述更加準確，使模型語義分割的能力更強，更加符合描繪山崩邊界之需求。此外，該模型採用全監督式學習方法，每一筆訓練資料都有明確且精確的標籤，透過成對的輸入、輸出資料，建立起彼此間的映射關係，模型得以表現穩定，但也受限於樣本給予之特徵，諸如不同的影像光譜值基準可能影響山崩自動判釋的準確性。針對2024年SPOT-6全臺鑲嵌影像及坡度圖訓練deeplab v3+模型，本研究預測結果之precision為69.16，recall為67.65，另，分別預測三張不同時間拍攝之影像，獲得之recall皆大於85，但precision皆小於43，如此成果顯示模型雖能辨識出山崩，但山崩誤判數量大幅增加。整體來說，在原資料集之預測結果，模型能藉由坡度有效辨別農田、河道等平緩區與山崩之差異，新資料集則受色階差異之影響，坡度資訊似乎無效化，農田及河道等平緩區誤判增加，另外陰影區誤判亦增加。未來應用上，就提升不同影像之模型泛化能力將是一大挑戰，必須審慎地研擬合適的模型泛化對策。

中文關鍵詞：山崩、山崩判釋、深度學習

基於GNSS速度場的空間聚類分析研究：以台灣地質分區為例

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台灣位處於歐亞板塊與菲律賓海板塊交界帶，地殼運動劇烈，地質構造複雜。為探討台灣地區地殼變形與地質分區之關聯性，本研究以GNSS連續觀測站所建立之速度場為基礎，結合地理資訊系統（GIS）與空間聚類分析方法，進行地質分區之分析。研究中使用開源GIS平台中的聚類分析插件工具，透過調整演算法參數（如群數、距離計算方法及標準化方式）進行實驗性分析，以評估不同參數組合對分群結果之影響。經由時序資料處理取得觀測站之水平速度向量後，分別以K-means與階層式聚類進行空間分區分析。

研究結果顯示，以此方法可辨識不同區域之速度場特徵，並提供一套可重現、具客觀性的地殼動態分析工具，有助於未來地質分區、斷層活動推估與區域地震潛勢之初步評估。

中文關鍵詞：GNSS速度場、GIS類聚分析、地質分區

南投縣東埔地區地熱資源探勘成果

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南投縣東埔地區位於臺灣中部，為一具有重要地熱潛力之區域。本研究以東埔溫泉及樂樂谷溫泉為主要探勘範圍，透過整合野外地質調查、地表線形分析、裂隙量測與應力反演、地球化學分析及大地電磁探測等資料，繪製地熱地質圖，並建構東埔地區三維地熱地質模型與地熱概念模式。研究結果顯示，本區受板塊擠壓作用影響，高溫岩體向上抬升，使脆韌轉換帶深度變淺，形成高地溫梯度，為地熱系統之主要熱源。區內發育有NE、NW、E－W及N－S向裂隙系統，天水由此深入地下受熱，並與部分深部地殼流體混合，形成碳酸鹽型熱水，推估溫度可超過136°C。熱水沿破碎帶向上移棲，受近地表低滲透岩體阻擋後轉向側向擴散，並於下切河道處湧出，形成東埔與樂樂溫泉。本研究辨識出5處具發展潛力之地熱構造，具有低電阻、高線形密度及高活化潛勢等特徵，推估平均總發電潛能約為15 MWe。其中 TP3 區熱源可能來自深度約 -7 公里之脆韌轉換帶，具高溫地熱田潛力，建議後續進行補充探測。此外，完成2口地質探勘井鑽鑿工作，其中包括深度為664公尺的和社1號井（HS-01）及302公尺的和社2號井（HS-02），並且透過井測作業，以輔助解析地下構造。

中文關鍵詞：地熱地質調查、流體地球化學分析、大地電磁探測、南投東埔

大屯山雨水氫氧同位素南北麓特徵

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本研究利用由北至南橫貫大屯山系強降雨的降雨氫氧同位素值空間分布，比較經金山到台北盆地南北兩麓不同強降雨系統氫氧同位素值差異，在2023年10月至2024年6月，總共採集包含東北季風、梅雨以及颱風等強降雨事件雨水樣品35件，透過分析雨水的氫氧同位素與d-excess推測其補注來源特性。

結果顯示，研究區域內東北季風、梅雨及颱風強降雨在南北兩麓同位素形成迎風面較重，背風面較輕；d-excess介於9～26‰，分別為東北季風d-excess介於14～26‰、梅雨d-excess介於9～15‰、颱風d-excess為13‰；另外、20231004小犬颱風的d-excess為13.59‰、20231204東北季風的d-excess為14.78‰，兩者d-excess應相差非常大，但實際d-excess差異卻不大。以台灣東北季風而言，降雨應含有非常高的d-excess(25‰)，其意義代表氣團濕度低，d-excess是降雨水氣非平衡蒸發的指標，也是蒸發速率的指標，本研究結果的d-excess也可做為解釋降雨南北兩麓氫氧同位素變化的重要因素。

中文關鍵詞：大屯火山群、d-excess、氫氧同位素

潛在大規模崩塌判釋與數值地形資料計量分析112年度與113年度工作成果

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因應經濟部地質調查及礦業管理中心整合內政部之空載光達數值地形更新案資料及完成臺灣全島坡地範圍剩餘約1萬9千餘平方公里未判釋區域之潛在大規模崩塌判釋之規劃，推動「潛在大規模崩塌判釋與數值地形資料計量分析」計畫，自111年起以5年分年分區辦理。

透過團隊開發之分析程式產製視覺化的數值地形資料，本期計畫中主要精進的成果為兩期品質分析圖與兩期地形變異。以99年-104年地調所(現為地礦中心)光達成果與105年起內政部空載光達更新成果等兩期光達成果為分析資料，以品質分析圖呈現原始資料之點雲穿透率差異；採用兩期數值地形相減後，凸顯地形崩塌下降及堆積抬升之區域，可有效輔助計畫內之潛在大規模崩塌判釋作業使用。參考Varnes(1978)之潛在崩塌模型以及日本地滑學會(2021)之潛在崩塌地不同階段地形演育樣態模型，判釋發育顯著之潛在大規模崩塌、其內部細部特徵以及潛在活動塊體，並進行潛在大規模崩塌現地調查。

112年度與113年度本計畫工作範圍為雲林縣、臺中市、南投縣、苗栗縣、新竹縣、桃園市、新北市、臺北市、基隆市、花蓮縣與宜蘭縣。數值資料分析每年執行1,060幅1/5,000圖幅，潛在大規模崩塌判釋每年執行426幅1/5,000圖幅。光達數值地形成果資料合併加值及視覺化處理包含水域資料位相處理、DEM/DSM多方向陰影圖、光達成果品質分析圖、數值地形坡度圖、DEM/DSM降階後全台數值地形成果、兩期光達品質比較分析圖及兩期地形變異分析圖。潛在大規模崩塌範圍與細部特徵判釋共判釋出潛在大規模崩塌數量合計2,525處。本計畫2年完成10處潛在大規模崩塌現場調查，112年度南投縣-仁愛鄉-D858之潛在大規模崩塌地形特徵，除人為活動區域外，多有留存且活動特徵顯著，坡面存在2處滑動體具有明顯活動徵兆。本處坡面內雖無保全對象，但崩塌材料移動至東眼溪後形成土石流潛勢溪流(投縣DF010)之土砂材料來源，影響下游；113年度國道5號通過新北市-石碇區-D007趾部，坡面存在2處具有明顯活動特徵之滑動體，由公路單位持續檢測中。

中文關鍵詞：光達數值地形、地形變異、品質分析、潛在大規模崩塌、潛在活動塊體

Depth-Dependent Co-Seismic Velocity Change of the 2024 Hualien Earthquake Observed from MiDAS

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The 2024 Hualien Earthquake provides a unique opportunity to investigate crustal responses to strong ground shaking. While surface seismometers have revealed significant co-seismic velocity drops using passive interferometry of ambient seismic noise, information regarding the depth-dependent effects of earthquakes remains limited. To address this, we use data from the Distributed Acoustic Sensing (DAS) array of the Milun Fault Drilling and All-inclusive Sensing project (MiDAS), located approximately 20 kilometers from the epicenter, to investigate depth-dependent co-seismic velocity changes. The dense spatial sampling and high temporal resolution of DAS data enable detailed and high-resolution analysis. We analyze the surface section of the DAS array using surface wave dispersion analysis and the borehole section using P-wave travel time measurements. At the MiDAS site, characterized by a thin sediment layer overlying a thick conglomerate, our results show substantial reductions in seismic velocity (up to 30%) in the top 100 m, with the magnitude of the change decreasing with depth. These findings highlight the value of borehole-based dense arrays like MiDAS in capturing near-source crustal responses and provide new insights into the depth extent of earthquake-induced damage in the shallow crust.

Keywords:MiDAS, Co-seismic velocity change, Hualien Earthquake

頻譜分解屬性應用於不同地質環境之研究

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頻譜分解屬性為震波屬性之一種，其將震測資料分解成不同頻帶的震波訊號，可透過不同頻帶的訊息反映目標地層的地質特徵形貌與厚度，不僅可瞭解石油系統或碳封存場址的儲集層分布，並可藉此瞭解該地層所屬的地質沉積環境。本研究利用海上與陸上不同區域的三維震測資料進行頻譜分解分析，並搭配三原色融合的展示方式，可將三維震測資料中的地質特徵以視覺化的方式清楚展現。首先將三維震測資料進行20 Hz、30 Hz與40 Hz的頻譜分解，然後將這三個頻段的資料分別對應三原色的紅色、綠色與藍色，再進行顏色的融合，在目標地層的層面上則可顯示清楚的地質特徵。研究結果可顯示目標地層所屬為陸相沉積環境或海相沉積環境，展示的地質特徵有古水道、濁流砂體與沉積物分布等。藉由頻譜分解的頻率所對應的厚度，可估算古水道的厚度，亦可反映儲集層厚度。此外，進一步在不同的時間切面或地層切面展示，可瞭解目標地層在沉積時期處於海水面上升或下降的狀況。頻譜分解屬性技術可做為輔助或強化震測解釋的作用，並透過視覺化展示，精細描繪儲集層的分布，提升對該區域沉積環境的認識。

中文關鍵詞：震波屬性、頻譜分解、三原色融合、古水道、濁流砂體

Quantify Biogenic Sedimentary Proxies in Marine Sediments Using VIS-NIR Reflectance Spectra

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Rising atmospheric CO_2 concentrations from anthropogenic emissions have triggered drastic climate changes. The current CO_2 level reaches ~420 ppm—comparable to those observed during the Pliocene epoch. However, the Plio-Pleistocene transition marks a rapid drop in CO_2 levels, significant global cooling, and reduced marine productivity. Understanding this transition is essential for evaluating the Earth's future under the global warming of the current high CO_2 conditions. One key to advancing our understanding lies in better reconstruction of biogenic sediment proxies, particularly the total organic carbon (TOC) and carbonate contents. The reflectance spectroscopy methods have shown such potential, however, existing models often lack accuracy due to regional sediment composition heterogeneity and visible spectrum-only data. This study aims to develop rapid, non-destructive regression models for better estimating quantitative TOC and carbonate contents using reflectance spectra in a wide range VIS-NIR (350–2500 nm). Samples used in this study were collected from core MD972148 (19.79673°N, 117.54266°E) in the northern South China Sea (SCS) and river terrace outcrops (22.88920°N, 120.40228°E) of the Pliocene–Pleistocene Gutingkeng Formation at the Erren River. After spectral measurements using an ASD LabSpec spectrometer and first-derivative transformation, Varimax-Rotated Principal Component Analysis (VPCA) and stepwise regression were applied to establish proxy estimation models and evaluate their performance across spectral ranges. The results indicate that: (1) models focusing on specific spectral wavelength ranges significantly improves the estimation of TOC and carbonate content.; (2) carbonate content estimation models had moderate success ($R^2 = 0.32$), partly limited by contents range mismatch. This work contributes a newly-advanced modeling approach that integrates both marine and outcropped sediment spectra, demonstrating the feasibility and advantages of VIS-NIR spectroscopy in quantitative estimation of biogenic sedimentary proxes. It offers an efficient alternative to traditional geochemical analyses, particularly valuable for expanding high-resolution paleoceanographic and paleoclimatological reconstructions in the northern SCS.

Keywords:Reflectance Spectroscopy, TOC, Carbonate, Gutingkeng Formation, South China Sea

High-Resolution Imaging of the Shanchiao Fault and Basin Structures in Taipei Metropolis Using Dark-Fiber Distributed Acoustic Sensing

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The Taipei Metropolis, home to nearly one-quarter of Taiwan's population, sits atop a sedimentary basin bounded by the active Shanchiao Fault. Despite its potential to generate M6+ earthquakes, the fault's geometry and structural characteristics remain poorly constrained due to Quaternary cover and limited high-resolution seismic data. Soft sediments and complex fault structures modulate seismic waves, leading to amplified and prolonged ground shaking. In this study, we use Distributed Acoustic Sensing (DAS) to transform a telecommunication cable into an ultra-dense linear seismic array across the Shanchiao Fault. By applying ambient noise cross-correlation and beamforming analysis, we extract Rayleigh-wave phase velocity dispersion curves along the cable. These are subsequently inverted using a Markov Chain Monte Carlo (MCMC) method to generate a high-resolution 2D shear-wave velocity profile across the fault zone. The results reveal a clear velocity contrast between the Taipei Basin and the Linkou Tableland, delineating the location and fault geometry of the Shanchiao Fault. Spectral ratio analysis further reveals clear frequency-dependent site amplifications on the Taipei Basin side and highlights potential fault zone locations. By linking dominant frequency and subsurface velocity structure, we improve understanding of local site effects and seismic hazard. Our results demonstrate that DAS with existing telecom cables is a powerful tool for mapping detailed fault and basin structures in urban environments.

Keywords:Dark-Fiber Distributed Acoustic Sensing, Shanchiao Fault, Ambient noise, Beamforming method, Markov Chain Monte Carlo method

Pore fluid REE signatures in a sediment-hosted hydrothermal environment: Insights from Mienhua Submarine Volcano, southern Okinawa Trough

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Intense hydrothermal activities have been identified within a sediment-hosted hydrothermal system situated in thesouthern Okinawa Trough. In 2024, geochemical analyses of trace elements and rare earth elements (REE) wasundertaken on sedimentary pore fluids collected from the vicinity of the Devil Chimney at the hydrothermal field in theMienhua Submarine Volcano (MHV) and Earth Dragon Volcano (EDV) regions. The EDV fluids exhibit negligible variation in Cl and Mg concentrations, with a total REE concentration reaching approximately 800 pmol/L, alongside a PAAS-normalized REE pattern marked by a 'MREE bulge' without an Eu anomaly. In contrast, the MHV field revealsdepth profiles of the trace elements and total REE concentrations in pore fluids, characterized by significantly depleted Mg and elevated Cl levels, indicative of brines formed through phase separation. These profiles demonstrate a distinct enrichment of trace elements at the bottom water-sediment interface, which rapidly diminish with depth. In MHV pore fluids, the overall concentration of total REE is substantially lower compared to the vent fluids documented in 2019 from the same area, where REE levels varied from 5512 to approximately 68000 pmol/L. However, the PAAS-normalized REE pattern of MHV fluids (MHV-DV1-GC2) displays a 'MREE bulge' with a distinct positive Eu anomaly at greater core depths (113 – 258 cm below the seafloor), differing from patterns observed in seawater and other sites. Within this specific depth interval, the presence of bitumen, wax, greasy luster, and opal were noted, indicating that MHV fluids areinfluenced by robust hydrothermal activity. This suggests a more pronounced hydrothermal signal compared to the previous collection in 2019. The potential origin of the significant temporal variation in REE contents in MHV pore fluids warrants further investigation.

Keywords:southern Okinawa Trough, hydrothermal fluid, pore fluid, trace element, REE

臺南地區牛山構造斷層之運動學模型

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臺灣位於歐亞板塊與菲律賓海板塊的碰撞帶，造山作用使該地區地震活躍。六甲斷層是臺灣西南部的活動斷層，其走向與牛山背斜西翼地層之走向平行，距離生產半導體的高科技工業園區不遠。儘管地質、地球物理以及井下資料確認出六甲斷層的位置，但仍不清楚其地表下完整之形貌。前人提出了多種與斷層相關的褶皺模型，包括是否有向西突破斷層的脫卸褶皺（detachment fold），以及向西伸向的斷層延展褶皺（fault propagation fold）。本研究旨在根據地表與地下資料重建多條構造地質剖面，以提出六甲斷層及其相關褶皺型態的三維幾何模型。

牛山背斜軸線呈南北走向，並分別向南北傾沒。在六甲斷層附近，地層以大角度向西傾斜，背斜東翼也被另一條向東逆衝的斷層（“ A ”斷層）所截切，地層則以較緩的角度傾斜。地表斷層線與井下資料顯示，六甲斷層向東傾約 40°到 50°。另一方面，地表與井下地層傾角顯示牛山背斜前翼（西翼）較淺之地層應為高傾角。由井下資料推估六甲斷層位移約 200 公尺， A 斷層位移約 170 公尺。根據所建構的構造平衡剖面，牛山背斜東西兩翼地下的構造深度不一致；東翼的深度淺於西翼的深度。為了解釋牛山背斜地下獨特的構造形態，本研究提出牛山構造之運動學模型，推測過去有盲斷層位於現今的牛山背斜之下，此盲斷層可能具有脫卸斷層（detachment fault）之性質，形成牛山背斜的雛形。之後，牛山背斜受擠壓形成高傾角甚或倒轉的地層，進而形成褶皺衍生斷層（fold accommodation fault），如六甲斷層和 A 斷層-該兩條衍生斷層可視為脫卸斷層向上突破的高傾角斷層。最後牛山背斜深部一規模更大的斷層彎曲褶皺（fault bend fold）作用形成東西兩翼深度不一致的構造現象。

中文關鍵詞：活動斷層、脫卸褶皺、斷層彎曲褶皺、褶皺衍生斷層

Phase equilibria modelling of basaltic rocks from the Vesuvian surface: Implications for the silicic melt generation

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Venus is a telluric planet with a similar size, composition, and mass to that of the Earth. The Vesuvian crust is mainly divided into lowland (~80%) and highland regions (~10%) based on their surface elevation. The lowland regions are characterized by the featureless lava plains, whereas the highlands consist of crustal plateaux, tesserae terrane, and volcanic troughs. The presence of evolved silicic igneous rocks on the Vesuvian surface has long been debated. Phase equilibria modelling using the basaltic compositions obtained from the Venera 14 and Vega 2 lander missions is employed to estimate the melt compositions generated by the partial melting of these rocks. The phase equilibria modeling results using the THERMOCALC software indicate that the tonalitic-granodiorite-trondhjemite melts can be generated through partial melting at shallow crustal depths (<10 kbar) with a water content of 0.4 wt.%. These results suggest the potential existence of evolved silicic rocks in the crust of Venus under the above-mentioned conditions.

Keywords:Venus, Crustal melting, Phase equilibria modelling

Decoding Sedimentary Pyrite Records Through In-Situ Sulfur Isotope Analysis

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The comprehensive investigations of petrography, clumped isotope thermometry (T-Δ_{47}), and in-situ sulfur isotopic and trace element analyses of pyrites had long been applied for elucidating the paleo-environments and sedimentation processes. This study presents a successful application on the basal Doushantuo cap carbonates, which deposited immediately following the Marinoan Snowball Earth. Our findings demonstrated that the majority of the analyzed pyrites originate from reduction of marine sulfates, primarily through thermochemical sulfate reduction (TSR), with minor contributions from microbial sulfate reduction (MSR) during dolomitization. Overall, the occurrence of pyrites and their $\delta^{34}S$ populations are controlled by H_2S generation, transportation, and storage. MSR- and TSR-derived H_2S are recorded by different pyrite generations, each exhibiting distinctive $\delta^{34}S_{py}$ values within a cm-sized specimen. The $\Delta^{34}S_{CAS\text{-}py}$ values of MSR-derived pyrites collected from two depths indicate a slight increase in seawater sulfate concentration during two transgression stages in the aftermath of the Marinoan Snowball glaciation. This study highlights the significance of employing multiple approaches at microscopic scales to elucidate sedimentation processes during post-glacial periods.

Keywords:pyrite, NanoSIMS sulfur isotopic analysis, clumped temperature, Ediacaran

臺灣西北部陸海域之二氧化碳地質封存系統分析及潛力場址評估

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國發會規劃我國的「2050淨零排放」行動方案，預計於2050年時，每年將利用二氧化碳捕獲與封存方式，減碳約4020萬噸。如此巨量的碳封存規模，至少約需開發40至80個二氧化碳地質封存場。前期研究指出臺灣陸海域約有487億噸的二氧化碳地質封存潛能，足以應付我國碳封存需求。我國急需建立碳封存潛在場址清單，以利後續進行實質之二氧化碳地質封存工作。

為回應碳封存的選址需求，本研究針對臺灣西北部濱海區與海域，進行盆地尺度之地下地層分析及評估二氧化碳潛在的封存量。本區臨近林口發電廠、大潭發電廠以及數個二氧化碳主要排放源；深度介於800公尺至3500公尺有R2、R3、R4等三套二氧化碳封存系統，適合二氧化碳地質封存。本研究彙整及解釋向中油公司購買的陸域與海域反射震測剖面及井下資料，並結合本研究新收集的陸海域反射震測剖面及火花放電剖面之整合分析，繪製二氧化碳封存層與蓋層之深度及厚度分布，勘定具碳封存潛力之目標場址，建立三維地質模型、評估二氧化碳封存量。根據陸海域反射震測及井下資料解釋成果，研究區域各地層空間分布趨勢皆為向東南傾斜、向西北抬升，陸域地層相對結構完整較無缺失，側向厚度變化不大，構造規模較小；海域地層側向厚度變化較明顯，各地層有向東南增厚，向西北變薄的趨勢，特別是R2封存系統可封存巨量二氧化碳，其深度淺，未來開發成商轉碳封存場之成本較低。

中文關鍵詞：臺灣西北部、二氧化碳地質封存、碳封存系統

臺灣本土之岩石力學參數相關性及經驗公式初探

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有鑑於國內近期正推動多項岩石力學與隧道工程相關之大型公共工程建設，如蘇花安、北宜直鐵及台電大光明電廠等，均須優先具體掌握岩石力學參數特性，方能搭配現行各種AI-based模型與數位孿生等建模技術，提供設計規劃及施工單位精準的提出合適之各類解決方案，符合工程安全品質之要求，據此，本研究將蒐集臺灣本土過去相關岩石力學試驗之參數，並進行整合分析，嘗試建立本土化之岩石力學參數相關性，而後提出參數轉換經驗公式，以利提供工程實務面之不同參數間轉換依據。本研究研析之岩石力學參數包含單壓強度、抗張強度、楊氏模數、孔隙率及體積模數等，岩性則涵蓋變質砂岩、泥質岩、砂岩、板岩、大理岩、片岩及片麻岩等，經文獻資料整理、參數分布分析及多變量關聯性分析等工作後，進行系統性之分類統計與相關性探討，據以依岩性建立各類參數間之經驗關係式。

分析結果顯示，不同岩性之間，岩石力學參數雖具差異性，但整體仍存在一定之相關性，其中，岩石單壓強度、抗張強度與楊氏模數間具有正相關性，而岩石孔隙率與體積模數間則呈現負相關性。透過資料比對與回歸分析，本研究已初步建立數組參數轉換公式，包含抗張強度與單壓強度、抗張強度與靜態楊氏模數、抗張強度與動態楊氏模數、有效孔隙率與體積模數等，相關成果不僅有助於臺灣本土岩石力學行為之模擬與預測，亦可應用於岩體工程設計、地質安全評估等領域，提升岩石工程參數使用之準確性與科學性，未來亦可持續納入新發表之試驗數據，持續更新本土化參數轉換經驗公式，並進一步發展相關之岩石力學應用模型。

中文關鍵詞：岩石力學、試驗參數、經驗公式

恆春半島內陸斷層之觸發型慢滑移事件：大地測量資料與地震序列模擬之整合分析

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藉由整合2002至2022年間3條精密水準測量路線、13個連續GNSS站、37個GNSS移動站，以及基線反演模型與斷層錯位模型之綜合分析，本研究曾提出，恆春斷層在2006年M_L 7.0屏東外海地震後，被誘發出一長期且目前仍持續中的慢滑移事件（Slow Slip Event, SSE）。根據地表速度場分析結果，其空間變化大致以恆春斷層以東約1-2公里處為界，並可劃分為5個時期：（1）2002至2006年屏東外海地震發生前的震間期；（2）地震後至2010年4月；（3）2010年4月至2013年；（4）2013年至2016年；（5）2016年至2022年。後續的基線反演模型顯示整個恆春斷層面上皆存在能量累積，特別集中於中北段淺層區域；斷層錯位模型則指出滑移速率亦遍佈整個斷層，並呈現由南往北遞進之特性。綜上成果，本研究發現第5時期的速度場與滑移速率分布已逐漸趨近於第2時期之型態，暗示著此慢滑移事件已釋放大部分累積的能量並進入尾聲。然而，恆春斷層中北段淺層之主要應變累積區域仍有部分能量未被釋放。為了進一步探討此慢滑移事件，本研究結合前期研究中修正並簡化的斷層跡、臺灣地震模型（Taiwan Earthquake Model，TEM）提供的斷層幾何，以及2006年地震後推估之初始應力條件，進行恆春斷層地震序列模擬，以探討其摩擦特性，期望能進一步釐清恆春斷層未來是否仍具有發震潛勢。

中文關鍵詞：慢滑移事件、恆春斷層、地震序列模擬、地震潛勢

A 100-year record of nearshore fish ecological changes in the Taiwan Strait

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The Taiwan Strait, a highly dynamic environment with rapid sedimentation and rich biodiversity, offers a unique setting for studying the impact of anthropogenic changes on nearshore fish ecology. Once a vital fishing ground, the region's fisheries collapsed in the 1980s due to overfishing that began in the 1950s. Today, the area's fish ecology faces additional threats from ongoing global warming, overfishing, and environmental degradation, reflecting trends seen in nearshore fisheries globally. This study examines historical fish assemblages and their relationship with anthropogenic activities during the last 100 years based on sediment records. Otoliths or fish ear stones recovered from the top 100 cm of two marine sediment cores collected from the Taiwan Strait, along with Pb210 dating, provides a high-resolution ecological proxy for the past 100 years. The region's high sedimentation rates and shallow depths offer exceptional temporal resolution, enabling the detection of subtle ecological changes driven by both natural and human-induced stressors. The results establish a pre-industrial baseline and quantify the impact of anthropogenic activities on local fish assemblages, providing valuable insights into fish population dynamics. These findings will support improved ecological models and management strategies, contributing to the conservation of biodiversity and sustainable fisheries in the Taiwan Strait.

Keywords:Taiwan Strait, ecological baseline, overfishing, otolith

東部地區之土壤層性質與水力特性初探

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土壤層位在岩層上方，多半由母岩風化形成，其水力特性與完整岩石及透水裂隙差異甚大，本研究為探討東部地區的地表之土壤層特性與空間分布，將針對東部地區之土壤層進行一般物性試驗、阿太堡試驗與土壤三軸透水試驗等，獲取全面性的調查資料。本研究以花蓮縣秀林鄉為研究區域，探討其地表之土壤層分布特性，並進行薄管土壤採樣與土壤地表入滲工作。透過室內試驗瞭解所採土壤樣本之一般物理特性、土壤結構與土壤之水力傳導係數等，並在飽和與壓密狀態下，分析水力傳導係數之分布；地表入滲試驗則可蒐集淺層土壤的入滲特性，瞭解東部地區之地表淺處地表水補注特性。

本研究針對東部地區不同流域以及乾濕季進行土壤採樣，探討研究區域之土壤層物理性質與水力特性之空間分布特性，以及不同季節對土壤特性的影響。本研究之分析結果，提供此花蓮縣秀林鄉之土壤層空間分布資訊與乾濕季變化情形。

中文關鍵詞：土壤調查、室內試驗、地表入滲、水力傳導係數

從應力反演與後投影法解析2022年關山池上地震序列

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在花東縱谷地區，存在兩大主要斷層系統，分別是向西傾的中央山脈斷層系統與向東傾的縱谷斷層系統。在2022年關山—池上地震序列發生之前，僅有縱谷斷層系統在1951的台東花蓮地震序列時地表可明顯觀察到破裂跡象，而中央山脈斷層系統則主要透過背景地震活動分布進行識別。近期研究已指出，2022年這兩起地震事件與中央山脈斷層系統具有高度相關性，分別呈現南向與北向的破裂方向。然而，有關地震破裂過程在時間與空間上的演化仍缺乏更多詳細的說明。因此，本研究採用地震後投影法，針對2022年9月17日與18日於花東縱谷中南段發生的關山地震與池上地震進行分析，旨在釐清其破裂過程的時空變化，並探討破裂面與中央山脈斷層及縱谷斷層兩大斷層系統之構造關聯性。此外，研究亦蒐集2021年至2022年間發生於該區域的地震事件，並以關山與池上地震作為時間節點，將資料劃分為三個時期。運用DBSCAN空間分群演算法，將每個時期的地震進行空間分布上的分群，再進行應力機制解反演，並建構關山地震和池上地震發生後之庫倫應力分布，藉此比較三個時段的局部應力場變化及兩地震所造成的庫倫應力變化，進一步分析地震發生前後區域應力的調整與轉移。後投影法結果顯示，關山與池上地震的主要破裂面皆位於西傾的中央山脈斷層系統，但東傾的縱谷斷層系統亦出現部分破裂跡象，顯示兩者間可能存在交互作用。池上地震的發震點位於關山地震之震後庫倫應力增加的區域，而應力場反演結果指出，同一時期斷層兩側的應力狀態存在差異，不同時期間亦有變化，反映出大地震事件有機率誘發另一起規模較大的地震，並對局部構造應力場造成了調整與重新分布。此外，對此地震序列進行不同時間段Vp/Vs值的比較並統整以上的分析結果，推論此區域在關山地震之後可能受到孔隙率增加及流體的影響，進而導致觸發池上地震的發生。

中文關鍵詞：2022年關山池上地震序列、應力反演、後投影法

Adjoint Tomography of Taiwan: Enhanced Seismic Imaging through Full-waveform Inversion

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The Taiwan orogenic belt lies at a complex convergent boundary characterized by strong tectonic heterogeneities. While numerous tomographic studies have been conducted to investigate the orogenic architecture, they rely on traditional traveltime tomography based on ray theory. This simplification limits the exploitation of rich information contained in full waveform characteristics and finite-frequency effects. To address these limitations, we employed adjoint waveform tomography using a misfit function based on frequency-dependent multi-taper traveltime differences between observed and synthetic waveforms. Our inversion was carried out based on a 3D ray-based tomographic model, using data from 88 moderate earthquakes (M_w 4.0-6.0) recorded by 108 broadband stations. We simultaneously updated V_p, V_s and density using the L-BFGS optimization algorithm to improve the waveform fitting. We performed 12 model updates across two period bands (10-50 and 8-30 s), with further iterations targeting shorter periods down to ~4 s. The results show a ~25% misfit reduction within each period band, along with enhanced structural contrasts in the updated models. Several key features including subducting slabs, Tatun magma reservoir, and accretionary wedge structures are revealed and better resolved primarily in the V_s model. We demonstrate the capability of waveform inversion to resolve multi-scale tectonic structures and its potential to support more detailed structural interpretations.

Keywords: Adjoint Tomography, Full-Waveform Inversion, Velocity Structures, Taiwan Orogenic Belt

自製全天影像儀觀測台灣地區大氣輝光與電離層擾動

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利用自製全天影像儀 (all-sky imager, ASI)設置於鹿林、南瀛天文台等地，配合地面全球定位系統 (Global Positioning System, GPS) 接收機觀測台灣地區大氣輝光亮暗帶與其伴隨之電漿泡以及電離層擾動，探討電離層中電漿泡與大氣輝光現象。全天影像儀同時分別記錄全波段與630nm帶通濾波影像，透過天空中的星點，將影像校正並投影至地理座標系統上，當全天影像儀觀測電離層大氣輝光二維結構時，GPS接收機同時紀錄全電子含量 (Total Electron Content, TEC)和TEC 擾動指數(Rate of TEC Index,ROTI)。將全天影像與TEC擾動指數(ROTI)疊合進行比對，結果顯示大氣輝光亮暗帶會分別對應TEC擾動指數 (ROTI) 之增減(弱強)。無過濾之全波段全天影像與630nm帶通濾波全天影像比較，對於移行電離層擾動(Traveling Ionospheric Disturbances, TIDs) 全波段影像可以觀測，630nm帶通濾波影像則無法觀測， 於電離層大氣輝光亮暗二維結構之影像中630nm帶通濾波影像相對於全波段影像更為清晰，因此於春季觀測電離層大氣輝光結構時主要使用630nm帶通濾波影像，夏季進入移行電離層擾動(TIDs)活躍時期則主要使用全波段影像觀測，當雲層遮蔽或相機視野受限的狀況以GPS接收機觀測資料加以輔助。預期實驗結果可以得到電漿泡於各個季節、時段發生機率、規模、移動速率、高度、位置，與移行電離層擾動(TIDs)是否有相互影響。

中文關鍵詞：全天影像儀、全球定位系統、電漿泡、移行電離層擾動

Assessment of Active Tectonics Using Geomorphic Indices in the Badlands of Southwestern Taiwan

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The badlands of Southwestern Taiwan lie within an active fold-and-thrust belt, where surface geology mainly consists of the erodible Gutingkeng Mudstone. In the absence of fluvial markers of river incision, geomorphic indices of the small drainage basins in the badlands appear instrumental in evaluating spatial variations in tectonic uplift, which range from 5 to 60 mm/yr. This study integrates high-resolution (2.5 cm) UAV-derived Digital Terrain Models (DTMs) with geodetic datasets (leveling, GNSS, InSAR) to investigate the interplay between uplift and erosion. Geomorphic metrics such as the hypsometric integral (HI), hypsometric curve, and basin relief (BR) were extracted using MATLAB Topo Toolbox and ArcGIS. Three sites were selected based on lithological consistency, varied structural settings, and decadal uplift rates. Site 1 (4755 m²), located in a very rapid uplift domain, exhibits high HI and BR values and convex to S-shaped curves, suggesting sustained long-term tectonic uplift. Site 2 (2739 m²) shows intermediate decadal uplift rates, S-shaped curves, and lower mean HI and BR than at Site 1, reflecting a more balanced influence of uplift and erosion. In contrast, Site 3 (5062 m²), affected by higher decadal uplift rates than Site 2, displays a similar mean HI to Site 2 but with greater variability, slightly lower BR values, and hypsometric curves ranging from convex to concave. This variability suggests locally variable erosion, possibly due to lithology, bedding attitude, fractures, or slope orientation. We plan to extend our approach to additional sites to improve statistical representativity and better constrain the spatial patterns of active deformation.

Keywords:Tectonic uplift, Hypsometric Indices, Badlands, Gutingkeng Formation, Drainage Basins

Site Effect Study for Kaohsiung City, Taiwan, Based on Shallow S-Wave Velocity Structures

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Ground response analysis provides insights into how seismic wave propagation can be affected by near-surface geological conditions. In particular, amplification of ground motion in soft sediments can result to greater damage from earthquakes. The Kaohsiung metropolitan area in southern Taiwan is underlain by layers of Quaternary alluvial deposits. The objective of this study is to estimate site effects in this area using the one-dimensional Haskell method. This numerical approach is used to calculate theoretical transfer functions and estimate predominant frequency at different depths from the surface to the bedrock.

Shallow S-wave velocity (V_s) structures (about 0-2000 m) were previously calculated based on microtremor array measurements conducted at 26 sites within the Kaohsiung area (Huang et al., 2025). Given that the Tertiary basement exhibits V_s of 1,500 m/s, the depth of Quaternary alluvium in the area ranges from 400 m to 1,300 m. Velocity profiles from this prior work are essential for evaluating frequency-dependent site amplification. Based on the V_s structures at these sites, we further calculate the theoretical transfer functions at the surface relative to six depths (i.e., 50, 100, 200, 400, 700, and 1000 m) and five V_s layers (i.e., 350, 550, 750, 1000, and 1500 m/s). According to these results, we estimate the predominant frequencies of the sedimentary layer at different depths. The predominant frequencies at the surface relative to the six depths gradually decrease with depth, while the predominant frequencies at the surface relative to the five V_s layers gradually decrease with increasing V_s.

Keywords:Site effect, Kaohsiung area, Haskell method, theoretical transfer functions, shallow S-wave velocity structures

以微區X射線螢光光譜技術解析西大墩遺址玉器之白化現象

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本研究運用微區X射線螢光光譜技術（Micro-XRF），針對臺中市西大墩遺址出土之玉器進行非破壞性元素分析，探討其白化現象與礦物化學變化之交互關係。玉器未白化區域之分析結果顯示其化學組成及微量元素分布變化與臺灣東部豐田閃玉特徵高度吻合，確認此批玉器原料源自臺灣豐田地區，為史前玉器原料溯源提供重要實證。進一步分析白化區域之元素分布，發現可區分為兩種類型：其一為化學組成與未白化區相似之區域，其主要元素（如矽、鎂、鈣、鐵）比例維持穩定。但微量元素之相對含量呈現變化，尤其鉻與鎳之相對含量發生反轉，未白化區域通常鉻大於鎳，而白化區域則呈現鎳大於鉻，顯示鉻元素在閃玉結構中較不穩定，易於風化過程中遷移。此類輕微白化區域之主要成分未見顯著改變，而微量元素含量雖發生變化但未完全流失，支持前人研究所提出之觀點，白化現象因埋藏環境中水分滲入，導致玉器纖維組織鬆散化所造成。另一類為化學組成顯著變化之嚴重白化區域，其特徵為鎂/矽比明顯下降，而鈣/矽與鐵/矽比顯著上升，此變化反映原始閃玉之礦物結構已發生轉變，或遭破壞並被次生礦物取代。值得注意的是，鉻、錳、鎳等微量元素並未隨鎂元素流失，反而呈現保留甚至局部富集現象，推測其遷移行為可能受控於風化過程中所形成的含鐵氧化物或次生礦物。本研究結果顯示輕微白化區域仍能保留原始玉料之成分特徵，可有助於閃玉原料之鑑定與溯源；而嚴重白化區域之元素分布模式與礦物相轉變，則可為重建埋藏環境之風化歷程提供關鍵線索。

中文關鍵詞：微區X射線螢光光譜、西大墩遺址、閃玉白化

利用影像辨識系統探索微體化石在空間中的分佈與應變分析的潛力——TPS 31A同步輻射光束線應用於泥岩樣本掃描

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泥岩層中微體化石具備作為構造應變指標的潛在價值，但泥岩細小、脆弱的特性使傳統前處理困難。本研究探討泥岩樣本從採集、定向到切割的前處理流程，並以TPS 31A同步輻射光束線進行CT掃描，目標在於建立高解析三維影像的標準作業流程。實驗在高雄田寮區採集古亭坑層定向泥岩，採回後先進行回歸定向，再以雙鋸片切割機沿三軸切割並以卦限標記方向。最終將樣本切割成5×5×20㎜長方體，此尺寸考慮TPS 31A二倍倍率下最大適用厚度約7-8㎜。然而，切割過程中發現樣本易碎、黏膠加固效果有限，且該尺寸單一樣本中僅能觀察到約3-5顆微體化石；同時，掃描過程之儀器參數影像重建等，需依靠人工校正。針對上述技術挑戰，本研究亦探討回歸定向、切割與拋磨等步驟產生的定向誤差及技術上如直接乾切等改善方向，並朝向更穩定、高效的前處理效果改良流程，為後續結合影像辨識系統進行微體化石空間分佈與應變分析提供可靠基礎。

中文關鍵詞：泥岩、微體化石、定向切割、電腦斷層掃描、應變分析

Multi-Mode Ambient Noise Phase Velocity Tomography in Southern Taiwan Using Frequency-Bessel Transform and Voronoi Partitioning

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Phase velocity dispersion derived from ambient noise cross-correlation functions (NCFs) between stations has become a powerful tool for imaging subsurface structures. However, most traditional studies focus only on fundamental mode surface waves, which provide poor depth resolution for shear velocity structures. To overcome this limitation, we apply a multimode surface wave tomography approach in southern Taiwan using data from the CWA, BATS, and the dense SALUTE array deployed since October 2021. This region marks a critical transition from continental subduction to arc collision, making detailed imaging essential for understanding its tectonic structure and evolution. We utilize the Frequency-Bessel (F-J) transformation to extract multimode dispersion information from the NCFs of vertical component. We adopt a Voronoi partitioning strategy that randomly and repeatedly divides the study area into multiple subregions, enabling a balance between spatial resolution and the stability of measured dispersion curves without relying on predefined subarray ranges. A semi-automatic procedure is then employed to extract Rayleigh wave dispersion curves from the F-J spectrograms. By averaging results from 300 Voronoi realizations, we generate period-dependent phase velocity maps for both the fundamental mode and the first higher mode of Rayleigh waves and estimate associated uncertainties.

The fundamental-mode phase velocity maps at periods of 4-12 seconds reveal a prominent low-velocity zone (below ~2000 m/s) in southwestern Taiwan, primarily beneath the Pingtung Plain and extending northward through Kaohsiung and Tainan to the southern edge of the Peikang Basement High (PBS). This low-velocity feature is most distinct at shorter periods (4-8 s), suggesting it is mainly confined to the upper crust (< 10 km depth) and associated with the Quaternary thick, unconsolidated alluvial deposits filling the coastal plain areas. In contrast, the Central Range, particularly its eastern part composed of the exhumed, highly-metamorphosed Pre-Tertiary basement rocks, exhibits the highest phase velocities. Unlike short-period fundamental-mode phase velocities, which correlate with shallow lithostratigraphic variations, the first higher-mode phase velocity maps at 3-4.5 s display a different pattern. Lower phase velocities are observed across the Coastal Plain and the western portion of the Western Foothills, while velocities progressively increase eastward toward the Central Range. The most distinct low-velocity anomalies appear beneath the PBH, likely reflecting the presence of relatively lower-rigidity crustal materials at intermediate depths (> 10 km). By integrating both fundamental and higher mode phase velocity maps, we aim to achieve improved crustal structures beneath southern Taiwan.

Keywords:Ambient Noise, Surface Wave Dispersion, Phase Velocity, Frequency-Bessel Transform, Voronoi Partitioning

Deciphering the Multi-Fault System of the 2024 Mw 7.4 Hualien, Taiwan Earthquake Using Seismic and Geodetic Datasets

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The April 3, 2024 M_W 7.4 Hualien earthquake was the largest earthquake in Taiwan in almost 25 years, and it has resulted in thousands of aftershocks so far. The intricate fault distribution in eastern Taiwan adds challenges to determining the fault geometry and slip distribution associated with this event. Although the USGS finite-fault solution indicates an overall east-dipping fault rupture, inversions based on geodetic observations suggest a west-dipping thrust fault. To better constrain the fault geometry and slip distribution of the Hualien earthquake, we combine strong motion seismic, GPS, and InSAR datasets using joint finite fault inversions. We first use a Bayesian inversion scheme to constrain the most probable fault parameters including source location, depth, strike, dip, rake, and slip with the coseismic GPS displacement solutions from the Nevada Geodetic Laboratory. We then use a finite fault inversion method to estimate slip distribution on this fault geometry with a 3 km sub-fault patch size. For the seismic dataset operated by the Taiwan Strong Motion Instrumentation Program network (TSMIP), we first explore the fault parameters by random search for a half-million parameter combinations. The results from individual GPS and seismic inversions prefer two main slip patches on two different fault planes, suggesting that a deeper west-dipping fault plane around 35 km depth may have triggered a shallower west-dipping fault around 20 km depth. A joint inversion with these two fault planes can yield a total variance reduction > 75%. This multi-fault geometry is also in good agreement with the relocated aftershocks. The total seismic moment of the two faults is equivalent to M_W 7.39. Additionally, preliminary Coulomb stress change analysis indicates better consistency between Coulomb stress increase and aftershocks. Our analysis suggests a multi-fault system during the 2024 Hualien earthquake. It also highlights the value of leveraging dynamic seismic as well as static geodetic measurements such as GPS and InSAR for earthquake source inversions.

Keywords:2024 Hualien earthquake, finite fault inversion, triggered coseismic slip, seismology, geodesy

Applications of Modern Borehole Logging Technologies in Geothermal Reservoir Exploration

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Modern borehole logging technologies have become essential in geothermal reservoir exploration, offering high-resolution and multi-physics data critical for detailed characterization of subsurface structures, rock properties, and fracture systems. Among these, the Formation MicroImager (FMI) and Sonic Scanner are advanced tools widely applied in research and field development. The FMI utilizes dense arrays of microelectrodes to generate resistivity-based borehole wall images, enabling the identification of fractures, bedding planes, and fault zones with near-core-level resolution. Such data support three-dimensional fracture network modeling and hydraulic property estimation, especially in core-deficient intervals. FMI further facilitates in-situ stress field reconstruction and failure mechanism analysis when integrated with borehole sonic data. Complementarily, the Sonic Scanner measures P- and S-wave velocities using multi-pole acoustic arrays, allowing for the derivation of elastic moduli, stress anisotropy, and principal stress orientations. These parameters are crucial for evaluating porosity, fracture reactivation potential, and borehole stability under high-temperature, high-pressure geothermal conditions. These tools provide a comprehensive dataset for constructing physically consistent and spatially continuous 3D reservoir models, informing well placement, reservoir classification, and injection–production strategy. Their outputs also form the basis for thermo-hydro-mechanical coupled simulations and serve as core inputs in advanced reservoir modeling workflows. As data science and AI-driven analytics evolve, logging data's automated integration and interpretation will further elevate their role from diagnostic tools to foundational components of intelligent geothermal energy systems. Overall, modern borehole logging enhances exploration and development accuracy and bridges the gap between geoscientific theory and engineering practice, thereby playing a pivotal role in the transition toward sustainable and high-efficiency geothermal utilization.

Keywords:Borehole Logging, FMI, Sonic-Logging, Geothermal reservoir , Farctures analysis

大甲溪谷關段地質景觀與地熱資源之綜合評估-社會地質學與跨域協作的視角

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大甲溪發源於中央山脈與雪山山脈交會地帶，長期受到造山運動與強烈河流侵蝕作用的影響，形成了峽谷、曲流、河階與沖積扇等多樣地貌，展現出臺灣年輕地殼構造的動態演化與複雜的地質歷程。在大甲溪中游的谷關段，主要由變質砂岩與板岩構成，屬於雪山山脈南緣的一部分。該地區兩岸可觀察到褶皺、背斜、斷層、層理與沉積構造等地質特徵，具有顯著的地質教學與研究價值。

谷關地區的水文條件優越，地層裂隙孕育出天然溫泉，泉溫介於50至75度之間，溫泉露頭主要分布於大甲溪北岸，已知有十餘口溫泉井，顯示出明顯的地熱徵兆。基於這些自然條件，谷關被列為臺灣地熱潛能區之一。經濟部地質調查及礦業管理中心運用地質調查、地球物理探測、地球化學分析與鑽探等方法，建立了谷關地區的地熱地質資料與圖像。此外，為解決山林地形限制，研究團隊透過衛星遙測與光達技術進行輔助探測，對地熱資源的分布進行初步判識與潛勢評估。根據探勘結果，谷關屬於具備中高溫地熱系統特徵的地區，具有開發深部地熱資源的潛力。

谷關地區的地質意義不僅體現在自然科學層面，也與地方發展脈絡密切相關。從社會地質學的視角來看，地質環境與人類社會之間存在密切的互動，建立出地方文化、產業發展及風險治理的多重關係。谷關自日據時期即為水利與溫泉觀光的重鎮，形成了聚落與相關設施。然而，該地區在1999年921地震及2004年敏督利與艾利颱風中遭受重創，突顯了地質環境既是資源也是限制的雙重特性。

隨著全球能源轉型的推進，谷關成為地熱開發的焦點之一。地熱資源的開發涉及土地利用、資源分配與環境影響等多方面議題，亟需跨領域的協作與知識共享，以確保資源開發的可行性與公平性。本研究從地質學跨域實踐、地熱資源開發與地方產業連結等層面切入，探討谷關地區地質特性的多重意義與應用潛力。同時，研究倡議將谷關地質與地熱資源納入大甲溪流域的知識導向旅遊導覽體系之中，藉此促進地質教育、能源轉型與地方永續發展。

中文關鍵詞：地熱開發、地質災害、社會地質學、永續能源、知識旅遊

3-D Surface Deformation Fields of the Longitudinal Valley Suture Derived from Multi-Sensor InSAR Velocities

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Interseismic deformation is the gradual accumulation of strain in the Earth's crust along tectonic plate boundaries, culminating in the abrupt release manifested as earthquakes. The Longitudinal Valley fault is a well-known creeping fault located at the convergent boundary between the Philippine Sea Plate and the Eurasian Plate. Its creeping rate is as high as 20 mm/yr near Chihshang Township through varied geodetic observations. However, the comprehensive interseismic creeping behavior along the fault trace remains unknown. The typical method to observe interseismic deformation is to use the GNSS network with the highest precision. However, GNSS measurements in previous studies offer only a broad overview of surface deformation, lacking the spatial detail to reveal smaller-scale creeping/locked fault traces. Determining interseismic fault locking depth is challenging without high-resolution crustal deformation data. In contrast, InSAR provides centimeter-scale precision and high spatial resolution, enabling detailed observations of surface deformation. Previous research utilized line-of-sight (LOS) velocity or LOS velocities combined with GNSS to observe the creeping behavior of the oblique Longitudinal Valley fault. However, these observations are either limited to a single direction or lack sufficient resolution in the north-south direction. Therefore, we used Sentinel-1 and ALOS-2 imagery (2015-2020) to generate 3-D velocity fields through Small Baseline Subset InSAR (SBAS-InSAR). With the high-resolution velocity fields, we identified more detailed geological structures and their behaviors. We found the Yuli fault exhibited 2-3 mm/yr of creep in the E-W direction before the 2022 Guanshan-Chishang earthquake, a phenomenon not previously reported. Additionally, an inferred structure near the previously mapped east-dipping Chimei fault appears to be west-dipping based on our N-S and U velocities and leveling data. This inferred structure may represent an extension of the Central Range fault, potentially intersecting the Chimei fault. Our findings could facilitate the development of accurate models for mitigating seismic hazards.

Keywords:Interseismic deformation, SBAS-InSAR, GNSS, Longitudinal Valley Suture

動態降雨山崩潛勢模式更新-以南部地區為例

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動態山崩潛勢模式係透過探討山崩時空變遷，來釐清前期事件對於後期事件誘發山崩之關聯性，據以提供複合事件誘發山崩之熱區預測，進而橋接地震與降雨兩種山崩潛勢模式，並結合即時地震、即時降雨資料，來建置地震-降雨關聯性動態山崩潛勢模式。本研究基於集集地震建置地震誘發山崩潛勢模式成果，初步以中部地區建置降雨誘發山崩潛勢模式，以利後續兩種山崩潛勢模式橋接。然而降雨誘發山崩之特性有地域性的差異，若將中部地區建置之潛勢模式，於其它地區使用，其結果具有相當程度的偏差。因此，以中部地區之降雨誘發山崩潛勢模式分析流程，針對南部地區建置降雨誘發山崩潛勢模式，除更新不同區域之潛勢模式，同時檢驗分析流程是否需要調整。本研究於南部地區挑選賀伯颱風(1996)、納莉颱風(2001)、海棠颱風(2005)及莫拉克颱風(2009)，配合6 m數值地形建置基礎山崩潛感，並據以分析基礎山崩潛感與各事件之山崩崩壞比、雨量因子間的關係，擬合崩壞比曲面，繪製山崩崩壞比圖。各分區結果顯示基礎潛感圖預測訓練事件之正確率即可達80~90%，山崩崩壞比圖預測驗證事件之正確率亦可達80%左右，顯見上述論述之建構分析流程可適用於其它分區。動態降雨山崩潛勢模式之成果未來將提供防災使用，但崩壞比圖為連續數值，使用上較不直觀，因此，將山崩崩壞比以崩塌潛勢呈現，並區分為高、中高、中、低潛勢等四級，可較為容易理解。此外，為了更聚焦重點崩塌區域，本研究以斜坡單元推估誘發山崩熱區，此熱區具有山崩發生區的意義，與衛星影像判釋之山崩範圍比對，兩者多有重疊，但衛星影像判釋之山崩範圍通常是包含了發生區加上運移區，故兩者有局部不同之處。山崩潛勢及山崩熱區可於災中即時告警，判斷是否疏散避難，於災後快速發布災害地點，掌握最佳救難路線，對於防減災能提供更有效的作為。

中文關鍵詞：山崩、山崩潛感、颱風

翡翠水庫水域邊坡潛感分級與重點關注邊坡

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翡翠水庫是臺北都會區重要的水資源來源，但臺灣多山且具有地質脆弱、坡度陡峭和水流湍急等不利於土體安定的條件，加上多地震、暴雨集中等外在因素，使得崩塌、地滑、土石流、山地洪災等天然災害經常發生。為了避免崩塌土石造成庫容減損，及早掌握重點邊坡初期坡地災害，即時進行預防及整治工程，全庫區邊坡健檢有其必要性。本研究蒐集1980至2022年間各單位建置之山崩目錄，篩選出翡翠水庫集水區範圍之崩塌地，此外，藉由觀察歷史山崩目錄可知，資料涵蓋的40餘年間，翡翠水庫集水區共計發生745處山崩，累加總面積共127.8公頃。另觀察2011至2022年之山崩目錄，可發現近10年內翡翠水庫集水區發生山崩的機率偏低，僅發生153處山崩，累加總面積10.1公頃，且其中93.2%的崩塌地皆為復發型態。據此，顯見近10年內翡翠水庫集水區之邊坡相當穩定，無新增崩塌，主要多為原地復發之崩塌。肇因翡翠水庫集水區面積廣大，針對每一處邊坡進行詳細分析效益不大，且不符合經濟效益。因此，本研究針對水域邊坡範圍之自然邊坡進行初步健檢，利用歷史山崩發生頻率配合地形地質資訊進行潛感分級，擬定出重點關注邊坡，並作為提供後續詳細分析及處置規劃之擇定邊坡參考依據。

中文關鍵詞：山崩、山崩潛感、重點關注邊坡

Imaging the Discontinuous Structure beneath Southern Taiwan with CCP Stacking of Receiver Functions

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Southern Taiwan and its eastern offshore region lie in a pivotal transition from subduction to arc-continent collision, making it significant for studying subduction-collision structures and orogenic processes.

We employ common-conversion point (CCP) stacking of receiver functions (RFs) to image discontinuous features associated with the subducted Eurasian continent and Luzon forearc-arc basin beneath this critical transition zone. Combining teleseismic waveforms from permanent BATS stations and the amphibious SALUTE array, we perform a free-surface transformation (Kennett, 1991) on 3-component P-waveforms to better separate P wave energy and SV wave energy. A frequency-domain deconvolution was subsequently applied to obtain RFs for individual events.

The resulting RFs exhibit notable backazimuthal variations, especially at stations near the N-S striking Chaochou Fault (CCF), which bounds the Backbone Range Slate Belt to the east and the Coastal Plain and Western Foothill to the west. Using the predicted Ps ray paths and traveltimes for the 1-D IASP91 velocity model, we migrate P RFs from time to depth axis at 1-km intervals and stack Ps amplitudes at common-conversion bins with various sizes adapted by the first Fresnel zone. The resulting CCP stack image reveals significant lateral variations in the upper-lower crust interface and the Moho of the Eurasian continent beneath the western coastal plain. Additional shallower upwarping crustal discontinuities are observed beneath the Central Range, which may reflect the vertical velocity change associated with basal accretion that contributes to the growth of Southern Taiwan orogenic wedge. Positive conversions at ~15 km depth beneath the eastern coast and adjacent offshore region likely marks the Moho of the subducted oceanic forearc crust.

Keywords:Receiver Function, Common-Conversion Point Stacking, Southern Taiwan, Moho Discontinuity, SALUTE

苗栗地區X井岩性與井測曲線特徵之綜合解釋分析

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在淨零碳排政策路徑上，碳封存扮演著關鍵負碳技術的角色。欲瞭解蓋層與灌注儲集層之岩性及物性，展開鑽井地質探勘、井下電測為前期評估重要工作之一。臺灣西北部錦水頁岩與桂竹林層為良好的蓋儲系統，在西北部之陸海域皆具有相當封存潛能。本研究整合苗栗通霄地區X井之鑽井與井下電測資料，針對所鑽遇之錦水頁岩與桂竹林層，進行岩屑、岩心及各項井測曲線(自然伽馬(GR)、電阻、聲波等)特徵綜合判釋，探討不同岩性區段之井測物性反應。結果顯示，錦水頁岩厚148公尺，桂竹林層厚345公尺，其中包含魚藤坪砂岩段(197公尺)、十六份頁岩段(36公尺)以及關刀山砂岩段(112公尺)。整體而言，頁岩段多產生擴徑現象，井測曲線易失真；砂岩段則可維持良好井徑，保留砂岩的各項物性反應。位於桂竹林層魚藤坪砂岩段上部，具有一層厚約15公尺之砂岩，具有GR值低、深淺電阻曲線分離、聲波速度偏慢之特徵，且帶有些微氣徵，推估有較佳的孔隙率與滲透率，做為儲集層之評價較高。關刀山砂岩段中部有一層厚12公尺之砂岩，亦具有類似物性特徵。本研究成果不僅提供苗栗通霄陸域井下新資料，亦對於臺灣西北部陸域碳封存潛能評估帶來實質參考價值。

中文關鍵詞：井測曲線、桂竹林層、魚藤坪砂岩段、關刀山砂岩段、碳封存

透過P波極化特性研究嘉南地區淺層構造

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地殼的淺層構造具有較低的地震波速和衰減係數等特性，因此對地震動的各個方面皆會產生顯著影響，並在工程、資源勘探及其他應用領域中扮演關鍵角色。在傳統的層析成像分析下，地表下數百米的構造通常解析度不足，往往僅能依靠井測數據或大範圍震波勘測進行詳細分析，成本高昂導致研究範圍受限。是故，本次研究目標以P波極化特性探討高地震潛勢的台灣嘉南地區淺層構造，藉以得到可靠的淺層構造資訊。近年於台灣嘉南地區佈設密集地震網，收錄大量高品質地震波形資料，提供豐富的P波資訊。其極化的深度敏感度主要受控於頻率和地層剪切波速的影響。本研究測試不同的頻率及可解析深度範圍，藉以得到最佳的收斂效果。而密集地震網其較短的站間距與相對較高的記錄頻率，則為深入研究淺層地殼的性質與動力學提供了獨特機會。透過密集地震網的觀測資料，求得各測站下方的一維淺層速度模型，進而整合成三維的淺層速度模型，用以研究密集陣列網下方的淺層三維速度構造。由於密集陣列網的區域涵蓋嘉南平原及西部麓山帶，初步成果可清楚反映由東向西沉積層厚度逐漸加深的地質特徵、及麓山帶下方堅硬岩盤的位置等。本研究建立的高解析淺層速度模型，將有助於後續進行更準確的波傳模擬與場址效應分析，對於提高地震災害的評估將有顯著助益。

中文關鍵詞：P波極化、淺層速度、密集陣列

Leveraging Forward Modeling in Magnetotellurics for Quality Control and Predictive Analysis

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Magnetotellurics MT is a commonly used geophysical method for exploring subsurface conductivity by measuring natural variations in the Earth's electromagnetic field. It is especially useful for imaging both shallow and deep structures. However, the data it provides can be heavily affected by noise from both natural and human-made sources, which can make interpretation challenging. One way to deal with these issues is by using forward modeling. While forward modeling is often seen as just a step before inversion, it can actually play a helpful role throughout the MT workflow. It can be used to check inversion results, test how well algorithms perform, plan survey setups, and predict how different conditions might affect the data. Running synthetic models in controlled settings also makes it easier to understand how sensitive the method is to certain subsurface features and how noise or survey design might change the results. This can be especially helpful in areas where the field environment is complex or limited. Using forward modeling more actively can support quality control and give more confidence in how the final results are interpreted.

Keywords:Magnetotelluric, Forward Modeling, Noise, Predictive Analysis

北臺灣煤礦業文化路徑的推動與民眾參與之經驗

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地球的地質科學之於臺灣的地質資源，臺灣的地質環境是一個相對年輕且劇烈變動的島嶼，卻蘊含多樣化的礦產，如：閃玉、硫磺、煤炭、石油、金銅礦…等，臺灣的地質資源及其背景，因應人類文明的發展，在形成產業的過程中，數度與世界史、區域發展史產生交集。「煤炭」是促進工業革命得以成功的關鍵礦產，而煤礦產業近代在臺灣的發展，自十七世紀的大航海時期至清代、日治時期、戰後的工業轉型，皆在臺灣近代化的發展中扮演一定的角色。隨著民國90年（2001）1月份臺灣最後一處經濟導向開採的煤礦場歇業後，直至民國108年（2019）新平溪煤礦於當年度7月19日正式廢止採礦權止，臺灣的煤礦業宣告走入歷史。有鑒於歐洲文化路徑的推動經驗，並促進公民參與形塑臺灣主體的共同價值，文化部文化資產局在行政院重要社會發展計畫之架構下，於民國110年（2021）推動文化路徑（Cultural Route）的發展策略，預計於民國114年（2025）底完成階段性的建置。

礦業文化路徑（Cultural Routes of Mining Industry）的路徑主題，係以北臺灣木山層（下部含煤層）、石底層（中部含煤層）、南莊層（上部含煤層）等產煤地層所構成的產業鏈為基礎，建構北臺灣煤礦文化路徑（Northern Taiwan Coal Mining Culture Route）的區域路徑；臺灣的煤礦業停止開採20餘年後，涵納在地質教育或區域性地質背景的基礎之上，試圖透過多元化的民眾參與策略，如：展演策劃、體驗路徑、聯盟組織運作以及辦理至今已進入第三屆專業導覽解說人員培訓的知識體系再建構…等行動方案，搭建社會參與的橋樑，進而推動產業遺產（Industrial Heritage）的文化資產保存、記憶的世代傳承、詮釋、轉譯與和解，更有助於促進產業遺產或工業地景的活化。

中文關鍵詞：煤礦業文化、社會參與、文化路徑、地質教育、地景保育

The Impact of Land Subsidence on Horizontal Displacement: A Case Study of the Pingtung Plain

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We analyzed surface deformation pattern in the Pingtung region during the dry and wet seasons using GNSS continuous data from 2016 to 2024 in this study. Based on the coordinate time series analysis, the dry season is defined as November to May, and the wet season as June to October. The long-term trend of GNSS time series was removed before calculating transient 3D displacements during these seasons. The detrend results show that in the dry season, the reduced rainfall and lower groundwater levels lead to significant surface subsidence, with horizontal movement toward the subsidence center. For instance, during the dry season in 2016, maximum subsidence was 13.8 cm and horizontal movement was 2.6 cm. In the wet season, increased rainfall and groundwater recharge caused a maximum uplift of 19.6 cm, with horizontal movement showing an outward displacement trend, reaching 3.9 cm. To further validate GNSS observations, DInSAR results were derived from Sentinel-1 satellite images for surface displacement analysis. Integration of GNSS and InSAR data confirm that the changes of horizontal displacements are mainly driven by elastic deformation from groundwater variation. In addition, the average subsidence of 2-3 cm/yr in Pingtung after seasonal effect removal represents a long-term, irreversible plastic deformation, which will influence long-term horizontal displacement and potentially impact the linear structure safety and fault potential assessments.

Keywords:Land Subsidence, Seasonal Deformation, Geodetic Data, Horizontal Displacement

嘉南平原地震密集網微震分析

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本研究利用2023年新港密集地震網及2024年義竹與太保密集地震網觀測到的大量微震事件，探討嘉義平原下方可能存在的孕震構造與盲斷層，旨在了解未知孕震構造的分布範圍及破裂機制。此外，根據台灣地震模型團隊於2020年發布的台灣地震潛勢圖，嘉南地區在過去百年內未發生大規模地震，顯示該區未來發生大地震的潛勢較高，因此有必要針對此區域進行充分的防災準備。近年來，深度學習人工智慧技術廣泛應用於科學研究領域，包括地震學相關研究。本研究結合深度學習模型PhaseNet Plus進行自動地震波相挑選與極性判定，從連續波形記錄中提取微震事件的P、S波到時及極性方向。接著，運用非監督式學習方法GAMMA進行波相關聯，並彙整地震目錄。為了驗證自動波相挑選與極性判定的準確度，本研究繪製各波相的到時與極性分布，進行人工檢查與修正。之後，使用VELEST反演研究區域的一維速度構造，並依據更新後的速度模型，重新定位微震事件。本研究透過HypoDD-3D利用三維速度構造進行最終的定位，並比較初始位置與HypoDD-3D的定位結果。此外，透過P波極性方向計算微震的震源機制解。最終的重定位結果顯示，在嘉義縣義竹地區9～12公里深度處存在一條向南西傾斜且東西向的微震帶，此結果與前人研究所提出的義竹斷層特徵一致; 而新港震群則與梅山斷層的破裂機制一致，推斷應為其分支斷層的活動所為。透過微震定位與震源機制解的分析，本研究得到的新港及義竹震群破裂機制為右移的東西向走滑斷層，而太保震群則以東傾的逆斷層為主，具有較深的震源深度。後續研究工作將進一步探討發震構造的地震成因，並進行地震災害潛勢評估。

中文關鍵詞：AI auto-picking、Phasenet Plus、GAMMA

古代社會韌性與環境適應—以兩千年前的 Blihun 漢本遺址為例

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國定考古遺址 Blihun 漢本遺址位於台灣東北部和平溪下游北側，臨近山海交界地帶，是一處橫跨新石器末期至金屬器時代的重要史前聚落。遺址地勢坐落於沖積扇扇頂與坡腳交界處，面對東北季風強降雨作用頻繁的複雜地形環境。本研究結合考古遺構、人為遺留現象與地層觀察，探討古代聚落在面對災害風險下的空間配置、再居策略與災害應對行為，並從歷史生態學的視角，理解史前人群如何透過長時段的經驗累積與環境互動，持續調整其聚落空間行為。

本研究以發掘區P2S與P2N的地層剖面與遺構分布為主體，聚焦於兩個主要文化層（L6 與 L4）。L6 文化層（約 2000–1600 BP）保存有多組由駁坎分隔的住屋單元，伴隨柱洞、火塘、鋪石與板岩排水溝構成整體聚落格局。該層晚期遭遇厚約 2–3 公尺、內含粉砂與礫石的土石流崩積層（L6c）覆蓋，推測為強降雨引發之土石流。災害發生後，住民並未放棄聚落，而是在地勢稍低的東側區域重新組織居住空間，並持續使用相似的構造技術與水利設施，反映出聚落空間的調整與重建。

L4 文化層（約 1600–1000 BP）柱洞逾百處，反映不下於 L6 住屋結構的規模。但是，部分生活面出現短期水相堆積、礫石滾落與駁坎傾斜等現象，顯示聚落仍面對水災與小規模崩積風險。與 L6 相似的排水或蓄水設施亦見於本層，顯示人群對水文環境的理解與應變能力。儘管仍保留多處駁坎與柱洞，L4 的建築單元多呈局部段落，規模與結構不如 L6 層集中完整，顯示聚落配置可能趨於分散，並歷經多次修補或調整。雖災害頻仍，聚落仍持續維持並調整空間配置，呈現災害—重建—再居的循環。

漢本人所構築的駁坎、排水道等水利設施，可視為史前人群回應環境風險的知識化表現。這些設施所展現的技術延續與水文理解，凸顯人群面對災害時，由歷史記憶所得的傳統知識、空間實踐與集體應變能力。Blihun漢本作為高災害風險區的聚落樣態，提供研究者細緻觀察古代災害沉積與人地互動關係的珍貴案例，也顯示考古學研究方法在理解古代聚落與環境互動的重要跨學科價值。

中文關鍵詞：Blihun漢本遺址、社群韌性、歷史生態學、災害考古學、古代水利設施

HypoFault3D: Software for Constructing 3D Seismogenic Structure Models from Hypocenter Data

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We present the beta version of HypoFault3D, a software designed to construct three-dimensional models of seismogenic structures using earthquake hypocenters, focal mechanisms, and velocity models. With recent breakthroughs in deep-learning-enhanced earthquake cataloging, such as body-wave arrival picking and first-motion polarity determination, the volume and precision of earthquake catalogs have improved dramatically. These advancements pave the way for high-resolution investigations of complex seismogenic structures. Moreover, state-of-the-art absolute hypocenter location algorithms incorporating station correction terms, along with refined relative location techniques, enable event localization with sub-kilometer accuracy. Leveraging these high-quality datasets, HypoFault3D allows researchers to delve into critical geophysical processes with the seismogenic structures, especially where fault systems are intricately entangled, as exemplified by the 2024 M7.4 Hualien and 2025 M6.4 Chiayi earthquakes. This beta release introduces two core modules: Click2Strike and Click2Plane. Click2Strike enables intuitive strike determination by allowing users to manually trace linear or spline features on a map, which are then used to generate vertical cross-sectional profiles. Click2Plane extends this interactive approach by allowing users to delineate complex fault geometries on depth-versus-distance profiles, enriched with projected hypocenters, focal mechanisms, and velocity model attributes. The resulting structure is then smoothed and modeled using a radial basis function to produce a refined 3D fault geometry. To showcase its capabilities, we applied HypoFault3D to model the 2024 Hualien earthquake sequence, the 2025 Dapu earthquake sequence, and the subduction systems of the Philippine Sea Plate – Ryukyu Trench and the Eurasian Plate – Philippine Sea Plate. We believe HypoFault3D represents a significant step forward in seismotectonic analysis, combining user-friendly design with robust scientific rigor.

Keywords:Seismogenic structure, software, HypoFault3D

2025年3月28日Mw 7.7緬甸地震：由表面波相速分析所顯示的不對稱雙向破裂與破裂速度變化

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震源歷時會造成表面波相速的時間延遲，本研究利用此特性來調查2025年M_W 7.7緬甸地震的破裂方向性，藉此分析其基本的破裂特徵。將主震與其附近參考地震的雷利波相速走時相減可得到隨測站方位變化的震源歷時，依震源破裂方向性原理可以得到破裂方向、破裂歷時、破裂長度、破裂速度等等。結果顯示緬甸地震的是一個非對稱的雙向破裂(asymmetric bilateral faulting)事件，由震央往南的破裂方向為352°、破裂歷時32.3 s、破裂長度79.5 km及破裂速度2.46 km/s，而往北的破裂方向為174°、破裂歷時70.1 s、破裂長度301.5 km及破裂速度4.3 km/s。很顯然地往南呈現的是次剪力破裂(subshear rupture)，而往北則是超剪力破裂(supershear rupture)。整體上，緬甸地震的破裂長度(L)約為380 km，震源歷時約70 s。另以遠場SH波的非負解時間域解迴旋所得的震源時間函數，顯示其地震矩(M_0)為3.83 x 10^{20} Nm，相當於M_W = 7.65。M_0與L的關係似乎符合Romanowicz (1992, GRL, p481-484)對大的走向滑移地震的提議，即M_0 = 1 x 10^{18} L。

中文關鍵詞：緬甸地震、雷利波、破裂速度、超剪力破裂、震源時間函數

鐵砧山碳封存示範場址之微震與地表變形背景基線監測成果

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依據國際碳封存場址開發經驗，二氧化碳灌注可能導致地層壓力變化，導致微小破裂誘發微震，甚至引起地表微幅變形。為掌握灌注作業前場址之儲蓋層穩定性與地表狀態，建立背景基線為碳封存風險評估與長期監控之重要基礎。台灣中油公司配合政府淨零碳排目標於苗栗鐵砧山執行碳封存示範計畫，並自113年起進行微震與地表變形監測工作，建立灌注前的背景基線。微震監測部份於封存場址範圍內設置4座寬頻地震站，並整合鄰近地震測站資料，建構地震觀測網。監測期間自113年4月至114年3月，封存場址內未觀測到任何微震事件，顯示該地區目前處於穩定狀態，無異常地震活動發生。地表變形監測部份採用精密水準測量資料及干涉合成孔徑雷達資料進行分析，觀察地表抬升與沉降變化。初步分析結果顯示，觀測期間地表變形幅度小，無明顯地表變動行為，成功建立初步之地表變形背景基線，待未來持續進行水準測量且延長觀測期間，以掌握短期與長期變化趨勢。整體而言，目前成果已初步完成鐵砧山二氧化碳封存場址灌注前微震與地表變形之背景基線建立，提供未來碳封存作業前後之異常變化比較依據。後續將配合實際注入作業，持續進行監測與分析，作為確保碳封存作業安全性與場址穩定性之重要依據。

中文關鍵詞：碳封存、微震監測、地表變形、背景基線

Preliminary field, geochemical, and geochronological results from the Korba granites, Central Indian Tectonic Zone

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Peninsular India is composed of four Archean-Paleoproterozoic cratons (Bastar, Bundelkhand, Dharwar, Singhbhum) that amalgamated sometime during the Late Paleoproterozoic-Early Mesoproterozoic. The final collisional belt between the cratons of southern India (Bastar, Dharwar, Singhbhum) and northern India (Bundelkhand) is referred to as the Central India Tectonic Zone (CITZ). Although the timing of collision is not known, there are a number of Batholiths within the CITZ that likely record the final stages of collision. 'Late Archean' Chhotanagpur Gneissic Complex (CGC) of the CITZ includes 'undifferentiated' Korba granites and associated meta-sedimentary rocks, but very little is known about the Korba granites including their petrogenesis and age. In this study, we report the preliminary geochemical and geochronological results from field work. Granites, pegmatites, and meta-sedimentary rocks were collected from Korba District, Northern Chhattisgarh. The granites are peraluminous, alkali-calcic to calc-alkalic in composition and composed of K-feldspar (30-40 vol%), plagioclase (10-20 vol%), quartz (~30 vol%), and muscovite (15-25 vol%), with accessory amounts of tourmaline (~5%), amphibole (<5%), garnet (<1%), and beryl (<1%). Sillimanite-bearing pegmatites are found throughout the Korba granites and suggest that there was period of late stage Al-rich fluid fluxing. Blocks (1-10 m wide) of meta-sedimentary rocks are found within the granites and may represent a roof pendant. The preliminary *in situ* zircon U-Pb geochronology results indicate a Late Paleoproterozoic (1800-1600 Ma) emplacement age. The Korba granites are compositionally similar to the muscovite-bearing peraluminous granitoids (MPG) category, indicating that they were mostly likely derived by partial melting of sedimentary rocks during crustal thickening associated with continent-continent collision.

Keywords:Central Indian Tectonic Zone, peraluminous granite, sillimanite-bearing pegmatite, geochemistry, zircon U-Pb geochronology

末次冰期後濁水溪沖積扇海域層序地層初探：以超高解析度反射震測資料為例

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濁水溪沖積扇為臺灣面積最大的沖積扇之一，往北最遠可延伸至大肚溪，南至北港溪，海岸線總長約76公里。自全新世最大海漫面（MFS）且有相關紀錄以來，主要河流於水下三角洲沉積，隨著三角洲往海域前積，逐漸變成現在陸域的沉積環境。雖然陸域井下紀錄建立完整的層序地層研究，對於近海處的沉積分布特性和千年尺度高精度的層序研究，尚未有明確的答案。本研究使用超高解析度（UHR Seismic）的單頻道震測剖面，進行層序地層分析並追蹤不同地層單元的三角洲沉積物在空間上的變化趨勢，探討自最近一次最大海漫面以來三角洲水下的地層演育。

本研究利用臺中彰化外海超高解析度震測反射資料，位置主要分布於濁水溪出海口以北的海域。聲源使用電火花，單頻道接收器。其中解迴旋資料處裡後，垂直解析度提升一倍，垂直解析度可達數十公分。有利於辨識出更細微的地層訊號並對更低階級（sequence hierarchy）的層序單元做出小尺度地質事件的解釋。依據震測地層學原理將全新世測線進行層序地層分析，標記出主要層序邊界（SB）、最大海漫面（MFS）、海進體系域（TST）及高水位體系域（HST）的位置。並且與海岸的鑽井資料最近距離僅相距五公里內，可同時與井的結果對比，提供可能的沉積環境和年代控制。

分析結果顯示，高水位體系內沉積物堆積形態呈現明顯的向海下下覆（downlap）與前積特徵，反映了不同時期三角洲沉積物向海域的逐步推進過程。將震測分析結果與前人於陸域井資料所獲得的層序地層與地層年代資料進行對比，最大海漫面深度相近年代約六千年前。離海岸線十五公里內，高水位體系域由河流作用主導，內部三角洲沉積物存在三個主要不整合面，可以劃分出四期不同的地層單位，推測沉積中心為由南往北遷移的過程。此研究成果有助於釐清彰化外海全新世三角洲沉積環境的演化過程，對於臺灣中部沿海古環境與沉積動力機制研究提供重要參考依據。

中文關鍵詞：層序地層、超高解析度反射震測資料、濁水溪沖積扇、全新世

臺灣海膽化石生物帶與南港層區域地層對比初探

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在前人的研究中有提到南港層在日治時期是分為下部的「湊合層」和上部的「南港砂岩」。在基隆地區此地層可以分成五段：碩仁段、暖暖砂岩段、大華段、新寮砂岩段、十分寮段。前人根據超微化石將碩仁段下部為NN3, 碩仁段上部、暖暖砂岩段及大華段屬NN4，新寮砂岩段屬NN5.　另外，在文獻中，暖暖砂岩段及新寮砂岩段皆有海膽化石記錄。在北海岸的南港層中，前人有鑑定出N8和N9浮游性有孔蟲化石帶及NN4及NN5超微化石帶。然而，在金瓜石礦區內，因受熱水作用，大部分超微化石溶蝕嚴重無法鑑定，故層位鑑定困難。本研究嘗試探討沙錢海膽化石在熱水變質作用下之埋藏學，並嘗試用沙錢海膽來探討原始南港層地層層位。

中文關鍵詞：地層學與古生物學、生物地層學、埋藏學、沙錢、西部麓山帶

無人機空中磁力探測技術評估及應用

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傳統的地面磁力探測方法受限於地形陡峭、植被茂密及人員進出不便等挑戰，難以滿足現代地球物理調查的需求。為此，經濟部地質調查與礦業管理中心（前身為中央地質調查所）自2012年起引進空中磁力三軸拖鳥技術，利用直升機進行臺灣北部及東部的大範圍空中磁力探測，成果豐碩。然而，直升機載空中磁力探測因飛行速度快，適合大範圍地質構造調查，無法對小範圍場址進行較精密的調查。無人機）以飛行速度慢及飛行高度低的優勢，可與直升機空中磁力探測互補。

為評估無人機空中磁力探測的可行性，本研究進行了一系列試驗，包括：無人機干擾試驗、預定測線吊掛假體（Dummy　bird）飛行、無人機爬升能力計算、類地貌飛行剖面計算等，確保空中磁測資料品質及無人機性能在崎嶇地形可安全地進行。

研究區域位於花蓮縣紅葉地熱潛能區，面積約25平方公里，地形起伏高度達1000公尺，部分區域平均坡度超過35%，使用無人機吊掛磁力拖鳥沿預定測線進行探測是一項挑戰。為比較無人機與直升機空中磁力探測的差異，本研究採用與直升機磁測相同的方式進行測勘規劃，但縮小測線間距與飛行高度。無人機磁力資料經過日變化修正、國際地磁參考場移除(IGRF removal)、高度修正與調平處理後，獲得紅葉地熱潛能區全磁力異常圖。資料處理後之全磁力異常圖與2017年空中磁力探測結果進行疊合比較，結果顯示兩者在磁力異常的趨勢及位置一致，證實了無人機磁力探測的可靠性。除資料特性一致外，無人機全磁力異常圖在側向的解析度及磁力異常值強弱對比上均更明顯。

本研究評估無人機空中磁力探測技術的可行性與優勢，未來將繼續深化此技術的應用，為地質及地熱調查提供一種高效、精確的小範圍場址調查方法。

中文關鍵詞：無人機、空中磁力、紅葉地熱

An Update on the development of New Low-Cost MT Instrumentation

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Several world widely use MT instruments are made by leading companies, such as Phoenix and Metronix.
The performance of those sets of MT instrument have been proven for decades by earth scientist and engineers. However, the sale price for each set of instrument is overwhelming for university especially in developing countries. Therefore, we tried to assembly a low-cost MT instrument, called NCUMT. Several problems, such as the internal noise, the performance of electric and magnetic sensors, and data recording settings had been improved by arranging the instrument layout, calibrating the sensors, and several trials on digital settings. The performance of NCUMT were tested by comparing the signals and Apparent Resistivity result with Phoenix MTU-5A. Both signals and Apparent resistivity value from NCUMT are slightly higher than Phoenix. As a result, improving the signal recording of NCUMT are still challenging in the development of NCUMT.

Keywords:low-cost, Magnetotellurics, instrumentation

Using UAV Photogrammetry to Analyze Surface Grain Size in Gravel- and Cobble-Bed Rivers

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Sediment grain size in stream beds is an important factor for understanding fluvial process. Grain size is one geomorphological feature of a river reflecting river dynamics, such as transportation and deposition processes, stream power, flow history and the origin of sediments. Besides, the change of grain size after natural disaster, such as typhoon and landslide, is another issue worth to concern. Therefore, how to acquire grain size data efficiently and accurately is an important work. In previous studies, high resolution image-based grain size analyses are limited in patch scale, while site scale studies are limited in resolution to few centimeters. On the other hand, grain size detected in images is the “2D” grain size, and the difference between 2D grain size and actual 3D grain size are rarely discussed. In this research, we use UAV (Unmanned Aerial Vehicle) flying at a low altitude to capture millimeter level resolution images in gravel- and cobble-bed rivers. With structure-from-motion photogrammetry, point cloud and orthoimages are generated firstly, then grain size is detected from these two outputs respectively. Results showed that medium grain size has around 10-30 mm difference between 2D and 3D grain sizein both a- and b-axis, and grain size detected from images are slightly underestimated to actual grain size. For point cloud segmentation, grain sizes between 10 mm and 250 mm showed good correspondence with actual 3D grain sizes, while smaller and larger grains didn't perform well in segmentation. These findings can serve as a reference for future studies on particle size analysis using imagery and point clouds.

Keywords:Surface Grain Size, UAV, Structure-from-Motion, Point cloud, Orthoimage

Natural Frequencies of Low-Rise Reinforced Concrete Buildings Determined With QSIS

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The Quake Structural Integrity System (QSIS) is an innovative and cost-effective platform for continuous seismic monitoring and post-event structural health assessment. It leverages low-cost MEMS accelerometers and cloud-based computing to capture and process real-time data through a scalable workflow. In this workflow, local devices record ground and building motions; a central server manages data aggregation and preprocessing; and a web-based interface provides user-friendly visualization and device management.

We deployed QSIS in several mid-height (4–5-story) reinforced concrete (RC) buildings in Taiwan and collected seismic data from January 2021 to April 2025. Through spectral analysis, cross-correlation of ambient vibrations, and seismic interferometry, we tracked changes in key structural parameters such as mode shapes and eigenfrequencies across daily, weekly, and annual timescales.

Notably, we observed a decline in eigenfrequencies following major seismic events, indicative of stiffness reductions and early-stage damage. Meanwhile, seismic interferometry analyses yielded consistent impulse response functions, underscoring the capability of this multi-parameter approach to capture subtle structural variations that may precede more pronounced changes.

This integrated approach offers a promising pathway for early damage detection and continuous structural health monitoring. These findings demonstrate the utility of QSIS for both near-real-time and long-term monitoring, enabling rapid post-event damage assessment and supporting resilient urban development strategies in seismically active regions. Additionally, the system's cost-effectiveness and scalability facilitate the deployment of dense networks of instrumented buildings in Taiwan's urban centers, providing critical insights into structural integrity before, during, and after major earthquakes.

Keywords:Structural Health Monitoring, Strong Motion Building Arrays, MEMS Accelerometers, Seismic Interferometry, Social Resilience

Reservoir sizes of the CL hot spring sites: Inference from spring water compositions

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The reservoir size of hot spring sites is critical for assessing the energy capacity of a geothermal system and has commonly been estimated by geophysical exploration. Here, we provide a geochemical approach for constraining the reservoir sizes of the hot spring sites in the Chung-Lun (CL) region, southern Taiwan using water major cation content.

Hot spring waters were collected from 5 sites, labeled as CL-1, CL-2, CL-3, CL-4, and CL-5. The first three sites are located at east of the Yun-Shuei creek, whereas the other two were at the opposite side. River waters (CL-6) were also collected for comparison. Six sets of samples were collected in two months on weekly or bi-weekly basis.

The CL hot spring waters are characterized by Li, Na, K, Rb, Cs content of 1.7–11, 3800–14000, 90–450, 0.1–1.1, and 0.002–0.06 ppm, respectively, along with 2.9–24 ppm Si, 1.4–11 ppm Al, and 15–115 ppb B, typical of sodium-chloride type. In the Na versus Li, K, Rb, and Cs plots, two linear trends are formed; one by CL-1 samples alone and another by CL-2, CL-3, and CL-5 samples. These two linear trends converge at the origin point of the plots, implying involvement of meteoric water. They then diverge toward high concentration ends with the CL-1 trend having higher Li, K, Rb, and Cs concentrations, reflecting the control of two distinct enriched water components. The Na-B plot further segregates CL-5 samples from the trend. It is, therefore, inferred that the reservoirs of these hot spring sites are isolated from each other. According to the sampling locations, these hot spring sites are separated by ~300 m that can be a reference parameter for the size of the reservoirs of these hot springs.

Keywords:hot spring, geothermal, reservoir

斷層帶粉碎岩石的發現與隱示

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斷層岩石紀錄了斷層作用，其中斷層帶的粉碎岩石產狀與斷層作用中的剪切、滑動形成的岩石特徵非常不同。斷層帶的粉碎岩石與強烈斷層作用有緊密的關係，像是地震破裂的傳播方向、地震產生的動態高應變率載荷。本研究以MiDAS的斷層帶岩心，發現一段具有粉碎岩石特徵的斷層岩石。根據岩象觀察、X光繞射分析、同步輻射X光繞射分析、勞氏繞射分析，對自然界的斷層岩石進行微分析。另一方面，進行單壓和5MPa圍壓條件的岩石三軸實驗，以合成石英為試體，實驗達尖峰強度後，對已破壞試體進行微構造觀察。微構造結果顯示斷層岩石有強烈的、廣泛的微米尺度破裂。粉碎狀的、無內聚力的斷層岩石是純石英，無明顯剪切構造，亦無非晶質材料出現，勞氏繞射結果顯示，相較於斷層帶其他岩石或圍岩的石英，粉碎狀石英的殘餘應力遠高於其他深度。本研究比較斷層岩石與實驗室的破壞試體，發現微構造的差異，排除粉碎狀石英是由靜態壓縮造成。另外，斷層帶可能出現的破裂因素逐一排除，如熱應力導致的破裂、或剪切的磨細作用。而非晶質的出現可能是斷層剪切的作用或是風化而產生，說明此一粉碎岩石，是近期的強烈斷層作用而產生。

中文關鍵詞：斷層作用、斷層岩石、粉碎、米崙斷層

Expanding the Paleoclimate Toolbox: 3-OH Fatty Acids as a Palaeothermometry Proxy

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The most pronounced impacts of global climate change are expected to occur within terrestrial ecosystems and human societies. Despite this, reliable temperature proxies for terrestrial environments remain limited. Recently, bacterially derived lipids known as 3-hydroxy fatty acids (3-OH FAs) have emerged as promising molecular tools for paleoclimate reconstruction due to their demonstrated biochemical sensitivity to environmental variables such as temperature and pH. These biomarkers offer the ability to reconstruct both parameters independently and can also provide isotopic information through routine analytical techniques, extending the capabilities of established proxies such as glycerol dialkyl glycerol tetraethers (GDGTs) and alkenones. While 3-OH FAs have shown considerable potential, their applications to key terrestrial climate archives – peat, lake sediments and stalagmites- remain comparatively underexplored. Here, we show the utility of 3-OH FAs as a terrestrial palaeothermometry proxy from multiple terrestrial archives, including lake sediments and stalagmites, spanning diverse geographical and ecological settings. Our findings reinforce the reliability of 3-OH FAs as a proxy for reconstructing past temperatures and ultimately expanding the palaeoclimate toolbox.

Keywords:3-hydroxy fatty acids (3-OH FAs), biomarkers , paleoclimate reconstruction, stalagmites, lake sediments

Hydroclimate Variability in the Mainland Southeast Asia during the Last Glacial Maximum

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Hydroclimate variability across mainland Southeast Asia during the Last Glacial Maximum (LGM) remains insufficiently understood, despite the region's critical role in modulating heat and moisture transfer from the equator to higher latitudes. In this study, we investigate sedimentary sequences from the Lower Central Plain of Thailand—located approximately 5 km from the present-day inner Gulf of Thailand—using geochemical proxies (notably K/Ti ratios), mean grain size analysis, and pollen assemblages. Our multi-proxy results reveal a phase of intensified fluvial runoff and increased precipitation between 26.5 and 24.6 cal ka BP. This was followed by a marked reduction in discharge from ~24.6 to 24.1 cal ka BP, broadly corresponding to Heinrich Event 2. A continued decline in runoff persisted until ~23 cal ka BP, after which precipitation levels rose again between 23 and 22.8 cal ka BP. An abrupt shift to significantly drier conditions ensued after 22.8 cal ka BP. Comparison with other palaeoclimate records from Sundaland suggests that the Intertropical Convergence Zone (ITCZ) did not undergo a substantial northward shift during the LGM. Instead, the region likely experienced a tropical wet–dry climate regime, resembling modern savanna-like conditions with pronounced seasonal contrasts. Reduced precipitation over western Sundaland is consistent with a weakened summer monsoon, possibly counterbalanced by increased land–sea thermal gradients resulting from the exposure of the Sunda Shelf. These findings highlight the spatial heterogeneity of hydroclimate patterns across the region during the LGM, challenging the prevailing paradigm of uniformly cool and arid conditions across tropical latitudes.

Keywords:Mainland Southeast Asia, the Last Glacial Maximum, the Intertropical Convergence Zone, Savanna climate

Natural periodic soil movements in long-term monitoring - causes and consequences

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Periodic signals in monitoring time series may originate either from sensor behaviour—particularly due to temperature sensitivity—or from actual, reversible movements of soil layers driven by variations in temperature and water content. Ideally, sensor-related influences can be minimized through calibration or correction procedures (a priori), but this approach is often complex and rarely fully effective—some residual effects almost always remain. As a result, periodic components are frequently removed during time series analysis without fully considering their origin. However, this process typically eliminates both sensor-induced artifacts and genuine cyclic soil responses. Consequently, such signals are often overlooked, with analytical attention focused primarily on long-term trends, velocity changes, or sudden displacements considered as main indicators of potential slope instability.

In our research, we focused on analysing the periodic signals themselves across different monitoring methods—remote sensing, terrestrial geodetic techniques, and subsurface geotechnical instrumentation. After accounting for temperature-induced measurement biases, we concentrated on natural periodic movements in near-surface soil layers. Our findings suggest that both temperature and water content can act as key triggers for these movements.

Field monitoring confirms that temperature gradients can induce measurable near-surface soil displacements, which were observed up to the depth of 4 m with reversible component of 5 to 8 mm in depth of 2.3 m. Laboratory tests show that even minor temperature changes (~1–2 °C) significantly affect soil parameters such as shear strength, compressibility, viscosity, and hydraulic conductivity. These thermal effects can alter pore water pressures and generate mechanical stress and strain within soil masses, leading to seasonal fluctuations in slope stability. Such effects are particularly pronounced in slow-moving landslides or slopes close to failure, shallow slides (less than 5 meters), and in soils with fractures or high clay content, where thermally driven processes and enhanced heat transfer dominate slope behaviour.

Keywords:Periodic movements, monitoring, temperature, water content, time series

SWOT 衛星於臺灣地表水體動態監測之潛力評估

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NASA 的Surface Water and Ocean Topography （SWOT）衛星任務，配備 Ka 波段的合成孔徑雷達干涉儀，旨在提供即時、高精度與大幅寬的面狀地表水文與海洋觀測資料，為水文研究開啟嶄新的應用機會。然而，因其觀測方法深具創新性與實驗性，各階層資料之準確性仍有待驗證。因此，本研究擬利用臺灣 14 座水庫歷史水位資料，以及桃園市內 14 個埤塘的現地水位量測，針對 SWOT Level 2 產品進行時間序列比對分析，以驗證其水面高程（Water Surface Elevation, WSE）資料的準確度。

針對 LakeSP Obs產品，我們首先設定水位閾值排除離群值，並根據水體面積做加權平均以確保各水體的整體水位高程之可信度。而在 Lake Pixel Cloud (PIXC) 產品中，則利用品質指標(Quality flags)與四分位數法剔除離群值，以萃取可靠觀測值。結果顯示，相較於 LakeSP Obs產品，Lake Pixel Cloud 產品在水位測量的標準差（STD）與均方根誤差（RMSE）方面均有顯著改善：在水庫方面的表現，標準差由 1.02 公尺降至 0.31 公尺，方均根誤差由 1.14 公尺降至 0.53 公尺；而在埤塘比對中，標準差由 0.39 公尺降至 0.16 公尺，方均根誤差則由 0.41 公尺降至 0.16 公尺。除此之外，我們透過客製化處理流程，可利用Lake Pixel Cloud 資料補足 LakeSP Obs中缺漏的點位，並提高水體偵測能力，使其可偵測最小面積達 100 × 100 公尺的水體，顯著優於SWOT任務原本設定的 250 × 250 公尺。本研究初步成果驗證 SWOT 任務在監測臺灣季節性水位變化上的應用潛力。

中文關鍵詞：SWOT、內陸水體、高程變化、衛星測高

營埔遺址石刀材質分析與產地推測-談新石器晚期大肚溪流域族群關係

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營埔遺址出土的石刀，年代約為距今2100－1800年前，屬新石器時代晚期。該遺址位於大肚台地南端，鄰近大肚溪，具交通要衝地理位置。石刀所用石材當中的閃長岩、斑狀安山岩與凝灰質砂岩具特殊性，均非來自大肚溪流域，其中閃長岩甚至可能源自濁水溪上游東埔地區。值得注意的是，閃長岩製的石刀呈厚背倒梯形，刀背加厚，寬度約50㎜，屬中部地區特有且分布有限的類型，可能具有特殊用途或文化意涵。目前這型石刀僅見營埔遺址及大肚溪對岸八卦台地北端的牛埔遺址，牛埔遺址也出土使用閃長岩的石刀。閃長岩的石器目前僅少量出現於臺中盆地南端的遺址，以及在埔里大馬璘遺址出土過1件石斧，盆地內及大肚台地西側未見使用這類石材。根據石刀類型和閃長岩石器分布來看，臺中盆地南端及兩台地交界處一帶，史前族群間有特殊親厚關係。至於閃長岩石材的來源是偶然或是刻意從他處帶入，是否跟此處獨特的地理位置有關，仍待進一步調查。

中文關鍵詞：營埔遺址、牛埔遺址、閃長岩、厚背石刀、大肚溪

ICESat-2 應用於臺灣潮間帶多時序地形重建之精度分析 —以大肚溪口濕地為例

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潮間帶是連接陸地與海洋的重要過渡區域，不僅具備豐富的生物多樣性與天然防災功能，其水位、地形與沉積物特徵亦易受外界環境影響而發生變化，因而成為觀測海岸變遷與氣候影響的重要地帶。臺灣四面環海，河川多呈東陡西緩，使西部沙岸孕育出多處重要濕地；加上位處副熱帶地區，氣候條件變化大，海岸線經常受到颱風、潮汐與沿岸流等營力作用影響而變動，突顯出潮間帶觀測與分析的重要性。因此，本研究利用 2018 至 2024 年間的 Sentinel-2 多光譜衛星影像進行潮間帶地形重建，並結合 ICESat-2 雷達衛星資料，針對不同時間範圍的觀測結果進行精度驗證，旨在找出重建精度最佳的觀測區間與最適合臺灣潮間帶監測的時間尺度，以提升後續地形監測的效率與可靠性。

本研究區位於大肚溪口重要濕地，首先蒐集 2020 年 6 月至 2024 年 1 月間通過的 ICESat-2 ATL03點雲資料，並選擇最低潮位者作為起始時間，針對三個月至兩年間的不同時間尺度進行潮間帶地形重建。方法上，先計算改良標準化差異水指數（MNDWI）判別水陸交界，再分析各像素的淹水機率並結合潮汐模式以計算高程值，最後以 ICESat-2 高程剖線進行精度驗證。結果顯示，各時段重建成果之整體均方根誤差（RMSE）介於 0.4 至 0.7 公尺之間，且隨觀測時間長度增加，模型精度普遍呈現提升趨勢，顯示本方法可有效評估不同觀測區間的重建表現，有助於找出最適合臺灣潮間帶地形觀測的時間尺度，作為後續濕地監測與海岸管理之參考依據。

中文關鍵詞：ICESat-2、Sentinel-2、大肚溪口、潮間帶地形、多時序分析

臺灣新型大地電磁接收系統發展及初步實場驗證結果

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大地電磁法（Magnetotellurics, MT）為一種被動式地球物理探測技術，利用天然電磁波場之時變特性，反演地下電性構造，具備探測深度大且空間覆蓋廣之優勢，廣泛應用於地熱資源評估與二氧化碳地質封存等深層地質構造之探勘工作。鑒於商用MT接收系統價格高昂，限制台灣於大規模地球物理探測之實施效率，本團隊研發完成ITRI-MT接收系統雛型機，期以提升國內自主量測技術之能量。本研究針對ITRI-MT接收系統之核心電路模組，包括資料記錄器、訊號放大器與相關電路設計進行系統性性能評估與優化，並以PHOENIX MTU-5C商用系統為參照進行現地測試與資料比對。初步測試結果顯示，兩系統於磁場分量（Hx、Hy、Hz）具有良好一致性，惟在電場分量（Ex、Ey）方面，ITRI-MT系統初期呈現響應不足之情形。經由強化前級放大器設計、調整類比數位轉換器（ADC）輸入阻抗、以及強化抗電磁干擾能力等工程改良措施後，有效降低系統背景雜訊並提升電場訊號之解析能力，同時本研究亦開發自動化資料處理軟體，整合量測結果與頻譜分析流程，經後續比對實驗驗證，ITRI-MT系統於全頻段內已具備與商用系統相當之頻率響應特性，並展現優異之訊號強度與動態範圍，顯示其具備應用於實地大地電磁探測之可行性與技術成熟度，為後續推廣應用與系統商品化奠定堅實基礎。

中文關鍵詞：大地電磁法、資料紀錄器、背景雜訊、電磁干擾、輸入阻抗

Water cycle and groundwater budget of Jeju Island

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Jeju Island has geological features with high permeability, so a large amount of rainfall is recharged into groundwater, and most of its water resources depend on this groundwater. The surface geology is composed of porous basaltic lava flows, which account for 92% of the island's total area, and the remainder is composed of sedimentary rocks (sedimentary layers), lava flows, and scoria cones. The underground geology is composed of multiple layers of lava flows, so it has very high horizontal and vertical heterogeneity, and due to the irregular distribution of permeable geological structures such as discontinuous distributions that regulate groundwater flow, collapsed lava caves (sumgol), clinkers, joints, fracture zones, and scoria, the hydrogeological characteristics can vary greatly by region and site. The water budget analysis of Jeju Island is the most basic process that must be performed for sustainable development, use, and management of groundwater. Previous analyses were based on the sum of precipitation abstracted by evapotranspiration and direct runoff, but in reality, groundwater use and the amount of the submarine groundwater discharge (SGD) flowing out to the sea must be considered. The annual SGD of Jeju Island is estimated to be 1,361~1,466 million m3/year (34~36.2% of total amount of precipitation). The water balance analysis of Jeju Island was first conducted in 1972 with the support of UNDP/FAO, and has been conducted every 10 years since then by the Korea Water Resources Corporation (K-water) for the purpose of establishing a water resources management plan. In addition, water balance analysis has been attempted by various organizations such as the Korea Rural Community Corporation (KRC), the Korea Institute of Geoscience and Mineral Resources (KIGAM), and the Korea Institute of Civil Engineering and Building Technology(KICT). According to the comprehensive results of the water balance analysis of Jeju Island conducted since the 1980s, the total precipitation volume is 3,303~4,046 million m3/year, of which direct runoff is 8.7–26%, evapotranspiration is 32.3–49.2%, and groundwater content is 38.7–46.1%. Jeju Island's water budget has been evaluated mainly by manual hydrological methods, and relatively recently, distributed hydrological models such as SWB, SWAT-K, and WetSpass-M have begun to be applied. However, the results from each model show significant differences, and recently its reliability is the key issue. For scientific and systematic groundwater management, it is necessary to develop a Jeju's model that reflects Jeju's hydrogeological characteristics, climate change, land use changes, and other changing environments. Additionally, the model should address the limitations of existing models and continuously validate and enhance its accuracy through actual observations, such as groundwater levels and stream discharge, to improve the reliability of the analysis results.

Keywords:Groundwater, Korea, Jeji Island

Pseudo-dynamic Source Modeling with 1-Point and 2-Point Statistics of Earthquake Source Parameters for Physics-based Ground Motion Simulation

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Ground motion prediction is a core element in seismic hazard assessment. However, developing accurate and reliable prediction methods for future destructive earthquakes remains a significant challenge. Traditionally, our community has focused on two main approaches: the construction of empirical Ground Motion Prediction Equations (GMPEs) and the use of stochastic ground motion simulation schemes. The empirical GMPE approach often suffers from a lack of recorded data, particularly in the near-source region for large events. Stochastic simulations, while useful, are also limited—typically generating only single-component and single-phase ground motions, which constrains their applicability. In recent years, researchers have increasingly turned to physics-based ground motion prediction, adopting either dynamic or pseudo-dynamic earthquake modeling methods. In this presentation, I briefly review the potential and challenges of the pseudo-dynamic source modeling method, which incorporates 1-point and 2-point statistics of earthquake source parameters. This approach represents one of the most recent developments in physics-based ground motion simulation. Within the framework of pseudo-dynamic ground motion simulation, the use of 1-point and 2-point statistics not only enables more realistic physics-based source representations but also provides an efficient means to quantify both epistemic and aleatory uncertainty in predicted ground motion intensities. Although many challenges remain, this method offers promising directions for advancing seismic hazard assessment through more physically grounded and statistically robust ground motion prediction.

Keywords:Earthquake, Seismic Hazards, Ground Motion Simulation

Earthquake Damages: Controlling Factors and Hazard Assessment

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Earthquake damage and casualty levels are influenced by various factors, including earthquake magnitude, seismic wave characteristics, distance from the hypocenter, and local geological conditions. While predicting earthquake damage patterns remains complex, case studies highlight the critical role of **surface rupture** and **fault damage zones** in determining damage distribution. Fault damage zones develop due to stress accumulation and rupture propagation, exhibiting complex deformation patterns that significantly impact seismic hazard assessment. This study investigates the key geological and seismic parameters that influence earthquake damage, including **fault geometry, fault type, rupture propagation, evolution stages, tip modes, slip sense, and exposed locations**. Based on field data, numerical modeling, and historical earthquake records, we can assess their impact on seismic hazards. Findings emphasize the necessity of incorporating **fault damage zone characteristics** into hazard assessments and site selection for critical infrastructure. By integrating multidisciplinary approaches, this study provides a **comprehensive framework for evaluating fault evolution and its implications for earthquake hazard mitigation**.

Keywords:surface rupture , Seismic hazard, fault damage zone

Eruption of a CO2-driven Cold-Water Geyser, Crystal Geyser in Utah

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Several cold-water geysers and springs are located adjacent to the Green River in Utah where two major east-west faults, the Little Grand Wash and the Salt Wash Graben faults, trend roughly parallel to each other. Among these springs and geysers is Crystal Geyser, located immediately north of the Little Grand Wash fault and approximately 6 km south of the town of Green River. Anomalously high soil-CO2 fluxes (>700 g/m2day) have been measured along traverses perpendicular to these two fault zones. During August 4-6 and September 1-5, 2010, we performed additional CO2 flux measurements adjacent to Crystal Geyser. The highest CO2 flux recorded was approximately 1,600 g/m2day. In this study, the fluid mechanics of the regularly erupting Crystal Geyser was investigated by instrumenting its conduit with pressure, temperature, pH, EC, and dissolved oxygen sensors, measuring every 1 minute during and between eruptions. Results of these measurements suggest that the time-scale of a single eruption cycle ranges from 30 to 40 hours and is composed of four successive eruption types with two recharge periods. Current eruption patterns exhibit a bimodal distribution although previous measurements and anecdotal evidence suggests that this pattern was different prior to recent seismic activity. The geyser's eruptions are regular and predictable, and reflect pressure, temperature, EC, pH, and dissolved oxygen changes resulting from Joule-Thomson cooling, endothermic CO2 exsolution, and exothermic CO2 dissolution.

Keywords:Geyser, Groundwater, CO2

Coastal uplifts and tsunami run-up associated with the 2024 Mw 7.4 Hualien earthquake

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On the morning of April 3rd, 2024, an Mw 7.4 earthquake struck the Hualien area in eastern Taiwan, causing significant damage in the city of Hualien and extensive landslides in the Central Range north of Hualien city. A subsequent tsunami also struck east Taiwan's coastal area, which was recorded by tide gauges at several harbors in Taiwan and Japan. To quantify the amount of coastal deformation associated with the 2024 Mw 7.4 earthquake and the plausible tsunami run-up, we conducted a series of surveys two days after the mainshock along the earthquake-affected area. Our results suggest that the mainshock is accompanied by significant coastal uplift, especially along the Milun Tableland's east margin and the Coastal Range's northeastern coast. The largest coastal uplift recorded by the uplifted oyster and corals exceeds 0.5 meters near the Hualien Harbor. The uplift recorded by the sea-level indicator is comparable to the deformation recorded by the ALOS-2 InSAR result and the observation from the GNSS network. The amount of coastal uplift gradually decreased northward and southward, forming a narrow patch of uplift zone along the northernmost Coastal Range in the south and the northeastern Central Range in the north, reflecting the size of the fault-ruptured patch underneath eastern Taiwan. Our study also showed that the plausible tsunami run-up along eastern Taiwan's coastline exceeded 2 meters in many places south of Hualien, which suggests the run-up height is about 2 to 3 times higher than the tsunami wave height recorded by the nearby tide gauges. Since the structural activity offshore eastern Taiwan is poorly constrained, our results highlight the need for a better understanding of offshore active structures in eastern Taiwan.

Keywords:Hualien earthquake, Coastal Deformation, Tsunami

由微孔珊瑚骨骼中鋇鈣比代用指標評估過去一世紀蘭嶼環境變遷

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人類活動可能對環境生態造成衝擊，然而由於歷史及觀測記錄的限制，不同區域長時間尺度下氣候變遷及人為作用對自然環境的影響尚需藉由地質材料中的代用指標來近一步評估。蘭嶼作為全台灣最晚開始現代化的地區之一，迄今未有完整涵蓋其過去開發歷史的環境變遷檔案，因此我們透過採集自蘭嶼的珊瑚岩芯，針對跨度達一百一十五年的珊瑚骨骼進行微量元素分析，以雙月解析度鋇鈣比代用指標重建蘭嶼南部四個時間段落、共計四十四年沉積物通量變化。其中四個時段涵蓋：封閉原始社會時期、二戰前後戰爭與建設時期、人口及觀光活動遽增時期以及伐林、基建、農牧業和低放貯存場等開發事件。結果顯示，珊瑚殼體中鋇鈣比的極值出現與降水量變化相關，具有季節性差異。除此之外，自上世紀初至今，蘭嶼沉積物通量由原始社會自然基線隨時間顯著增長近兩倍，可能反映當地人為土地利用方式變遷與開發事件。與前人研究相比，本研究將蘭嶼沉積物通量紀錄長度延伸至歷史上土地利用方式迥異的不同時段，提供百年時間尺度下，蘭嶼地區人類活動對區域水文環境影響的證據。

中文關鍵詞：蘭嶼環境變遷、沉積物通量、珊瑚鋇鈣比、土地利用變化

Rapid macroseismic assessment in the 2025 Mw 7.7 Sagaing earthquake using witness accounts from social media

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Rapid assessment of the damage and the seismic intensity is crucial for the earthquake disaster response. In the place where the seismic stations are sparsely distributed, the macroseismic data obtained from witness accounts through online platforms play an important role in characterizing the earthquake intensity in near real-time. Although many of these crowdsourced macroseismic data were collected and assessed through online questionnaires, photos and descriptions posted on social media can still provide timely assessments, especially in the regions where social media has a deeper reach to the community through the mobile internet and smartphones. In this study, we estimate the intensity of seismic ground motion by interpreting data gathered from community earthquake responses on social media for near-real-time damage and macroseismic assessment. Although the mobile internet's blockage and the firewall's emplacement significantly hindered internet communications in Myanmar, our assessment revealed widespread damage and shaking throughout central and lower Myanmar. Our results suggest that the degree of damage and seismic intensity distribution highly correlate to the amount of coseismic fault slip on the Sagaing fault over its extra-long rupture length. Most of the severe damage occurred in the city and town to the north, close to its epicenter. Moderate degree of damage was found along the central and southern part of the rupture, where the fault slip is less than that of the northern part of the rupture, and the rupture width was also significantly reduced. Our study shows that the social media data are complementary to other community-derived macroseismic maps, and highlights the importance of different observations when generating the seismic intensity map in Southeast Asia.

Keywords:Myanmar earthquake, Seismic hazards, Social Media

Compositional variation of Chung-Lun and Kuan-Tzu-Ling hot spring waters in response to the Tai-Po and associated earthquakes during 01/20-03/24, 2025

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It has been documented that spring water compositions may change prior or subsequent to earthquakes occurred near the spring sites. Here, we report the variations of major cation concentrations of the spring waters from Kuan-Tzu-Ling (KTL) and Chung-Lun (CL) region in southern Taiwan with response to the major earthquakes (M > 4), whose epicenter were within ~16 km of the spring sites, during 01/17-03/24, 2025. Six sets of water samples were collected from five CL sites (CL-1, CL-2, CL-3, CL-4, CL-5) and two KTL sites (KTL-1, KTL-7) on weekly or biweekly basis.

It was found that the concentrations of alkali metals and arsenic (As) in CL-1, CL-2, CL-3 spring waters are higher during the period of high seismic activity. Exemplified by CL-1, before and after the 01/21 Tai Po earthquake, the [Na] was > 1% and the [As] was > 1 ppm and reduced to < 0.9% and < 0.7 ppm, respectively, during the mitigation period (02/24-03/10). In contrast, the alkali metals and arsenic content in spring waters from CL-4, CL-5, KTL-1 and KTL-7 sites do not vary significantly with response to the above-mentioned seismic activity. The different compositional responses of spring waters might reflect structural controls, implying limited size of the water reservoirs. The reservoir of CL-1, CL-2, and CL-3 sites might be connected to some extent as inferred from their common compositional responses to seismic activity. Concentrations of minor cations and trace elements do not show systematic variations with seismic activities. However, these might be biased results from low concentration analysis and need to be verified by analytical procedures more precise than those for routine Q-ICP-MS analysis.

Keywords:hydrogeochemical changes, seismic precursor, Hot spring, M6.4 Tai-Po earthquake

Groundwater-Induced surface deformation using InSAR

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In Taiwan's southern coastal lowlands, land subsidence caused by prolonged groundwater extraction—especially for aquaculture—has heightened the region's vulnerability to sea-level rise. This continuous withdrawal lowers groundwater levels, reduces pore pressure, and gradually compacts the aquifer system, a process that manifests as measurable surface deformation. As the ground sinks, its capacity to retain and absorb rainfall may also diminish, disrupting natural infiltration pathways and weakening the potential for aquifer recharge. Whether this deformation is truly irreversible remains uncertain. However, experiences from other regions suggest that, under better groundwater regulation and managed recharge, uplift or stabilization is possible.

Various studies have investigated groundwater dynamics and their association with land surface changes in the Pingtung region. Although the link between groundwater extraction and surface deformation has been recognized, a complete spatial analysis of deformation behavior across the plain is still lacking. In addition, quantitative evaluations of how groundwater level changes influence surface deformation mechanisms remain limited. To characterize the spatiotemporal evolution of vertical land motion (VLM), we integrated multi-source geodetic datasets. High-resolution deformation fields and velocity time series were derived from Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR) using Sentinel-1A data from 2014 to 2023. These were cross-validated against ground-based GNSS and leveling measurements, which enhanced geolocation accuracy and ensured the robustness of the results. The PS-InSAR-derived deformation estimates showed strong agreement with in-situ benchmarks (R^2 up to 0.94), implying the reliability of the remote sensing approach.

To assess the hydrological forcing mechanisms, we segmented the observational record into 18 semiannual intervals categorized by rainfall intensity. This seasonal analysis revealed a clear deformation rhythm: pronounced land subsidence during dry periods—associated with increased aquifer depletion—and partial rebound during wet seasons due to episodic groundwater recharge. Cross-correlation analysis between groundwater fluctuations and surface motion indicated time-lagged poroelastic responses, with correlation coefficients ranging from 0.30 to 0.60 and delays of 23 to 99 days. These insights provide critical input for coastal risk mitigation by knowing water management strategies and identify zones of heightened vulnerability that require both further geological investigation and thoughtful integration into engineering and land-use planning frameworks.

Keywords:Coastal Subsidence, Seasonal Ground Deformation, Time-Lag Analysis, PS-InSAR, Rainfall Threshold for Deformation

Rapid Assessment of Elemental Radial Translocation and Mobility in Tree Rings Using iTrax Core Scanner

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Dendrochemistry has emerged in recent decades as an innovative environmental proxy. Trace elements such as mercury (Hg), lead (Pb), and cadmium (Cd) preserved in tree rings are increasingly recognized as indicators of industrialization, air pollution, and soil contamination. However, the application of dendrochemical records is complicated by the potential for radial translocation of elements within the tree, primarily due to physiological processes—especially during the transformation of sapwood into heartwood. This translocation can obscure the temporal resolution of tree-ring element profiles and represents one of the most significant limitations in using dendrochemistry as a reliable environmental archive.

To address this issue, it is essential to assess the mobility and radial translocation of elements within tree rings to evaluate the reliability and applicability of dendrochemical data. We developed a rapid assessment method for detecting radial translocation in tree rings through the following approach:

1. iTrax Core Scanning: We utilized an iTrax core scanner to analyze tree-ring core slices from four coniferous species native to Taiwan to identify elements and scanning parameters that yield reproducible signals.
2. ICP-MS Validation: After iTrax scanning, we selected five elements with a high linearity of signal response for further analysis using inductively coupled plasma mass spectrometry (ICP-MS) to evaluate the accuracy and reliability of the elemental signals derived from iTrax.
3. Elemental Distribution Across Tree-rings: We measured the distribution of elements across different tree ages for each species to assess radial translocation patterns between sapwood and heartwood.
4. Solubility-Based Mobility Testing: We implemented solution extraction methods to evaluate the mobility of elements within the tree rings by removing soluble and potentially mobile fractions.

Our results demonstrate that iTrax provides highly reproducible measurements for elements, including calcium (Ca), manganese (Mn), vanadium (V), chromium (Cr), iron (Fe), copper (Cu), strontium (Sr), and lead (Pb). In the ICP-MS analyses, estimated concentrations of Ca, Mn, Cu, and Sr from iTrax were significantly correlated with their actual concentrations ($r = 0.5–0.7$). Elemental trends of Ca and potassium (K) across sapwood and heartwood showed marked differences in all four species, while Mn exhibited similar trends in three of the species. Other elements did not show significant differences between wood zones.
After extracting soluble or mobile elements, the distinct trends for Ca, K, and Mn across sapwood and heartwood were no longer observed, indicating that these elements display mobility within the tree. Therefore, when using Ca, K, and Mn as environmental tracers, it is crucial to carefully consider the potential effects of radial translocation.

Keywords:dendrochemistry, tree ring, radial translocation, iTrax

921地震地質遺跡之監測與保存

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雖然規模7.3的集集地震在台灣中部產生了接近100公里長的地表破裂，但在25年之後僅剩下為數不多的地方可以找到地震殘留下的遺址。其中兩個著名的地點是隸屬於國立自然科學博物館的921地震教育園區與車籠埔斷層保存園區。前者保存集集地震損壞的光復國中校舍與操場，後者則是研究車籠埔斷層古地震的竹山槽溝原址保存(Chen et al., 2007, Huang et al., 2016)。比起前者，開挖深度達8公尺的斷層槽溝相對更容易損壞也更難保存。自從2013年開館以來斷層槽溝已經歷了六次的崩坍事件，從開館的第一個月就開始。其中五次發生在漕溝北牆的崩坍事件(2013年5月、8月、2015年8月、2016年9月與2017年6月)，起因為三層連續緻密的薄泥層(約5公分厚)造成近地表4公尺內的暫時棲留地下水軟化土層引起。由於園區周圍的擋水設施無法有效阻止沿斷層面入侵的地下水，最終利用三口抽水井減少棲留地下水來解決問題。此外，唯一一次發生在斷層漕溝南牆的崩坍事件是去年凱米颱風的暴雨所致。2024年7月25日的日雨量(505mm)為斷層館開館10年最大降雨量，是造成前一次北牆崩坍事件的1.5倍。全球暖化之下的極端氣候讓斷層槽溝的保存任務面臨更大的挑戰。

車籠埔斷層保存園區除了盡力延緩斷層槽溝的崩壞之外，讓民眾參觀地震遺址現地，傳播地震科普知識，了解過去兩千多年發生過五次類似集集地震的地震事件，還更進一步地針對近斷層面進行研究。利用捷克科學院所研發照相比對技術與磁通量變化監測，針對斷層面附近的應力改變進行日變化的觀測。目前觀測結果與集集地震的同震位移方向相近，但位移量非常的微小，需要更長時間的觀測與進一步的研究工作。

中文關鍵詞：集集地震、天然紀念物、邊坡破壞、地下水、極端氣候

臺灣西南部因泥體構造活動導致之複合式地質災害

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在全球各地，邊坡滑動發生沉陷的現象已廣為人知。然而，在臺灣西南部的山麓地區，旗山半天寮，卻在這些滑動區域上緣發現了一些持續存在超過30年、直徑約5公尺、呈圓頂狀的隆起構造，並對位於地滑範圍與其上部的建物造成嚴重損壞。為了理解這些隆起構造的成因及其對地滑活動的影響，本研究進行了實地調查，並於當地建立一個三維非接觸式光學定位系統。調查結果顯示，隆起構造與地滑皆位於活動中的車瓜林逆斷層之上盤。由於區域性的泥體構造快速隆升現象相當明顯，因此推測該局部隆起區為一個泥貫入筒(mud diatreme)。初步的三維光學觀測結果指出，該處破裂帶持續呈現左移與長期收縮的運動型態。在垂直方向上，目前沿破裂帶多呈現長期下陷的變形特徵。本研究推測，此破裂帶的變形主要受地滑與泥貫入筒所主導，而車瓜林斷層與泥基背斜可能會對這些構造的行為產生間歇性影響。泥貫入筒的隆升或擴張可能促進地滑的活動。因此本研究進一步認為，泥貫入筒中的高壓流體與氣體向上貫入可能誘發地滑活動，並導致持續性的下陷現象。此外，觀測到的走向滑移也顯示區域正處於抬升的過程中。因此，本研究提出厚層泥岩山區的地表變形主要受到三項因素共同控制：(1)逆衝斷層的錯動，(2) 泥體構造的活動，以及 (3) 地滑作用。這些因素彼此交互影響，共同塑造出目前所觀測到的複雜地形與地表變形行為。

中文關鍵詞：泥貫入筒、泥貫入體、車瓜林斷層、邊坡滑動

Response of the Longitudinal Valley Region to the 2022 Chihshang Earthquake: Insights from Integrated GNSS and InSAR Observations

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The study evaluates the surface deformation in Yuli, Taiwan, associated with the 2022 Chihshang earthquake (Mw 6.9), utilizing an integrated GNSS network and Differential Interferometric Synthetic Aperture Radar (DInSAR) data from both ascending and descending orbits. Located along the active tectonic boundary between the Philippine Sea Plate and the Eurasian Plate, the Longitudinal Valley presents complex deformation patterns. The inter-seismic GNSS analysis based on 41 stations across the region indicates systematic tectonic trends. The Coastal Range exhibited a northwestward motion averaging 36 ± 7 mm/yr, with a vertical uplift of 4 ± 6 mm/yr. The Longitudinal Valley showed a more subdued northwestward movement at 8 ± 3 mm/yr, accompanied by a vertical subsidence of −6 ± 7 mm/yr, suggesting a mechanical influence from the Coastal Range. In contrast, the Central Range demonstrated relative stability, with southwestward movement of 3 ± 1 mm/yr and a minor uplift of 0.6 ± 6.0 mm/yr. The coseismic analysis reveals varied displacement across major geologic units. The RTK GNSS observations show the Central Range shifted southwestward by 1.17 m with a vertical uplift of 1.1 m, while the Coastal Range moved northwestward by 1.18 m and subsided by 0.65 m. The Longitudinal Valley responded heterogeneously: its western segment displaced southwestward by 0.79 m with 0.63 m uplift, and the eastern segment moved northwestward by 1.02 m with 0.13 m of subsidence. DInSAR analysis highlights significant coherence loss primarily along the Yuli–Ruisui segment representing the major damaged, while relatively minor damaged was observed from Chihshang to Guanshan. The line-of-sight deformation derived from DInSAR also indicates that surface deformation ceased near the Wuhe Tableland, suggesting the presence of a structural or kinematic boundary. Furthermore, the Yuli Fault exhibits a west-side-up motion, based on coseismic analysis possibly linked to the westward-dipping Central Range Fault system. Observations south of the Wuhe Tableland, particularly from extended GNSS and DInSAR surveys toward Ruisui, imply a termination or segmentation of deformation, which could correspond to unmapped fault structures. These findings underscore the importance of integrating GNSS and InSAR data for understanding complex earthquake-related deformation, and they point to the necessity for continued monitoring and advanced modeling of subsurface fault geometry in this seismically active region

Keywords:2022 Taitung Earthquake, Yuli Fault, Longitudinal Valley, Segmented deformation

Enhanced Atmospheric Nitrogen and Phosphorus Deposition Alleviates Phosphate Limitation in the Western North Pacific

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The North Pacific Warm Pool (NPWP) is an oligotrophic region were nutrient availability limits phytoplankton growth, a critical component of the biological carbon pump. This nutrient limitation is expected to worsen with increasing seawater stratification caused by global warming, restricting the vertical transport of nutrients to surface waters. However, current estimates of atmospheric nitrogen (N) and phosphorus (P) deposition may be underestimated due to the scarcity of open-ocean rainfall measurements, which are essential for quantifying wet deposition. This study investigates the contribution of wet deposition of nitrogen and phosphorus in the western North Pacific Ocean. Our results indicate that rainfall delivers more phosphorus relative to nitrogen (with N:P ratios ranging from 0.8 to 9.1—substantially lower than the Redfield ratio of 16:1 in the ocean). This suggests that anthropogenic phosphorus inputs from agricultural burning and industrial emissions may mitigate phosphate limitation, particularly in regions with a deepening phosphacline. Measured wet deposition fluxes of nitrate + nitrite and phosphate range from 0.3–0.75 mg-N m^{-2} d^{-1} and 0.1–0.25 mg-P m^{-2} d^{-1}, respectively—approximately 4 to 7 times higher than previous model-based estimates (0.014–0.055 mg P m^{-2} yr^{-1}). These findings suggest that atmospheric nutrient supply to the open ocean has been substantially underestimated.

Keywords: Western North Pacific Ocean, Atmospheric Wet Deposition, Nutrient Limitation, Global Warming, Biological Carbon Pump

運用多時序雷達影像偵測地表覆蓋變化 – 以西南沿海為例

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衛星遙測資料已廣泛運用在地表覆蓋的判識運用上，然而傳統光學影像在雲覆蓋與水氣影響下，對長期地表變化的監測有所限制。相較之下，合成孔徑雷達（Synthetic Aperture Radar, SAR）較不受水氣與日照限制，且對地表紋理變化較為敏感，具備長期、穩定觀測地表變遷的能力，可補足光學衛星影像的不足。

因此，本研究以臺灣西南沿海地區為研究範圍，收集2016年至2024年間C波段之Sentinel-1 GRD影像，用以觀察地物與水體的時序變化。研究分為陸域及海域兩部分，首先，使用SNAP軟體將所有影像進行標準化前處理流程後，陸域部分將多時序資料堆疊，並選取特定時間段的極化波段組合假色影像，以觀察地表覆蓋變化。而海域部分則根據潮位資料，每年選取3至5張低潮位影像，計算各年份的平均後向散射係數強度值，將不同年份的平均值分別指定為假色影像波段，用以觀察海岸與水體的變化特徵。

從研究成果中可觀察出低潮線及地表覆蓋的變化，如海岸與陸地交界處的彩色帶狀區域即顯示出不同年份間潮線或沙洲邊界的變遷；而從呈現彩色調的規則農田區域則反映了農作物種植或耕作狀態在不同年份間的轉變。透過多時序雷達資料整合，此研究可作為後續土地分類、變化偵測及空間規劃應用的基礎。

中文關鍵詞：地表覆蓋變化、Sentinel-1、合成孔徑雷達

Changes in the activity of the Hsiaogunshui mud volcano, southwestern Taiwan, during and after the 2025/01/21 Dapu earthquake

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Fluid circulations associated with earthquakes were observed at various scales, from shallow groundwater monitoring wells to upper-crustal tomography datasets, with open questions on their potential roles on tectonic stress accommodation or fault lubrication. In southwestern Taiwan, numerous mud volcanoes are located close to faults, most of which being creeping. Monitoring mud volcanoes may reveal whether fluids circulation is associated with transient deformations measurable by geodesy. This study focuses on changes in the activity of the Hsiaogunshui mud volcano (HGS) seconds to weeks before and after the Dapu event. HGS is located in the Gutingkeng mudstone domain of the Western Foothills, near the Gutingkeng Fault, 43 km SSW of the Dapu epicenter. We developed a method to quantify the volcano activity using a seismometer buried near the vent and a thermo-piezometer set at the vent bottom. Before the event, HGS consisted of a 1 m diameter and 1.5 m deep vent, with nearly-continuous outflow of gas and mud. Periods with rather regular and short inter-eruption times (about 17 s) alternated with periods with more irregular and less energetic eruptions with a longer inter-event time (about 35 s). Right after the Dapu P-wave first arrival, P-T observations indicate an increased flux of slightly warmer fluids during 8.7 min, followed by a progressive stop of the vent activity within few days. The activity migrated to a new vent 3 m away. This quasi-instantaneous response of the mud volcano shows the high sensitivity of the system to dynamic seismic waves. Further investigations are on-going to understand the longer-term variability of the mud volcanoes activity in the area.

Keywords:Fluids, Dynamic triggering, Shale tectonics, Instrumentation, Coseismic

高屏溪流域有機碳來源及微生物分解作用的時空變化

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河流微生物透過分解有機碳獲取能量，對碳的生物地球化學循環、營養鹽轉化與能量傳遞具有關鍵作用。這些微生物能夠利用從單醣至複合高分子等多樣碳源，並隨環境變動而調整代謝活動，為生態系統變遷的重要指標。有機碳來源涵蓋陸源輸入與水體初級生產力，造成微生物功能的空間異質性。此外，在季風氣候區，降雨模式的季節性變化進一步影響有機碳輸送及微生物代謝活性，但相關研究仍有限。本研究以高屏溪流域為研究地點，此流域具多樣土地利用與顯著水文季節變化，為研究微生物與碳交互作用的理想場域。研究設於三條支流與一處下游點，共九個樣點，採集河水與沉積物樣本。共進行四次採樣，其中一月與九月分別代表乾季與濕季，群落組成分析以此兩時期為主。微生物群落結構透過 16S rRNA 基因測序解析，並進一步以 Biolog EcoPlate 進行群落層級生理分析(CLPP)，以探討微生物碳源利用特性。

16S rRNA 測序結果（包含 DNA 與 RNA 層級）顯示，水體微生物群落結構在乾濕季間的組成變化明顯，主要菌門為變形菌門、藍菌門與擬桿菌門。濕季中變形菌門相對豐度高達 50.0%，乾季降至 35.6%；而藍菌門與厚壁菌門則從濕季的 1.4% 與 0.34% 上升至乾季的 23.3% 與 12.6%，呈現高度季節敏感性。沉積物群落在濕季與水樣差異明顯，例如曲桿菌門在沉積物中相對豐度較高，反映棲地對微生物群落結構的影響。基於RNA的活性微生物群落分析亦顯示，支流樣點間微生物群落結構較為相似，而出海口樣點則明顯異於主流樣點，反映環境與水文條件對活性群落結構的顯著影響。主成分分析（PCA）顯示，CLPP 碳源利用在水體與沉積物間具顯著空間差異，沉積物亦呈現季節變化趨勢。熱圖結果指出，沉積物微生物具較廣泛的碳利用能力，而水體群落則呈現出較專一的代謝模式。整體而言，本研究突顯了環境與時空因子在塑造河川微生物代謝功能中的複雜交互作用，並為理解河川碳循環提供了重要見解。這些發現不僅強化了我們對河川生態系統中微生物碳循環動態的理解，也為評估氣候變遷與對河川生態系統功能影響提供了基礎科學依據。

中文關鍵詞：河川微生物、碳源利用、季節變化、空間異質性

A Study on Paleoenvironmental Changes Around DP Lagoon

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The "abrupt rise of water in Ka-teng Harbor", recorded in the Taiwan Gazetteer (Taiwan Caifangce), has been suggested as a tsunami event in 1781, possibly triggered by an earthquake or a submarine landslide. This record has been considered the only credible historical evidence of a tsunami in southwestern Taiwan. However, no geological evidence currently supports this claim. To investigate the authenticity of this record, this study drilled eight sediment cores, each approximately 12 meters deep, in the southeastern part of Dapeng (DP) Lagoon, in areas that were reclaimed before the 20th century. Six cores were collected from inland areas, while two were obtained from the barrier island. The cores were further classified into lithofacies units based on sedimentary characteristics and X-ray fluorescence (XRF) analysis. Additionally, selected samples were sent for AMS radiocarbon (14C) dating to establish age models for the cores. The results reveal that the six inland cores primarily contain muddy sediments interspersed with several sand layers, whereas the two cores from the barrier island are mainly composed of sand. The basal sediments of the inland cores are generally dated to around 1.5 ka, with sandy layers consistently found in deposits younger than 0.3 ka. The presence of these coarser grains within an otherwise stable depositional environment suggests high-energy events, particularly those corresponding to the "abrupt rise of water in Ka-teng Harbor". However, these sandy deposits consist of fine to very fine sand with yellowish mottled textures and lack marine indicators such as shell fragments, suggesting a fluvial rather than marine origin. Therefore, we conclude that the sandy layers at the top of the six inland cores likely represent geological records of extensive flooding and river discharge directly into DP Lagoon following river diversions between the 1700s and 1800s. This conclusion is further supported by Qing Dynasty maps.

Keywords:DP Lagoon, Paleoenvironmental changes, Ka-teng Harbor, AMS radiocarbon datin

印尼西爪哇東部火成岩的地球化學與年代學

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印尼爪哇島是巽他島弧的一部分，巽他島弧是印澳板塊向北隱沒至歐亞大陸板塊下所形成。爪哇島分為西爪哇、中爪哇以及東爪哇，本研究區域在西爪哇的東部。前人有針對西爪哇東部進行全岩地球化學的研究，但過去受到技術與儀器精準度的因素，鮮少有鋯石鈾鉛定年法的研究。因此，本研究在西爪哇東部的八座火山岩體(Ciremei火山群、Guntur火山群、Galunggung火山群、Cikuray火山群、Papandayan火山群、Malabar火山群、Patuha火山群、Tangkuban Parahu火山群)共 採集54個火成岩樣本，並利用鋯石鈾鉛定年結合全岩地球化學的分析方法，來探討西爪哇東部的岩漿地球化學特徵與來源成因以及火山岩體自新生代以來岩漿活動隨時間的演化。

根據鋯石鈾鉛定年的分析結果顯示，西爪哇東部在新生代以來的岩漿活動分為四期，依序為中新世(5.6百萬年)、上新世(3.7-3.5百萬年)、早更新世 (1.2-0.8百萬年)以及晚更新 世(0.5-0.1百萬年)。全岩地球化學的分析結果顯示，西爪哇東部的四期岩漿皆為次鹼性序列，岩性涵蓋基性的玄武岩到酸性的流紋岩。微量元素都呈現輕稀土元素(LREE)富集與高場力鍵結元素(HFSE) 虧損以及鈮鈦鉭極度虧損的現象，此為島弧岩漿的典型特徵。

藉由分析結果得知，前三期的火山體在空間分佈上由南到北有越年輕的趨勢，第四期的火山岩體則散佈於整個西爪哇東部。北方Rear-Arc的火山岩體(Ciremei、Tangkuban Parahu)相較於南方Volcanic Front火山岩體(Guntur、Galunggung、 Malabar、Cikuray、Papandayan、Patuha)其LREE/HREE的值較大，此表示Rear- Arc相較Volcanic Front所受到的部分熔融程度較小。未來將執行放射性同位素的分析方法，以利於深入瞭解各時期岩漿來源的特徵。

中文關鍵詞：西爪哇東部、巽他島弧、全岩地球化學、鋯石鈾鉛定年法

台灣西北部二氧化碳封存潛能與長期行為之數值模擬研究

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碳捕集與封存（CCS）是減緩溫室氣體排放的重要策略之一。在台灣，活躍的構造環境與斷層系統對地下二氧化碳封存的可行性造成挑戰。本研究針對台灣西北部沿海地區進行封存潛力評估，結合地質建模與知名多相流耦合化學反應傳輸模擬軟體TOUGHREACT進行現地大尺度二氧化碳灌注期間與停止灌注後之移棲、溶解與礦物沉澱溶解反應等行為之數值模擬，探討長時間尺度下特定區域的物理與化學行為、封存表現與潛在風險。研究整合多條震測剖面、岩心掃描與觀音井資料，建構涵蓋真實地形與多斷層系統之三維地質模型，進行商業規模二氧化碳注儲模擬，並考慮多種不同情境，模擬二氧化碳注入後的羽流遷移、壓力變化與封存機制（包含構造封存、殘餘相封存、溶解封存與礦物封存）。

由於溶解封存與礦物封存機制可逐步將 CO₂ 轉化為更穩定型態，有助於長期減緩洩漏風險，因此本研究的另一重點是藉由逐步增加場址尺度的複雜性，結合文獻列舉的幾十種化學反應進行探討，包含水體酸化與孔隙率變化，並逐步促進礦物碳酸鹽沉澱反應的過程。儘管礦物封存初期貢獻較小，但其長期不可逆性有助於提升整體封存穩定性與永續性。本研究亦進行地質非均質性（如層狀結構與斷層）對封存容量與洩漏風險的關鍵影響探討。

中文關鍵詞：多相流-反應傳輸模擬、溶解與礦物封存、地質異質性、封存機制、洩漏風險評估

動力分析用垂直向輸入地震歷時挑選之探討

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輸入地震歷時為進行結構動力分析或地盤非線性反應分析的重要基石，藉由國家地震工程研究中心開發的「臺灣工址輸入地震查選平台(INMOST)」，可有效取得合於規範面及實務面的水平向實測地震紀錄，助提升分析結果的可靠度與穩定性。對於前述挑選輸入地震所依據之標的水平設計反應譜，為現行耐震設計規範給定的線段型式簡化反應譜，而規範垂直設計反應譜取為水平反應譜之2/3或1/2倍。

經由對更多地震紀錄的觀察發現，垂直與水平兩方向譜值之比，或稱V/H譜值比，深受譜週期、地震規模、震源距離與場址條件的影響，在短週期段有顯著高值且一般超過2/3或1/2，在中、長週期段一般小於2/3或1/2。而因規範垂直設計反應譜與實際垂直向地震反應譜存在一定程度的差異，故欲挑選出動力分析使用的垂直向輸入地震歷時，實屬不易。對此，近期國家地震工程研究中心採用臺灣最新的地震動資料庫與地震動預估式(GMPE)，研究本地垂直向地震動的非線性特性，提出了臺灣垂直設計反應譜的簡化譜形決定公式，其控制參數包括譜週期、工址短週期及一秒週期水平譜加速度係數，以能更為接近臺灣垂直向的地動特徵。

INMOST後設資料庫係依據現行規範的水平設計反應譜，篩選出譜形相近、大震度值及對應地盤條件的臺灣地區實測地震紀錄。本研究將檢視這些具有較佳水平譜形相合度的種子輸入地震，其垂直譜形與最新研擬的垂直設計反應譜之間相應關係，並探討水平向與垂直向的定比係數(scale factor)關聯性，助提供未來我國規範修訂垂直設計反應譜之參考依據。

中文關鍵詞：垂直向設計反應譜、V/H譜值比、耐震設計規範、實測地震歷時篩選、INMOST平台

利用微地動分析探討台灣北部大屯火山區的淺層地質構造

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台灣島位於菲律賓海板塊與歐亞大陸板塊的碰撞邊界，其北部隱沒作用促使琉球火山島弧西緣大屯火山群（Tatun Volcano Group, TVG）的形成。中更新世以來，該區域的應力場由擠壓轉為張裂，導致深部岩漿上湧，形成大規模火山活動。此構造轉變也同時促使台北盆地沿山腳斷層（Shanchiao Fault）發育成半地塹構造，而火山岩厚度分布、岩盤深度變化及東北向線性構造等證據，均顯示正斷層作用持續影響該地區。

本研究採用微地動方法探討大屯火山區的淺層地下構造與特徵，目前於新北市三芝區、金山區及台北市北投區佈設 14 個陣列，並使用 SmartSolo IGU-BD3C-5 三分量寬頻地震儀，設定取樣率為 125 Hz、記錄時間在 2 至 4 小時，儀器的增益為 6 dB，並透過 SoloLite 和 SoloPro 軟體進行資料前處理。陣列位置參考 LiDAR 數值高程模型（DEM）判釋之斷層線形特徵，部分陣列保持 30 % 測站重疊以提升資料的解析度。資料的陣列分析採用高解析頻率－波數（F-K）法（high-resolution frequency-wavenumber method），單站分析則採用單站頻譜比（HVSR）法（horizontal-to-vertical spectral ratio method），並用表面波逆推法進行 S 波速度構造的逆推。最後，將微地動分析的結果、LiDAR 判釋之斷層線形特徵及區域地質資料進行交叉驗證，以探討大屯火山區之淺層地下構造。

中文關鍵詞：微地動、單站頻譜比法、高解析頻率－波數法

Cloud Velocity Observed by Using an All-Sky Camera at Longyearbyen

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An all-sky camera (ASOMEA 5C) is used to observe the cloud velocity over Longyearbyen on 22 August 2024. The optical flow method is applied to analyze a sequence of images during the nighttime period at 20:38 LT (local time). Results show that the cloud velocity of 4-5 m/s northeast northward has a good agreement with that reported by the local airport's meteorological observation station. Meanwhile, for aurora observations at Longyearbyen in winter, we further conduct a test by applying the optical flow method on 630nm airglow images observed by an all-sky camera at Taiwan in the nighttime of 17 February 2024. The velocity of airglows derived by the optical flow method well agrees with that derived by the nonguttural-time-intensity plots. This indicates that all-sky images can be employed to observe the cloud velocity and aurora drifts over Longyearbyen.

Keywords:all-sky cammera, Longyearbyen, cloud velocity, aurora drift, airglow