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Oral Report O-O-1

應用落地型大型語言模型建構對話式地理資訊系統–以臺灣離岸風電地質與環境感知系統為例

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摘要

海域地質調查不僅對於海洋資源開發、環境保護及防災減災具有重要意義，更是推動離岸風力發電產業發展的關鍵基石。經濟部地質調查及礦業管理中心（以下簡稱地礦中心）持續於臺灣西部海域執行多頻道反射震測、電火花震測、底拖聲納-底質剖面探測及岩心採樣等精密調查。基於「地質是公共財」之理念，地礦中心將上述成果彙整至「臺灣離岸風電地質與環境感知系統」(以下簡稱感知系統)，提供各界進行規劃、分析與研究之重要參考。

然而，感知系統內含豐富的空間屬性與多樣化的調查成果，傳統選單式介面對非 GIS 專業的使用者仍具備操作門檻。另海域調查資料屬國家重要資訊資產，在提升檢索便利性的同時，如何確保數據隱私與安全性亦是系統發展的重要課題。

本研究針對感知系統開發一套整合「落地型大型語言模型(On-premise LLM)」的對話式互動介面。相較於公有雲端 AI，本系統完全部署於本地端硬體，確保所有查詢歷程與敏感坐標資料皆在本地端處理，達成「資料不出境」的安全標準。

技術層面結合了檢索增強生成（RAG）與空間意圖解析技術。系統可針對平臺內既有的圖層資料如震測剖面、岩心採樣及地質基礎知識進行深度語意理解，使 AI 能精準辨識如「底質剖面」、「電火花震測剖面」或「岩心採樣」等專業圖資實體。透過開發「Text-to-Spatial Query」引擎，系統能將使用者的自然語言指令自動映射為精準的空間查詢語法。

本研究已成功於感知系統中實現「以意圖導向為中心」的檢索模式。使用者可透過對話進行精準範圍查詢：「我想知道東經 120.12 到 120.42，北緯 24.1 度到 24.5 度有哪些調查資料？」系統接收指令後，能即時解析經緯度坐標，並自動從感知系統資料庫中篩選出對應範圍內的調查成果資料。不僅解決了傳統需手動操作多步驟功能，未來更能讓使用者直接以專業語意進行數據篩選（如：查詢特定範圍內具有高潛勢斷層的測線資料）。這不僅優化了感知系統的操作介面，更為「地質公共財」的應用提供了新型態的技術路徑。未來，本系統將進一步整合多模態感知與動態報告生成功能，在確保國土資訊安全的前提下，持續協助產官學研各界於離岸風電開發中，進行更精確的地質分析與決策規劃。

中文關鍵詞：離岸風電、落地型大型語言模型、對話式地理資訊系統、環境感知、意圖導向檢索

Oral Report O-O-2

臺灣海峽北部觀音地台—古觀音次盆地淺部沉積與速度構造

Shallow Sedimentary and Velocity Structures of the Kuanyin Platform–Kuanyin Sub-Basin in the Northern Taiwan Strait

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摘　要

本研究分析 2024 年 9 月於臺灣海峽北部觀音地台北部與古觀音次盆地收集之底質剖面、電火花反射震測及海底地震儀震測資料，並整合 2018 年震測成果，建立桃園外海高解析沉積構造與 P 波速度模型。電火花反射震測剖面顯示沉積層厚度自觀音地台向古觀音次盆地方向逐漸增加之沉積楔狀分布。極淺層地層反射層平行且連續，未見明顯活動斷層，顯示近期沉積環境相對穩定。海底地震儀震測資料走時反演顯示 0–0.2 公里深度的 P 波速度約為 1.50–1.65 公里/秒，0.2–0.5 公里深度增加至 1.65–1.85 公里/秒，0.6–1.0 公里深度達 1.85–2.00 公里/秒。整體沉積層 P 波速度側向變化小，推測研究區近期未受火成活動影響。在古觀音次盆地北緣與基盤高區交界處辨識多條東南傾向之正斷層，形成階梯狀下陷構造。這些正斷層多僅延伸至雙程走時 0.3–0.7 秒之沉積地層，活動性有限。於約 0.8–0.9 秒雙程走時處辨識一高振幅交角不整合面，推測為早漸新世區域抬升與侵蝕事件所致，標誌張裂作用終止與後期穩定沉積階段之分界。其上覆地層厚度增加，且地層平行，顯示中新世以後沉積物主要自東南側供給，並於古觀音次盆地持續堆積。本研究首次整合高解析反射震測與海底地震儀資料，確認研究區為構造穩定，但沉積厚度變化顯著之前陸盆地邊緣地體。本研究將建立仿 3D 沉積界面模型，以深化桃園外海沉積構造與弧陸碰撞後構造演化之理解。

Oral Report O-O-3

台灣西北部造山帶海域的變形前緣區活動構造研究

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摘　要

新竹-苗栗位於台灣西北部造山帶前緣，高科技產業與離岸風場密集。此區域的東-西向斷層是沿既有正斷層反轉逆衝所形成，包括湖口斷層、新竹斷層、龍港斷層。1935 年新竹發生規模 6.8 以上的地震，有些餘震發生在海域，了解海域構造對於離岸風場地震災害評估至關重要。台灣北部造山帶的變形前緣在竹苗地區延伸至海域，海域斷層與褶皺構造亦受到基盤形貌與既有構造影響。為釐清更詳細的褶皺構造及斷層分布，本研究收集電火花高解析震測資料進一步了解。結果顯示，台灣北部造山帶的變形前緣共可以分成三種構造型態。苗栗外海的褶皺構造及其伴隨的逆衝斷層以高角度切穿海床，垂直抬升率約為 0.67~1 mm/yr，褶皺地層則顯示其構造反轉以逆衝斷層為主未受基盤阻擋。新竹外海的摺皺構造及其伴隨的逆衝斷層則是以高角度逆衝至約海床下 300 公尺後，轉為低角度逆衝斷層切穿海床，垂直抬升率約為 0.33~0.67 mm/yr，顯示高角度逆衝的反轉斷層已達到極限，以受板塊擠壓影響為主形成低角度逆斷層。褶皺地層進一步顯示反轉的逆衝斷層受基盤阻擋產生旋轉，不同於苗栗外海，新竹外海以及湖口近岸的斷層都帶有橫移的特徵。新竹外海更是觀察到切穿海床的橫移拉張斷層沿摺皺軸分布，暗示板塊往前(往西)擠壓的力量受到基盤阻擋在摺皺內部累積一定的應力，並產生局部變形。雖然垂直抬升率較低，但數量密集又切穿海床的斷層以及劇烈抬升的摺皺使得受既有構造影響的孕震潛勢值得被納入評估。湖口外海則觀察到摺皺構造及其伴隨的逆衝斷層未切穿海床且被約 200 公尺厚的水平沉積地層覆蓋，顯示其已未活動。這三種不同的構造型態及地體構造解釋暗示造山作用由北向南傳遞。回過頭來檢視離岸風場目前開發位置，其中，劇烈抬升出露海床的褶皺與切穿海床的斷層多分布在新竹外海風場場址內側。或許在變形前緣外側，湖口及苗栗外海的風場位置，地震災害風險才會較低。

Oral Report O-O-4

中央山脈海域延伸段在後碰撞垮塌轉換到弧後張裂之構造:宜蘭海脊的構造解析

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摘　要

台灣東北部正經歷後碰撞時期的垮塌作用，逐漸轉換到東北外海的沖繩海槽弧後擴張環境。南沖繩海槽最南部邊緣有宜蘭海脊。地體構造上，宜蘭海脊經歷過造山運動，正處於造山垮塌與沖繩海槽弧後盆地張裂的作用，同時屬於中央山脈側構造向海延伸段。然而，其經歷的轉換作用過程卻缺乏研究。宜蘭平原至宜蘭海脊的海陸構造連結探討也因為海域調查資料空白而缺乏。本研究使用多音束水深、底拖側掃聲納及底質剖面、電火花高解析震測、空氣槍震源多頻道反射震測，搭配地震資料及陸上震測資料進行海陸連結的地體構造解釋。可以從淺部的高解析地層剖面與海底地形特徵，詳細分析後碰撞垮塌轉換到弧後張裂之間的地質構造演變。宜蘭海脊從地形上可以區分為北宜蘭海脊與南宜蘭海脊，從震測剖面上則可以觀察到三個不同的聲波基盤特徵，分別解釋為北宜蘭海脊褶皺構造(NYR fold)、中央山脈西翼基盤、中央山脈東翼基盤。研究結果顯示，宜蘭陸棚底下的雪山山脈基盤與 NYR fold 相連，所以 NYR fold 也是造山運動所遺留下來的摺皺構造，並因為後碰撞的垮塌作用形成一系列北偏東 45 度的正斷層。隨著中央山脈西翼基盤側向脫出，近岸段的 NYR fold 開始受到影響，正斷層由北偏東 45 度逐漸轉變為北偏東 60 度走向，並可能連接自宜蘭平原的濁水斷層，往外海延伸隨中央山脈西翼基盤結束而終止。外海段的 NYR fold 在地形上呈現出北偏東 60 度到 75 度走向的構造脊，可能受沖繩海槽張裂作用影響，開始往西南方向垮塌。南宜蘭海脊的近岸段是中央山脈東翼基盤延伸，中央山脈東翼的旋轉脫出與中央山脈西翼基盤之間形成一左移斷層，可能是三星斷層的延伸。側向脫出的中央山脈東翼基盤，在南宜蘭海脊外海段，與往西南方向垮塌的 NYR fold 形成約北偏西 60 度走向的正斷層帶，可能帶有橫移拉張的機制。結合底質剖面與陸上水準觀測結果顯示，北偏東 60 度走向的正斷層系列及其延伸的濁水斷層與蘭陽溪口，是現今宜蘭海域斷層最活躍以及宜蘭平原下陷量最大的地方。換言之，宜蘭平原現今的拉張主要是來自中央山脈西翼基盤側向脫出的影響。

Oral Report O-O-5

「宜蘭外海裂谷地形、斷層及火山主題圖」繪編及未來展望

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摘　要

經濟部地質調查及礦業管理中心自民國105年起，連續多年執行臺灣東北海域礦產資源潛能調查相關計畫，運用國內持續精進之海域地球物理及地質探勘技術，於調查過程中累積豐富的海域調查資料，確認宜蘭外海裂谷具有活躍斷層活動與海底火山熱液系統。鑑於調查所獲之海床地形、斷層及海底火山等資料，係不可或缺的國土基礎地質資訊，遂於民國112年啟動「宜蘭外海裂谷地形、斷層及火山主題圖」之繪編工作，期作為後續海域調查研究，以及政府國土空間規劃、礦產資源永續開發管理與防災政策研擬之重要參據。本主題圖涵蓋範圍為東經121度45分至123度10分，北緯24度35分至25度20分，內容涵括海床地形特徵、海底峽谷、斷層分布與延展，及海底火山分布等主要單元。配套編寫之說明書依各主題進行系統性文獻回顧、地球物理資料解釋及地質調查成果說明。繪編期間多次召開專家學者審查會議，就區域地質背景與構造解釋等核心議題凝聚共識，確保成果之學術嚴謹性與實用性。本主題圖及說明書已於民國114年完成初稿。在海域斷層構造方面，依地理區位將宜蘭外海裂谷區域劃分為三大斷層系統：北坡底斷層系統、中央谷地斷層系統及宜蘭海脊斷層系統；海底火山則依空間分布分為三群：北坡底火山群、橫貫弧後火山帶及中央谷地火山群。主題圖預計於民國115年完成定稿，並同步完成主題圖與說明書之出版前置作業及英文版說明書之編譯。成果將以紙本及地理資訊系統專案電子檔兩種形式對外供應，冀望本主題圖能成為我國海域地質與礦產資源研究之重要基礎資料，並持續支持國土永續發展與海洋科學之深化研究。

Oral Report O-O-5

Compilation and Future Prospects of the "Thematic Map of Topography, Faults and Volcanoes in Rift Valley Offshore Ilan"

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Abstract

Since 2016, the Geological Survey and Mining Management Agency of the Ministry of Economic Affairs has conducted multi-year programs assessing mineral resource potential in the northeastern offshore Taiwan. Using advancing marine geophysical and geological exploration technologies, these programs accumulated extensive survey datasets, confirming active fault systems and submarine volcanic hydrothermal activity within the rift valley offshore Yilan. Recognizing that the seafloor topography, fault, and submarine volcano data constitute indispensable foundational geological information, compilation of the "Thematic Map of Topography, Faults and Volcanoes in Rift Valley Offshore Ilan" was initiated in 2023, intended to support marine survey research, spatial planning, sustainable mineral resource management, and disaster prevention policy. The map covers seafloor topography, submarine canyons, fault distribution, and submarine volcanoes. An accompanying report provides literature reviews, geophysical interpretation, and geological findings by theme. Expert review meetings built consensus on regional geology and structural interpretation. A draft was completed in 2025, classifying faults into three systems — Northern Slope Base, Central Valley, and Ilan Ridge Fault Systems — and volcanoes into three groups — Northern Slope Base Volcano Group, Cross Back-arc Volcanic Trail, and Central Valley Volcano Group. Finalization is scheduled for 2026, with publication materials and an English report compiled simultaneously. Outputs will be released in both print and GIS formats, serving as a foundational resource for marine geological research and national sustainable development.

Oral Report O-O-6

近岸震測探勘技術發展與應用

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摘　要

在過去幾年在國科會補助之「潮間帶震測探勘分析技術研發」整合計畫的成果展示了在近岸震測技術發展、設備研發與購置，同時台灣研究團隊跟日本東京大學與日本株式会社地球科学総合研究所（JGI, Inc.）緊密合作進行共同震測技術與設備研發，進而完成基礎近岸設備、技術與野外工作流程等建置，並提出適合台灣海峽近岸震測調查的在地化方可行性方案，在這樣的技術發展基礎下完成近岸震測探測，突破了台灣過去以來對於近岸調查的侷限性。在技術與設備發展測試上，本計畫嘗試使用陸域震盪震源車、海上空氣槍、泥槍與自製海陸域震源，並同時搭配陸上無線接收器、自製節點式海底地震儀(ocean bottom node, OBN)與商用節點式海底地震儀進行試驗，經過多次試驗已可掌握依據台灣近岸環境搭配不同的震測探勘策略與設備配置。在測試結果上，小能量空氣槍(90 cu.in.)、泥槍(40 cu.in.)或自製海陸域震源(marine PASS)搭配OBN的結果，其探測深度可達2公里以上，另外，震源震盪車搭配OBN其探測深度可以超過3公里深，可以涵蓋林口觀音外海碳封存蓋層與儲集層的深度。其試驗結果顯示，在震源方面，不需仰賴大型研究船的空氣槍，經由震源訊號疊加，小能量空氣槍之成果可比擬大型空氣槍陣，展示小工作船即可進行工作，而在接收器方面，利用OBN具有４分量的特性，可以在吵雜的潮間帶環境提升反射震測資料品質，並可以同時提供PP與PS震測剖面，在這傳統的拖纜(streamer)是無法達成的。

Oral Report O-O-7

臺灣離岸風場海域洋流及廊道地質環境分析-三維波流互制動態下之風機基礎數值模擬分析

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摘　要

本研究旨在透過高解析度三維數值模擬與地球物理調查資料整合，深入探討臺灣西部苗栗海域（海洋風場與海能風場）及東北部北方三島海域之離岸風機基礎穩定性。隨著臺灣離岸風電進入「區塊開發」階段，風機規模由 6MW 提升至 8MW 甚至更高功率，其大型結構基礎對局部流場的干擾，以及與海床地質的動態交互作用，成為工程設計之關鍵課題。

研究採用 Splash3D 三維多相流數值模式，結合大渦模擬（Large Eddy Simulation, LES）與流體體積法（Volume of Fluid, VOF），模擬 6MW（樁徑 6m）與 8MW（樁徑 8m）單樁基礎，在 50 年重現期極端波流條件下之三維流場動態。模擬成果顯示，在水深 20 公尺之淺水區，6MW 基礎下游會產生顯著之渦旋脫落現象（Vortex Shedding），其尾流擾動範圍達樁徑之 8.33 倍（約 50 公尺）；而 8MW 基礎在水深 30 公尺區雖直徑較大，但受波浪粒子運動擾動相對輕微，回流現象反而趨向樁前上游側發展。此外，本研究針對北方三島火成岩地形進行實測底床模擬，評估其作為未來深水風場之可行性。研究成果為離岸風場佈署優化與局部沖刷防護工設計提供了重要之科學數據與物理機制解析。

關鍵字：離岸風電、Splash3D、大渦模擬法、流體體積法、三維波流互制

Oral Report B-O-8

Decoupled pathways of pyrogenic and organic carbon burial in the Taiwan Strait

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Black carbon (BC) in terrestrial and marine sediments is a key tracer of carbon dynamics, long-term sequestration, and regional carbon (C) budgets. Comparing BC with bulk organic carbon (OC) is essential because their contrasting sources and preservation behaviours better constrain burial pathways and C cycling. The Taiwan Strait is a shallow, high-energy marginal sea where monsoon-driven hydrography and growing human activity regulate sediment transport and C burial. To quantify post-industrial changes in the regional C budget, we analysed sediment cores from multiple sites across the strait together with modern surface sediments from major Taiwan rivers as terrestrial endmembers. Biogeochemical proxies include BC, OC, total nitrogen and stable C isotope ($\delta^{13}C$ of bulk OC and BC) along with grain size data, and magnetic susceptibility used as complementary tracers to resolve coupled changes in organic matter (OM) sources, combustion inputs, terrigenous inputs, transport energy and C cycling. BC accounted for ~1.11–20.93% of the OC measured in sediment cores across the Taiwan Strait. Frequent decoupling between BC and OC burial fluxes indicates that different processes regulate bulk organic and pyrogenic C burial in the strait, with the former controlled mainly by source mixing and preservation and the latter by episodic combustion inputs and localized sediment accumulation. By integrating riverine endmembers with cross-strait sediment archives, this study constrains the influx of OC and BC to the strait and elucidates the mechanisms governing their transport, burial and preservation, thereby improving regional and global C budget estimates.

Oral Report B-O-9

Subsurface fabric-controlled oxidation flux of petrogenic organic carbon in metamorphic terranes

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Mountain building uplifts and exposes unweathered subsurface rocks to near-surface environments, where rock-bound organic matter is oxidized and ultimately contributes to CO_2 emissions. While metamorphic rocks constitute a large portion of active orogens, the degradability of their associated highly graphitic carbon remains poorly constrained. Here, we directly measured subsurface CO_2 fluxes from boreholes drilled into black schist at the hilltop and the base of a hillslope within a small mountainous catchment in eastern Taiwan. As the subsurface fabrics are highly heterogeneous and anisotropic, we used a one-dimensional reaction-diffusion model to constrain CO_2 production and transport within rock formations. The results demonstrate that the subsurface fluxes are highly dependent on formation fabrics and topographic positions. Using field measurements to constrain the model, we estimate that potential oxidative weathering proceeds at rates between 2 and 9 tC km^{-2} yr^{-1}. The high area-normalized emissions, combined with the ample volume of subsurface metamorphic rocks in active orogens, underscore the high reactivity of graphitic carbon for microbial exploitation in the subsurface and the significance of this deep carbon pool in the geological carbon cycle.

Keywords: petrogenic organic carbon, CO_2 flux, gas transport

Oral Report B-O-10

Hydroclimate and Human Forcing Drive Nitrogen Cycling Shifts in a Tropical Mountain Lake

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Abstract

Closed small-basin consider as a sensitive integrator of climate variability and human disturbance. This study focuses on small lake, named Jiaming (JML), situated in southeastern Taiwan to understand the ecological and biogeochemical changes due to climate and land use changes. For this, diatom and organic geochemical proxies (C, N, C/N, $\delta^{13}C$, and $\delta^{15}N$) has been analyzed in JML core, covering last 3.8 ka. Records showed wetter climate during ~3.8–2.4 and ~1.6–0.8 ka, and comparatively drier conditions during ~2.4–1.6 and ~0.8–0.3 ka. The persistent dominance of acidophilic diatom taxa indicates that lake-water conditions remained acidic throughout the last 3.8 ka, with partial buffering occurring last ~2.4 ka. This ecological gradient was largely controlled by variations in OC input and its coupling with N-cycling. Elevated OC loading during wetter periods (~3.8–2.4 and ~1.6–0.8 ka) corresponded to shifts in N cycling. Earlier interval was dominated by denitrification, likely driven by intensified human activity and increased runoff, which enhanced O_2 depletion and introduced organic waste inputs. In contrast, later wetter phase showed greater NH_4^+ assimilation and possible N2-fixation, reflected in comparatively lower $\delta^{15}N$. During drier intervals (~2.4–1.6 and ~0.8–0.3 ka), OC loading declined to intermediate levels. Enhanced water-column mixing during these periods likely favored nitrification-dominated N cycling, resulting in slight increases in $\delta^{15}N$. By disentangling the roles of hydroclimate variability and human disturbance, this study highlights how tropical mountain lakes respond to coupled external forcing and internal biogeochemical feedbacks.

Oral Report B-O-11

Linking Sea Temperature to Oyster Shell Chambering

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Abstract

Chambering structures in oyster shells represent interruptions in biomineralization between successive aragonite and calcite layers, and was historically attributed to tributyltin (TBT) contamination. Although TBT had been banned for two decades, chambering in oyster is still common, indicating that environmental factors beyond heavy metal pollution, such as seawater temperature or pH may significantly influence biomineralization in shell. To investigate the environmental controls on oyster shell chambering, this study integrates multiple analytical techniques, including micro-computed tomography (Micro-CT), micro-X-ray fluorescence (Micro-XRF) elemental analysis, micro-Raman spectroscopy, and cathodoluminescence (CL) imaging. Cultured and wild oyster shells collected from the western coast of Taiwan were systematically examined. Non-destructive Micro-CT analysis used to evaluate the relationship between the shell thickness index (STI) and internal chambering characteristics. In wild oysters, a significant negative correlation was observed between STI and both chamber number and chamber volume ($P < 0.01$, $n = 21$), whereas no statistically significant relationship was found in cultured specimens, indicating that STI is not a universally applicable proxy for shell chambering. Micro-XRF and CL analyses further demonstrate that the formation of chambering structures is not directly linked to organotin or heavy metal contamination, but is instead associated with temperature-influenced biomineralization processes. Elemental mapping reveals enrichment of Mn and Fe within chamber regions, suggesting secondary incorporation during or after chamber formation. In addition, adjacent aragonitic layers exhibit elevated Sr/Ca ratios (~0.3), indicative of calcification under relatively high seawater temperatures. Consistently, these regions display strong red cathodoluminescence, attributed to Mn activation, reflecting temperature-dependent trace element incorporation and crystal growth kinetics. The spatial co-occurrence of elevated Sr/Ca ratios, Mn enrichment, and intense CL signals defines a coupled temperature–trace element–luminescence system, suggesting that chambering structures record growth under elevated temperature conditions rather than simple pollutant exposure. By integrating non-destructive imaging with shell geochemical analyses, the study

establishes link between oyster shell chambering and seawater temperature, identifying temperature as environmental factor control on oyster shell biomineralization.

key words：Oyster shell chambering; Biomineralization; Seawater temperature; Micro-CT; Cathodoluminescence

Oral Report B-O-12

Microbial role in CO_2 fluxes along the river-estuary continuum in a rapidly uplifting catchment of eastern Taiwan

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Abstract

The contribution of river metabolisms to carbon cycling is an unsolved question, but not well examined in the catchment susceptible to the modulation of active tectonics. This study aims to quantify the rates of autotrophy and heterotrophy, and to identify the community compositions and potential members involved in these microbial processes in the Beinan River in eastern Taiwan. To address this, river water samples were collected in both the wet and dry seasons for incubations amended with ^{13}C-labeled dissolved carbon dioxide and amino acids. The analyses revealed a general pattern pointing to the higher rates in the wet season than in the dry season, and for heterotrophy than for autotrophy. The obtained rates were further scaled up, resulting in the catchment-scale CO_2 evasion of ~10^7 mole yr^{-1}, a range constituting several percent of the CO_2 flux derived from pyrite-induced weathering, oxidation of petrogenic carbon, and the river-air exchange. The community compositions generally varied with season for most upstream sites and with more abundant sulfur or nitrogen metabolizers in the wet season, as opposed to more abundant phototrophs or heterotrophs in the dry season. This study highlights the complex and dynamic nature of river metabolisms that contribute to carbon evasion in oligotrophic mountainous systems prone to the impacts of rapid uplift and erosion.

Oral Report B-O-13

澎湖水道發現的鳥類化石之形態及年代研究

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摘　要

臺灣的鳥類化石紀錄極為稀少，目前有的鳥類化石僅有台南市左鎮區菜寮溪出土的雉科未定種，以及嘉義地區八掌溪出土的紅喉潛鳥與潛鳥未定種，且未有地質年代相關的討論，說明目前對於臺灣遠古的鳥類化石多樣性的了解非常有限。本研究報導一件發現自澎湖水道的鳥類肱骨，該件標本依其具有明顯且深的肱骨頭切跡(head incisure)、不具外髁上突(ectepicondylar process)、低矮的三角肌嵴(deltoid crest)、三角肌嵴及二頭肌嵴(bicipital crest)的相對位置與整體尺寸，初步推斷為大型雁鴨科鳥類的左肱骨。為了進一步確立該標本之分類學歸屬，本研究收集現生雁鴨科鳥類的肱骨，進行初步的形態比較。透過界標數位化處理固定角度拍攝的標本照片，去除尺度與姿態差異，再以主成分分析（PCA）評估研究標本與現生對照標本之形態關係。此外，本研究亦利用電腦斷層掃描（CT）重建標本三維構造，以觀察沉積物覆蓋區域之骨骼特徵及內部構造。由於澎湖水道化石之經典年代問題，本研究採集附著於標本表面的沉積物，並分離其中之超微化石，透過與既有生物地層資料比對，推估其相對年代範圍。本研究預期可釐清該鳥類化石之分類位置與可能年代，並為澎湖水道動物群補充缺乏的鳥類化石紀錄。若確認其屬於大型水禽，亦將提供更新世期間臺灣海峽古環境與生物地理演化的重要線索，並為未來臺灣鳥類化石研究建立基礎資料與分析方法。

中文關鍵詞: 更新世、生物地層學、幾何形態測量學、雁鴨科、澎湖動物群

Oral Report B-O-14

Morphological and Molecular Identification of a Freshwater Microalga Isolated from Taiwan for Green Synthesis of Zinc Oxide Engineered Nanoparticles and its application in Pb(II) Remediation from Aqueous System

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Abstract:

Microalgae-mediated nanoparticle synthesis offers a green and sustainable approach for heavy metal removal from contaminated water. In this study, a freshwater microalgal strain isolated from Taiwan was identified as *Chlorella sorokiniana* (strain MS-CCU-25; NCBI accession PX641099) based on morphology and rbcL gene sequencing. The strain exhibited rapid growth with a high specific growth rate ($\mu = 0.356$ day^{-1}) and short doubling time ($T_d = 1.9$ days), indicating strong adaptability and biomass productivity. Photosynthetic pigment analysis over 30 days showed maximum chlorophyll a (9.41 mg L^{-1}), chlorophyll b (5.87 mg L^{-1}), carotenoids (1.52 mg L^{-1}), and total pigments (16.80 mg L^{-1}) on day 20, followed by a decline, indicating peak metabolic activity during mid-log phase. Microalgal extract was used as a bio-reductant and stabilizing agent for green synthesis of ZnO engineered nanoparticles (ZnO ENPs) using zinc sulfate heptahydrate. UV-Vis analysis showed an absorption peak at 383 nm, FTIR confirmed Zn-O

vibrations (400-600 cm^{-1}), TGA indicated thermal stability up to 550 °C, and XRD confirmed a crystalline hexagonal wurtzite structure. Batch adsorption studies revealed that Pb(II) removal was influenced by pH, dosage, concentration, contact time, and temperature. Maximum removal efficiency (95%) was achieved at pH 4. Increasing adsorbent dosage improved removal efficiency but reduced adsorption capacity, while increasing Pb(II) concentration (50-250 mg L^{-1}) increased q_e (118-600.11 mg g^{-1}). Optimal adsorption occurred at 6 h and 30 °C, suggesting stable, likely exothermic behavior. Overall, *C. sorokiniana* MS-CCU-25 is a promising biological platform for sustainable synthesis of efficient ZnO nano-adsorbents for Pb(II) remediation.

Keywords: *Chlorella sorokiniana*; ZnO engineered nanoparticles; green synthesis; heavy metal remediation; eco-friendly adsorbents.

Oral Report ST1-O-15

Integrating Microfossil and Geochemical Evidence to Refine the Paleoenvironmental Evolution of the Szekou Formation

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Abstract

Abundant fossil assemblages indicate that the Late Pleistocene Szekou Formation in southern Taiwan was a highly productive and biodiverse environment. Despite many uncertainties in the spatiotemporal distribution of fossils, current interpretations suggest that the Szekou Formation was formed in a paleo-lagoon environment, dating approximately between 30,000 and 260,000 years.

The discovery of the whale fossils in 2022 raises a new question, calling for a better environmental framework for the paleo-lagoon. Integrating sedimentary characteristics, molluscan, and foraminiferal assemblage analyses, this study constrains the strata containing the whale fossils to the lowest part of the Szekou Formation. Within this formation, the ratio of planktic and benthic foraminifera indicates that the paleobathymetry fluctuated between 10 and 100 meters throughout the entire sequence. Meanwhile, the dominance of suspension-feeding bivalve assemblages (66%) reflects the abundance of particulate organic matter (POM) in the environment. Coarse-grained sediments surrounding the whale fossil and geochemical indicators (C/N ratio: 20.6–23.0; δ13C: –22.4 to –22.9‰) collectively indicate terrestrial organic matter input. In contrast, core samples exhibit a more stable marine organic matter signature.

By integrating core and outcrop materials, stable isotope ratios, and fossil assemblage data, this study aims to reconcile prior discrepancies and clarify the environmental conditions under which the whale died, the depositional settings that favored its preservation, and the stratigraphic and temporal framework of its occurrence.

Keywords: Paleo-lagoon, $\delta^{13}C$, C/N ratio, Foraminiferal assemblages, Hengchun Peninsula

Oral Report ST1-O-16

澎湖化石動物有沒有到達臺灣？
古地理視野下的古哺乳動物分佈研究

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摘　要

臺灣過去的古生物研究一直受到考古學影響，單純的以區位來劃分動物群，長期以來，澎湖水道出土的哺乳動物化石，被賦予了「澎湖動物群」或「臺灣陸橋動物群」等稱號。然而，透過對更新世晚期古環境的重新審視，我們必須校正一個關鍵觀點：這些動物並非透過「陸橋」聯結臺灣與福建，而是在特定的冰河期地理格局下，僅棲息於如今已淹沒的「澎湖台地」及其周邊陸棚。

根據地質與海平面變化資料，在距今 30,000 至 16,000 年前，海平面曾降至現代海平面以下約 50 公尺甚至更低。此時的澎湖並非島嶼，而是由數次火山噴發後的玄武岩流所構成的廣大熔岩台地。然而，這座台地在古地理上並未與臺灣本島形成無礙的「陸橋」，當時古閩江由北向南流經澎湖台地的東側的寬闊淡水水道南北貫穿，實質上截斷了澎湖台地與臺灣本島（當時為嘉義外海濁水溪、大甲溪形成的三角洲）之間的陸路聯繫。再者澎湖與臺灣之間存在深水溝槽（如澎湖水道深處），即便在極端冰河期，兩地之間仍被古河道與低窪深水區一分為二，動物難以橫跨。因此澎湖台地的動物群難以跨越陸橋抵達臺灣本島。

以生物地層對比的觀點下，古生物學研究的核心在於重建古生態與氣候。因此在定義化石動物群必須排除海洋生物，例如：該區域採集的鯨魚、海豚等海洋哺乳動物或海龜遺骸，反映的是海進與海退交替間的產物，與陸生動物的年代存在衝突，因此不應計入同一動物群作為討論。

儘管澎湖海溝發現了極其豐富的脊椎動物化石，但這些物種在臺灣本島（如台南左鎮）的化石紀錄中卻極為罕見或完全缺失，更加說明原本在台地上的動物受限於東側深溝，只能沿著西北方高地遷移，無法進入臺灣。「澎湖動物群」應是一個獨立的生物群落地帶，從未真正抵達台灣。

Oral Report ST1-O-17

臺灣化石犀牛之分類問題：基於牙齒形態特徵的初步比較研究

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摘要

儘管臺灣在地質年代上相對年輕，然而其地層中仍蘊藏豐富且多樣的化石紀錄。其中，犀牛為臺灣古生物研究中的代表性類群之一，自臺灣北端的新北八里至南端的高雄旗津，皆有犀牛化石的採集紀錄。臺灣犀牛最初被命名為早坂中國犀(*Rhinoceros sinensis hayasakai*)，其後經系統分類研究後歸入新屬—島犀屬(*Nesorhinus*)，並更名為早坂島犀(*Nesorhinus hayasakai*)。然而，此次分類修訂主要依據桃園大溪出土之犀牛上顎齒列化石，相較之下，與現有其他臺灣產犀牛化石在形態特徵上與該標本仍存在一定差異，因此難以確定這些化石是否同樣可歸屬於早坂島犀。本研究依據文獻中對早坂島犀及其近緣物種所描述之牙齒特徵，並針對國立臺灣博物館特展—臺灣有犀所展出之 5 件臺灣產犀牛上顎化石標本分別進行形態比較，並透過特徵差異比例推論其各自最可能之親緣關係。比較結果顯示，該 5 件標本皆與早坂島犀之特徵差異程度最低，其次為同屬之菲律賓島犀(*Nesorhinus philippinensis*)，最後才是屬外之犀牛物種，顯示該 5 件標本應歸屬於島犀屬，並極可能屬於早坂島犀，補強了臺灣產犀牛分類地位，並降低先前僅依單一標本進行分類所帶來之不確定性。然而，仍需更多地層年代資料及系統性分析以進一步驗證其分類地位及演化關係。

Oral Report ST1-O-18

ST1：地層學與古生物學

澎湖水道化石群整合型研究

Penghu Channel Fossil Assemblage—A Synthesis Research

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本整合型研究計畫旨在探討澎湖水道大型哺乳類化石群的年代歸屬、埋藏環境、棲地型態及其與早期人類活動的時空關聯。長期以來，澎湖水道化石因缺乏原生層位與完整出水紀錄，其科學詮釋存在高度不確定性，特別是針對「澎湖原人」的年代與物種分類，在國際學術界引發激烈討論。為回應這些關鍵科學問題，本計畫由八個子計畫組成，採取「跨指標整合」策略，圍繞四大科學問題：1.) 年代建構：整合放射性碳定年、古蛋白分析與高解析海洋岩心指標，建立跨更新世至全新世的時序框架，評估是否存在多期混合或再沉積現象。2.) 埋藏重建：結合沉積相分析、底棲固著型生物群聚與殼體元素特徵，重建化石在海床的停留時間與搬運歷程。3.) 棲地解析：運用古海洋水文指標與動物形態特徵，解析澎湖水道在冷乾陸橋與暖濕淺海環境轉換過程中的生態特性。4.) 人獸互動：整合族群結構與行為證據，評估澎湖水道作為更新世人類與巨型哺乳類互動及遷徙窗口的可能性。技術上，本計畫將建立由微體至大型化石的多尺度非破壞性成像平台，整合成像資源包括同步輻射 X 光顯微成像、XCT 以及擬添購的桌上型 CT，並導入 AI 輔助識別與三維重構技術。

關鍵詞：地球歷史；氣候變遷；臺灣海峽；全球海水面變化；陸橋動物群；古環境重建；X 光斷層掃描成像學

Oral Report ST1-O-19

ST1：地層學與古生物學

澎湖水道海撈水牛化石碳十四測年學、古蛋白學與族群結構研究

^{14}C radiocarbon chronology, paleoproteomics and population structure based on water buffalo fossils recovered from the seafloor of the Penghu Channel

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從臺灣周遭海域海底打撈上岸的海撈骨，統稱澎湖水道動物群。從 2015 年起，申請人團隊已陸續收集 1000 多件動物化石，以水牛屬 *Bubalus* sp. 為主。刊登在 Science 期刊之澎湖原人研究將臺灣古生物學研究推向國際焦點的同時，也引來一些質疑聲浪。本團隊的初步成果及評論有幸獲 Science 期刊編輯允許，線上發表在該文討論區。原文作者群也正式回覆本團隊的評論並要求本團隊精益求精將完整研究成果投稿發表讓大家檢視。本研究依回覆意見要求增加更多碳十四測年學及古蛋白學研究數據，並且統計水牛牙齒化石來分析族群結構。

關鍵詞：巨型動物群滅絕；氣候變遷；末次冰盛期；全新世大暖期；臺灣海峽；陸橋動物

Oral Report ST1-O-20

以骨骼鑑年法探討島嶼化翠斑草蜥的年齡結構與生長模式

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摘　要

龜山島為台灣最年輕的火山島，約於20萬至2萬年前形成，提供臺灣陸域生物新的島嶼環境，並因其地理隔離而具有生物地理研究價值。島嶼形成後，因棲地面積、資源、族群密度與捕食壓力的改變，生物常在形態、生理、生活史與行為上產生一系列的變化，統稱為島嶼症候群 (island syndrome)。其中，龜山島的翠斑草蜥 (*Takydromus viridipunctatus*) 族群已確認呈現相較於台灣族群更大的體型，為典型的島嶼巨大化現象，使其成為探討族群生活史演化差異之良好材料。然而，目前此島嶼化現象尚缺年齡結構與生長模式的詳細探究。先前草蜥屬的研究大多以形態學方法推估年齡結構，但多數爬行動物為有限生長，當個體達到性成熟後體型會趨於穩定，此時傳統形態學將失去其有效性。骨骼鑑年法 (skeletochronology) 為檢測脊椎動物年齡的經典方法，其利用骨骼組織年週期出現的生長停滯線 (line of arrested growth, LAG) 可確切量化個體年齡，同時亦可揭示如生長速率及性成熟年紀等生活史特徵，反映個體所經歷之環境變化與病理學相關資訊。本研究採集龜山島及台灣宜蘭地區之翠斑草蜥，以骨骼鑑年法結合族群標放之形質資料，檢驗島嶼族群是否有特殊的年齡結構與生長模式。骨組織學分析將使用趾剪標記後之趾骨進行，透過組織冷凍切片計數生長停滯線並量化線間之距離，藉此了解族群的年齡結構與生長速率，搭配族群標放的形態資料，將能完整探究年齡結構與生長模式是否出現島嶼化轉變。結果預期龜山島族群將呈現較長壽及性成熟延後等特徵。生長速率在族群間無顯著差異，島嶼較大體型為性成熟延後所導致。本研究將透過骨組織學與外部形態的整合分析，建立探討島嶼化現象更完整的研究框架。

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Oral Report ST1-O-21

Originations and modern distribution of Astriclypeoidea with new fossil evidence from India

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The closure of the Ceno-Tethys Seaway during the Miocene reorganized marine connectivity between the Mediterranean and the Indo-West Pacific, yet the biogeographic consequences of this transition remain debated. Fossil astriclypeid sand dollars, characterized by limited dispersal and distinctive lunule morphology, provide an effective proxy for understanding how Ceno-Tethys Seaway closure affects biogeographic dynamics. This study evaluates astriclypeid morphological affinities using Miocene fossil assemblages from three key regions along the former Tethyan corridor: the Mediterranean, the Kutch terrane of western India, and Taiwan. Traditional and geometric morphometric analyses of two-lunule taxa (*Echinodiscus*, *Amphiope*, *Paraamphiope* and *Sculpsitechinus*) and five-lunule taxon (*Astriclypeus*) are conducted using both linear, reduced landmark (5-landmark), and expanded landmark (11-landmark) datasets. All morphometric results consistently show that specimens from India cluster morphologically with specimens from Taiwan, and are distinct from Mediterranean specimens. By combining fossil occurrences, morphometric analyses, modern distributions, and published molecular data, this study hypothesizes that the restriction and closure of the Ceno-Tethys Seaway already eliminated effective east-west dispersal of sand dollars before the Early-Middle Miocene. Long-term geographic isolation between the Mediterranean and the Indo-West Pacific likely led to the independent evolution of two astriclypeid lineages. The Mediterranean lineage became extinct during the Pliocene, whereas the Indo-West Pacific lineage likely experienced extensive faunal exchange, continued to diversify, and ultimately contributed to the formation of the present-day diversity and distributions of astriclypeid sand dollars. In combination with fossil evidence, the living populations of *Astriclypeus* represent survivors of an old stock originated during the Ceno-Tethys.

Keywords: Ceno-Tethys, Miocene biogeography, Morphometrics, Astriclypeoidea, lunule

從海底資料到風場決策：離岸風場地質影響因子的整合實踐

蘇品如[1]、陳松春[1]、林依蓉[1]、許家濬[2]、堯勁豪[1]、石同生[1]、邱禎龍[1]、羅聖宗[2]

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摘　要

臺灣海峽為離岸風場主要開發區域，由於地質條件複雜且具空間變異性高，大量海域調查資料如何轉化為規劃階段開發商及民眾可理解的資訊，仍是風場開發與政府決策的重要課題。本研究以區域尺度海域地質調查資料為基礎，嘗試將地質資訊整合為可供風場規劃參考之地質影響因子架構，建立從海洋質資料到決策資訊的整合方法。

研究整合震測、聲納、水深及海床影像等海域地球物理與地質資料，辨識與風機基礎條件相關之五項地質影響因子，包括斷層、流體活動、沙波飄移、背斜構造及堅硬地層。依據各因子之分布深度、空間範圍及單位面積占比進行區域尺度判釋，劃分高、中、低潛勢分布區。此潛勢分級反映地質條件對工程可能產生之影響程度，而非工程安全或風險等級判定。

研究成果建立離岸風場地質影響因子潛勢分布圖，並整合於離岸風電地質與環境感知系統中，提供政府規劃與風場開發前期評估之參考。透過將複雜的海域地質資料轉譯為可理解的影響因子資訊，可協助辨識需關注之地質條件並提升規劃階段之資訊效率。惟實際工程設計仍須透過場址尺度之詳細地質調查進一步確認。

Oral Report EG1-O-23

Fracture initiation, propagation, and energy dissipation in crystalline rocks in eastern Taiwan

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Abstract

Linking the mechanical properties of geomaterials across scales and unraveling their 4D evolution requires insights from long-term borehole monitoring (LTBM). Installing a real-time borehole observatory is a priority in eastern Taiwan to monitor earthquake behavior. This research characterizes the mechanical and fracture properties of crystalline host rocks, including Paleozoic-Mesozoic marble and granitic gneiss in the Hualien area to construct a site-scale mechanical model for the LTBM system. Cylindrical core samples were subjected to triaxial compression at a displacement rate of 5×10^{-5} m/s, indirect tensile, and direct shear tests. Results show marble exhibits a brittle-ductile transition with strain hardening at confining pressures (P_c) of 55 MPa, while granitic gneiss remains brittle from 1 to 80 MPa. In the brittle regime, marble displays higher peak strength and Young's modulus than gneiss, though the trend reverses for tensile and residual strengths. Analysis of the post-yield regime reveals that marble exhibits Class II failure (positive post-peak moduli) with violent stress drops up to P_c of 35 MPa, transitioning to Class I (negative post-peak moduli) at higher pressures. Conversely, granitic gneiss transitions from Class I ($P_c \leq 20$ MPa) to Class II ($P_c > 30$ MPa). Due to its capacity to store and release more strain energy under the in-situ overburden pressure up to 15 MPa, marble may serve as the more violent pathway for fracture propagation. Future work will investigate dynamic elasticity and acoustic emissions to evaluate the potential for supershear rupture.

Oral Report EG1-O-24

不連續面特性對於岩體強度與變形行為之影響

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摘　要

對於工程地質而言，岩體邊坡穩定性受到不連續面與岩體材料性質影響，其中不連續面不僅會降低岩體強度，亦可能造成顯著力學異向性。不連續面包含岩體內部之節理、層理或其他構造，使得岩體力學特性隨著方向而有所改變，對於邊坡穩定性具有潛在影響。然而，岩體巨觀行為受到微觀結構控制，小尺度岩體變形行為與邊坡破壞特徵相互關聯，且節理岩體具有尺度效應。因此，本研究採用以離散元素法為計算基礎之顆粒流軟體(Particle flow code, PFC)，以國立陽明交通大學陽明校區之岩體特性建立三維岩體模型，進行單軸壓縮試驗模擬。研究中設計八組岩體體積，藉由計算單壓強度以評估完整岩體之代表性單元體積(representative elementary volume, REV)，決定適當的岩體模型尺寸。而後，以此岩體體積作為基準，建立含節理之岩體模型，考慮三組不同直徑節理與不同角度進行力學分析，透過計算彈性參數以定量節理特性對於岩體強度與變形行為之影響。

根據模擬結果以及統計分析顯示，完整岩體之代表性單元體積為$3.5\,m \times 3.5\,m \times 7\,m$的圓柱型岩體。加入節理後，岩體強度隨節理角度呈顯著變化，當最大主應力與節理夾角約為45°時，強度達最小值，顯示當節理於該方向時最容易被破壞。此外，隨著節理尺寸增加，岩體強度呈現明顯異向性，表示不連續面大小對於岩體在不同方向上的力學性質影響顯著；在岩體變形行為方面，在壓縮過程中，軸向應力與應變關係則顯示，當夾角介於45°~60°時，岩體相對較容易發生變形；且隨著節理尺寸增加，應力與應變之異向性特徵趨於明顯，表示岩體變形行為受節理尺寸影響顯著；相對無圍壓強度以及楊氏模數，泊松比受到節理尺寸與角度變化較不具敏感性，顯示節理特性對岩體側向與軸向變形比例影響較為有限。

本研究經由REV分析確定具有代表性力學特性之岩體尺寸，可作為後續連續體數值模擬模型設計之基準；藉由量化節理幾何特性對岩體力學異向性之影響，釐清其對岩體強度與變形行為之機制，辨識岩體潛在破壞條件；研究成果有助於連結邊坡穩定分析與工程設計之應用。

中文關鍵字：代表性單元體積、岩體強度、彈性參數、力學異向性、岩體破壞機制

Oral Report EG1-O-25

先進測繪於順向坡層面位態空間變異判釋及災後崩塌區位之關係探討-以台7線68.7K為例

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摘　要

順向坡之層面位態具有空間變異性，惟高陡岩坡受地形條件限制，傳統人工量測常面臨可及性不足、量測效率有限及空間代表性不足等問題，較難完整掌握大範圍坡面不連續面分布及層面位態變化。若僅以單一代表性位態描述整體坡面，可能忽略局部變異及其工程意義。

本文以台7線68.7K順向坡為例，該區位於四稜砂岩地層，現地岩性以厚層淺灰色變質砂岩為主，局部可見硬頁岩與變質砂岩互層。本研究於2024年利用UAV與地面光達進行精細測繪，針對坡面裸露層面進行位態判釋，並比較不同區段之空間變異特性。結果顯示，60-90 m區段之層面位態變異較其他區段明顯，其Fisher-k值相對偏低，顯示該區層面位態較為分散，可能反映局部受層間剪裂或構造影響較為顯著。

2026年1月18日崩塌發生後，本研究再以UAV進行災後精細建模，並透過正射影像、地形差異分析及剖面比對檢視災前後地形變化。結果顯示，本次崩塌主要落於60-80 m區段，與災前辨識之位態變異較大區段相近。綜合而言，本案例顯示先進測繪除可提高調查效率外，亦可掌握順向坡層面位態之空間變異特性，相關成果可作為後續分區判釋、運動學分析及邊坡維護管理之參考。

Oral Report EG1-O-26

利用隧道開挖面影像進行三維地質模型之機率式更新

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摘　要

隧道工程常受限於地質調查數量及密度，使得不確定性高的工程地質條件難以被充分掌握，導致施工階段往往面臨較高的地質不確定性與其延伸之風險。目前三維地質建模常依賴商用軟體，優異的建模與展示效果是一大特色，但其建模方法不易藉由施工階段實時產生之資料進行動態更新。在隧道施工期間已產生大量隧道開挖面影像與紀錄，目前係作為隧道支撐類型選擇之依據，然鮮少藉以即時動態反饋至地質模型之更新流程。

為盡可能將地質模型貼近現實以抑低不確定性，如何將隧道開挖面影像與紀錄做為三維地質模型之數位依據為一大挑戰，因此，本研究以石門水庫至新竹聯通管隧道為分析案例，採用演算法透明與擴充性高的開源軟體 GemPy 做為地質模型更新架構，透過隱式建模與高斯過程回歸（GPR）方法，將數張開挖面影像上提取之層面特徵資訊，作為地質模型更新之依據。此方法不僅能隨開挖過程動態修正地質構造之幾何邊界，更能進一步量化地質模型不確定性，最後透過資訊熵（Entropy）量化地質風險，獲取開挖面後方預測風險熱區，並將其轉化為施工支撐類型調整之參考，在提升施工階段決策效率下，同時抑低施工風險。

本研究做法不僅能在不額外新增地質調查情況下，依既有施工過程資料提升地質預測之可靠度，同時抑低地質模型不確定性，往後亦可作為風險評估與工程決策最佳化之依據。

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Oral Report EG1-O-26

Probabilistic Updating of Three-dimensional Geological Models Using Tunnel Face Images

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Abstract

Tunneling projects are often constrained by limited geological investigations, leading to high uncertainty and predictive risks during construction. Current 3D modeling relies on commercial software, which lacks the flexibility to integrate real-time data or couple with probabilistic models like Gaussian Process Regression (GPR) due to their "black-box" nature. Although tunnel face images are frequently recorded, they are rarely used for model refinement.

To address this, this study uses the Shimen Reservoir-to-Hsinchu tunnel as a case study and employs open-source GemPy to develop an update framework. By integrating geological features from face images with implicit modeling and GPR, the framework dynamically adjusts structural boundaries and quantifies spatial uncertainty. The innovation lies in converting probability distributions into Information Entropy to predict risk hotspots and inform support adjustments, enhancing decision efficiency and safety. This research demonstrates the potential of open-source modeling to improve predictive reliability using existing data, providing a robust reference for risk assessment and engineering decisions.

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(2) Degree/Grade: Master's Student / 1st Year

Oral Report EG1-O-27

Development of a 3D Heterogeneous Hydrogeological Model for Simulating Groundwater Flow and Land Subsidence in the Taipei Basin, Taiwan

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Abstract

Groundwater overexploitation in the Taipei Basin caused long-term groundwater decline and severe land subsidence. After groundwater pumping was restricted, groundwater levels recovered, but rising groundwater also introduced potential geotechnical concerns, especially land subsidence and soil liquefaction. To evaluate these issues, this study developed a three-dimensional (3D) heterogeneous hydrogeological model (HHM) to simulate groundwater flow and land subsidence in the Taipei Basin, Taiwan. A total of 708 boreholes were used to construct the model. The unconsolidated sediments were classified into two main layers: the upper Songshan Formation, dominated by mud (silt, and clay), and an underlying confined gravel aquifer. A 1D continuous-lag Markov chain model and geostatistical methods were used to characterize spatial heterogeneity in the upper layer. Results show longer continuity in the north-south direction than in the east-west direction. Fifty HHMs were generated, and one representative model was selected using a method of borehole verification. The representative HHM was incorporated into groundwater modeling, including a steady-state phase (2005-2015) and a transient phase (2016-2022). Simulation outcome of groundwater flow showed good agreement with observation data, with steady-state R^2 values of 0.96 and 0.83 and RMSE values of 0.52 and 0.45 m for the first and second layers, respectively, while transient calibration and validation achieved R^2 values of 0.82 and 0.81 and RMSE values of 1.66 and 2.63 m, respectively. The model estimated a total pumping rate of 40.087 million m^3/year for both layers. Simulations indicate up to 25 mm of subsidence over seven years, mainly in central Taipei Basin. Based on the present results, future work will focus on identifying key groundwater level associated with land subsidence and soil liquefaction, as this information would be highly valuable for both groundwater resources management and engineering geology.

Keywords: Heterogeneous hydrogeological model, Groundwater flow, Land subsidence, Markov chain model, Taipei Basin.

空載光達數值地形模型與地質建模於地質測繪及隧道工程之應用：以東澳隧道為例

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摘　要

由空載光達取得之高解析度數值地形模型已廣泛應用於山崩調查與地質測繪，用以辨識區域尺度之地質構造與地形地貌特徵。然而，在隧道工程領域中，能夠明確建立地表地形地貌表徵與地下岩體特性之間關聯的實際案例仍相對缺乏，特別是在構造複雜之變質岩地區。

本研究以台灣東北部東澳隧道地區為例，針對板岩帶與片岩帶交界帶之岩體特性，整合高解析度空載 LiDAR DEM 與依據隧道開挖斷面所建構之地質模型進行探討。研究利用 LiDAR DEM 及其衍生之地形分析圖資判釋地形與地貌特徵，並透過現地地質調查與隧道開挖紀錄，取得岩性、構造特徵及岩體條件之直接觀測資料，進一步整合於視覺化地質模型中，以探討地表地形特徵與地下地質構造之結合，及其與隧道地質災害發生位置之岩體工程特性之間的對應關係。

研究結果顯示，板岩與片岩交界區、斷層帶、侵蝕溝發育區及重力變形區之微地形特徵，與地下岩體特性具有良好對應關係。1 m 網格 DEM 所呈現之細微地形可清楚描繪侵蝕溝與崩塌崖的位置，並據以判釋重力變形邊坡之範圍；斷層帶附近出露之侵蝕溝線形可跨越集水區延伸；此外，重力變形範圍內之地下岩體普遍呈現開裂並發育滑動面。LiDAR DEM 於區域尺度上可追蹤斷層之延伸，並於場址尺度上有效辨識崩塌崖等關鍵地貌特徵。

綜合而言，本研究透過結合高解析度 LiDAR 地形分析與地質建模，並輔以隧道開挖與相關地質紀錄之比對，可提升地質測繪成果之解釋能力，並強化構造複雜地區隧道工程之風險評估能力。

Oral Report S1-O-29

有限斷層偵測法(FinDer)導入對地震預警效能之影響：近四年臺灣災害性地震回放分析

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摘　要

臺灣位於板塊交界帶，災害性地震頻繁，地震預警系統於地震減災工作中扮演關鍵角色。交通部中央氣象署現行地震預警架構以點震源模型為基礎進行規模與震源參數估算，然而在中大型地震條件下，點震源假設可能低估破裂尺度與影響範圍，進而影響警報正確性。有限斷層偵測法（Finite-Fault Rupture Detector, FinDer）透過線震源幾何表徵破裂之走向與長度，可更合理地描述震源破裂範圍，並提升震度預估之準確性。本研究與蘇黎世聯邦理工學院地震服務中心合作，利用SeisComP平臺進行歷史波形回放測試，針對近四年五起臺灣災害性地震事件進行分析，評估導入FinDer後對我國地震預警效能之影響。結果顯示，於過去四年五起災害性地震案例中，FinDer可有助於提升地震警報準確性並改善震度預估表現。相關成果將可作為未來地震預警多演算法整合之重要依據與基礎。

Oral Report S1-O-30

The asperity energy concentration phenomenon naturally emerging in 0-D stochastic friction dynamics

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Abstract

Modeling earthquake rupture dynamics often requires stochastic approaches to address the impracticality of analytical solutions for asymmetric many-body systems. We propose a stochastic Langevin model where complexity is reduced through a random force accounting for uncertainties in fault heterogeneity and structural collisions. In this framework, the random term captures unresolved heterogeneity at a macroscopic scale; it does not assert that rupture at the scale of specific fault patches is inherently random. A critical challenge arises when applying 0-D models to complex faulting: can they reproduce the heterogeneous energy distribution observed in nature? Intuition suggests that the exponential slip distribution from a 0-D process may lack sufficient tail behavior to satisfy the asperity criterion, where a small fraction of fault area releases most seismic energy. We validate this by examining spectral properties of synthetic velocity fluctuations; results demonstrate that the model output is not arbitrary white noise; rather, the velocity spectra exhibit a Lorentzian form characterized by a single corner frequency. This spectral structure indicates that system memory is governed by a characteristic timescale determined by the load ratio, reflecting a competition between frictional dissipation (which erases memory) and external driving (which sustains motion). We further evaluate the steady-state slip distribution using the Fokker-Planck equation against empirical asperity scaling relations. Using the criterion that asperities are regions where slip exceeds 1.5 times the average, and squared slip as a proxy for energy release, we find that the top ~22% of the statistical area contributes ~81% of the total energy. This prediction lies within the 20–30% range observed empirically for asperity area fractions, suggesting that energy concentration emerges from stochastic frictional dynamics without explicit spatial heterogeneity modeling.

Oral Report S1-O-31

中文摘要格式範例 中文摘要含空白限定 800 字

降低地震預警震度預估誤差：基於路徑特徵與規模相依性之場址因子修正

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摘　要

摘要內容

地震預警系統（EEWS）的核心效能，取決於能否在極短時間內準確預估地動參數（如 PGA），以爭取防災應變之黃金時間。為了短時間內提供可靠的震度預估值，以達到快速預警之目的，中央氣象署地震預警系統現行作業採用地動預估式（GMPE）搭配各測站之平均場址放大因子 (S_i) 進行修正。然而，本研究檢視現行系統之預估結果發現，預測值與觀測值之間仍存在顯著之系統性殘差（Systematic Residuals），顯示傳統靜態、單一的場址修正架構，難以充分涵蓋複雜的三維地質效應與動態破裂特徵。

本研究直接比對未包含場址放大因子之現行 GMPE 預估值與實際觀測值，深入解析預估殘差與潛在物理機制之關聯。觀測結果顯示，預估誤差具有高度的空間與震源相依性：在路徑效應方面，震波穿越不同構造之非均質體（如高耗散之造山帶或低衰減之板塊隱沒帶）以及震源深度的差異，會導致特定傳播路徑產生規律性的震度高估或低估；在震源效應方面，此系統性偏差亦隨地震規模增大而顯著加劇，反映出大地震潛在的破裂方向性（Rupture Directivity）特徵。上述現象表明，震波實際的能量衰減深受三維傳播路徑與動態震源條件之共同影響，已非傳統靜態單一修正架構所能充分描述。

基於上述觀測特徵，本研究預計針對不同震源區域、地震規模與深度等條件，重新建構一組具備動態調整能力之場址因子 ($Dynamic\ Dynamic\ S_i$)。此方法將捨棄傳統的靜態單一平均值，把整合「傳播路徑特徵」與「震源參數」的動態 S_i 直接導入預警流程中。透過此修正策略，預期將能有效收斂系統性殘差，顯著降低預估值的均方根誤差（RMSE），進而提升地震預警系統在各種震源情境下之精準度與可靠性。

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Oral Report S1-O-32

Multi-layer inversion of shear wave splitting data reveals subduction zone dynamics

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Abstract

Shear wave splitting is widely used to probe seismic anisotropy, but its depth resolution is limited. Building on the formulation of Silver and Savage (1994), we apply a Bayesian inversion that explicitly accounts for uncertainty in shear-wave polarization orientation (θ) to resolve multilayer anisotropy from splitting parameters. We apply this approach to source-side S and SKS data from the Cocos subduction zone, and to SKS data from station NNA above the South America subduction zone and station SNZO at the southern Hikurangi margin. Subduction in all three regions is shallow to flat, minimizing dip-angle effects on SKS. The inversion yields tightly constrained fast directions for both upper and lower anisotropic layers. Three-layer inversions show progressive rotation with depth consistent with two-layer solutions, but are not required by the data. In the Cocos system, the upper-layer fast direction is unambiguously aligned with Cocos plate motion in the NNR reference frame, consistent with subduction-entrained flow. In contrast, beneath NNA and SNZO, the upper and lower layers exhibit trench-subparallel and trench-normal anisotropy, respectively—opposite in layering order to the poloidal–toroidal flow structure predicted by dynamic models. If both layers reside in the subslab mantle, the trench-parallel upper layer flow would decouple the deeper mantle from the slab, raising questions about how the apparent subduction-driven flow is maintained at depth. Alternatively, the upper layer may reflect deformation within or above the slab. Possible sources of trench-parallel anisotropy include frozen-in oceanic lithospheric fabrics, trench-parallel mantle-wedge flow, or inherited fabrics related to nearby continental shear zones. These results highlight the complexity of subslab dynamics and demonstrate the value of probabilistic multilayer inversion for interpreting shear-wave splitting.

Oral Report S1-O-33

A Unified Earthquake Catalogue for Indonesia (1904-2024): Harmonizing Multi-Agency Seismic Datasets

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Abstract

Indonesia is one of the most active seismotectonic region that frequently triggers destructive earthquakes. To better understand the impacts of earthquakes, scientists aim to characterize the spatiotemporal behavior of seismicity. This effort often relies on the earthquake catalogue which contains the hypocenter parameters and other seismic characteristics. However, in practice, obtaining a complete and reliable earthquake catalogue is challenging due to heterogeneity in earthquake determination standards among different operational monitoring systems, yet such data are essential for ensuring the reliability of the resulting outputs. To address these limitations, we establish a unified earthquake catalogue for the period 1905–2024 based on multi-agency datasets from the Agency for Meteorology, Climatology, and Geophysics (BMKG), the International Seismological Centre–Global Earthquake Model (ISC-GEM), and the United States Geological Survey (USGS). To integrate these catalogs, we retain well-constrained hypocenters, exclude preliminary earthquake parameters and incomplete metadata, and apply globally and nationally adaptive spatial–temporal windowing together with magnitude uncertainty criteria to identify and remove duplicate events based on network-specific criteria. The resulting refined catalogue comprises 141,178 events (data reduction of 21%) dominated by shallow earthquakes at depths ≤ 60 km, while the most magnitudes ranging primarily from Mw 4.0 to 6.0. Thus, this refined catalogue provides a robust input for constraining source characterization models, seismicity analysis, and seismic hazard assessment for the Indonesian region.

Oral Report S1-O-34

DBLoc3D: A Deep-Learning-Empowered Regional-Scale Earthquake Cataloging System

DBLoc3D：基於深度學習驅動的區域地震目錄系統

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Abstract

Taiwan hosts one of the world's densest seismic networks, yet routine operational cataloging currently relies on semi-automatic workflows that utilize only a fraction of available stations. To bridge the gap between data volume and catalog precision, we present DBLoc3D: a fully automated earthquake cataloging system designed to process continuous waveforms from approximately 700 stations. The workflow integrates the deep-learning-based RED-PAN phase picker with a 3D-velocity-informed backprojection association algorithm and location procedure, followed by rigorous post-processing for relocation and focal mechanism inversion. While offshore and deep event detection remains constrained by network geometry, DBLoc3D's high fidelity was validated through the 2025 M6.4 Dapu earthquake sequence using additional independent dense array recordings as a benchmark. This rigorous comparison demonstrated the system’s ability to illuminate intricate fault architectures, establishing DBLoc3D as a robust backbone for next-generation regional earthquake monitoring and seismic hazard assessment in Taiwan.

Oral Report S1-O-35

Seismic low-velocity zones and their implications for fluid migration in the crust of New Zealand: inferences from Rayleigh wave ellipticity

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Abstract

Seismic low-velocity zones (LVZs), commonly associated with partial melt and/or fluid presence, exert a fundamental control on crustal strength and seismicity. Here, we constrain the distribution of crustal LVZs in New Zealand using Rayleigh wave ellipticity measurements in the 9–48 s period band, derived from 112 seismic stations in 2009~2011. The observed ellipticity exhibits strong spatial coherence with tectonic domains. We invert the ellipticity data for station-specific 1D shear-wave velocity structures using a Markov-chain Monte-Carlo approach. The inverting models reveal island-wide LVZs that spatially correlate with volcanic systems and major fault structures. Beneath volcanic regions, the tops of the LVZs coincide with independently inferred depths of subvolcanic magma reservoirs, whereas LVZs elsewhere occur within a comparable depth range. The bases of these LVZs are systematically located at or above the brittle–ductile transition. We interpret these LVZs as signatures of melt and/or pore fluid release linked to distinct tectonic processes. In contrast to fluid accumulation below the brittle–ductile transition, our results indicate upward fluid migration within the middle-to-upper crust, likely facilitated by fault systems. The mechanisms governing the upper extent of fluid migration beyond volcanic regions remain unresolved and need further investigation.

Oral Report EE-O-36

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作者：徐毅振 Hsu, Yi-Chen

中文題目：基隆 400 年桌遊：跨域結合地球科學與大航海時代台灣文史的科普創作遊戲

英文題目：The transdisciplinary scientific-historical-cultural board game for college and social education: the Age of Discovery since 1626 Keelung, Formosa.

投稿類型：口頭報告

摘要：1626 年，西班牙殖民者為了對抗荷蘭東印度公司，抵達現今的基隆展開殖民統治。在此同時，世居當地的巴賽原住民，以及早已頻繁進出基隆的日本人、琉球人、漢人海商及海盜，共同建構起基隆 400 年的大航海時代。巴賽原住民與一般印象中擅長打獵武勇的原住民不同，是以高超航海技術、多語言能力及精打細算性格來從事航海貿易為業。他們使用一種稱為"bangka"的雙側舷外邊架艇，以其對天氣的海流的認知，航行遠達台灣東部。也由於台灣北部受多山地形及惡劣氣候影響，農作食糧有限，巴賽原住民捕魚、採集沙金、煤礦及硫磺跟來到基隆的外國人交易布料、鐵器，再轉運至台灣其他原住民部落換取米糧、獸皮。巴賽原住民獲取足夠生活物資後即不再工作，並未為了累積資本的商業行為而過度濫採天然資源，呈現資源永續的行為。本研究便是以 400 年前台灣北部巴賽原住民與世界各國人士貿易交流生活為核心，以角色扮演、探索地圖、天災事件及資源商業貿易等重要元素，建構出一套兼具地球科學、海洋技術、歷史文化、環境永續、遊戲趣味性的桌遊，並實際推廣至大學校園及社區大學，促進學生及在地民眾感受地質資源、氣候條件及環境變遷對人文活動的重要影響，以及環境及人文永續發展的思考。

中文關鍵字：基隆 400 年，大航海時代，地礦資源，氣候變遷，永續發展，科普文史跨領域桌遊，社會教育

英文關鍵字：Keelung 400 anniversary, Age of Discovery, geological resources, climate changes, sustainable development, transdisciplinary scientific-historical-cultural board game, social education

Oral Report SG1-O-37

臺灣螺溪石地質科學特徵及來源研究

Geological characteristics and origin of Luoxi inkstone from Taiwan

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摘　要

螺溪石主要描述在濁水溪 (舊名螺溪) 所撿拾適合做硯的石頭，因具有發墨性良好、墨汁黑亮、貯水經久不乾、不傷毛筆等特性，清代開始出現，日治時期更受重視，螺溪硯蔚為風潮。五、六十年代政府雖推廣毛筆書寫，但隨書寫型態轉變逐漸沒落，近年因文化資產保存再次浮出檯面。然而螺溪石取得仍僅限於河床，並無穩定礦脈可供原石製作。因此透過當地業者及溪床螺溪石與可能來源地層岩樣，進行岩相與化學組成分析，比對出最吻合的地層。

本文以業者確認的螺溪石及濁水溪中上游白冷層、達見砂岩、玉山主山層與十八重溪層硬頁岩為研究對象，分析其礦物組成與主要、微量元素，並利用偏光顯微鏡、能量散佈光譜儀 (EDS) 和全岩化學分析。結果顯示螺溪石為硬頁岩，主要由黏土礦物及少量石英、斜長石、白雲母、綠泥石組成。石英顆粒易刮墨條，白雲母混入墨汁增反光，細緻顆粒提升貯水性，黏土礦物硬度低不傷毛筆，符合硯石特性。主要元素上，螺溪石富含Al_2O_3、貧CaO，A/CNK與K_2O/Na_2O均顯富鋁特徵，代表雲母類礦物多，SiO_2含量約60~70%，與硯石特性吻合。

與白冷層、達見砂岩、玉山主山層及十八重溪層之硬頁岩比較：在岩相上，達見砂岩可分為黏土質和粉砂質，整體較為細密，玉山主山層礦物顆粒大小不一，有許多裂隙，白冷層礦物礦物顆粒大約500μm，顆粒大小差異性小。在礦物組成比例上達見砂岩以黏土礦物為主，玉山主山層和白冷層則是以石英與斜長石為主。從主要元素上，SiO_2、Al_2O_3與K_2O的含量，玉山主山層SiO_2高，白冷層Al_2O_3與K_2O偏低，達見砂岩其中一個樣本Al_2O_3與K_2O也偏低；在微量元素上，本文以澳大利亞後太古代平均頁岩 (PAAS) 作為對比發現，玉山主山層樣本皆呈現Eu虧損，Zr和Hf高，代表含有許多鋯石；而白冷層樣本則是Sm、Eu、Gd、Tb、Dy和Ho較吻合外，其他微量元素皆與螺溪石差異較大，達見砂岩亦同。而十八重溪層三個樣本都相當接近螺溪石。根據前述，認定十八重溪層中的硬頁岩最為相似，但並非十八重溪層中所有硬頁岩都是適合製硯的石材。

中文關鍵字：螺溪石、硬頁岩、十八重溪層、電子顯微鏡、X射線螢光光譜儀

英文關鍵字：Luoxi inkstone, Argillite, Shihpachungchi Fm., SEM, XRF

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近代建築修復中的材料真實性探究：臺灣洗石子材料的鑑定與考證

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摘要：

19 世紀末，臺灣進入近代化進程。隨著殖民政府為行政治理而大量興建官署建築，日本近代建築技術與審美觀念亦被引入並在臺灣實踐。此一時期建築裝飾逐漸由早期較為簡樸的形式，轉向更為多樣且複雜的表現。隨著鋼筋混凝土構造的普及，建築裝飾的表現方式亦更加靈活，材料選擇亦趨於多元。在此背景下，天然石材因供應與成本因素逐漸難以滿足需求，促使建築表面出現以擬石效果為目的的材料與工法，洗石子即為其中重要的裝飾技術之一。

然而，洗石子工法的起源及其在臺灣的傳播途徑至今仍未完全釐清。現行文化資產修復工程於修復前調查時，多著重於歷史文獻與建築形式的考證，而洗石子材料本身在史料中記載有限，導致修復實務往往僅能依據顏色與骨材粒徑進行推測，對於材料組成與來源的辨識相對不足。此一情形與《威尼斯憲章》所強調之「修復應尊重原始材料之真實性與不可臆測性」原則之間存在一定落差。

本研究以近代建築洗石子為研究對象，運用拉曼光譜進行材料鑑定，並結合田野調查與歷史文獻分析，以釐清洗石子材料之礦物組成及其可能來源。研究成果旨在建立近代建築洗石子材料辨識的方法基礎，並為文化資產修復工程提供科學化之判識依據，以落實文化資產修復中材料真實性的原則。

關鍵字：洗石子、近代建築、真實性原則、文化資產、拉曼光譜

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地質保育與防災治理：連結地質公園發展之機制與實踐

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摘　要

地質公園為聯合國教科文組織自1997年推動之國際框架，旨在促進地質遺跡保育、環境教育、地質旅遊與社區參與，並以具代表性的地質背景為基礎，建構自然、生態與人文共融共存的價值體系。地質公園的運作奠基於地質科學，而地質調查為其發展的重要基礎。

臺灣位於歐亞板塊與菲律賓海板塊交界，活躍的板塊運動與複雜的地質構造形塑出多樣化的地質遺跡與地景。隨著社會逐漸重視資源利用與環境保育，自2000年代起參考國際經驗推動地質公園，並納入《文化資產保存法》制度架構中發展。

同時，臺灣地質調查已長期且系統性累積大量地質與環境資料，涵蓋基礎地質、資源地質與災害地質，並依《地質法》劃設地質敏感區，顯示研究取向已延伸至防災與保育等公共議題。透過資料開放與整合，亦促進社會溝通與公眾參與。

在此背景下，本研究將地質公園視為地質防災與保育的重要實踐場域，透過公開資料與案例分析，探討地質調查如何與其發展相互連結。結果顯示，解說設施、教育教材、資料庫系統、二維與三維圖資展示，以及戶外地質體驗等機制，有助於將專業地質知識轉化為可理解並可參與的公共資源。

整體而言，臺灣地質公園建立於良好的地質基礎之上。比較日本青森縣下北地質公園與越南德農世界地質公園（Dak Nong UNESCO Global Geopark）之發展經驗，未來可在地質遺跡、地景保育等議題上合作，擴大彼此發展的空間，在《地質法》與《文化資產保存法》制度架構下推動協作，深化地質保育與防災治理之目標。

中文關鍵字：地質公園、地質調查、地質遺跡保育、地質防災、地質資料轉譯

英文關鍵字：Geoparks, Geological Surveys, Geoheritage Conservation, Geological Disaster Prevention, Geological Data Translation

英文題名

Geoconservation and Disaster Risk Governance: Mechanisms and Practices Linking Geopark Development

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Keywords: Geoparks, Geological Surveys, Geoheritage Conservation, Geological Disaster Prevention, Geological Data Translation

國際地質保育發展回顧與國內發展的展望

A review of international progress in geoconservation and its prospect in Taiwan

紀權宥[1.2]

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地質保育的議題近年在國際上逐漸盛行，隨著時代的演進也發展出不同面向的倡議與工作，本文從國際地質遺跡保育學會(ProGEO)的發展來回顧35年來的進展。1991年提出的迪涅萊班宣言是近代地質保育的起始點，在「保護地球記憶」的倡議之下，歐洲各國的學者組成了歐洲地質遺跡保育學會(ProGEO的前身)，時值澳洲學者Sharples提出地質多樣性(geodiversity)的概念，歐洲各國也啟動地質遺跡盤點的工作，並於2000及2004年成立了歐洲地質公園網絡及世界地質公園網絡，推動全球地質保育風潮，2009年Geoheritage期刊也因而誕生。2010年代為了呼應自然保育的議題，地質保育的工作因而轉向於國際自然保育聯盟(IUCN)倡議保育完整的自然—地質多樣性與生物多樣性，從2008年起，每四年一度的世界保育大會中皆完成重要的決議，2014年於世界保護區委員會中籌組了地質遺跡專家小組，致力於推動IUCN的重要政策，2020年出版了《保護區地質保育指南》，2025年則出版《關鍵地質遺跡區域》，成為全球自然保育政策推動的重要參考資料。

國內的地質保育的學術研究及政策推動約起源於1980年代，雖累積不少研究成果與公告多處的保護區，但因缺乏學術討論風氣，且多數保護區的主管機關缺乏地質專業人員，因此在整體政策推動與民眾認知都進展緩慢。在現有的政府組織框架下，如何將IUCN倡議的地質保育概念及方法納入現行的保育政策，扭轉單以生物為保育對象的實踐將是關鍵。一方面可以學術角度向主管機關林業及自然保育署倡議地質保育的概念，促使更多研究得以進行；一方面在地質學術界舉辦相關的研討，引起學界的響應；另一方面從民間進行推廣，如地質生態導覽、

地質多樣性日活動，讓民眾接觸到更廣泛的地質保育議題，進而提高社會的共識。

關鍵字：地質保育、地質遺跡、地質多樣性、自然保育

Keywords: geoconservation, geoheritage, geodiversity, nature conservation

文資法下的地質保育探討：以地質公園指定為例

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摘　要

地質公園作為地質保育的策略之一，納入臺灣《文化資產保存法》下已邁入第10年，並催生出11座地方級地質公園，成果豐碩，但其中仍有諸多實務問題值得釐清與探討。本報告詳細爬梳「九份金瓜石水湳洞地質公園」之指定歷程、並對照臺灣其他地質公園之指定歷程相關資料，分析指定歷程中盤點、提報、評估、審議、管理維護等各階段遭遇問題，作為往後推動地質公園之參考。

首先，地質公園提報階段即要求申請人參酌評估報告應載明事項，諸如符合指定基準具體內容、土地權屬範圍面積、遭遇威脅與未來保育策略等，雖可能維持提報品質且避免浮濫提報，但也意味此階段即需納入專家學者參與，以撰寫出合於規格之提報表，但這是否會造成提報內容過於學者中心、而弱化原地質公園強調地方社群「由下而上」推動之精神？再來，地質公園之提報與評估階段多採質性方式敘述地質遺跡價值，但這可能造成提報內容缺乏客觀性；又受政府採購慣例，評估者受機關委託後，評估工作多在1年內即需完成，評估者恐無足夠時間與能力快速消化該地質遺跡價值相關之龐大資料，造成提報表與評估報告內容雷同、缺少批判性意見之結果。最後，由於指定地質公園的宗旨為保育重要地質遺跡，指定後的管理維護最為重要，實務上卻常出現地質公園倉促指定而無妥善規劃管理維護計畫，或是因無法協調出管理維護者，致使地質公園審議進度拖延之情況。

本報告建議地質公園指定之期程，應以資源盤點至提報階段時間最長，盤點期間應盡量納入地方社群意見與專家學者判斷，撰寫出高品質之提報內容；另應預先考量管理維護可行作為，以利地質公園指定後之實質推動。評估階段除有質性描述外，應研發具通用性的量化評估方法，以利評估者於短期（至少1年）內完成具客觀性與批判性之評估報告，供審議人員做出合宜之審議決議。

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從興趣激發到地質素養養成：非正式教育中的地質學習與科學傳播實踐

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摘　要

由於地質科學具備高度的場所依附性，結合在地景觀的地方本位教育（Place-Based Education, PBE）被認為是促進學習動機與理解的重要途徑（Semken et al., 2017）。透過與環境的互動所建立的「地方感」（Sense of Place），可將抽象的地質過程轉化為可感知的個人經驗。然而，地質學涉及多種空間與時間尺度，理解門檻相對較高，因此透過觀察、討論與實作等多元學習形式的整合，有助於降低學習困難並提升參與度。

本報告整理作者近年於臺灣規劃與執行之地球科學科普與教育實踐經驗，包括親子地質營隊、博物館導覽以及野外地質考察等活動。在教學設計上，首先於野外考察與地景導覽中，透過直接觀察岩石、地形與地質構造，引導參與者建立與地方環境的連結，以實踐地點導向教育的理念。其次，在活動設計上結合講解、觀察記錄與互動討論，使參與者透過視覺、實作等多重感官參與學習過程，形成多模態的學習環境。此外，亦嘗試自行開發簡易桌遊或情境任務，利用遊戲化學習激發動機，透過任務挑戰與合作互動，增進討論並提升活動的參與度與持續投入。

由實務觀察可發現：第一，在親子共同參與的學習情境中，家長常透過提問與提示引導孩子進行觀察與思考，形成類似認知支架的互動模式。第二，不同家庭背景的參與者在提問頻率與參與程度上呈現差異，此現象可從「科學資本」（Science Capital）的概念加以理解（Archer et al., 2015）。此外，長期參與者在野外觀察與問題提問上的表現普遍較為突出，具有實作元素的學習活動對學童具有較高吸引力，在適度開放的操作情境下，孩子常展現出創意性的觀察與表達。家長亦回饋，活動前先行安排的基礎知識導入行前課，有助於孩子在實地觀察與討論時理解相關地質概念。透過上述經驗整理，本文嘗試討論不同地質科學傳播形式的執行成效，並為非正式地質教育在長期經營上的發展提供實務參考。

關鍵字：地質教育、非正式科學教育、地方本位教育、科學傳播、科學傳播

Oral Report SG2-O-42

From Interest to Geo-literacy: Practices of Informal Geoscience Learning and Science Communication

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Abstract

Geoscience is strongly place-based in nature, and place-based education (PBE) has been widely considered an effective approach to enhance learning motivation and conceptual understanding in geoscience education (Semken et al., 2017). Through interactions with natural environments, the development of a "sense of place" can transform abstract geological processes into tangible personal experiences. However, geoscience concepts often involve complex spatial and temporal scales, which can present challenges for learners. Integrating observation, discussion, and hands-on activities in science communication and educational programs may help lower these barriers and promote engagement.

This study summarizes a series of informal geoscience learning practices conducted in Taiwan, including family-oriented geology camps, museum-guided activities, and field-based geological excursions. These activities emphasize direct observation of rocks, landforms, and geological structures, aiming to connect participants with local geological environments. In addition, instructional designs combine explanations, observation records, and interactive discussions to create multimodal learning experiences. Simple educational board games and scenario-based tasks were also developed to incorporate elements of game-based learning and enhance participant engagement.

Practical observations suggest that parents often play an important role in guiding children's observations and reflections, forming interactions similar to cognitive scaffolding. Differences in participation and questioning patterns were also observed among families with different backgrounds, which may relate to variations in "science capital" (Archer et al., 2015). Furthermore, hands-on activities appear particularly engaging for younger participants, often encouraging creative observations and expressions. Parents also reported that pre-activity introductory sessions helped children better understand geological concepts during field observations and discussions. These experiences provide insights into the dynamics and practical characteristics of different science communication approaches and the long-term development of informal geoscience education.

Key words: Geology Education、Informal Science Education、Place-Based Education、Science Communication、Field-based Learning

Oral Report GP-O-43

Assessing Potential Subsurface Contamination From a Burned Building Using Vertical Electrical Sounding: A Case Study at NDHU

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Abstract

A catastrophic fire at the National Dong Hwa University (NDHU) chemistry laboratory in Hualien, Taiwan, on April 3, 2024, released toxic combustion byproducts, raising concerns about potential subsurface contamination. This study aims to evaluate the effectiveness of time lapse Vertical Electrical Sounding (VES) in detecting post-fire subsurface anomalies and distinguishing contamination signals from hydrologically driven variations. Six months of VES surveys (April 2024–March 2025) were conducted at five stations surrounding the site using the Schlumberger array, with investigation depths reaching 60 m. Resistivity data were processed using EarthImager 1D and interpreted alongside pre-fire borehole logs and rainfall records to assess temporal and spatial variations. Results reveal three key patterns: (1) a persistent low-resistivity anomaly at Station 2 (27.9–82.4 Ω·m) at mid-depths (1.5–3 m), suggesting possible localized infiltration; (2) consistently high resistivity (>2,500 Ω·m) at Station 3, indicating stable, uncontaminated subsurface conditions; and (3) pronounced seasonal resistivity fluctuations correlated with typhoon induced rainfall, demonstrating the dominant control of hydrological processes on subsurface conductivity. While no conclusive evidence of widespread contamination was identified, the study establishes a robust framework for differentiating hydrological effects from potential contamination signals in post-fire environments. These findings highlight the value of time lapse VES as a cost effective tool for long term environmental monitoring and post disaster site assessment.

Oral Report GP-O-44

利用微地動分析推求台灣北部火山區的淺層地質構造及斷層特徵

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摘　要

根據經濟部地質調查及礦業管理中心對台灣北部活動斷層的研究，山腳斷層是一條位於台灣北部的第二類活動斷層，可以分成南北兩段。其中北段從台北市北投區向北延伸，經過大屯火山區後延伸至新北市金山區，長度約為 21 公里，類型為正斷層。由於北段經過大屯火山區的部分被火山岩所覆蓋，再加上該區域大部分的斷層跡可能被覆蓋在大規模地滑的堆積物之下，以至於目前還無法研判山腳斷層經過大屯火山區的明確位置。

本研究參考大屯火山區現有的地質剖面圖，針對山腳斷層可能的分佈範圍進行微地動單站及陣列量測。我們使用三分量寬頻地震儀在新北市金山區、三芝區以及台北市北投區佈設 12 個陣列（包含單站），並利用單站頻譜比（HVSR）法及高解析頻率－波數（F-K）法進行單站及陣列資料分析，最後採用 Differential 及 Stochastic 逆推技術來推求 S 波速度構造。

從新北市金山區兩個陣列的 S 波速度構造中，我們觀察到兩者在梯度變化上存在些微差異，現有的地質資料則是推測此區域的斷層跡位置接近地下不整合沉積面（382.4 m）。新北市三芝區至台北市北投區（A－A’）由於可能受到斷層上盤向南的沉降作用，導致岩層往南產生地滑，從 SZXH01 至 SZXH02 速度構造之間的梯度變化可以觀察到在 476 公尺深的位置出現變化（波速從 943 m/s 提升至 4324 m/s），目前推測該區域可能是地滑區。而台北市北投區（B－B’）在 BTDT02 至 BTDT03 速度構造之間存在明顯的梯度變化。最後我們利用 H/V 的結果繪製 A－A’ 與 B－B’ 測線的 HVSR 剖面，目前我們觀察到 HVSR 剖面與現有的地質剖面圖在斷層特徵上出現部分的相似之處，而此結果反映的是否為斷層的位置，在未來參考更多相關地質資料以及其它研究成果後，將會幫助我們釐清此一關鍵議題。

Oral Report GP-O-45

台灣陸域零支距垂直震測剖面之資料處理研究

曾柏諺

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本研究對一口台灣陸域探勘井的零支距(Zero Offset)垂直震測剖面(Vertical Seismic Profile, VSP)資料進行資料處理相關研究，資料處理流程包含雜波衰減、直達波零支距修正與基準面修正、球面擴散修正、地表一致性振幅平衡、波場分離、反射訊號增強、解迴旋及走廊疊加(Corridor Stack)。走廊疊加結果與由井測聲波及密度曲線獲得之合成震波結果進行比較。整體而言，走廊疊加結果與合成震波在主要地層介面及層間介面的反射特徵上，其振幅相對關係與波形特徵皆展現良好的一致性。

Oral Report GP-O-46

利用多高度量測驗證無人機空中磁力探測於台灣崎嶇地形之應用

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摘　要

地熱能為重要的再生能源，其開發高度依賴地下構造特徵，特別是在具高地熱潛勢的區域。在此類研究中，磁力探測是一項重要的地球物理工具，可用於辨識隱伏岩體侵入、估算磁性源體深度，以及解析埋藏岩脈或斷層構造。傳統區域性航空磁力調查雖能有效涵蓋大範圍區域，但其解析度常受限於測線間距較大及飛行高度較高；相對而言，地面磁力測量雖能提供較高解析度資料，卻往往因地形崎嶇或交通不便而受到限制。無人機空中磁力探測可有效克服上述限制，並在地形複雜區域取得高解析度磁力資料，本研究利用搭載於多旋翼無人飛行系統上的全場純量磁力儀進行磁力量測，無人機依據所規劃之測線自動飛行，並採用地形跟隨模式，使飛行高度維持在距地表的固定高度，相較於傳統航空磁力測量，無人機空中磁測能更接近地下磁性源體，並透過多個飛行高度量測可用以計算磁場垂直梯度，作為反演地下磁感率分布的重要約束條件。本研究將無人機空中磁力探測方法延伸應用至含熔岩流之變質岩地層，並觀察到不同飛行高度下呈現不同的磁力異常型態，目前相關研究正持續透過數值計算與模型分析，探討此高度依賴之磁場特徵，並進一步精進地下磁性源體分布之解釋。

Oral Report GP-O-47

Phase Field Modeling and Migration of EM Data

相位場的模擬與偏移成像運用於電磁資料

ABSTRACT

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Solution of geo-electric problems for modeling/migration/imaging can be implemented through well-known Phase field extrapolation either in forward or backward manner. Electromagnetic (EM) propagation of low frequency (EM diffusion) signals and neglecting displacement currents can be simulated by staggered Fourier Chebyshev pseudo-spectral computations. The idea in terms of “EM migration” can be track back to works proposed by Drs. Zhdanov and Frenkel during 1982-1987. Downward continue the EM data can be performed by some seismic processing technique such as FK, Phase-shift Plus Interpolation or one-way wave equation for migration/image relative resistivity section. The output is an interpretable direct image of the conductivity anomalies present. The algorithm is implemented in the frequency domain. Imaging of relative resistivity can be obtained by processing E and H pseudo-sections separately. A single composite image of EM reflections is obtained by differencing E and H images. For deep imaging that are far from the surface, image enhancement can be produced by the superposition of many frequencies. A wide band frequencies should be collected for MT/EM observation data. The “reverse process” or “upward continuation” of a heterogeneous 2D resistivity model can be served as modeling approach. The direct analogies of the assumptions involved is EM reflectivity and conduction are separable and no multiple reflections can be produced from proposed approach. Thus, the main restriction is the resistivity/conductivity variation or contrast could be sufficiently small. The phase field method requires the assumption of local continuity of conductivity. In real Earth, this approximation is usually, but not always, reasonable. Such restriction could be alleviated by layer stripping that allow imaging below a high conductivity contrast through the subtraction of the effects of the material above the interface. A problem that has yet to solve is the inclusion of current channeling effects. Such limitation may produce frequency dependent artifacts in the proposed current algorithm. Fast computations with large mesh spacing can be achieved while process very large datasets. Proposed EM model/migration approach can be applied in the context for hydrocarbon, mining, groundwater and geothermal explorations.

Keywords: 相場、擴散、電阻率、波場延續、電導率、向下延拓、向上延拓、偽剖面、橫向磁場、橫向電場、大地電磁
Keywords: Phase field, Diffusion, Resistivity, Wavefield Continuation, Conductivity, Downward continuation, Upward continuation, Pseudo-section, Transverse Magnetic (TM), Transverse Electric (TE), Magnetotelluric

Oral Report GP-O-48

Could the Mobile MT Work in Taiwan?

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Abstract

No and possibly yes.

Oral Report ER3-O-49

Integrated Geophysical Insights into the Structural Controls on Geothermal Systems in the Tatun Volcano Group, Northern Taiwan

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Abstract

Geothermal systems suitable for power generation require sufficient temperatures, favorable structural conditions, and reservoir permeability at depths shallower than ~3–5 km. This study investigates geothermal resources and prospective development sites in the Tatun Volcano Group (TVG), northern Taiwan, using a new magnetotelluric/audio-magnetotelluric (MT/AMT) dataset integrated with gravity, magnetic, microseismic, borehole, and geological information. A 3D resistivity model was constructed from MT inversion, and seven geological cross-sections were developed using the kink method and refined with multiple geophysical constraints to relate resistivity structures to subsurface geology. Two geothermal systems are identified—the Mt. Qixing–Matsao–Mt. Shamao and Mt. Huangzui–Dayoukeng–Mt. Dajianhou systems—each characterized by a low-resistivity clay cap (<10 Ω·m) overlying a moderately resistive reservoir

(10–60 Ω·m). A deep high-resistivity batholith and steep intrusive bodies spatially align with the Jin-shan and Shan-chiao faults. Both geothermal systems occur within hanging-wall domains, which also host dense microseismic clusters, whereas adjacent footwalls consist of either high-resistivity volcanic units or thick conductive altered zones, both indicative of low-permeability conditions that inhibit fluid flow. These relationships demonstrate that fault architecture governs the localization of fractured reservoirs and hydrothermal upflow pathways. We interpret the batholith as the principal magmatic heat source and the fault-controlled structural framework as the primary regulator of reservoir distribution. Together, these findings highlight the hanging-wall regions of the Jin-shan and Shan-chiao faults as priority targets for future geothermal exploration and development in the TVG.

Keywords:

Tatun Volcano Group (TVG), geothermal exploration, Magnetotelluric (MT), fault-controlled geothermal system

Oral Report ER3-O-50

以Power density方法進行地熱開發潛能估算

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摘　要

在全球淨零轉型趨勢下，地熱能因具備穩定基載供電與低碳排放特性，逐漸成為能源發展重點。然而，地熱資源蘊藏於地下深處，受地質構造與儲層條件影響甚鉅，於開發初期充滿高度不確定性，因此潛能估算與風險評估成為投資決策關鍵。本研究以地熱開發潛能估算為主軸，說明從資源調查、概念模型建立到發電容量推估之整體流程，並強調不確定性分析在決策中的重要角色。

針對地熱資源與開發潛能評估，首先須整合區域地質構造、地球化學、地球物理與既有鑽井溫度資料，建立地下概念模型，推估熱源位置、儲集層深度及流體循環機制。本研究將利用Power density法進行資源量推估，然而，由於資料密度不同與地下地質條件的變化，使模型結果存在一定風險與誤差。因此，透過機率分布方式，圈繪出高(P90)、中(P50)、低(P10)開發成功機率之地熱好景區。透過不同開發情境推估井位成功率、預期發電容量與投資回收期，使決策者得以量化風險與報酬，在有限預算下選擇最具價值之探勘與開發策略，為未來地熱規模化發展提供實務參考。

空載重力測勘作業之 GPS 定位品質與精度特性探討

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摘　要

本研究針對空載重力測勘中之 GPS 定位精度進行系統性分析，以確保重力量測成果之品質與可靠度。研究分別評估 GPS 臨時基站與飛航軌跡定位之後處理精度。臨時基站部分，於花蓮日光輕航機場周邊共佈設 9 期時段的基站，並利用 RTKLIB（Demo5 b34k）進行 static 與 static-start 模式解算。所有成果以 Q=1（固定解）作為品質門檻，其水平精度多優於 0.3 cm，高程精度介於 1–2 cm；僅 2025 年 4 月 22 日因作業因素造成精度略降。

飛航軌跡定位使用 NovAtel Waypoint Inertial Explorer (8.90 版)程式，採差分定位與緊密耦合（tightly coupled）方式，整合機載慣性導航資料以求得重力儀基準中心點之三維坐標。品質指標統計顯示，多數航次有七成以上資料落於 Level 1，且超過九成資料落於 Level 2 內；定位較差的情況主要出現在轉彎、爬升、航路變化等姿態變化較大之時段。標準差分析顯示，水平精度大多在 6 cm 以內，垂直精度則大多於 3 cm 以內。值得注意的是，部分案例出現垂直向標準差小於水平方向之現象，可能源自慣性導航系統對垂直方向穩定性之補強，以及水平方向合成統計所造成的偏大效應。

整體而言，本研究成果確認本年度空載重力測勘之 GPS 定位精度良好，可有效提供重力量測資料後續處理所需之高品質時空定位參考。

關鍵字：空載重力測勘;GPS 定位精度;慣性導航系統

Oral Report ER3-O-52

利用震源機制解與剪力波分離解析苗栗泰安地熱區應力特性與裂隙分布

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地熱探勘與開發是臺灣推動淨零碳排的重要能源策略之一，然而建立足以反映地下構造與流體移棲路徑的地熱地質模型，仍是地熱探勘的重要挑戰。本研究利用密集地震網資料，分析苗栗泰安地熱區可能的裂隙分布及應力狀態，結合地質構造資料，研判該地熱區潛在地熱通道分布及開發地熱發電可能性。我們在約 25 公里見方區域內布設 62 台三分量短週期地震儀（平均站距約 2 公里），進行為期一個月的微震監測，利用搭載深度學習模組的微震資料處理系統，判識並定位約 1000 筆地震事件目錄，用以分析震源機制解與剪力波分離，推估地下應力狀態與裂隙方向。震源機制解透過 P 波初動極性判定並結合多種解算方法篩選穩定結果；剪力波分離分析則計算 S 波快波極化方向與延遲時間，以推估地下裂隙系統特徵。研究區域震源機制解以走向滑移型為主，顯示區域應力場以水平剪應力為主要控制機制；剪力波分離結果指出地下裂隙系統主要有兩組方向，分別為西北—東南向（NW–SE）與南北向（N–S）。其中 NW–SE 向裂隙與震源機制解所反映之區域應力方向一致，顯示此組方向可能是受現今構造應力控制；而 N–S 向裂隙則與地表地質調查所辨識之斷層走向相符，可能反映既有構造所形成的裂隙分布。此外，2024 年由臺大新碳中心與中興工程所建立的泰安地熱地質模型指出，地熱流體通道主要位於溫泉區，呈現由東向西向地表移棲的特徵，而流體移棲通道整體走向呈南北向。本研究判識的南北向裂隙系統在溫泉區東西向範圍內具有連續性，與地熱模型流體通道方向一致，顯示地下裂隙構造可能形成控制地熱流體移棲的重要通道。此結果為既有泰安地熱地質模型提供地下應力場與裂隙分布的地震學證據，並支持該模型對地熱流體路徑的推論。

關鍵字：地熱探勘、微震監測、P 波極性震源機制解、地熱地質模型

Oral Report ER3-O-53

The geochemical signatures for geothermal potential in Miaoli region

苗栗地熱潛能區的地球化學特徵

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苗栗有多處溫泉分佈，雖然其中大多集中在苗栗泰安汶水溪沿岸，但於大湖區域及大安溪上游仍有幾處溫泉開發或溫泉露頭。苗栗地區位於麓山帶的褶皺–逆衝斷層帶中，伴隨造山運動形成的東西向推覆構造與快速抬升的基盤地層餘熱， 屬於沉積岩層地熱。 根據紀錄，泰安溫泉區、大湖地區與大安溪上游等區域之溫泉相關研究資料仍相對稀少，目前僅有少數溫泉井之溫度量測與水質分析紀錄， 此外，多數野溪溫泉露頭於歷次風災後已被掩埋。為了解苗栗溫泉的分布在內麓山帶的特性，配合地礦中心地熱潛能區之調查，本研究針對苗栗的溫泉進行地球化學調查。 針對泰安區域內的鑽井及溫泉位置從東到西排列為泰安公井、騰龍溫泉、警光溫泉、泰安野溪溫泉、日出溫泉、湯悅泉井、錦水泉井、虎山泉井， 大湖區域的湖畔花深井， 大安溪流域的天狗野溪溫泉進行調查， 為了解區域背景值， 於附近的洗水坑、汶水溪及大安溪也進行採樣。 調查內容除了現地水溫、酸鹼度、導電度的測量，也進行了多種地球化學的特徵分析，包含溶解無機碳濃，陰、陽離子，以及水的氫、氧同位素，以了解苗栗內三個區域溫泉的地球化學特性之差異。

現地溫泉水溫的範圍在 31 到 61 ℃ 之間， 酸鹼度的範圍在 7.0 到 8.6 之間，導電度的範圍在 1.0 到 5.7 ms/cm 之間，氯離子濃度範圍在 0.04 到 12.5mM 之間。 未來將整合其他地質調查成果進行區域性討論，藉以探討不同區域分布是否造成地球化學特性的差異，以利後續作為評估地熱發電潛力之參考依據。

Oral Report ER3-O-54

南橫東段地熱流體特性與概念模式

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摘　要

本研究針對南橫東段地熱流體進行採樣及地化組成分析，採集地熱流體樣本包括：(1)地質探勘深井之井口熱水與不同深度井下原地流體(TT-HD-01-01井 601m、700m、802m；TT-HD-02-00井700m、1075m、1120m、1560m)、(2)井口溫泉水(碧山六口溫泉井、霧鹿天龍飯店井、錦平民宿井)、(3)地表溫泉水(轆轤溫泉)與(4)溪水(新武呂溪、大崙溪、霧鹿水源)樣本，蒐集化學成分分析、水質分類圖與同位素指標等多元資訊，藉以釐清熱液來源、補注機制、儲集層特性與潛在結垢問題，並整合提出南橫東段地熱概念模式。

霧鹿地區井下原地熱水與溫泉熱水皆屬於碳酸氫鈉型(NaHCO3)型，顯示其屬中性至弱鹼性的深層循環熱水，推測為深部熱水經岩層長時間加熱後形成的成熟熱液。TT-HD-02-00井下較淺熱水與較深熱水分成兩群，淺處熱水與溫泉井熱水較接近，可能有冷水混入，而深處熱水與TT-HD-01-01井下熱水較接近，顯示該深度範圍補注水體具穩定、單一來源，未受顯著側向流入或不同類型流體混入。氫氧同位素分析進一步佐證上述推論。無論為井下熱水樣本、溫泉井或地表溫泉與溪水樣本，其$\delta^{18}O$與δD值皆分布於全球天水線或其附近，顯示水體主要為大氣降水滲入後經地溫加熱所得，並未經顯著水岩同位素交換作用。特別的是，TT-HD-01-01井在井下637 m處鑽遇片岩與變質花崗岩破碎界面，也是該井溫度最後的區段，熱水自兩岩層界面深部破碎帶往上遷移，在上湧過程中受到些許冷水混入，推論裂隙沿變質花崗岩體周圍發育，而成為一個主要上湧熱液通道，上述推論亦可在轆轤溫泉獲得佐證。為了推估儲集層溫度，分別使用矽含量與陽離子比例進行地球化學地質溫度計估算，但這三種地質溫度計的結果出現差異，這反映出地球化學地質溫度計受礦物平衡條件與區域地層控制影響甚大。TT-HD-01-01井中所採3點樣本，其二氧化矽地溫計推估儲集層溫度約為82°C 至91°C，鈉鉀溫度計估算溫度達210°C 至215°C，鈉鉀鈣溫度計亦為186°C至188°C。TT-HD-02-00井中所採4點樣本，其二氧化矽溫度計估算熱水儲集層溫度介於76℃至114℃，鈉鉀溫度計估算溫度介於78℃至111℃，鈉鉀鈣溫度計估算溫度介於79℃至100℃。轆轤溫泉水其二氧化矽地溫計推估儲集層溫度約為115°C，鈉鉀溫度計估算溫度達242°C，鈉鉀鈣溫度計為193°C。配合TT-HD-01-01熱水乃循岩層界面破碎帶通道向上遷移之概念，以及TT-HD-02-00井底2000m溫度預期可達145°C，推測霧鹿地區區域儲集層溫度應可達200°C以上。

Oral Report ER3-O-55

GEOthermal SEISmic AI Platform (GEOSEIS-AI) for Deep and Supercritical Geothermal Exploration

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In the pursuit of deep geothermal energy (depths exceeding 3 km), the limitations of traditional surface exploration often render the subsurface "invisible." This study presents an integrated seismic exploration framework: the GEOthermal SEISmic AI Platform (GEOSEIS-AI). This platform leverages high-density microseismic monitoring networks and advanced deep-learning (DL) techniques to resolve the "four pillars" essential for geothermal development: heat source depth (temperature), stress states (pressure), fracture distributions (pathways), and fluid properties. Building upon the architecture of the Real-Time Microearthquake Monitoring System (RT-MEMS) (Sun et al., 2025), GEOSEIS-AI utilizes deep-learning phase picking and earthquake localization to accelerate the processing of massive datasets. Key seismic observables—including high-resolution seismicity, focal mechanism, shear-wave splitting, and seismic tomography—are employed to directly characterize these four parameters. We demonstrate the platform's capabilities through two distinct case studies: a metamorphic region in Taiwan focusing on deep geothermal potential (Huang et al., 2023) and a volcanic region in Japan targeting supercritical energy (Tsuji et al., 2025). By mapping the spatial distribution of micro-earthquakes, we identify the Brittle-Ductile Transition (BDT) interface. Since seismic activity ceases as rocks transition from brittle to plastic states at high temperatures (350-400°C), the "seismic-quiet zone" serves as a proxy for the top of the heat source. Identifying these thermal upwellings is essential for targeting high-enthalpy drilling sites. Each microseismic event acts as an in-situ rock mechanics experiment. By analyzing P-wave first motions with DL techniques, we resolve the local stress field (extensional vs. compressional) and faulting styles. This provides vital data for assessing wellbore stability and distinguishing between dilated, fluid-conductive faults and compressed, sealing structures. Utilizing shear-wave splitting techniques, we quantify the density and orientation of subsurface fracture networks. This provides a "pre-drilling ultrasound" that identifies high-permeability zones and informs hydraulic fracturing strategies for Enhanced Geothermal Systems (EGS). Through Vp/Vs ratio analysis, we can differentiate between solid lithology and fluid-filled pores, and more critically, the identification of fluid phases (liquid water, steam, or melt), where high Vp/Vs ratios act as strong indicators of geothermal fluids or magmatic bodies. The results show that GEOSEIS-AI significantly enhances the resolution of reservoir imaging and provides critical insights into induced seismicity monitoring in the future as well, proving it to be a powerful tool for the sustainable geo-energy exploration.

Keywords: GEOSEIS-AI; Deep Geothermal Energy; Supercritical Energy; Deep Learning; Microseismic Monitoring; seismicity; focal mechanisms; shear-wave splitting; seismic tomography.

Oral Report ST1-O-56

臺灣鱷類化石新紀錄：濁水溪鱷類頭骨形態描述及分類

A New Crocodylian Fossil from Taiwan: Morphology and Taxonomy of a Skull from the Zhuoshuei River

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現今臺灣沒有現生鱷類分布，但過去曾有不少鱷類化石紀錄，尤以長吻鱷科(Gavialidae)佔多數。目前已正式發表的物種包含來自澎湖中新世的潘氏澎湖鱷(*Penghusuchus pani*)，與來自臺南更新世的臺灣豐玉姬鱷 (*Toyotamaphimeia machikanensis*)。本研究描述一件來自臺灣中部濁水溪流域之鱷類頭骨標本，本標本保存狀態良好，具高度完整之上頜，除局部輕微破損外，僅缺失基枕骨、基蝶骨，以及右方骨、右方軛骨、右翼骨、右外翼骨與部分右顴骨。

由於伴隨本標本出土之沉積物缺乏超微化石，本研究針對其下游較老地層進行採樣分析。結果顯示，該處有指準化石 *Discoaster kugleri* 與 *Sphenolithus abies*，屬於超微化石分帶NN7；更下游處則有指準化石 *Sphenolithus heteromorphus* 與 *Cyclicargolithus floridanus*，屬於超微化石分帶NN4–5。鑑於上述超微化石分代皆屬中新世中期，結合地質圖資料與文獻紀錄，推論其可能為侵蝕自中中新世地層，並移置卓蘭層及頭嵙山層等上－更新世地層之二次化石。未來將針對濁水溪更多沉積物樣本進行採樣分析，以確認其年代。

在形態學觀察中，顯示本標本具有細長的吻部，且第七顆上頜齒顯著增大，此為包含澎湖鱷屬 (*Penghusuchus*)、豐玉姬鱷屬 (*Toyotamaphimeia*)及韓愈鱷屬(*Hanyusuchus*)在內之東亞長吻鱷類的典型形態特徵。進一步檢視其他特徵，本標本單側有五顆前上頜齒與十六顆上頜齒、第九與第十上頜齒間具明顯吻部收縮、不具有上顳孔向後延伸至鱗狀骨的淺窩，以及位於眶後柱基部的顴骨腹側，具有一凹陷等特徵，結合其可能的生存年代進行比較，綜合判斷最接近的是豐玉姬鱷屬，但仍與目前已發表之物種存在些許形態差異。本研究將採用 Iijima 與 Kobayashi 於2019年提出的 254 項形態特徵矩陣，並包含83個分類群，利用最大簡約法建構親緣關係樹，以進一步釐清其演化地位。

長久以來馬來鱷與恆河鱷在形態與分子上存在分類衝突，東亞鱷類化石在近年被視為解開此爭議的關鍵，本標本的發現，不僅能為此議題提供新的形態證據，也進一步拓展了我們對臺灣鱷類化石多樣性的認知。

中文關鍵字：親緣分析、長吻鱷科、東亞鱷類、豐玉姬鱷屬、鈣質超微化石
英文關鍵字：phylogenetic analyses, Gavialidae, East Asian crocodylians, *Toyotamaphimeia*, calcareous nannofossil

Oral Report ST1-O-57

A New Insight into the Linkage between Osteocyte Lacunae Morphologies and Flight Behavior in Paraves Revealed by Synchrotron X-ray Nano-CT

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Abstract

Bone characteristics play a crucial role in flight abilities in vertebrates; however, the relationship between bone internal microstructures and flight behavior remains unclear. Recent studies of mammalian osteocytes have demonstrated that osteocytes can act as mechanoreceptors, responding to mechanical loads experienced by bones, which suggests that the morphology of osteocytes correlate with locomotion patterns in vertebrates. Based on this perspective, we hypothesize that the flight behavior of birds is also likely to influence the osteocyte morphology. To precisely access the 3D morphology of osteocyte lacunae, we used a synchrotron high-resolution transmission X-ray microscope at Taiwan Light Source (TLS 01B1). With a resolution of 60 nm, this technique enables accurate 3D reconstruction of osteocyte lacunae and avoids errors common in traditional 2D analyses. This study analyzed extant birds and fossil specimens, including dromaeosaurids and Cretaceous bird specimens. Longitudinal sections from humeral mid-shafts were sampled to examine osteocyte lacunae morphology. We found that the volume of osteocyte lacunae has positive correlation with body mass in extant birds, and the data from the fossil specimens show a similar trend. Our result also demonstrates that birds with various flight modes exhibit significant differences in the volume, and morphology, of osteocyte lacunae. This study highlights that osteocyte lacunae morphology reflects mechanical stress from flight

behaviors, offering valuable insights into the flight behavior in paraves.

Keywords: transmission X-ray microscope, flight ability, evolution, bone cell

Oral Report ST1-O-58

一件內含帶羽毛前肢和腳爪的緬甸琥珀之形態分析與分類學研究

Morphological Analysis and Taxonomic Study of a Feathered Forelimb and Pedal Remains in Mid-Cretaceous Burmese Amber

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摘要

過往翅膀與羽毛的化石紀錄多出現在平面的石板化石上，如德國的始祖鳥(*Archaeopteryx*)與中國熱河生物群的中國鳥龍(*Sinornithosaurus*)，不過更細微的特徵容易在埋藏的過程中受到擠壓進而變形、失真。琥珀因特殊的形成過程，相比於石板化石更能完整地保留生物立體的構造細節與特徵。這類發現可見於全球各處，如加拿大含羽毛的琥珀樣本提供了羽毛演化的關鍵線索、緬甸琥珀中更發現帶羽毛的虛骨龍類(coelurosaurians)尾巴、與反鳥類(Enantiornithes)的雛鳥遺骸，其體表的羽毛皆被保存下來。除了羽毛外，還有一件緬甸琥珀標本包裹反鳥類腳爪，其第三趾遠比其他趾長，這種形態未曾在現生鳥類中觀察到，這些琥珀化石都可幫助古生物學家進一步探討羽毛的演化歷史和中生代恐龍與鳥類的多樣性。

本研究標本為一件來自緬甸東北部胡康河谷(Hukawng Valley)的琥珀，年代約為99Ma。內含一個帶羽毛的前肢與左後肢末端。由於標本無法以破壞性方式得知珀中結構，本研究利用非破壞性的電腦斷層掃描取得內部構造影像，並透過 Dragonfly 軟體進行 3D 重建。結果顯示，前肢帶有 11 根正羽(pennaceous feather)，有著不對稱的羽片並保有羽小枝(barbule)，前肢因羽片不對稱性明顯，為初級飛羽的特徵，故推測該部位為指骨；腳爪保存了帶爪的第一到四趾，並以前三趾後一趾的方式分布，因其第一趾反握、彎曲的爪子與腳趾比例推斷屬於反鳥類，且腳趾的分布與彎曲的爪子適合抓握，故推測可能為樹棲的反鳥類。本研究未來將透過調整掃描參數以獲取更清晰的影像與辨識更多特徵，最後利用有限元素分析探討該標本保存之腳爪的形態功能。

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利用現生鳥類羽毛微結構分析反推琥珀內含恐龍羽毛之棲息地

Establishing a Habitat Inference for Amber-Preserved Dinosaur Feathers Based on Extant Bird Feather Microstructure

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摘　要

羽毛是鳥類最具特徵性的外皮衍生物，其演化歷史可追溯至中生代的非鳥類恐龍。自 20 世紀末，中國遼寧熱河生物群與世界各地陸續出土大量保存羽毛印痕的恐龍化石標本，說明了羽毛在非鳥類恐龍中的廣泛分布，且呈現出從絲狀羽到不對稱飛羽的演化序列。然而，印痕化石僅能保存羽毛的二維輪廓與大致形態，羽枝直徑、羽枝間距、羽小枝排列及結節等精細微結構往往在化石化過程中無法保存下來，限制了我們對遠古羽毛功能性特徵的深入理解。

白堊紀中期的緬甸琥珀（約 9900 萬年前）使正羽、飛羽與絨羽等多種類型的羽毛得以三維立體形式完整保存，從羽枝直徑、羽枝間距、羽小枝排列、結節形態到羽片表面紋理等細微特徵，部分標本甚至保留了完整的羽枝及羽小枝層級結構與色素體。儘管如此，目前對琥珀羽毛的研究多聚焦於分類學的形態描述。

本研究整合超過 240 種鳥類之體羽、絨羽及副羽的形態測量資料，建立涵蓋陸生、濱岸、涉水、漂浮至潛水等各棲地類型的鳥類羽毛微結構定量資料後，利用主成分分析處理這些資料，並透過同步輻射的高精度顯微測量技術，獲得包埋於琥珀的恐龍羽毛高解析度數據，進而將現生鳥類羽毛與棲地環境之關係應用於琥珀羽毛標本，以回推琥珀羽毛原主之棲息地環境。

關鍵字：鳥類、羽毛、微結構、琥珀、恐龍

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以介形蟲重建晚更新世屏東大鵬灣古水文變遷

蔡名憲[1]、汪良奇[1]
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摘要

本研究透過青洲一號岩心介形蟲紀錄、結合花粉、有機地球化學指標（TOC、TN、C/N、$\delta^{13}C$）、磁感率與粒徑統計等多指標資料，重建大鵬灣 24000 年以來的的環境演化歷程。研究結果顯示，大鵬灣沉積環境經歷由陸域向濕地、再至瀉湖，水域形成逐漸由開放轉至封閉瀉湖的長期轉變。

約 24000-18000 cal BP，磁感率較低且穩定，反映高能河相或洪氾沉積相，此時瀉湖尚未形成。18000–10000 cal BP 期間，由沿岸漂沙形成的大鵬灣沙洲逐漸堆積，介形蟲大量出現，以廣鹽性 *Sinocytheridea impressa* 為優勢種，顯示海平面上升使半封閉水域逐漸形成，瀉湖環境開始發育。10000–6000 cal BP 為瀉湖發育成熟階段，生產力與有機質保存度達最高，花粉資料顯示紅樹林與濕地高度發育；粒徑與磁感率皆反映低能、細粒沉積，為封閉度最高的瀉湖階段。約 6000 cal BP 以後，瀉湖逐漸開放，花粉顯示草本與農耕花粉增加，指示人類活動開始影響流域沉積。

在 800、3400 與 8600 cal BP 時，磁感率出現突然上升，且介形蟲族群改變的現象，顯示短時間強烈輸砂或海水侵入事件(例如颱風風暴潮、洪水回灌或其他高能事件)；其中在 8600 cal BP，*Neocytheretta* 幼體數量突然增多，顯示外海水體快速進入瀉湖。上述事件層反映瀉湖對自然極端事件之敏感性，但目前證據不足以單獨指認其為海嘯事件。

本研究顯示，自然水文變化、海平面變動與人為干擾共同控制大鵬灣的長期沉積演化，對理解臺灣西南沿海瀉湖系統的形成與環境敏感性具重要意義。

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日月潭矽藻化石紀錄所揭示之環境變遷
Diatom Records of Sun Moon Lake and Environmental Changes

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摘　要

日月潭原為構造形成之天然湖泊，自當地有人類活動紀錄以來，皆為重要水源地，並於1919-1934年間動工建造水力發電廠與水壩，改變其集水區及沉積環境。根據年代深度模型，日月潭短岩心SUMO20-4含有近500年沉積紀錄，另一長岩心SML則涵蓋過去19000年的沉積歷史，其中SML岩心已有良好的孢粉紀錄研究，本研究旨在提供高解析度的近代矽藻資料，並補足SML岩心中缺少之矽藻計數結果。

以矽藻物種、豐度變化趨勢可以很好的反應水體環境的改變，SML岩心之 矽藻計數分析結果隨深度有明顯的不同，且與孢粉紀錄解釋之水文環境變化相異；SUMO20-4岩心提供近代高解析度的鑑定結果，同樣具有顯著的豐度與物種變遷，尤其可指示出建造水壩的時間點。本研究輔以沉積物中地球化學指標如穩定碳同位素($\delta^{13}C_{org}$)比例、有機碳(TOC)濃度等性質，解釋與花粉紀錄相異的矽藻分析結果，補足水文環境條件資訊，並期望進一步完善台灣中部水文氣候、森林、水域生態系之變遷，並還原近代人類活動對影響積環境改變的紀錄。

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澎湖一千五百年來之古海嘯事件與沈積物

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台灣島與台灣海峽南部坐落於海嘯風險極高的南海東北角，地震、火山噴發、與海底山崩都是無所不在的海嘯源。雖然過往的文字歷史鮮有重大災害的紀錄，但是本團隊 2019 與 2023 年在澎湖諸島的古海嘯沈積物調查，發現在 4 到 17 世紀期間，有 6 個海階剖面共累積多達 4 起致災性的海嘯波堆積層——崖頂殼灰質玄武岩礫石層 (cliff-top shelly basalt gravel) 。為了檢驗與探索這些海嘯堆積層與同類型堆積物的分布與再現間隔，我們又新分析了 10 個額外的海階剖面。

新事件層除了證實之前的 4 起古海嘯之外，還有 2 次發生在 8–10 世紀間與 18–19 世紀間。所有的堆積層都具有共同的特徵：侵蝕底面、基質支持、淘選極差，下伏古土壤剖面，經過古海平面校正後的標高仍遠超過百年週期的暴潮高度。它們反映懸浮沈積物豐富的濁流與類湧浪 (bore-like wave) 複合作用，是典型的海嘯沈積機制。年代模式計算的再現間隔範圍相當分散，在 600– 20 年之間，平均間隔為 251 ± 30 年，符合本地區多元而不規律的海嘯源。在 1781、1661、與 1353 年有津波或異常高潮的歷史紀錄，年代與本研究相近。

中文關鍵字：崖頂海嘯礫石層、再現間隔、4—19 世紀、澎湖、台灣海峽，南海

Natural Hydrogen Generation and Productivity in Basaltic Rocks from the Korean Peninsula: Insights into Water–Rock Interaction Mechanisms

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Abstract

Natural hydrogen generated by water–rock interaction is gaining attention as a potential low-carbon energy resource, but the hydrogen-generating potential of basaltic rocks remains less constrained than that of ultramafic systems. This study examines hydrogen generation during high temperature-high pressure water-rock interaction of compositionally diverse basaltic rocks from the Korean Peninsula and evaluates the mineralogical and redox factors that control reaction progress. Hydrogen-generation experiments were integrated with whole-rock geochemistry, X-ray diffraction, scanning electron microscopy coupled with energy-dispersive spectroscopy, X-ray photoelectron spectroscopy, and geochemical modeling. The results show that hydrogen production varies systematically among basaltic samples and can be classified into distinct behavioral types. Mineralogical and surface-chemical observations indicate that hydrogen generation is closely linked to the dissolution of Fe(II)-bearing silicates, oxidation of ferrous iron, and the formation or transformation of Fe(III)-bearing secondary phases. Geochemical modeling further suggests that hydrogen generation is controlled by bulk Fe availability, reaction progress, fluid evolution, and iron redistribution among secondary minerals. These results highlight basaltic rocks as a meaningful source of natural hydrogen and provide a framework for evaluating hydrogen productivity in basalt-hosted crustal systems.

Assessment of MRMT Parameter Transferability under Varying Pe–Da conditions

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Abstract

Non-Fickian solute transport in heterogeneous subsurface environments is commonly described using multirate mass transfer (MRMT) models, which capture tailing behavior through multiple immobile domains with distinct mass transfer rates. A standard calibration approach involves first estimating the MRMT parameters from conservative tracer breakthrough curves (BTCs), and then extending these parameters to reactive conditions by fitting only the retardation factor. Despite the widespread adoption of this workflow, the extent to which parameters derived from conservative tracers remain valid for reactive solutes across different flow and reaction regimes has not been rigorously examined. This study investigates the limits of such parameter transferability through pore-scale reactive transport simulations spanning a range of Péclet (Pe) and Damköhler (Da) numbers. The fitting follows a hierarchical scheme in which conservative tracer-calibrated parameters serve as prior constraints, so that the reactive BTCs are first reproduced by adjusting only the retardation factor. Where its correction proves insufficient, the mass transfer coefficients are subsequently recalibrated, followed by the domain volume fractions if needed. The degree of additional correction required at each Pe–Da condition is then mapped onto an empirical phase diagram, delineating regions where the conventional tracer-based parameterization holds and where it progressively fails. The resulting framework offers practical guidance on the applicability limits of the standard MRMT calibration strategy for predicting reactive solute transport in structurally complex pore geometries.

Oral Report EG1-O-65

Evaluation of prediction models for slope stability on road cut slopes using machine learning

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Abstract

With approximately 70% of South Korea's land being mountainous, constructing artificial slopes is essential land use, yet these slopes remain vulnerable to failures triggered by intense rainfall. While a cut-slope management system (CSMS) has been implemented to assess road slopes nationwide, previous machine learning studies utilizing this database often overlooked detailed preprocessing and statistical analysis, focusing primarily on data completeness (Nam et al., 2020; Woo et al., 2020). To address this gap, this study leverages 20 years of nationwide site investigation data to propose an advanced slope stability prediction model using XGBoost (XGB) and LightGBM (LGBM) algorithms. The initial dataset underwent rigorous preprocessing, including label encoding for categorical variables and standardization to remove outliers, resulting in a refined dataset of over 21,000 samples. Statistical analyses, including cross-tabulation and Pearson's correlation, were conducted to assess variable relationships. The analysis revealed that several expert opinion variables were excessively correlated with the output variable due to similarities in investigation and calculation methods, posing a severe risk of data leakage during the model training process. To rigorously verify this leakage, multiple cases were analyzed by comparing prediction performances across different variable combinations and sequentially removing highly correlated inputs. The evaluation confirmed that including these expert variables caused feature leakage, exhibiting abnormally high and unrealistic prediction scores. Consequently, these variables were excluded, establishing a finalized, reliable dataset of 31 input variables for the prediction models. The final models were trained with a 7:3 train-test split, utilizing Bayesian Optimization and K-fold cross-validation for hyperparameter tuning. Performance evaluations demonstrated that while both algorithms were effective, LGBM generally outperformed XGB, exhibiting a smaller variance between recall and precision across different output values. Furthermore, feature importance analysis highlighted factors such as soil depth, upper slope angle, slope length, and height as critical predictors for stability. Ultimately, the study concludes that when precise and accurate slope stability predictions are required, utilizing the LGBM algorithm alongside a meticulous preprocessed dataset is the most appropriate and highly effective approach.

Toward a Retrieval-Augmented LLM Framework for Communicating Uncertainty in Engineering Geological Disaster Knowledge

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Abstract

In engineering geology and disaster risk reduction, hazard assessment cannot be fully described using deterministic thresholds alone. Steep slopes do not always fail, while gentler slopes may collapse depending on geological conditions, rainfall, and local histories. Disaster occurrence is governed by complex interactions among internal factors such as geology and geomorphology, external triggers such as rainfall, and accumulated site-specific conditions. In addition, hazard-prone areas are often indicated by qualitative knowledge, including geomorphic interpretation, local place names, past disaster records, and community-based oral traditions.

This study proposes a conceptual framework for a disaster knowledge platform using a large language model (LLM) combined with retrieval-augmented generation (RAG). The objective is not to automate hazard judgment, but to support local decision-making by organizing heterogeneous knowledge sources while explicitly communicating uncertainty. Disaster reports, scientific literature, monitoring data, and local knowledge are stored as an external knowledge base, and the LLM retrieves and reconstructs relevant information into context-dependent explanations.

The framework is based on five principles: delegation of final judgment, explicit uncertainty representation, respect for historical knowledge, translation of monitoring data, and cumulative knowledge growth. This approach shifts the role of artificial intelligence from deterministic prediction to the communication of uncertainty.

Oral Report EG1-O-67

Passing Down Past Disaster to the Next Generation: Natural Disaster Memorial Monuments in Asian Region

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Abstract

In Japan, GSI leads efforts to collect information on the locations and records of Natural Disaster Memorial Monuments. As of the end of 2025, 2,403 such monuments have been made publicly available. Conversely, information on such monuments outside Japan is lacking, and it's seems that no systematic compilation of data exists. The authors have collected information on them in countries visited in the past. This report introduces some of these findings in Asian Region.

In China, the disaster ruins from the 2008 Sichuan earthquake are preserved and open to the public.

In Taiwan, a large-scale landslide in 2009 buried Xiaolin Village, causing significant damage. A memorial park was developed near the village's relocation site after the disaster. Furthermore, the 1999 magnitude 7.6 earthquake caused fault displacement in central Taiwan, significantly deforming structures, ground surfaces, and slopes. Portions of these structures and ground surfaces are preserved at multiple locations and displayed as disaster ruins.

In Nepal and Bhutan, accidents frequently occur where people and vehicles are buried or fall down slopes due to slope failures or heavy rains. At sites where major accidents occur, temples, stupas, and memorial monuments have been erected, and the accidents and disasters are passed down through oral tradition. There are also ruins in Kathmandu where the base of a tower that collapsed in the 2015 earthquake has been left as is, serving as a monument that conveys the tragedy of the disaster.

We hope to use opportunities such as this international conference to collect more information about monuments. If you have any information, please share it with us.

Oral Report EG1-O-68

Hydrochemical Signatures of Springs Controlled by Active Faults in the Suwa Region, Central Japan

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Abstract

This study aimed to characterize the spatial distribution of water quality in the Suwa region, Nagano Prefecture, Japan, and to evaluate the influence of groundwater flow changes associated with active faults. Water samples were collected from 74 sites between August and December 2025.Electrical conductivity (EC), pH, and water temperature were measured three times at each site using a multiparameter meter, and average values were used.

In Chino City, EC decreased downstream due to mixing of canal and stream water, but increased again near faults, suggesting inflow of high-EC fault-related water. Three sites along the Chino Fault showed similar EC, indicating a common origin. Analysis limited to springs showed a weak correlation between EC and fault distance. However, high EC values were observed at fault locations, whereas distant sites showed no high EC, suggesting fault influence.

Future work will incorporate discharge data and major ion analyses to better constrain water sources and mixing processes

A Study on Improving the Efficiency and Accuracy of Slope Surveys Using Mobile Devices

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Abstract

In Japan, based on the “Act on Sediment Disaster Countermeasures for Sediment Disaster Prone Areas” which aims to establish a system for early warning and evacuation against sediment disasters, approximately 700,000 areas nationwide that are at risk of landslide damage had been designated by the end of 2025. In recent years, as detailed topographic data has become available through aerial LiDAR surveying, numerous new slopes requiring investigation have been identified, making the improvement of field survey efficiency and accuracy a pressing challenge. In this report, author propose a method for recording location data using low-cost, general-purpose mobile devices and report on case studies that verify its effectiveness.

First one is a method that combines mobile devices with SfM-MVS. By capturing a series of photos of slopes using a mobile device application and constructing 3D point cloud model and obtained the coordinates of specific points. Since this method allows for comprehensive recording of slope conditions, it helped reduce the workload of topographic analysis and facilitated visual understanding during explanations to residents. On the other hand, the time required for analysis remained a challenge in terms of efficiency.

Second one is a method combining mobile devices with RTK measurement. An RTK rover was mounted on a mobile device to acquire high-precision coordinates for key points during area delineation. Although the amount of data collected was minimal, this approach achieved a dramatic improvement in work efficiency.

Oral Report S2-O-70

長形結構物於不同作用力下之動態反應

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摘　要

長形建築物因具有土地利用效率高及採光和通風良好等優點，在都會區已成為常見的建築型態。成功大學校園內的資源工程學系新館，為一棟長53公尺、寬12公尺、高50公尺的12層樓建築，以此作為探討長條型建築物在承受不同作用力（如微地動、颱風及地震）下之動態行為的場址實屬合適。為進行多軸向（平移與旋轉）振動觀測，本研究使用多個速度型地震儀陣列，於不同樓層量測平移速度，並以一台R-1地震儀觀測結構物的旋轉率。共振主頻是瞭解結構物運動特性的基本參數，本研究利用數個小時的微地動資料進行時頻分析和快速傅里葉變換，經建築物在短軸與長軸平移，以及垂直軸旋轉方向的振動資料分析，得到其共振主頻分別為1.23 Hz、1.78 Hz和1.82 Hz，此與結構模態分析結果相近，顯示微地動資料可作為建物基本特性評估之良好工具。此外，研究期間亦收錄三個（2023海葵、2023小犬、2024凱米）颱風的完整訊號，當風速越大，短軸平移分量的振幅顯著變大，且垂直軸與長軸的旋轉率亦隨風速起伏，顯示在強風下，運動行為主要與建物形狀有關。為探討建物在較大地動時之反應，本研究選取2023/08/16至2024/09/30間，收集到的500筆規模介於3.0至6.37，且訊噪比良好的地震資料進行分析。根據結構物四個角落平移分量的振幅統計結果，位於電梯側的振幅較小，遠離電梯側的振幅較大，兩者發生最大振幅的機率分別為4-11 %和42-44 %，顯示結構物具不對稱的特性。再者，利用平移地震儀陣列計算所得之結構物旋轉率，與R-1地震儀觀測結果大多非常近似。然而，在長軸兩端（電梯側與遠離電梯）的對角線上，其中有一方向之計算旋轉率明顯偏低，經與結構物的位移軌跡比對後，該方向之旋轉變化較不明顯，顯然僅使用單一旋轉地震儀難以完整描述結構之非剛性行為，例如剪切變形。這些發現有助於深入了解如何改善建築物，以增強其抵禦地震或颱風事件的能力。

Oral Report S2-O-71

Insights into Non-Ergodic Ground Motion Modeling in Taiwan: 3-D Physics-Based Simulations of an M8 Ryukyu Earthquake using Recipe-Based Sources

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Abstract

The Ryukyu subduction zone offshore eastern Taiwan possesses significant seismogenic potential, exemplified by the 1920 M8 earthquake. However, even to date, the scarcity of near-field data leaves the ground motion characteristics of such mega-earthquakes poorly constrained, posing a threat to seismic hazard assessments. To estimate potential ground motions in inland eastern Taiwan from future mega-earthquakes, we simulated an M8 scenario earthquake using characterized source models (CSMs) based on the "Recipe" procedure. We employed a 3-D finite-difference method to conduct 1,728 full-waveform simulations, incorporating kinematic fault-rupture parameters, including rupture directivity, rupture speed, source time function, and asperity distribution, along with two recent tomographic velocity models and topography. Synthetic waveforms generated at 4,950 virtual stations were analyzed using RotD50 spectral accelerations (SA) at 1, 3, and 5 s. Detailed analysis highlights two notable characteristics of the dataset: first, rupture speed and directivity primarily govern the spatial variability and intensity of ground motions; second, tests demonstrate that utilizing a Gaussian source time function with periods of 2, 5, and 9 s yields optimal performance for assessing SA at 1.0, 3.0, and 5.0 s, respectively. We further calculated non-ergodic terms based on the CH20 GMM. The patterns clearly delineate northeastern Taiwan's geological domains: high values in the Ilan area (SA 1.0 s) and Longitudinal Valley (SA 1.0, 3.0, 5.0 s), and low values in the Coastal Range. These patterns mirror the crustal velocity structure, highlighting the dominance of path effects over relatively weak source effects. Consequently, our extensive simulation datasets provide a foundation for refining current GMMs and facilitate the transition toward non-ergodic seismic hazard assessments, thereby improving the accuracy of ground motion predictions for future mega-earthquake scenarios in the region.

Oral Report S3-O-72

When Does Ambient-Noise Interferometry Yield Green's-Function Travel Times? A Measurement-Centric α=r/λ Threshold and Symmetric-TDCF Bias

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Abstract

Ambient-noise interferometry is widely used to measure surface-wave travel times from time-domain cross-correlation functions (TDCFs), yet its classical motivation often invokes source homogeneity or diffusivity that is rarely satisfied in field settings. Here we revisit Green's-function (GF) travel-time recovery from a measurement-centric perspective using a phase-delay travel-time definition and the stationary-phase interpretation. We focus on the dimensionless parameter α=r/λ (station spacing over wavelength), which controls both the validity of high-frequency (HF) approximations and the effective width of the stationary-phase zone. Using finite-α (near-field) expressions for a one-sided (single-branch) phase-delay measurement, we quantify convergence to the HF asymptote and show that the HF approximation becomes accurate to within 1% once α≥3. This provides an estimator-level justification for the widely adopted ambient-noise tomography criterion α≳3. We further highlight behavior not emphasized in prior asymptotic treatments: under homogeneous source condition with symmetric TDCFs (both causal and acausal contributions), the commonly used T/8-corrected ("common") estimate can retain an α-dependent bias with phase-cycle/branch sensitivity at moderate α, with convergence toward the true travel time evident only at sufficiently large α. Field measurements from the ANCC–CIEI dataset and a Taiwan experiment exhibit similar α-dependent patterns in symmetric-TDCF travel times, indicating that bias from symmetric processing is expected and not always eliminated by standard windowing when wave packets overlap. We recommend reporting α distributions and measurement operators alongside dispersion results, and treating symmetric-TDCF travel times as controlled approximations whose accuracy is governed by α and stationary-phase-zone sampling.

Oral Report S3-O-73

Imprints of Cretaceous Magmatism on the Oldest Pacific Lithosphere: Evidence From Seismic Anisotropy

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Abstract

Hotspot chains and Cretaceous large igneous provinces (LIPs) in the southern Pacific are spatially associated with the South Pacific Superswell and have been linked to the possible presence of a “superplume” in the deep South Pacific mantle, potentially rooted near the Pacific LLSVP at the core–mantle boundary. To decipher the impact of Cretaceous magmatism and to further improve our understanding of the thermal evolution of oceanic plates, we analyzed Pacific Array Oldest-1 and Oldest-2 OBS data and applied the ambient noise tomography method to constrain the 3-D isotropic and anisotropic Vs structure.

In the inverted isotropic Vs structure, the Magellan Seamount Trail exhibits relatively low velocities compared to the two adjacent LIPs, with prominent Vsv reductions of up to ~5–10% within the crust and uppermost mantle (~30 km depth) and Vsh reductions of up to ~1.5% within the crust. These anomalies may be associated with the Rarotonga plume, which may incorporate enriched mantle components, including EM1-like signatures, that are enriched in volatiles and incompatible elements and could potentially contribute to reduced seismic velocities. The resulting radial anisotropy in the crust exhibits distinct characteristics between the Magellan Seamounts and the two adjacent LIPs. The seamounts show strong radial anisotropy, which may be suggestive of well-developed, horizontally oriented crystallized sills. In contrast, the LIPs exhibit weaker radial anisotropy. We interpret this anisotropic signature as reflecting former magma conduits, through which large volumes of magma were transported vertically from deeper sources to the surface over a relatively short timescale. These findings suggest that, although the seamounts and LIPs beneath the southern Pacific seafloor were likely formed by secondary magmatic sources, the oceanic plate has remained affected by these magmatic processes and continues to preserve clear seismic signatures of such activity.

Oral Report S3-O-74

Rayleigh Wave Excitation and Propagation during Typhoon Infa (2021): Insights From a Dense SmartSolo Array in the Hualien Region

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Abstract

Characterizing Rayleigh waves within the ambient seismic wavefield encodes the coupling among the ocean, atmosphere, and solid Earth. In this study, a dense array of 47 SmartSolo three-component seismometers was deployed in the northern part of eastern Taiwan (July 15-August 3, 2021). Based on the array, we investigate how typhoon-generated ocean swell excites Rayleigh waves across multiple period bands (1-2 s, 2-4 s, and 4-8 s). Two complementary approaches are combined. Single-station polarization analysis extracts time-varying dominant back-azimuths (BAZs) to represent Rayleigh wave arrival directions at receivers, while three-component Matched Field Processing (MFP) identifies the spatial distribution of potential excitation regions where nonlinear ocean-wave interactions drive seafloor pressure fluctuations. The geometrical consistency between MFP-resolved source locations and dominant BAZs provides coherent results of Rayleigh wave generation and propagation during typhoon forcing. During Typhoon Infa (July 15-31), 4-8 s Rayleigh wave BAZs shifted dynamically between north and SE, consistent with ERA5 mean wave directions; MFP correspondingly identified offshore excitation regions aligned with these arrival BAZs, confirming remote typhoon swells as the dominant sources. The 1–2 s band exhibited stable BAZs reflecting near-shore coastal wave interactions, while the 2–4 s band showed transitional behavior arising from mixed local and remote contributions. These findings demonstrate that dense arrays resolve frequency-dependent Rayleigh wave source dynamics during typhoon passages, with implications for ocean–atmosphere monitoring in typhoon-prone regions.

Oral Report S3-O-75

Tracking Super Cyclone Amphan in the Bay of Bengal: Integrating Oceanic, Atmospheric, and Seismological Perspectives with Modeling

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Abstract

Understanding storm behaviour across oceanic regions is crucial for establishing real-time warning systems from a seismological perspective. The Bay of Bengal, located in the northeast Indian Ocean, frequently experiences intense cyclone activity, particularly during the summer monsoon season. This study presents a comprehensive analysis of Super Cyclone Amphan using data from twelve land-based seismometers surrounding the Bay of Bengal. Frequency-dependent polarization analysis. Is applied to identify the sources of microseisms, while power spectral density and time-frequency spectrum analysis are employed to track the temporal and spatial evolution of Amphan induced seismic signatures. Vertical component seismic recordings exhibit a strong correlation with ocean wave heights, with correlation coefficients exceeding 0.9. Using ocean wave fields simulated by the WAVEWATCH III model, we model the theoretical source regions of double-frequency microseisms were generated by Super Cyclone Amphan. Our results show both Class I and Class II microseism generation mechanisms which originate from regions trailing the cyclone's center and from reflections off nearby coastlines, respectively. This study demonstrates the potential of seismic observations to complement meteorological data for storm tracking and real-time monitoring applications.

Oral Report NH1-O-76

山區地表變形之光流分析案例研究—以馬太鞍溪堰塞湖與立霧山裂隙為例

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光流技術（Optical Flow Method）為一種基於影像灰階梯度與亮度恆定假設之位移估算方法，可解析連續影像間之像素位移向量場。本研究將多期數值地形模型（DEM）轉換為坡度圖並進行灰階正規化處理後，採用 Lucas–Kanade 光流法解算不同時期地形間之水平位移場，並分析事件前後潛在活動坡地之空間差異。

本研究延續先前採用兩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、內政部民國 105–112 年）所產製之臺灣山區坡度圖進行光流地形變化分析之成果，並進一步依不同案例特性整合多期資料深化探討。在此架構下，選定馬太鞍溪堰塞湖與立霧山作為代表性案例進行分析。馬太鞍溪堰塞湖案例使用民國 104 年、111 年及農業部林業保育署航遙測分署於民國 114 年 8 月至 11 月取得之多期 DEM 資料，以解析災變前後坡地周緣之地形特徵變化；立霧山案例則採用民國 104 年、111 年及地礦中心民國 113 年之 DEM 坡度圖，比較 0403 花蓮地震前後地形差異，探討山頂裂隙與地震擾動之關聯性。

分析結果顯示，馬太鞍溪案例於民國 104 年至 111 年間，坡頂冠部已出現大範圍水平地表位移現象，並伴隨張裂隙生成，顯示災變前即存在持續之變形行為；災後 DEM 數據顯示，西北側已崩塌坡面暫無明顯活動跡象，惟於東北側殘餘坡面及堰塞湖壩體堆積區河道兩側仍可辨識零星小規模崩塌。另於立霧山案例，山頂東側辨識出與稜線近乎平行之地表變形帶，其空間分布與 0403 花蓮地震後新生裂隙位置相符；現地調查亦觀察到稜線張裂之明確跡象，顯示該變形帶可能受地震擾動影響。

整體而言，光流分析可作為多期地形資料中辨識潛在活動坡地之工具，對地震後山區變形徵象之快速判識與後續現地調查規劃具有參考價值。

關鍵字：大規模崩塌、數值地形模型、光流技術、地表變形

Key words：Large-scale landslide, DEM, Optical Flow, Surface deformation

從源頭到運移路徑：基於觀測樣本的淺層山崩幾何尺度分析

From source to runout: geometric scaling of shallow landslides based on a consistent inventory

張瓊文　李錫堤　許晉瑋　謝有忠#

淺層山崩或稱為岩屑崩滑型山崩通常崩塌體積較小，由全臺數值航照山崩目錄統計可知，16 萬多處的岩屑崩滑山崩之中，90%以上山崩面積小於 1 公頃，80%以上山崩面積小於 0.5 公頃，多為表層土砂崩塌。其運移範圍的推估，除了以物理模型試驗獲得一般性原則外，主流仍是藉由視摩擦係數與崩塌體積之統計關係，以取得合理之視摩擦角。然而淺層山崩大多數崩塌土方的移動最遠點通常也還在坡面上，視摩擦角與山崩之平均坡度可能很相近，此視摩擦角在應用於推估山崩影響範圍並不方便。國外雖有 CONEFALL 法(Jaboyedoff and Labiouse, 2011)由山崩最高點以視摩擦角向下坡處透過圓錐掃描方式圈繪影響範圍，然而這較適用於地形變化大的山坡或大型的崩塌地。以臺灣的岩屑崩滑特性而言，這種圈繪方式所得之影響範圍可能太大。

為了解岩屑崩滑型山崩之運移距離，本研究在數值航照山崩目錄的基礎上，配合正射航照、數值地形日照陰影圖、坡度圖及衛星影像等相關資料，重新判釋山崩樣本之崩塌源頭區，並得到山崩長度與山崩源頭區面積之對數關係分布成正比，呈現良好之冪次關係。

在正射航照影像上崩塌源頭區通常呈現較為鮮亮的灰白色，土砂運移堆積區域則為較暗的灰白色或透出植生的綠色色調，崩塌源頭區與土砂運移堆積區的界線可能會在山坡坡度有明顯變化的地方。本研究於全臺篩選出 622 處山崩提供山崩運移距離分析之用，在主要的岩性分區、坡度分級及各流域中均有樣本分布。

本研究經統計回歸得到山崩長度與山崩源頭區面積的冪次方呈正比關係，次方值為 0.4768，接近 0.5，與運移指數(runout number)之概念相近，也就是山崩長度與面積平方根組合構成的無因次量(Wallace & Santi, 2021)，其為描述山崩延伸性與運移行為的替代指標，並定位為可用於比較不同事件與不同地形背景的運移量測框架。不過，運移指數(runout number)所使用之面積為含運移距離之整體山崩面積，與本研究之源頭區面積不同。

經統計分析，本研究所使用之山崩樣本源頭區面積與山崩總面積間呈現良好的比例關係，而山崩樣本之山崩長度與總面積呈冪次關係，次方值為 0.51，符合運移指數的概念。山崩幾何量測之間所呈現的冪次尺度關係，長期以來常被置於

比例法則(scaling laws)與尺度不變性(scale invariance)的理論脈絡下加以討論。既有研究指出，天然山崩在不同區域與不同規模下，其面積、體積與長度等幾何量往往呈現冪次分布或冪次尺度關係，顯示山崩現象具有某種程度的尺度不變特性，而不僅是單一規模或單一事件的結果(Hergarten, 2002；Malamud et al., 2004)。這類尺度行為常被解釋為在複雜地形與多重控制因子下，自然系統於統計意義上所展現的幾何相似性。

山崩運移範圍的評估大多以簡化的幾何指標與經驗法則為基礎，分析已發生山崩之崩塌體積、崩塌體移動高度、崩塌體移動距離、地形特性等，統計各參數間之相關趨勢，找出具有代表性的線性關係式，例如視摩擦係數和體積呈反比的趨勢(Corominas, 1996; Finlay et al., 1999; Baum et al., 2018)，以作為運移潛勢與影響範圍的快速推估方式。然而，這類指標往往會受到山崩體積推估及運移路徑之地形變化的影響，使得在不同地形條件間的可比較性受到限制。為了以較低的地形偏差描繪運移特徵，近年有研究提出以山崩長度與面積組合構成的無因次量，作為描述山崩延伸性與運移行為的替代指標，並將其定位為可用於比較不同事件與不同地形背景的運移量測框架(Wallace & Santi, 2021; Santi, 2025)。在此脈絡下，山崩的長度與面積之間若呈現穩定的尺度關係，將有助於以單一或少數可穩健量測的幾何量推估運移相關特徵，並提升跨事件、跨區域的比較能力。

Wallace & Santi (2021)提出之山崩運移指數，其應用方向是針對既有山崩的型態分析。而應用於山崩預測時，一般降雨或地震事件所推估之山崩區位比較趨向發生區，也就是山崩源頭區。因此在進一步推估其運移範圍時，以山崩源頭區面積與山崩長度的關係，更方便於推估預測崩塌之最遠到達距離，並依此作為控制條件以進行運移範圍的模擬。本研究成果將源頭到運移的幾何連結明確化，使得運移量測框架能更直接地落實於危害範圍的推估與比較。

關鍵詞：淺層山崩、運移指數、比例法則

Oral Report NH1-O-78

山崩與地滑地質敏感區屬性資料特性與精進更新

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摘要

本中心自民國113-115年完成全島「山崩與地滑地質敏感區」之劃定，並於110年至今辦理各縣市之山崩與地滑地質敏感區之修正公告(變更)，其資料屬性為「歷史山崩目錄」、「光達數值地形判釋之地表變形資料」及「順向坡」三者聯集組成，因此，一筆山崩與地滑地質敏感區可能同時涵蓋一種以上的屬性資料。開發單位或技師在面臨開發區域坐落於山崩與地滑地質敏感區，應先了解其屬性資料特性，並具以進行山崩與地滑地質敏感區基地地質安全評估。有關屬性資料成果，可參考本中心「山崩地質資訊雲端服務平臺」。

歷史山崩目錄是依據衛星或航照影像判釋之崩塌地區，本中心已將崩塌地編製為歷年判釋之山崩資料，顯示其逐年復發性或崩塌變動範圍，因早期影像解析度和定位精確度不足，造成非自然崩塌誤判或判釋範圍位移者，現階段已於變更計畫中重新檢討修正；另近年因新證據如高精度光達數值地形資料測製，可用以揭露崩塌地之微地形特徵，進而圈繪出潛在大規模崩塌，考量其判釋面積10公頃以上且山區分布眾多，本中心以崩塌地形特徵分級表進行分類分級，供未來篩選高風險特徵之區位並有效投入防災量能；順向坡亦採用高精度的數值地形資料進行坡向分析，準確計算坡面的平均坡向，並與現地地層位態核實是否符合順向坡之地形，本中心亦進行順向坡滑動潛能分類，將全臺約18,000處順向坡以滑動潛勢等級分為高中低三個等級。

前述屬性資料本中心已於平臺公開，相關精進成果於檢核校閱後會逐步釋出。惟本中心公開之山崩資料，是建立於全臺區域尺度(廣域)調查，開發單位辦理土地開發行為時，仍應以現地地質調查及地質探勘成果，做為實際致災風險之探討依據。

關鍵字：山崩與地滑、地質敏感區、地表變形、崩塌、順向坡

Oral Report NH1-O-79

Exploring Seismic and Rainfall Coupling Effects on Landslide Hazards in Mainland Southeast Asia Using PlanetScope Imagery

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Abstract

The coupling of seismic ground motion and intense precipitation is a critical factor affecting the cascading landslide hazards. While such effects are well-documented in Taiwan and Japan, they remain poorly constrained in Southeast Asia. To enhance our understanding of the interaction between earthquakes and precipitation in landslide hazards, this study investigates landslides triggered by the 2022 Mw 5.9 Kengtung earthquake and the subsequent Tropical Storm Mulan in the Golden Triangle Area using PlanetScope satellite imagery. We identified over 800 earthquake-induced landslides after the mainshock, all located in the region where the seismic intensity is higher than IV on the Modified Mercalli Intensity (MMI) scale. This result suggests a lower threshold of peak ground motions to trigger landslides than the global dataset. The distribution of these landslides is primarily controlled by topography, lithology, and rupture directivity. We further identified more than 800 rainfall-induced landslides after the Tropical Storm Mulan within our selected areas, showing that the subsequent storm triggered far more widespread mass movements than the antecedent earthquake. Our analysis suggests a positive correlation between the density of rainfall-induced landslides and antecedent earthquake ground motion when the antecedent earthquake intensity exceeds MMI IV. Our result suggests that even moderate-magnitude earthquakes can significantly amplify landslide hazard potential from subsequent rainfall-induced events in Mainland Southeast Asia, causing an unexpected cascade of hazards near the earthquake-affected area.

2025台灣重大坡地地質災害事件
Major Landslide and Slope Geological Hazard Events in Taiwan, 2025

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地震活動、颱風降雨與河川侵蝕等因素共同作用下，使臺灣成為全球大規模崩塌與衍生堰塞湖事件發生頻率較高的地區之一。大規模崩塌發生後不僅造成地形驟變與直接破壞交通等硬體設施，也可能阻塞河道形成堰塞湖，間接對下游聚落與基礎設施造成潛在威脅。因此，了解大規模崩塌的形成機制與活動性特徵，並提升堰塞湖風險判識能力，對於臺灣坡地災害防治具有重要意義。

2025年間臺灣發生3起重大坡地地質災害事件，分別為花蓮馬太鞍溪堰塞湖事件、太魯閣立霧溪燕子口崩塌事件，以及雲林草嶺大型崩塌與堰塞湖事件。這3個案例分布於不同地質環境與地形條件下，反映出臺灣坡地崩塌與堰塞湖形成機制的多樣性。馬太鞍溪事件主要為大規模山崩造成河道阻塞而形成堰塞湖。太魯閣燕子口崩塌則發生於峽谷型高陡岩壁環境，崩塌型態以岩體崩落與落石為主。雲林草嶺地區則為臺灣歷史上著名的大型崩塌區域，該區受順向坡地質構造、河川侵蝕與降雨影響，過去曾多次發生大規模山崩並形成堰塞湖，顯示其具有長期活動性的地形演化特徵。

本研究透過多種地形與遙測技術對上述案例進行分析，包括空載光達多期地形資料比對、光學影像判釋，以及影像變形分析方法如光流分析（Optical Flow）與粒子影像測速法（PIV）等。空載光達資料透過不同年度資料的比較，可以辨識地表微小的高度變化與坡體變形情形；光學影像則可提供大範圍地表觀測資訊，有助於掌握崩塌區域的空間分布與變化情形。光流與PIV等影像分析技術則可透過影像像素位移計算地表可能的變形方向與活動特徵，進一步輔助判識山體是否存在潛在變形或活動跡象。

結果顯示不同地質環境下大型崩塌的活動性與災害特徵具有顯

著差異。草嶺地區可觀察到長期地形變形與坡體活動跡象，顯示其為具有持續活動性的崩塌系統；相對地，峽谷型岩壁崩塌如燕子口案例，可能在災前缺乏明顯變形訊號，屬於較為突發性的崩塌型態。此外，大型崩塌與堰塞湖形成往往受到多重因素影響，包括地層構造、岩性分布、河川侵蝕作用以及地震與降雨等觸發因素，顯示坡地災害的形成具有高度複雜性。透過多時序地形資料與遙測影像分析，可更完整地了解山坡地形的長期演化與崩塌活動性，並提升對潛在大型崩塌區域與堰塞湖風險的判識能力。未來持續整合地質調查、遙測監測與災害應變制度，將有助於提升臺灣在面對大型崩塌與堰塞湖事件時的整體防災能力與國土安全管理。

中文關鍵字
坡地地質災害，堰塞湖，空載光達，光流，粒子影像測速法
Keywords in English
Slope Geological Hazards, Landslide-Dammed Lakes, Airborne LiDAR, Optical Flow, Particle Image Velocimetry (PIV)

Oral Report NH1-O-82

Constraining the Timing of Post-Earthquake Debris-Flow Activity Using a Single Seismic Station

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Abstract

The 2024 Hualien earthquake increased hillslope susceptibility to subsequent rainfall-driven debris-flow activity in eastern Taiwan. This study investigates whether continuous records from a single seismic station near the Chongde Tunnel, a hotspot of post-earthquake debris-flow activity along the Chongde-Heping coastal highway corridor, can be used to constrain the timing of possible debris-flow events after the earthquake. The main objective is to examine whether characteristic microtremor or high-frequency seismic signals can provide a useful record of time-dependent mass-movement activity and to evaluate their relationship with rainfall observed at nearby highway rain gauges. Six rain gauges are distributed within about 20 km of straight-line distance along the corridor, but rainfall variability remains substantial even at this spatial scale, suggesting that local triggering conditions cannot be represented by a single precipitation record. In this context, the study compares the timing of candidate seismic signals with rainfall observations from multiple neighboring gauges to explore the temporal relationship between possible debris-flow occurrence and spatially variable rainfall. The expected outcome is a preliminary framework for documenting post-earthquake debris-flow activity and for examining how such activity relates to local rainfall patterns along the highway corridor. This approach may contribute to hazard monitoring in mountainous coastal areas where field verification is limited and where rapid identification of debris-flow timing is important for post-earthquake risk assessment.

Keywords: Debris flow, Seismic Signals, Rainfall

Oral Report P-O-83

Experimental constraints on the thermal structures in Earth's deep mantle: global and regional

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Earth's deep mantle is featured by a number of thermochemically heterogeneous structures, such as large low shear-wave velocity provinces, ultralow velocity zones, subducted slabs, and mantle plumes. These heterogeneities co-exist and dynamically interact with each other over Earth history. Thermal conductivities of these heterogeneous structures hold a key to influence Earth's available energy, geodynamics, and thermochemical and geodynamo evolution, yet remain poorly constrained. Using our recently developed, novel combination of an ultrafast optical spectroscopy and laser-heated diamond anvil cells, we have precisely measured the thermal conductivity of important lower mantle minerals with variable representative chemical compositions. This allowed us to model the thermal conductivity profiles for pyrolytic lower mantle and iron-rich oxides or melts for the seismic ultralow velocity zones above the core-mantle boundary. I will discuss their effects on the thermochemical evolution at the lowermost mantle and core along with the geodynamo evolution.

Oral Report P-O-84

Lattice Thermal Conductivity of Bridgmanite in Lower Mantle

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Bridgmanite, with a composition generally described as (Mg,Fe,Al)(Si,Al,Fe)O_3, is the most abundant mineral in the Earth's lower mantle and therefore plays a key role in affecting mantle dynamics, seismic velocity structure, and thermal evolution of the Earth's lower mantle. The thermal conductivity of bridgmanite especially controls the heat transport in the deep Earth and affects the heat flux across the core-mantle boundary. However, existing estimates of bridgmanite's thermal conductivity with variable composition remain uncertain, with discrepancies among experimental, theoretical, and extrapolated results. Here, we directly measure the thermal conductivity of (Fe,Al)-bearing bridgmanite at lower-mantle pressures and temperatures (up to ~120 GPa and ~2300 K) using time-domain thermoreflectance (TDTR) combined with laser-heated diamond anvil cells (LHDAC). At room temperature, bridgmanite's thermal conductivity initially increases with pressure up to ~40 GPa (with a pressure derivative of ~ 0.25), followed by a gradual decrease and then a plateau above ~60 GPa. High-temperature measurements reveal a monotonic decrease in the thermal conductivity with increasing temperature (T), scaling approximately as $T^{-0.43}$. The observed pressure and temperature dependencies in our results are broadly consistent with previous studies.

Oral Report P-O-85

Thermal Conductivities of Magnesiowüstite and Basaltic Glass: Implications for the Thermal Evolution of Earth's Deep Mantle

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Knowledge of the thermal properties of deep mantle materials is critical for investigating the thermal evolution and dynamics of the deep Earth. At the lowermost mantle, there are two types of seismic low-velocity structures—large low-shear-velocity provinces (LLSVPs) and ultra-low-velocity zones (ULVZs). The characteristics of ULVZs are of great interest, as they are considered to influence the thermochemical evolution around the core-mantle boundary where the ULVZs are present, including the heat flux and formation of mantle plumes, etc. Inferring from seismic observations, candidate materials for ULVZs may be iron (Fe)-enriched or partial melt of the mantle. Given that magnesiowüstite is one of the major phases in the lower mantle, and basaltic melt is the possible composition of the basal melt differentiated from the magma ocean, both could be one of the major ULVZ-forming materials. In this work, we used optical pump-probe technique combined with externally-heated and laser-heated diamond anvil cells to measure the thermal conductivity of magnesiowüstite and basaltic glass at high pressure and temperature conditions. We show that the thermal conductivity of magnesiowüstite is significantly lower than that of the pyrolitic mantle, indicating that if ULVZs are composed of magnesiowüstite, the heat released from the core is locally accumulated around ULVZs, increasing their temperature. Such local high temperature anomalies around ULVZs would reduce local viscosity and promote formation of mantle plumes.

Oral Report P-O-86

Abstract Submission

P – Planetary Science

地球及行星內部構造與演化 Structure and Evolution of the Earth and Planets

Title:
評估生熱元素富集和地函熱導率對原始儲層穩定性的影響
(Assessing the effects of heat-producing element enrichment and mantle thermal conductivity on the stability of primordial reservoirs)

Authors:
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Abstract:
Thermo-chemical mantle convection models show that enrichment of heat-producing elements (HPEs) in large low shear velocity provinces (LLSVPs) greatly influences their long-term stability. Since internal heating was stronger in the past, thermal conductivity had a larger effect on buoyancy and dense pile erosion, making initial LLSVP volumes potentially much greater than they are today. Energy balance calculations indicate that a smaller initial LLSVP mantle fraction allows for more HPE enrichment to maintain the mantle's heat budget. For example, a 160 km initial layer (3% of the mantle) would require present-day HPE enrichment factors above 45 times the ambient mantle rate, much higher conservative factors of 10–20 used in earlier studies. Earlier models may have significantly underestimated HPE enrichment; conversely, if LLSVPs formed from a larger reservoir, enrichment based on present-day volumes may be overestimated. Our study uses LLSVPs with a primordial geochemical reservoir (consistent with undegassed $^{4}He/^{3}He$ signature and HPE enrichment) and presents convection models with time-dependent heating rates and enrichment set by initial mantle fraction. We specifically test how fully heterogeneous, including a radiative component, thermal conductivity affects LLSVP stability. We then generate synthetic seismic shear-wave velocity anomalies from our final temperature and composition fields, filter them with a tomographic model (HMSL-SPP06), and examine their distribution. Finally, we use present-day LLSVP volume and core-mantle boundary coverage as constraints to discuss possible initial conditions, heating scenarios, and thermal conductivity for an Earth-like mantle.

Oral Report P-O-87

Seismic signatures: mixing with a tomographic filter and identifying with cluster analysis

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Abstract

It has long been recognized that the statistical distribution of shear-velocity anomaly ($dlnV_S$) in the lowermost mantle shows some degree of asymmetry in the form of a slow velocity tail. This slow tail, implying a bimodal distribution from 2200 km depth toward the core-mantle boundary, is associated with the large low shear-wave velocity provinces (LLSVPs), the prominent feature on lowermost mantle tomographic maps. Yet, the phase transition to post-perovskite (PPv) at depth ~2600 km, if not happens globally, implies a trimodal distribution for $dlnV_S$., which seems to be absent from recent seismic tomography models. Here, we bring new insights on this question. First, we investigate the effect of the seismic tomography 'operator' on seismic velocity anomalies triggered by different possible lowermost mantle thermo-chemical structures. Overall, our results support the hypothesis that the LLSVPs observed at the bottom of the mantle are composed of hot, chemically differentiated material. They further show the mixing of seismic signatures due to tomographic filter, implying the statistical distribution of $dlnV_S$ (as well as V_P anomaly) may be richer and more complex than it appears to be from seismic tomography models. Second, acknowledging the mixing of seismic signatures inherent to tomography models, we then apply cluster analysis with trimodal distribution to four recent tomographic models and provide a probability map of PPv distribution, which may be used to better understand the lowermost mantle structure and facilitate future geodynamic studies.

Oral Report P-O-88

Mapping lowermost mantle seismic structures with core-diffracted waves

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Abstract

Pdiff and SHdiff waves, diffracted along the core-mantle boundary, are highly sensitive to the structures of the lowermost mantle. Using an automated procedure, we measure the absolute travel time residuals (δt_P, δt_{SH}) from cross-correlation (*cc*) and amplitude ratios (ar_P, ar_{SH}) between observations and synthetics for >2.02 million Pdiff+P and >1.96 million SHdiff+SH waves in multiple period bands. The gridded mean δt_P and δt_{SH}, $\overline{\delta t}_{P_g}$ and $\overline{\delta t}_{SH_g}$, exhibit a degree two pattern consistent with the Large Low Shear-Velocity Provinces (LLSVPs) observed in global seismic tomography models beneath Africa and the Pacific. Furthermore, the $\overline{\delta t}_{SH_g}$ are 2–3 times stronger than $\overline{\delta t}_{P_g}$, and $\overline{\delta t}_{SH_g}$ under the African LLSVP are stronger than under the Pacific LLSVP by a factor of 2–3. Besides, an anti-correlation between $\overline{\delta t}_{SH_g}$ and gridded mean amplitude ratios ($\overline{ar}_{SH_g}$) is consistent with velocity gradient variations at the base of the mantle. The distribution of the $\overline{\delta t}_{SH_g}/\overline{\delta t}_{P_g}$ ratio shows a broad, dispersive pattern, with the majority of the population between –2 and +5, in contrast to purely thermal effects predicted $\overline{\delta t}_{SH_g}/\overline{\delta t}_{P_g}$

ratio in the range of 1.7–2.6. Finally, the $\overline{\delta t}_{\mathrm{SH_g}}$ distribution is skewed to low-velocity, while the $\overline{\delta t}_{\mathrm{P_g}}$ distribution is Gaussian. Collectively, these observations point to thermochemical LLSVPs.

Oral Report P-O-89

Locally negative core-mantle boundary heat flux: simulations of mantle convection and implications for core dynamics

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Abstract

Heat flux at the Earth's core-mantle boundary (CMB) partially controls the outer core dynamics and its associated geodynamo. Lateral variations in temperature above the CMB trigger lateral variations in heat flux with low and high temperatures regions being associated with high and low heat flux regions, respectively. Variations in temperature are, in turn, controlled by details of mantle convection and mantle material properties. Here, we investigate the influence on CMB heat flux of two key parameters: the excess internal heating within piles of hot, dense material modelling the large low shear-wave velocity provinces (LLSVPs) observed by global seismic tomography maps; and the temperature-dependence of thermal conductivity. For this, we perform numerical simulations of thermo-chemical convection using the code StagYY. Our simulations show that the CMB heat flux is lower than the core adiabatic heat flux throughout the base of dense material piles, and that it can be locally negative, *i.e.*, heat flows from the mantle to the core. We further investigated the conditions needed for such patches to appear. A larger internal heating excess and a stronger temperature dependence of thermal conductivity both favor the development of negative heat flux patches. However, patches disappear if the piles excess heating gets too large. In this case, heat released in the regular mantle is strongly reduced, allowing plumes generated at the top of piles to extract more heat from these piles. Finally, our simulations predict relatively large CMB heat flux spatial heterogeneity, together with substantial temporal variations in this heterogeneity. Our findings support the hypothesis that partial stratification at the top of the core can occur beneath LLSVPs, reconciling geomagnetic and seismic observations. In addition, the CMB heat flux heterogeneity and temporal variations predicted by our simulations may play a key role in the occurrence of geomagnetic superchrons.

Oral Report P-O-90

Reconstructed upper-mantle heterogeneity domains in Southeast Pacific since the Cenozoic

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Abstract

Upper mantle heterogeneity is the consequence of mantle differentiation throughout the Earth's history, driven by material transportation within the upper mantle and across the planet's surface to the lower mantle. The resulting heterogenic domains likely evolved through time, reflecting the dynamic mantle evolution in deep time. Previous studies mainly relied on present-day basalts (e.g., MORB and OIB) to understand the upper mantle heterogeneity. However, the spatiotemporal evolution of ancient mantle heterogeneity remains poorly constrained.

In this study, we developed a technique to reconstruct upper-mantle domains back in time by restoring the basalts and published Pb isotopic ratios to their eruption locations using multiple plate reconstruction models including Müller et al. (2019). We test the new technique in the Southwest Pacific region, reconstructing the Zealandia-Antarctic geochemical domain and its boundary with the adjacent Pacific and Indian domains in the past ~60 Ma. In contrast to the published Zealandia-Antarctic domain restricted to the south hemisphere, we show a broader, more complete restored domain northwards to 10 °N latitude, which has a relatively stable boundary since ~60 Ma. The reconstructed Pb isotope signatures distinguish the far-traveled Philippine Sea plate from its surrounding ocean basins, with the basalts from the West Philippine Basin having a Zealandia-Antarctic signature that is distinct from Indian domain rocks from adjacent marginal sea basins. We further discuss the potential contamination from subducted sediments and deep-mantle plume in the Zealandia-Antarctic domain through time.

Oral Report ER2-O-91

花蓮富源地熱區地熱資源調查與潛能評估
Regional Geothermal Exploration and Potential Assessment of Hualien Fuyuan Geothermal Area

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摘　要

花蓮富源地熱潛能區位於臺灣中央山脈東翼地質區，是近年地熱探勘重點調查區域之一。為了掌握潛能區的地熱資源，本研究藉由地熱地質調查、大地電磁探測以及流體地球化學分析等多種地球科學探勘技術。其中，地熱地質調查包含線型判釋、應力分析及裂隙量測，提供熱水通道的位態相關資訊；經由大地電磁探測獲得三維電阻模型，可作為地熱構造及熱水通道的重要指標；藉由分析地熱流體之組成成分及氫、氧同位素，解析熱液來源與特性。富源地區的地表地熱徵兆主要出露於富源溪主流溪床，位於富源蝴蝶谷森林遊樂區園內，彙整本研究及文獻資料，顯示富源調查區熱水屬於碳酸氫鈉鹽泉，與其他位於中央山脈變質岩區的溫泉水質相似；氫氧同位素分析結果沿著天水線分布，推測熱水來源主要為天水補注。根據水質特性未來產生酸腐蝕的機率不高，但可能會有生產管線結垢的問題。鈉鉀地質溫度計推估儲集層溫度約介於110至160℃之間。將綜整上述地表地熱調查成果及前人文獻資料建立三維地熱概念模型。

中文關鍵字：花蓮富源地熱潛能區、地熱地質調查、流體地球化學分析、大地電磁探測
英文關鍵字：Hualien Fuyuan potential geothermal area, geothermal geological survey, magnetotellurics exploration, fluid geochemistry analysis

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瑞穗地熱潛能區數值模型初探

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摘　要

瑞穗地熱潛能區鄰近花蓮紅葉溫泉，為臺灣重要地熱潛能區之一，岩性以變質岩為主，包括石英雲母片岩、蛇紋岩、角閃石片岩。由於完整變質岩的孔隙率及滲透率極低，因此地下水大多經由破碎帶(含斷層)或是連通的裂隙流動，過去地礦中心調查結果顯示瑞穗地區大部分的潛在儲集層推測以玉里層紅葉段富含裂隙群的片岩為主，上覆岩體則為玉里帶瑞穗段的片岩及基性混合岩體，而根據野外的觀測，這些基性混合岩體主要組成是角閃石片岩及角閃石長石片岩，水文地質特性相對緻密而透水性較差。因此，目前地熱概念模式大多認為上述裂隙群可能為熱水儲集空間及通道，而該區域主要的斷層系統(紅葉溪斷層、江布南斷層、加星斷層)則屬於熱水上湧通道，可將深部熱液帶往淺部地層形成熱水儲集層。

本研究與紐西蘭奧克蘭大學合作，採用三維地質建置軟體(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，並串聯熱流模擬器(Waiwera)進行模型參數設定，運跑瑞穗地區合理的熱儲集層數值模型，藉以探討地熱案場地下熱流與水流空間分布、熱能資源量評估，綜合考慮岩石和流體的性質、熱傳性質、相變化和流體的物理特性，分析並量化地熱開發過程及各種可能發生情境的技術，並且於開發的過程可不斷加入實際生產資料反覆修正模型，降低預測結果的不確定性。

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台灣西部海域新生代盆地架構與碳封存潛能評估

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摘　要

政府間氣候變化專門委員會(IPCC)多項報導指出：溫室氣體導致「增強型溫室效應」，進一步強化了自然溫室效應，是造成當前全球暖化與極端氣候異常的主要原因。故如何減低碳排，已成為各國政府、能源公司及依賴化石燃料產業之重要課題，而碳封存技術將是解決此一議題的重要負碳科技之一。其中以鹽水層地質封存具備封存容量大、場址分布廣與長期安全性較佳等特性，因而受到國際間廣泛關注，全球亦已有多處鹽水層碳封存場址進入營運或規劃階段。台灣中油公司為國營事業機構，肩負國家能源穩定供應之責，並投入油氣探勘逾七十年，累積豐富之探勘資料，具備推動地質碳封存場址評估之基礎。本研究依據既有探勘成果、整合前人研究並利用地質、地物與井下資料，將台灣西部海域之東引島盆地、南彭佳嶼盆地、觀音次盆地、南日島盆地、台西盆地、澎湖盆地與台南盆地等 7 個沉積盆地，依盆地演化歷程劃分為前張裂期、同張裂期、後張裂期及前陸盆地期，並解釋新生代地層之封存系統，評估其封存潛能。本研究結果顯示台灣西部海域具有廣大且厚層之沉積盆地，各盆地之大地構造與沉積演化不盡相同，比如同張裂期沉積地層的保存狀況、前陸基底不整合面及解離不整合面的侵蝕情形等均有差異。其中，東引島盆地、南彭佳嶼盆地、觀音次盆地及澎湖盆地有觀察到同張裂期沉積序列有向上漸細的情形，此符合同張裂沉積理論模式；後張裂期則轉變為砂岩多於泥岩(頁岩)沉積的情形，但西南海域之台南盆地則相反，此可能與沉積物的供應來源及距離有關。後張裂期之後的沉積物組成，主要受控於全球海平面變化影響，沉積環境大部分於濱面至近濱、遠濱間循環，形成多套廣泛分布之儲-蓋層組合。綜合評估結果顯示，台灣西部海域各盆地整體具備高度發展地質碳封存之潛力，可作為後續場址篩選與細部評估之重要基礎。

中文關鍵詞：台灣海域碳封存潛能、盆地架構、地質碳封存

「二氧化碳捕捉後封存管理辦法」之法制架構探討

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摘要

為配合全球減碳趨勢並落實我國2050淨零排放目標，環境部氣候變遷署積極將「二氧化碳捕捉、利用與封存（CCUS）」列為國家關鍵戰略。為完善法制基礎並確保封存作業之安全性，依《氣候變遷因應法》第三十九條，並參考國際（如歐盟、日本、美國）主流法制規範經驗，研擬「二氧化碳捕捉後封存管理辦法」草案，以建立符合國際趨勢且兼具臺灣實務面需求之法規架構。

本辦法之核心在於建立CCS全生命週期的管理流程架構，藉由規範封存申請應備文件，明確作業流程與審查基準，例如在審查作業，區分「地表環境影響」與「地下地質安全」：依環境影響評估法於整體生命週期審查並評估地表環境衝擊影響，確保開發行為對周遭生態、水體及社會之影響最小化；而本辦法封存核准制度，著重地下地質專業領域，以審查細部地下地質資料、地質安全評估及緊急應變計畫之可行性，透過嚴謹的實質審查制度確保二氧化碳之長期穩定封存。

在風險管理面，本辦法要求事業提具財務保證以因應封存場址長期安全責任、建置透明化之即時監測系統、訂定具操作性之緊急應變措施，並明確規定封井後之監測年限為二十年。本辦法亦建立透明的資訊公開平台，消除公眾疑慮並建構安全、完善的地質封存環境，為國家淨零路徑提供完整的封存管理規範。

關鍵字：二氧化碳、封存、場址、監測、地質

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臺灣西部 CO_2 地質封存的構造環境與場址評估

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摘要

臺灣地處弧陸碰撞造山帶，自第四紀以來，西部麓山帶受地殼強烈變動影響，發育出一系列褶皺與逆衝斷層系統，且地震活動頻繁。若於此活躍帶進行 CO_2 封存，可能因地殼變形或斷層破裂導致封存氣體洩漏。因此，為尋求地質環境相對穩定的場址，評估重點應轉向遠離造山核心帶的西部海岸平原（前陸盆地），以及臺灣西北部的地殼變動較緩慢穩定的北部張裂帶。

針對場址的長期地質穩定性，須嚴格評估以下四大關鍵因素：（1）地震活動頻率：評估場址背景地震活動度。（2）斷層活動性：評估現有斷層活動風險及其誘發大地震之潛勢。（3）儲集層物性：需具備高孔隙率與高滲透率的岩層。（4）蓋層封閉性：需具備低滲透率且具延展性的厚層泥岩，以確保封閉效力。

區域地質潛力分析：

嘉南海岸平原（北港溪至曾文溪）：位於造山帶前緣的前陸盆地，受到東向西的輕微擠壓與沉陷作用，但此區地震頻率較高，風險控管相對複雜。

雲嘉海岸平原（北港溪至濁水溪）：地震頻率低。其中，雲嘉區域鄰近北港高區，具備發育良好的儲集層與蓋層組合，封存潛能較佳。

中彰投海岸平原（濁水溪至大安溪）：地處造山前期的臺西盆地沉積中心及造山時期的前陸盆地沉積中心，其深度 3,000 公尺以內的地層，可能缺乏高孔隙率與高滲透率的儲集層。

林口－桃園臺地：地處觀音高區周邊，屬於低地震頻率且無活動斷層分布的穩定區域，且具備優良的儲集與蓋層條件，是地質穩定性極高的候選區域。

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台灣西部陸域碳封存潛在場址之地質特徵評估

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摘　要

為達成台灣2050年淨零排放之政策，二氧化碳捕集與封存（CCS）已成為關鍵的減碳技術。台灣中油公司憑藉豐富的油氣探勘經驗與地質、地球物理資料，評估台灣西部陸域濱海之鹽水層地質碳封存潛在場址的地質特徵。

本研究整合桃園至雲林陸域共10口鑽井之井下地質與井測資料，及多條南北向為主的濱海二維震測剖面，評估西部濱海地下地質特徵。本研究利用聲波、密度井測數據及小波計算合成震波，再與震測剖面對比，透過對井震主要反射訊號進行校準，得到時-深關係。接著在二維震測資料上對碳封存潛在儲層及蓋層進行層位解釋，以追蹤地層在空間上的變化。

本研究描繪出兩套延伸廣泛的潛在儲蓋組合，其地層深度皆由北往南漸深，由東往西漸淺。第一套以錦水頁岩及其下方之桂竹林層與南莊層砂岩段作為潛在儲蓋組合；第二套則以打鹿頁岩與下方的打鹿砂岩、北寮層與石底層為潛在儲蓋組合。

依第一套儲蓋組合，本研究評定具有良好背斜構造之苗栗鐵砧山構造為合適之二氧化碳灌注試驗場址。透過整合井下地質資料與三維震測資料，建構鐵砧山場址之三維構造模型，再結合井測資料對儲層特性進行特性評估，隨後以地質統計方法，將井測資料拓展至構造模型網格中，建置不同岩石物理特性之三維地質模型。

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臺北盆地三維地質模型與力學特性精進研究

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摘　要

過去數十年來，已有許多學者與機構針對臺北盆地的地質架構進行研究，並劃分出松山層、五股層、景美層等沉積地層，隨著經濟部地質調查及礦業管理中心（下稱地礦中心）近年來強力整合「工程地質探勘資料庫」，納入了捷運工程、公共建築及大規模民間開發計畫的鑽孔資訊，目前臺北盆地已累積超過萬筆的鑽探資料。這些高密度的資料點位，為重新審視臺北盆地地質架構、提高地層邊界精度，以及建立更為細緻的力學參數統計模型提供了絕佳的契機。

早期文獻所建立的臺北盆地地質模型，多依賴少數單位深井，在空間分佈上存在明顯的空缺，導致等深線圖在邊緣區或局部構造處存在較大的不確定性。透過整合地礦中心萬筆以上的鑽探資料，本研究可針對以下關鍵地層進行三維地質模型：

1. **岩盤等深線：**透過大量深鑽孔資料，校正臺北盆地基盤（主要為第三紀岩盤）的深度分佈。
2. **景美礫石層等深線：** 景美層作為臺北盆地最主要且最具連續性的承載層與透水層，其厚度變化與頂面起伏對大型公共工程的風險控管至關重要。

本研究將採用地質統計學結合三維建模技術，主要工作流程包含：

1. **資料篩選與標準化：**自地礦中心資料庫提取臺北盆地範圍內的萬筆鑽孔，進行資料清理。針對不同年代、不同單位產出的表格進行標準化轉譯，確保後續分析。
2. **三維地質建模：**利用克利金法或其他進階插值算法，建立連續的地層界面。
3. **力學參數統計分析：**本研究不僅止於幾何特徵，更將進一步整理鑽孔中的試驗數據。統計物理特性與力學特性，進行統計分析，並探討其空間異質性。

本研究藉由地礦中心萬筆鑽探資料的整合與深挖，成功建立臺北盆地的三維地質模型，完成系統化大數據建模。這不僅是對前人研究的傳承與更新，更是利用現代資訊技術提升國土測繪精度的具體體現，我們將能更科學地預測與應對臺北盆地的地質災害與工程挑戰。

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評估裂隙現地特性之逐級流量注入分析：Tournemire案例

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摘　要

本研究以法國圖爾內米爾地下實驗站斷層帶為案例，探討逐級流量注入分析於裂隙現地特性評估之應用潛力。研究核心為SIMFIP現地試驗技術，藉由逐級提升注入流量，同步量測壓力、流量與裂隙三維位移響應，據以辨識裂隙由彈性變形、啟動開裂至導水性改變之關鍵轉折，能進一步約束現地應力控制下之水力–力學耦合行為。圖內米爾案例顯示，不同試驗區段在斷層破碎帶與斷層核心中呈現顯著差異，可能反映裂隙癒合、幾何分布與滑移傾向對裂隙延展壓力、第二壓力轉折點與最大注入流量之控制。相較於傳統水力壓裂法，本方法更能在既有裂隙條件下精細解析壓力–流量–位移之時空耦合特徵，對深部地質處置、斷層水力評估及地熱儲集層監測均具重要意義。

Advancing Microfacies Characterization in Sediment Cores: Integrating Quantitative CT Analysis with XRF Core-Scanning

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Abstract

Understanding sedimentary microfacies is essential for reconstructing depositional processes, resolving event stratigraphy, and interpreting sediment transport in complex source-to-sink systems. However, microfacies identification in fine-grained and heterogeneous sediment cores remains challenging, particularly where subtle textural and compositional variations are difficult to integrate in a consistent and reproducible way. Recent advances in core-scanning technologies provide new opportunities to address this issue. X-ray fluorescence core scanning (XRF-CS) enables high-resolution geochemical profiling and clustering, while X-ray computed tomography (CT) allows non-destructive imaging of internal sedimentary structures; however, CT-based interpretations are still largely qualitative and rarely integrated quantitatively with geochemical datasets. Here, we present an integrated workflow that combines a region-of-interest (ROI)-based quantitative CT framework with XRF-CS clustering to enhance microfacies characterization. The CT analysis extracts statistical and morphological descriptors of sedimentary textures along core profiles, which are co-registered with high-resolution geochemical clusters and evaluated using multivariate statistical approaches, enabling systematic linkage between sedimentary structure and composition. Using sediment cores from the Japan Trench as a case study, we show that coupled CT–XRF signatures provide robust discrimination of depositional facies and processes, allowing differentiation of event deposits such as turbidites and homogenized units, and offering insights into flow dynamics, depositional energy, and sediment source variability, thereby establishing a scalable and reproducible framework for data-driven microfacies analysis in deep-marine systems.

Oral Report ST2-O-100

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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摘　要

臺灣位處東亞季風與太平洋海氣交互作用敏感區，區域環境變遷同時受到季風環流、海氣模態、地形效應與人類活動影響，然而北臺灣山區具高時間解析度之晚全新世古環境紀錄仍相對有限。本研究以位於大屯火山群小油坑附近之鴨池沉積岩芯（DP20）為研究材料，整合放射性碳定年、花粉分析、磁感率、總有機碳穩定碳同位素及黑炭通量等多項代用指標，重建北臺灣過去約1680年來之植被、水文、火活動與集水區環境變遷。

年代模型顯示，鴨池岩芯記錄可回溯至約1680 cal yr BP，平均沉積速率約為0.19 cm/yr。花粉圖譜及 CONISS 分群結果顯示，過去約1680年來之環境變化可區分為三個主要階段。1680-1520 cal yr BP間，木本植物與莎草科比例相對較高，指示周邊以C3植群與濕地環境為主，並伴隨事件性碎屑輸入。1520-330cal yr BP間，木本植物比例整體偏高但呈現波動，顯示森林組成、水文條件及火活動具有明顯變異，其中約500-400 cal yr BP前後黑炭通量顯著增加，反映火活動增強及環境轉折。330 cal yr BP至今，禾本科比例上升、$\delta^{13}C_{TOC}$ 增加且磁感率升高，顯示植被結構轉趨開闊、C4植物相對增加，並伴隨坡面侵蝕與陸源輸入增強。

綜合多項代用指標，本研究認為鴨池過去1680年來之環境變遷並非受單一因子控制，而是區域水氣背景、環流調制與在地環境回應共同作用的結果。整體而言，早中期變化較可能主要反映自然氣候變率對植被、水文與火活動的影響；晚期尤其約 500–400 cal yr BP之後，人為土地利用、火活動與植被重組的影響逐漸增強，使集水區環境由以自然氣候波動主導，逐步轉為氣候與人為擾動共同塑造之狀態。本研究結果顯示，多代用指標整合可有效辨識北臺灣晚全新世環境變遷之階段性特徵，並為東亞季風邊緣區之古環境重建提供重要區域性證據。

Oral Report TT1-O-101

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，是台灣最大的構造之一，與台灣島的造山歷程密切相關。據前人研究，雪山山脈與中央山脈板岩區具顯著年代及變質度差異。過去對梨山斷層的調查受制於野外露頭難以辨認差異、露頭不連續、地形阻隔以及採樣密度不足，使得梨山斷層精確空間分布仍具不確定性。

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磁感率橢球體三軸方向與大小，計算各磁性參數。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，估算其所經歷之最高變質溫度，利用斷層兩側地層埋藏深度落差，了解斷層分布位置。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，檢驗AMS和RSCM實驗結合的成果，進而提供具多期應變歷史的斷層磁組構特徵。

關鍵字:梨山斷層、非均向磁感率、雷射拉曼光譜碳質物測溫

英文關鍵字: Lishan Fault,Anisotropy of Magnetic Susceptibility, Raman Spectroscopy of Carbonaceous Material

臺灣西南部嘉南地區之長期與短期地表垂直形變

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摘要

台灣西南部的嘉南地區自西部麓山帶延伸至沿海平原，其垂直地表運動同時受到構造活動與人為地層下陷的影響。本研究整合鑽井地層學及放射性碳定年法所得之長期垂直形變量，並與自 1991 年以來透過精密水準測量與連續全球導航衛星系統觀測所獲得的短期形變量進行比較。

千年尺度的長期紀錄顯示，自全新世以來，麓山帶地區以每年 0.4–3 mm 的速率緩慢抬升，而沿海平原則以每年 2–27 mm 的速率下陷，且下陷速率向海岸方向逐漸增加。此一趨勢反映出褶皺—逆衝系統中的變形特徵，在壓縮應力作用下，上盤持續抬升，而前陸盆地則逐漸下沉。相較之下，近期的大地測量資料顯示，沖積平原部分地區的下陷速率顯著加快，在地下水大量抽取區甚至超過每年 40 mm。麓山帶地區則維持穩定或微幅抬升，顯示現今地表形變為構造運動與人為活動共同作用之結果。長期與短期形變速率之間的顯著差異表明，現代地層下陷的速度遠快於自然地質速率，這主要是由於人類活動導致含水層壓密所致。

研究進一步指出，一個清晰的構造邊界將抬升的山地與快速沉陷的沿海平原分隔開來。鑽井證據顯示，上盤相對於下盤有長期抬升的現象，證實了構造前緣存在活躍的盲斷層。透過結合地質與大地測量數據，本研究區分了自然構造過程與人為活動造成之地層下陷，並估算了兩者的相對影響。綜合平原區的大地測量及鑽井證據結果，地層下陷的速率可以達到構造活動速率的十倍以上。研究結果不僅有助於深入理解地質構造如何支配地表形變，也為嘉南地區的沉陷災害評估、地下水管理及土地永續利用規劃提供了重要參考。

Oral Report T1-O-103

Active tectonic characteristics and seismic hazard potential of the Abra River fault system, northwestern Luzon, Philippines

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Abstract

The Philippine fault system is a primary seismogenic structure traversing the entire Philippine archipelago. On Luzon Island, the destructive 1990 M_W 7.7 Luzon and 2022 M_W 7.0 Abra earthquakes underscored this fault system's substantial seismic hazard potential. However, the precise location and characteristics of fault traces along some segments of this fault system remain poorly understood, particularly the Abra River fault system (ARFS) near the 2022 Abra earthquake epicenter. Therefore, this study aims to identify and characterize active traces of the ARFS based on tectonic geomorphic features using a 5-m resolution DEM, augmented by field investigations.

Based on geomorphic manifestations and results from our field investigations, we identified at least three major sinistral fault traces of the ARFS along the Abra River valley. Although our mapping results are generally consistent with the published map by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), the new mapping provides better constraints and information for previously uncertain segments. Geomorphic features and field investigations confirm recent activity and predominant sinistral motion of the ARFS, the latter is not consistent with the reverse-motion focal mechanism of the 2022 Abra earthquake. This suggests the ARFS was not the seismogenic source of the earthquake, and its accumulated strain remains unreleased. We estimated that the ARFS can generate $M_W > 7.0$ events, posing great seismic hazards for the area. Preliminary slip rates and recurrence intervals were also calculated, providing tentative fault parameters that can be further refined by future paleoseismic studies.

Please note the information in the bottom of abstract if you choose to attend to "the Students' Poster Competition".

(1) National Taiwan University/ Prof. J. Bruce H. Shyu
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Oral Report T1-O-104

結合構造地形及接收函數法探索嘉義斷層

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摘　要

台灣位處板塊邊界，除了東部之碰撞帶，西部則以一系列之覆瓦狀褶皺—逆衝斷層帶吸收其板塊縮短量，並發育許多未知之盲斷層。鑑於台灣西南部近期陸續發生多起規模5以上之地震（如新港、中埔及大埔地震），且歷史上該區亦曾發生多次災害性地震（如1906年梅山地震），顯示此區域存在許多未知的發震構造。針對歷史上造成許多死傷的梅山地震，近期研究指出其成因為梅山斷層與嘉義斷層錯動相互誘發所致。然而，目前對於此二斷層（特別是嘉義斷層）之地表變形特徵、地下幾何結構，以及兩者間的構造交互關係，仍缺乏深入了解。

因此，本研究聚焦於嘉義地區麓山帶前緣，透過測繪沖積扇與河階等地形指標分布，並透過其坡度變化辨識是否具有斷層活動特徵。此外，本研究亦透過分析河流陡峭度指標與河流蜿蜒度指標，探討跨越不同地質構造區之差異。為更瞭解嘉義斷層之三維幾何結構，本研究運用接收函數法（Receiver Function）結合Common Conversion Point（CCP）方法，建構該區之地下地層幾何結構。影像結果清晰顯示地層受嘉義斷層活動影響而形成斷層擴展褶皺（Fault-propagation fold），且其向地表延伸之軌跡與地表變形特徵之位置高度吻合。隨後，本研究利用高精度即時動態定位技術（RTK-GNSS），針對斷層沿線進行野外測量，以量化細微之地表變形特徵。

研究結果顯示，在梅山斷層以北區域，受限於現有地震測站分布密度及數值高程模型（DEM）之解析度，尚難以清晰觀測嘉義斷層造成之變形；但在梅山斷層以南區域，則可清晰辨識受嘉義斷層控制之地表變形特徵與地下幾何構造。資料進一步顯示，嘉義市區內至少存在三處顯著之地表撓曲現象。且CCP剖面觀察到此區域正處於九芎坑斷層與六甲斷層之構造轉換帶，因而呈現出複雜之地層擾動特徵。

【學生壁報比賽】參與者於摘要尾端註記

(1) 就讀學校/指導教授：國立中正大學/陳嘉俞、溫士忠
(2) 學位/年級：學士/四年級

Oral Report T1-O-105

牛山地區深部構造與大埔地震序列分布帶所代表的地體構造意涵

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摘要

近一兩世紀有些大地震所造成的地表破裂面和地表地質斷層在位置上有相當的一致性，然而，在地底下產生地表破裂面的震源和地表地質斷層向地下延伸構造之間的關聯性仍有相當的爭議，此對於未產生地表破裂面的震源與被觀察到地表活動斷層及其地下延伸構造之間的相關性尤然。就20250121嘉義大埔地震序列分布的樣態而言，其和地表六甲活動斷層及其地下延伸構造之間的關聯性所代表的地體構造活動意涵是本研究探討的主要議題。本研究利用三維地質建模，結合地表地質圖、震測剖面、井下資料，建立了六甲斷層之三維形貌。參考前人研究之大浦地震孕震構造，對比二者的空間特徵，進而了解該地區地體構造。

六甲斷層是臺灣西南部的活動斷層，為一南北走向由東向西逆衝之逆移斷層，長約21公里。本研究所重建的六甲斷層-牛山背斜地下構造形貌顯示，六甲斷層切穿牛山背斜西翼，在該背斜底部和低角度甚或水平的逆衝楔狀構造合而為一。該楔狀體沿一彎曲斷層由東向西逆衝，導致牛山背斜東翼地層淺於西翼。大埔地震震央位於牛山背斜軸東南方13公里處，震源深度約15至16公里，地震規模達6.4，根據新定位之地震分布帶，大埔地震群由一組共軛斷層所引發，包含一條東傾斷層以及一條更深處、西傾之盲斷層。其中向東部傾斜的地震分布帶深度自東南方的10公里向西延伸至5公里之處，傾角由27度轉為10度，走向近乎平行六甲斷層及牛山背斜軸之走向。該地震分布帶淺部的深度與傾角和牛山背斜底部低傾角之逆衝楔狀構造大致符合，且與該逆衝楔狀構造銜接。至於該分布帶傾角更陡(27度)的深部與該逆衝楔狀體向東延伸之斷坡構造合而為一。

根據上述大埔地震之東傾的孕震構造與六甲斷層-牛山背斜底部的低傾角逆衝楔狀構造銜接關係，顯示向東傾斜的孕震構造可能代表一涉入基盤的地下地質盲斷層，其淺部的構造作為六甲斷層-牛山斷層底部之逆衝低傾角楔狀體之斷坡的滑移面。

Oral Report EC-O-106

Historic Tsunami Deposits at Yukashi-Gata Lagoon along the Nankai Trough, Japan

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Yukashi-Gata Lagoon is a shallow lagoon along the Nankai Trough at Wakayama Prefecture, Japan. Historic records It was attacked several tsunami hazard during these 1500 years.

Recent Diatom Works at National Chung Cheng University 國立中正大學 reveals that the Ancient Tsunami traces at AD1361 Shohei/Koan Tsunami 康安/正平地震津波, AD1707 Hoei Tsunami 宝永津波, AD1854 Ansei Tsunami 安政津波 in the lagoon sediment by the diatom assemblages.

An abrupt sedimentation by the Tsunami Currents caused the complex diatom assemblages with Freshwater species, Marine benthic species, Marine Planktonic species, preserved in the Lagoon sediments.

Keywords; Tsunami Deposit, Lagoon, Nankai Trough Earthquakes, Diatoms

接軌國際趨勢：以 IUCN 自然解方(NbS)全球標準建構臺灣氣候韌性策略之評估架構初探

Aligning with International Trends: A Preliminary Study on Constructing an Assessment Framework for Taiwan's Climate Resilience Strategies using the IUCN Global Standard

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摘要 (Abstract)

隨著全球暖化加劇與極端氣候事件頻發，氣候治理已進入刻不容緩之關鍵時刻。「以自然為本的解決方案（Nature-based Solutions, NbS）」（以下簡稱自然解方）作為能同時兼顧減緩與調適的整合性策略，逐漸扮演國際氣候治理之關鍵地位。然而，概念理解與實務推動在國內外仍皆持續被討論與挑戰。本研究採系統性文獻回顧法，以世界保育聯盟（International Union for Conservation of Nature, IUCN）（以下簡稱 IUCN）之發展脈絡為主軸，剖析臺灣可以借鏡的過程，以更有效與國際趨勢接軌。研究發現，IUCN 全球標準提供了一套完整的環境與社會保障措施（Environmental and Social Safeguards, ESS），該時即希冀幫助有效釐清自然解方與傳統工程或單一保育等行動之差異，臺灣可據此避免國際間早期的摸索成本，並確保公共資源投入能精準對焦於具備長久韌性之氣候行動；此外，自然解方為應對複雜氣候問題，其核心價值在於突破傳統剛性工程（灰色建設）之單一功能侷限，轉而透過生態系統服務之整合（綠色基盤），創造兼顧防災韌性、環境永續與社會福祉之協同效益 (Co-benefits)，臺灣則需要加速將 IUCN 全球標準在地化，作為檢核國內氣候調適計畫之基礎依據，同時突破全球標準因通用性框架在成效量化層面的侷限，建立臺灣在地化的生物多樣性與環境基線數據，以完備科學實證基礎並落實具體之效益評估。整體而言，本研究認為藉由更精準接軌國際準則，將有助於奠定實務操作之公信力與深化相關治理思維，而能引領臺灣從單點防禦邁向全面韌性建構，具體實踐人與自然共榮之永續願景，達成氣候韌性與環境永續之雙重目標。

關鍵字：自然解方、氣候變遷調適、跨域治理、生物多樣性、社會挑戰

Keywords：Nature-based Solutions, Climate change adaptation, Cross-sectoral governance, Biodiversity, Societal challenges

Oral Report EC2-O-108

Holocene Diatom and Chrysophyceae assemblages at Toushe Peatland, Central Taiwan; Ancient flooding traces preserved in a peat bog during these 9000 years presumed by microfossils

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Toushe Peatland is located at a mountain basin, south of Sun Moon Lake, central Taiwan. The thickness of the peat layer exceeded more than 40m, and the peat continuously deposited for more than 120,000 years (older than the Last Inter- Glacial). In this paper, we analyzed diatom and Chrysophyceae assemblages at 133 samples of the top 5m sediment of the peat with 2-5 cm intervals, dated until ca 9,000 cal. years BP. The sediment was consisted of homogeneous peat bog, but thin silt–fine sand layers were observed at 56-68cm, 155-160cm, 205-240cm and 470- 476cm depth.

Toushe Peatland is a high peatland, and specific diatom flora (*Eunotia serra, E.lunaris* etc.) which prefer acidic water environment are prospered. At the top deposited (0-20 cm depth), Eunotia serra, E. lunaris were dominated. However, they could hardly be kept in peat sediments. Therefore, diatom fossil was barren in almost part of the peat bog layers.

Diatom assemblages were abundant at thin silt–fine sand layers at 56-68cm, 155-160cm, 205-240cm and 470-476cm depth. The dominated species were *Aulacoseira* spp., *Cymbella* spp., *Pinnularia* spp., and *Staurosira* spp., which were abundant at normal freshwater ponds, rivers, not in an acidic high peatland. They were derived into a peatland from surroundings by outwashes of heavy rain.

We found four flooding layers, Flooding I–IV, dated ca.7500 cal yBC (ca.9500 BP), ca. 2500 cal. BC (ca.4500 BP), ca. 1800 cal. BC (ca.3800 BP) and ca.600 cal. AD (ca.1400 BP), respectively. Recent acidic pond was performed after ca.1300 cal. AD (ca.700 BP)

Learning from Legacy Data: Unlocking High-Resolution Climate Proxies with Deep Learning

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Abstract

Reconstructing past changes in the oceanic carbon cycle is central to understanding long-term climate variability, yet converting high-resolution core scanning data into quantitative geochemical proxies remains a persistent challenge. Conventional quantification methods are site-specific and fail to generalize across the heterogeneous materials found in sediment cores. This bottleneck constrains our ability to produce high-resolution paleoclimatic records.

To address this challenge, we leverage the vast and underutilized wealth of legacy cores as an invaluable training resource. We introduce MAX (Masked Autoencoder for XRF), a self-supervised foundation model pre-trained on over 55,000 X-ray fluorescence (XRF) spectra from 30 legacy marine sediment cores. By learning universal spectral characteristics — including atomic emission line signatures — from this diverse archive, MAX acquires transferable geological knowledge that goes beyond site-specific quantifications. We demonstrate that MAX achieves high-accuracy quantification of total organic carbon (TOC) and $CaCO_3$ — the primary geochemical tracers of past oceanic carbon cycling — using only one-third of the quantification samples required by conventional methods.

Furthermore, we present our initiative to compile a global database of over 234 legacy cores and sites. Expanding this training foundation will further enhance MAX's generalizability across geological settings and machine series, establishing a scalable pathway for reconstructing past oceanic carbon cycle changes at unprecedented resolution and spatial coverage.

Oral Report EC2-O-110

Fire and climate reconstruction of eastern Taiwan using sedimentary black carbon in Liyu Lake sediments

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Abstract

Black carbon (BC), produced by the partial combustion of biomass, particularly during wildfires during pre-industrial era, preserved the signature of fires along with effective moisture conditions at the time of burning. In this study, BC analyses were performed on a sediment core from Liyu Lake to explore the fire and climate history of eastern Taiwan, covering the last 3000 cal yr BP. Our results indicated relatively wet conditions during 3000-2400, ~1500, and 800-0 cal yr BP, separated by drier intervals at 2400-1600 and 1400-800 cal yr BP. These wet–dry phases differed from western Taiwan records, likely due to the orographic influence of the Central Mountain Range, which modulates regional responses to western North Pacific SST and ENSO forcing and produces distinct windward–leeward hydroclimate patterns. BC flux identified three major fire episodes shaped by varying climate and land-use controls: a predominantly climate-driven forest-fire peak at ~2100 cal yr BP under dry conditions; low-intensity anthropogenic burning at 2800-2500 cal yr BP associated with Huakangshan land clearance; and a strongly human-modified fire regime over the last 800 years marked by elevated BC, CHAR, and agricultural expansion. Overall, vegetation dynamics were primarily moisture-driven, with fire acting as a secondary, climate-sensitive disturbance that intensified dry phases without fundamentally altering long-term forest cover.

Oral Report EC2-O-111

Spatial Patterns of Holocene Coral in Baishawan, Kenting, Southern Taiwan

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Abstract

Corals are ecologically significant organisms capable of preserving and reflecting long-term environmental changes in marine ecosystems. This study conducted a spatial analysis of coral distribution on the uplifted reef platform at Baishawan, Kenting, southern Taiwan, employing photogrammetry to document a survey area exceeding 400 m², from which a three-dimensional model was reconstructed and a two-dimensional orthomosaic image was generated for manual annotation. A total of 687 coral colonies were recorded and identified across five genera: *Acropora* (n = 317), *Platygyra* (n = 176), *Montipora* (n = 166), *Favites* (n = 25), and *Goniastrea* (n = 3), through manual annotation of the photogrammetric model. Within *Montipora*, 2 colonies were further identified to the species level as *Montipora foliosa*.

Hotspot analysis revealed a non-random, aggregated distribution pattern concentrated predominantly on spur structures, while grooves (14.19% of total area) exhibited little to no coral presence. Overall coral cover was estimated at 4.63%. The Simpson's Diversity Index (1 − D) of 0.66 indicates moderate dominance, with community structure largely governed by *Acropora*, *Montipora*, and *Platygyra*, were characterized primarily by encrusting and massive forms, reflecting that these morphotypes conferring greater structural resilience against wave action and disturbance. Two exceptionally large colonies were identified: a Favites colony (0.79 m², r ≈ 0.50 m) and a Platygyra colony (0.38 m², r ≈ 0.35 m), estimated at approximately 100–120 years old based on established linear extension rates (0.5–1.2 cm/yr). The age of these colonies, combined with geological records of local raised reefs dating to the early Holocene (~5,000 years B.P.; Peng et al., 1977). These findings contribute to a broader understanding of coral reef growth and preservation dynamics within the Holocene uplifted reef context at Baishawan.

Key words: Holocene uplifted reef, photogrammetry, spatial analysis, coral morphotypes

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學位/年級:Master/2

Oral Report EC2-O-112

Ocean Heat Transport Variability in the Western Pacific Warm Pool During the Last Deglaciation: Insights from TraCE-21ka

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Abstract

The Western Pacific Warm Pool (WPWP) serves as a pivotal nexus in the global climate system, undergoing profound thermal restructuring during major climatic transitions. Utilizing TraCE-21ka simulations, this study elucidates the evolution of the regional heat budget and identifies horizontal Ocean Heat Transport (OHT) as its primary determinant. While the overall intensification of OHT throughout the deglaciation (22–9 ka) is fundamentally anchored in rising ocean temperatures, millennial-scale fluctuations are predominantly modulated by ITCZ-induced perturbations in current velocity. Specifically, the latitudinal migration of the ITCZ reconfigures the tropical wind field, thereby shifting the equatorial current bifurcation point and redistributing the volume of warm water into its northward branches.

This kinematic regime, however, collapses during Heinrich Stadial 1. During this interval, a southward-shifting ITCZ theoretically favored the intensification of the Gulf of Papua Current; yet, this effect was precisely offset by a concurrent weakening of the South Equatorial Current, leaving the regional circulation virtually quiescent (+0.1%). Despite the absence of a kinetic surge, OHT nonetheless increased by 9.5%. This enhancement was underpinned by a thermodynamic warming signal—propagated from high latitudes via Antarctic Intermediate Water—rather than by velocity-driven flux. Such a decoupling underscores the functional independence of thermal and kinetic signals on millennial timescales, necessitating the use of independent velocity proxies to fully resolve the warm pool's heat budget.

Oral Report EC2-O-113

利用東海陸棚沉積物重建近一千兩百年東亞冬季季風與沉積環境變化

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摘要

東海陸棚閩浙泥質區對東亞冬季季風（East Asian Winter Monsoon, EAWM）及陸源物質輸送具有高度敏感性，為研究晚全新世季風變化和極端事件的理想區域。然而， EAWM 與沉積環境之長期變化仍有待進一步理解。本研究以閩浙泥質區的 W12-2 岩心作為研究材料，重建近一千兩百年沉積環境變化與 EAWM 強度之演變。岩心年代以 8 個層位的底棲有孔蟲(*Ammonia sp.*)放射性碳十四定年建立，並使用 COPRA 計算年代不確定性，涵蓋過去 1200 年之連續紀錄。本研究結合粒徑、反射光譜與 X 光螢光光譜儀（X-Ray Fluorescence, XRF），重建沉積物粒徑、礦物組成與元素變化。其中 Si/Al 與 Zr/Rb 反映粗細粒物質輸入的相對變化，K/Ti 則作為東亞冬季季風強度變化的代用指標。分析結果顯示，在中世紀氣候異常（Medieval Climate Anomaly, MCA:950-1250 CE）期間，粉砂含量上升且 K/Ti 降低，指示 EAWM 增強並強化中國沿岸流（China Coastal Current, CCC）之輸送作用。同時，高嶺土/膨潤石與綠簾石含量增加，顯示沉積物來源中閩浙沿岸河流的相對貢獻增加。然而，粒徑與與元素比值並未呈現一致變化，顯示於 MCA 期間沉積物可能受不同沉積過程影響。小冰期（Little Ice Age, LIA:1400-1850 CE）期間海表溫降低，洪水相關礦物指標下降，但 Si/Al 與 Zr/Rb 出現震盪，顯示該時期沉積環境變動加劇。此外，小冰期晚期(約 350-200 BP)粉砂含量增加且 K/Ti 降低，顯示該階段 EAWM 再度增強。本研究顯示閩浙泥質區沉積物可有效記錄晚全新世東亞冬季季風變化與沉積環境演變，並提供區域氣候變動之沉積學證據。

關鍵字:東海、東亞冬季季風、粒徑、反射光譜、XRF
Keywords: East China Sea, East Asian Winter Monsoon, Grain Size, Reflectance Spectroscopy, XRF

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結合長序列監測與多變量分析探討和平地區結晶岩區地下水水化學特徵之時空演化

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摘　要

本研究聚焦於臺灣東部和平地區之結晶岩(crystalline rock)，岩性以大理岩與片麻岩為主，然受限於地形陡峭及岩體緻密，該區長期地下水動態監測資料相對匱乏。本研究整合和平地區觀測井為期4年的地下水質量測數據，包含水體主要化學特性、微量元素及同位素等分析，旨在釐清結晶岩區域水化學特徵之時空演化，並解析水質季節性變異與長期穩定性。本研究透過多變量分析(multivariate analysis)識別水體空間異質性，進而探討補注來源與岩-水交互作用(water-rock interaction)差異，為區域水資源管理與永續利用提供具代表性之科學基礎。

本研究藉由兩個試驗井群，透過岩心判識與X光繞射(XRD)分析顯示，區域主要岩性以長英質及鐵鎂質片麻岩為主，主要礦物為石英(Quartz)、長石(Feldspar)及雲母(Mica)，其中石英與長石含量合計超過60%，部分樣品局部出現蝕變特徵。水質分析結果顯示，兩井群地下水均屬 Ca-HCO_3 型；長期監測數據亦指出，地下水中之鈣、碳酸氫根離子及保守性元素(如氯)受季節性乾濕變化影響較不顯著，反映出區域水文條件與外部鹽源輸入之穩定性。研究以主要溶質組成結合微量元素特徵與同位素標記，證實除受碳酸鹽類礦物溶解主導外，兩井群亦分別伴隨不同程度之矽酸鹽風化(Silicate weathering)與岩-水交互作用。而多變量統計分析結果顯示，透過聚類分析(HCA)樣本可分為兩大獨立群體；主成分分析(PCA)則進一步揭示，區域地下水體演化受控於岩-水反應強度與補注機制之差異，使兩井群在溶質富集程度與補注來源上呈現出顯著之空間差異性。本研究成果不僅填補東部結晶岩地區長期水質觀測之空白，亦為區域地下水資源管理與構造活動帶之深部循環演化模型提供關鍵的數據資料。

Oral Report V2-O-115

Sediment Provenance and Drainage Reorganization of the Red River, Northern Vietnam: Constraints from Detrital Zircon U-Pb Geochronology

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Abstract

Cenozoic India-Asia collision fundamentally reconfigured the geomorphology of Southeast Asia, driving reorganization of major river networks in response to the Tibetan Plateau uplift and regional deformation. The upper Yangtze River has long been inferred to have drained southward into the Red River prior to the Late Miocene, after which the sediment provenance of the Red River is considered broadly stable, dominantly with signatures of Yangtze and Songpan-Garzê blocks. These interpretations, however, rely primarily on modern fluvial deposits and offshore sediments, leaving the thick Cenozoic succession preserved in the Hanoi Basin largely unconstrained.

This study presents new detrital zircon U-Pb data from borehole samples of the Hanoi Basin to reconstruct the temporal and spatial evolution of sediment provenance within the Red River system. Sediment sources upstream of major confluences have remained broadly consistent through time, whereas the Hanoi Basin records distinct provenance shifts since the Late Miocene. The Ailao Shan-Red River Shear Zone (ASRRSZ), Phan Si Pan Uplift, and Song Chay Dome exerted a stronger influence on basin sedimentation than previously recognized. Fluctuations in their relative contributions document a progressive drainage reorganization. The Lo River was incorporated into the Red River system by the Late Miocene, followed by integration of the Da River in the early Pliocene. This Neogene catchment expansion was likely driven by kinematic reversal along the ASRRSZ (~12-5 Ma), modulated by concurrent regional climate change, and reflects the dynamic coupling between tectonics, drainage evolution, and sediment routing in the Red River system.

Oral Report V4-O-116

Is there old lithospheric mantle beneath Lutao?

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ABSTRACT

The active margin of East Asia is one of the best regions in the world to find mantle xenoliths hosted by mafic to intermediate volcanic-arc rocks. Mantle xenoliths of the Northern Luzon volcanic-arc are found on the island of Lutao. The xenoliths from Lutao and are primarily composed of spinel-bearing harzburgite with subordinate lherzolite and olivine pyroxenite and have not been metasomatized. All rocks have chondritic Sr–Nd isotopes ($^{87}Sr/^{86}Sr_i$ = 0.7044–0.7079; $\varepsilon_{Nd}(t)$ = 0.0–+1.5). The two-pyroxene equilibrium temperatures range from 900–1200°C and the oxygen barometry estimates yielded values of ΔFMQ = 0 to +2. The xenoliths are considered to be representative of the lithospheric mantle of the Philippine Sea Plate. However, it is posited that a portion of the Northern Luzon volcanic-arc covering the Coastal Range, Lutao, and Lanyu is built upon a sliver of old continental crust derived from the Cathaysia Block of South China. The Os isotopic values of the Lutao mantle xenoliths are compositionally similar to off craton subcontinental lithospheric mantle

($^{187}Os/^{188}Os$ = 0.1168 to 0.1267; γ_{Os} = -8.0 to -0.2) with mantle (T_{MA} = 0.07 to 2.12 Ga) and rhenium depletion (T_{RD} = 0.04 to 1.50 Ga) model ages ranging from early Mesozoic to Neoproterozoic (T_{MA} = 0.21 to 0.90 Ga; T_{RD} = 0.19 to 0.83 Ga). For the exception of one sample, the model ages are substantially older than the age of the Philippine Sea Plate (≤ 55 Ma). The Mesozoic to Paleoproterozoic model ages are contemporaneous with major crustal evolution events in the Cathaysia Block and supports the hypothesis that portions of the Northern Luzon volcanic-arc are built upon older continental lithosphere.

Oral Report V4-O-117

Geochemistry of Paleoproterozoic giant radiating dyke swarms on the Southern and Superior Provinces, Canada

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The Archean Superior Province and the Proterozoic Southern Province are located at the core of the Canadian Shield. These long-lived cratons preserve not only the legacies of distinct geological events throughout Earth's history but also world-class deposits of critical minerals (e.g., Ni, Cu, and REEs). Proterozoic large igneous provinces (LIPs) played a crucial role in crustal thickening processes and were preserved as extensive radiating dyke swarms following the erosion of their volcanic sequences. The mafic dyke samples in this study are primarily classified as gabbro (SiO_2 = 46–53 wt.%). The geochemical fingerprint diagram based on Th/Nb versus TiO_2/Yb is a useful tool to distinguish the signatures of different mantle sources for LIPs. Samples are classified based on their affinity to three end-members: subduction-modified lithospheric mantle (SZLM), mid-ocean ridge basalt (MORB), and ocean island basalt (OIB). The 2075 Ma Fort Frances dykes (FF) show a concentrated MORB signature (Th/Nb < 0.15, TiO_2/Yb < 0.8, La/Sm < 2, and Sm/Yb < 1.5). The 2125 Ma Marathon dykes display a trend from transition between MORB and OIB to SZLM (Th/Nb = 0.1–0.4, TiO_2/Yb < 1, La/Sm = 1.5–4, and Sm/Yb = 1–2.5). The 2167 Ma Biscatasing dykes, combined with previous studies, show a trend from MORB to SZLM (Th/Nb = 0.1–0.3, TiO_2/Yb < 0.6) and a slightly enriched LREE pattern (La/Sm = 1.5–2, and Sm/Yb = 1–1.5). The 2217 Ma Nipissing sills plot within the SZLM field (Th/Nb = 0.6–0.8, TiO_2/Yb < 0.8) but exhibit relatively flat to slightly enriched normalized REE patterns (La/Sm = 2.5–3.5, and Sm/Yb ≈ 1). Although the 2459 Ma Matachewan dykes show a trend originating from MORB, they plot mostly in the SZLM field (Th/Nb = 0.2–0.6, TiO_2/Yb = 0.3–0.5) with slight LREE enrichment (La/Sm = 2.5–4, and Sm/Yb = 1–1.5). The differences of geochemical signature between dyke systems suggest a mantle source variation under Canadian Shield, which might be related to the tectonic events.

key word: Superior Craton, Giant radiating dyke swarm, Paleoproterozoic

Oral Report V4-O-118

Distinct magmatic systems of the Hai Van granites in central Vietnam

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Key words: Indochina block, Hai Van granite, Truong Son belt, Kontum massif, U-Pb zircon dating, Indosinian Orogeny, Paleo-Tethys Ocean.

Abstract

Central Vietnam is formed by the junction of the Truong Son terrane and the Kontum massif. As a key tectonic and metallogenic unit within the Indochina block, this region contains several volcano-plutonic complexes. Among these, the Hai Van granite is one of the largest and is considered to extend across both the southern Truong Son belt (TSB) and the Kontum massif (KTM). Previous studies reported their similar geochemical characteristics, such as metaluminous, calc-alkali to alkali-calcic, and medium- to high-K signatures; however, new U-Pb zircon dating, mineral chemistry, and whole-rock geochemistry reveal fundamental differences in their magmatic evolution: (1) U-Pb zircon dating indicates a single magmatic episode at 430.0 ± 1.6 Ma in the TSB, related to northward subduction along the Paleo-Tethys Ocean and likely triggered by slab failure during the Ordovician-Silurian period, whereas the Kontum massif records episodic magma emplacement between 262.3 ± 1.9 Ma and 237.4 ± 2.1 Ma associated with a volcanic-arc setting related to the Indosinian orogeny. (2) Biotite thermobarometer indicates higher P-T (3.3-4.4 kbar, 644-693^{o}C, respectively) conditions and a narrow ΔQFM range (-0.9 to -0.8) for the Truong Son samples, suggesting a stable and reducing magmatic system; in contrast to lower P-T conditions (1.1-3.4 kbar, 614-680^{o}C, respectively) and a wider ΔQFM range (-1.0 to +0.56) for the Kontum samples, reflecting a transition from oxidizing to reducing environment. (3) Geochemically, the Truong Son samples are mainly magnesian with a wide Eu/Eu* range (0.25-3.24), meanwhile the Kontum samples are magnesian to ferroan with a narrower Eu/Eu* range (0.49-1.49) and locally contain microgranular enclave indicative of magma mixing. These differences demonstrate that the Hai Van granites from the southern TBS and the KTM represent products of separate intrusive complexes formed during distinct magmatic episodes rather than a single unified complex.

Oral Report V4-O-119

Slab Tear and Subduction Reinitiation Triggering Magmatism via Mush Short-Circuiting, Petrological Cannibalism, and Crustal Assimilation at Lutao Volcano

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Abstract

The Northern Luzon Arc (NLA) is one of the few active examples of arc-continent collision systems worldwide and is characterized by its unique “double arc” configuration. Lutao, located at the northernmost extent of the Luzon arc, is commonly regarded as the initial expression of the island arc branch. Previous studies on the Lutao debate over the coexistence of fractional crystallization, magma mixing, and crustal contamination remain enigmatic within a traditional liquid-dominated magmatic model. In this study, we re-evaluate the petrogenesis of the Lutao volcano using zircon U-Pb dating, whole-rock geochemistry, and Sr-Nd isotope analyses, within a "transcrustal magmatic system" model. Our results demonstrate that Lutao’s magmatic evolution was driven by three integrated mush-related processes: (1) Mush Short-Circuiting, reflecting rapid melt transport across the mush; (2) Petrological Cannibalism, remobilization and rejuvenation of pre-existing crystal mush; and (3) significant Crustal Assimilation during magma ascent and storage.

We propose that these processes were triggered by a major geodynamic transition associated with the "double arc" evolution. A shift in subduction dynamics—potentially

involving slab shallowing followed by slab rollback—triggered a slab tear within the South China Sea Plate. This tectonic rupture facilitated asthenospheric upwelling, which "re-ignited" the stagnant plumbing system beneath Lutao. This study provides an integrated framework for linking transcrustal mush processes with large-scale tectonic events, offering new insights into the origin of geochemical architecture in arc magmatism at convergent margins undergoing subduction reorganization.

Keywords: Slab tear; Double arc evolution; Transcrustal magmatic system; Lutao volcano; Northern Luzon Arc.

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Calcium Phosphate and its Role in Revealing the Petrogenesis of the Southampton Pallasite

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Phosphate minerals are important accessory phases in meteorites, acting as the primary carrier of rare earth elements (REEs), incompatible elements (Y, Zr, etc.) and halogens (F, Cl, OH). In pallasite (stony-iron meteorites), common phosphate minerals are present as merrillite, stanfieldite and farringtonite. In the Southampton pallasite, two phosphate phases have been identified: stanfieldite and the merrillite subgroup endmember keplerite. Stanfieldite, $Ca_4Mg_5(PO_4)_6$, has been found in pallasite, mesosiderite and few lunar meteorites, contrary to Merrillite $Ca_9NaMg(PO_4)_7$, which is ubiquitous in meteorites. Conversely, keplerite $Ca_9(Ca_{0.5}\square_{0.5})Mg(PO_4)_7$, a recent identified mineral, has only been observed in few meteorites, and in the Southampton pallasite occurs as primary and secondary mineral. Stanfieldite and the primary keplerite are located in the interstitial space between olivine crystals. Both of the minerals do not show chemical zonation, however, REEs concentration decreases from keplerite to stanfieldite. The chondrite-normalized REEs trends show an enrichment in LREEs (La_N/Yb_N = 1.5-3.1), and the Eu_N/Eu_N* anomaly differs among crystals (0.1-1.0). Secondary keplerite is enclosed in Mg-P rich alloy and shows a similar crystal structure to apatite based on its Raman spectra. Its CaO content remains similar to the original keplerite composition (45-48 wt.%), whereas P_2O_5 content is lower, ranging from 39 to 41 wt.%. The chondrite-normalized REEs pattern shows the same LREEs enrichment trend (La_N/Yb_N= 3.4) as the primary keplerite, however, Eu concentration is below detection limit. The secondary keplerite, and potentially stanfieldite, represents a hydrothermal alteration caused by Fe-rich fluid. In contrast, the primary keplerite is the primary Ca-bearing phosphate which reflects a late-stage high temperature and Na-depleted environment, bulk composition of REEs, and volatiles (F, Cl, OH) of the melt from which it crystallized.

#pallasite #phosphate #meteorites #planetary evolution

呂宋島弧的硼同位素地球化學觀測—初步結果與討論

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摘要

呂宋弧(Luzon arc) 由南北長 1200 公里的鏈狀火山島所構成，北端點為台灣海岸山脈，南端到菲律賓的民都洛(Mindoro)島，1 千 5 百萬年以來南中國海向東隱沒所形成，前人研究認為在不同年代有不等程度的大陸地殼物質混染，但對於岩漿的生成是源區混染或是在地殼中混染則有不同看法，此外在菲律賓段有雙島弧的討論和中洋脊隱沒的推論，還有年輕隱沒板塊直接熔融的埃達克岩議題。硼在島弧火成岩中來自隱沒物質，並且在加入地函的溫壓漸增的變質過程中產生同位素的分異，故可反映隱沒系統的物理條件，本研究透過硼同位素的觀察，嘗試了解對這些問題的意涵。目前完成分析海岸山脈和綠島蘭嶼樣本>40 個，以及菲律賓樣本 18 個，岩性依 TAS 分類屬於 basaltic andesite, andesite, dacite, 少數為 basalt。本研究首先透過岩石粉末 XRD 和萃取方式嘗試辨析可能的受風化影響的樣本，檢視是否對微量元素和硼同位素分析結果的代表性產生影響，並進行全岩地化分析，樣本年代方面，在海岸山脈與蘭嶼參考前人研究的地點年代，在菲律賓部分則採用本系老師定年結果；初步結果顯示海岸山脈與綠島蘭嶼在微量元素富集分布型態有顯著差異，而在硼同位素方面，當比較硼濃度、Nb/B 比值以及硼同位素值，可分辨出在海岸山脈、綠島蘭嶼和菲律賓火成岩存在系統性的差異：海岸山脈 Nb/B 比值 0.05 到 0.5, $\delta^{11}B$ -6‰ 到 10‰，綠島蘭嶼 Nb/B 比值 0.2 到 1.4, $\delta^{11}B$ -13‰ 到 5‰，菲律賓樣本 Nb/B 比值 0.2 到 2.5, $\delta^{11}B$ -6‰ 到 5‰；以 Nb/B 初步看隱沒流體進入的量以海岸山脈最為顯著類似一般的島弧，綠島蘭嶼和菲律賓部分則減少接近於較熱板塊的隱沒，然而 $\delta^{11}B$ 則變化大且重疊性高。本研究嘗試整合前人研究與測得的硼同位素資料來探討北呂宋島弧的岩漿生成和隱沒物理條件時空變化問題。

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2025年台灣花蓮馬太鞍巨型崩塌之地形分析及破壞機制

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摘　要

2025年7月21日花蓮馬太鞍溪上游支流望溪發生超大型山崩，崩塌材料先向東南崩落，高速移動沿望溪轉向南側進入馬太鞍溪，形成巨大天然壩並阻塞主河道。由災前後高解析度光達地形分析與正射影像判釋，崩塌影響範圍約570ha，體積高達3.36億m3，為目前臺灣山崩文獻紀錄中量體最大者；所形成天然壩最大厚度約250m，沿河道方向長約2,300m，潰決前溢流口高程約1,140m，下游壩趾高程約700m，顯示其壩體規模極為龐大。災前衛星影像顯示，2024年0403花蓮地震後，歷經凱米、山陀兒、康芮、天兔等颱風及2025年1月21日大埔地震後，來源區冠部沿稜線逐漸發育出長約1,280m之清晰圈合張裂縫，並於2025年7月經歷丹娜絲與薇帕颱風後崩塌。綜合地質資料、地形分析與現地調查，研判馬太鞍超大型山崩屬逆向坡構造，岩層受褶皺與剪切帶影響而呈彎曲與錯移，但仍可概分為綠色片岩夾大理岩、彎曲大理岩、黑色片岩與大理岩互層、厚層黑色片岩及綠色片岩層五個單元。主剖面分析顯示，崩崖頂高程約2,400m，推估剪出口高程約1,200m，水平距離約1,500m，崩塌體最大垂直深度約325m；最終崩崖較崩前張裂縫平均後退約50m，最遠可達260m，崩崖面坡度由上部58°向下漸緩至40°，視摩擦角自崩崖至望溪對岸與天然壩右岸分別為19°與16°。

據此研判，其破壞機制為冠部張裂縫擴展形成陡峭脫離面，下部厚層黑色片岩與綠色片岩於趾部發育剪出面，兩者連接後形成非典型楔形滑動。現地調查顯示，崩積層可區分為以綠色片岩、黑色片岩及大理岩為主之分布區；潰壩後殘壩仍局部保留具岩體結構之崩積層，表層則以巨礫與岩屑為主，呈現明顯不同之組成樣貌。殘餘崩積層表面另可見類似原坡面地表之地貌特徵，推測可能來自崩塌前坡頂；UAV近距離側視亦可辨識壩體局部不同材料分區，顯示壩體組成在岩性與組構上具有高度不均質性，值得進一步探討其對潰壩歷程之影響。

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Intense CO_2 Release from Channel Deposits Triggered by Catastrophic Collapse of a Landslide-Induced Dam in Eastern Taiwan

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Chemical weathering imposes a vital control on climate fluctuation by regulating the atmospheric CO_2 level through various processes that bear different degrees of dependency on geological material supply and chemical inertia. The extent to which these reactions proceed with major landscape changes in orogenic belts remains largely unconstrained. A landslide event in the Matai'an River in the Central Range of eastern Taiwan on July 21, 2025, generated 320 million cubic meters of deposits that were accumulated on the hillslope and dammed the river flow. Subsequent torrential precipitation associated with typhoons resulted in the overflowing and failure of the dam about two months later, re-distributing 52 million cubic meters of sediments along the river bank. Such a large quantity of lithogenic materials produced by mass wasting and fluvial processes on a monthly scale could be reactive for CO_2 production, thereby providing an unparalleled opportunity to constrain how extreme and what mechanism CO_2 evasion is manifested by material supply. In this study, direct measurements of CO_2 gas fluxes were performed at more than 100 sites, yielding gas accumulation at a rate spanning from 0.4 to 150 g-C/m^2/d. This range ranks among the highest ever reported for weathering processes in mountainous catchments. Analyses of carbon isotopic compositions further revealed that the collected CO_2 was predominantly sourced by pyrite-driven carbonate dissolution, with minor contributions from carbonate dissolution by atmospherically derived carbonic acid, and rock-bound and soil organic carbon. By multiplying the averaged flux with the sediment coverage area along the river, the emission of gaseous CO_2 was estimated at a rate of ~220 ton-C/d. This rate exceeded catchment-wise landslide-induced (this event) and pre-landslide baseline levels based on riverine chemistry by at least an order of magnitude. Such an enormous carbon export would persist until these landslide deposits are completely evacuated and pyrite is exhausted. Our results demonstrate that the jumpstart of carbon evasion through rapid weathering of bank sediments by transient and extreme landscape changes in active orogenic belts represents a missing link to complete the assessment on the catchment-scale carbon budget in active orogenic belts.

Oral Report NH1-O-124

潛在大規模崩塌兩階段評估法之發展與案例實證

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摘　要

臺灣地處造山運動活躍帶，地質構造破碎，目前在全球氣候變遷引發極端降雨之背景下，大規模崩塌災害之風險評估成為國土保安之關鍵課題。經濟部地質調查及礦業管理中心於莫拉克颱風後已在全臺判釋出2,500處潛在大規模崩塌，但亟需建立一套針對臺灣本土環境量身打造之分級與分類標準，以利最佳化防災資源配置，並降低可能引致之大規模崩塌災害風險。

本研究綜整Varnes(1978)與Hungr(2014)之國際山崩分類體系，並彙整日本地滑學會AHP評分法及挪威NGU風險矩陣之實務經驗，研擬一套適用於臺灣地質環境之兩階段評估方法學。第一階段之大規模崩塌分類與分級Level 1表格，係以高解析度空載光達LiDAR地形資料為核心，針對崩崖、滑動體、兩側邊界、趾部特徵及河岸侵蝕等七項關鍵地貌因子進行權重評分，旨在從2,500處潛在大規模崩塌中，系統化地初篩屬A與B級之高風險等級對象。第二階段之大規模崩塌分類與分級Level 2表格，則針對高風險之潛在大規模崩塌進行更進一步之活動性評估，過程中整合破壞機制判定、定性化不利穩定特徵勾選，並導入歷史崩塌頻率、裸露面積比及坡體應變率等定量指標進行量化分析。

為驗證本研究所擬定之兩階段評估方法於實務應用之適用性與可靠度，本研究選取具代表性之潛在大規模崩塌案例作為實證填表，並透過標準化填表流程進行兩階段評定。研究結果顯示，此兩階段評估流程能有效將定性之地形演育特徵轉化為客觀之活動性等級，實證結果與潛在大規模崩塌案例之現地崩塌特徵相符，證實本研究所建立之評估方法能精確判別高活動性之危險邊坡。承上所述，本研究建立之評估準則，不僅能釐清潛在大規模崩塌之演化階段，亦可作為山崩與地滑地質敏感區劃設、防災策略規劃及監測導入優先順序之科學化參考。

關鍵字：潛在大規模崩塌、大規模崩塌分類與分級Level 1表格、大規模崩塌分類與分級Level 2表格、活動性評估。

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Geologic and geomorphic controls on the 2025 Matai'an landslide

馬太鞍崩塌與堰塞湖的地質與地形控制初探

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2025年7月發生的馬太鞍（MTA）崩塌事件，並在台灣東部中央山脈地區形成大型堰塞湖，這是21世紀規模最大的山崩事件之一。在區域性地震及颱風強降雨之後，於2025年9月的壩體潰決造成重大的連鎖地表災害並且造成人員傷亡及基礎設施損壞，而殘留的大量崩塌堆積物對下游社區構成長期威脅。 MTA事件引起國內外各界關注，在各種研究中也促使我們探索：此類災難性事件究竟是偶然發生，抑或是在這個快速抬升、氣候潮濕山脈中反覆發生的現象？

本研究初步整合多時期衛星影像、歷史與現代航空攝影，以及DEM地形分析，以釐清MTA崩塌機制及區域性山崩歷史。在崩塌起始帶，野外調查與遙測觀測揭示出廣泛的土流型崩塌複合體，主要由風化及流化的泥質片岩碎屑組成，僅含少量巨礫級岩塊。這些物質起源於大理岩－片岩基岩接觸帶附近，該帶的破裂帶作為地下水導流通道，促進泥質片岩風化為富含黏土的易液化物質。時間序列分析揭示出強烈的季節性變化，以及崩塌前數十年地表水分保留（NDWI）增加與植被受壓迫的長期趨勢，為生成風化細粒物質並逐漸達到飽和創造了理想條件。

為使此快速抬升地形的坡面上累積約3億立方公尺的可滑移物質，本研究觀察到在MTA崩塌附近河道有顯著遷集點（裂點），作為局部基準面，形成較平緩的上游坡降，進而限制沉積物的連通性與輸送效率。使風化物質得以在2025年崩塌前大量聚積。此地形配置加上加速的基岩風化，使集水區上游的碎屑產出速率超過河流下切速率。因此，大量風化崩積物在坡面上持續堆積，直至被地震地面振動及颱風觸發因素突破力學閾值。

Oral Report NH2-O-126

Enhancing H.E.P Dam Safety from natural hazard in Taiwan: A Spillway-focused Analysis

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Abstract:

Taiwan's large reservoirs operate within one of the world's most active plate-boundary systems and are subjected to strong tectonic and hydrological stresses, while many aging dams require elevated safety consideration. This study develops an integrated multi-hazard framework combining reservoir-triggered seismicity (RTS), regional probabilistic seismic hazard analysis (PSHA), flood frequency analysis, and time-lag correlation analysis using Gumbel and Log-Pearson Type III models to evaluate spillway and structural performance for Feitsui, Shihmen, Zengwen, and Wushantou reservoirs. The northern reservoirs (Feitsui and Shihmen) show very weak correlations ($r \approx 0.16–0.20$) at lags of +6 and −3 months, while the southern reservoirs (Wushantou and Zengwen) exhibit similarly weak correlations ($r \approx 0.14–0.20$) at −4 to −5 months, indicating limited and delayed hydrological influence on seismicity. PSHA within a 1° × 1° grid predicts Safety Evaluation Earthquake (SEE) magnitudes of approximately Mw 7.7–7.9 for Taiwan-wide high-hazard design. An increase in moderate to strong events after 2018 mirrors pre-1999 Chi-Chi seismic build-up, suggesting elevated future hazard potential. Flood frequency results indicate that some dams may not safely withstand probable maximum floods (PMF), raising cascading failure concerns in interconnected systems such as Zengwen–Wushantou. Overall, the findings underscore the critical need for inflow-based, integrated multi-hazard dam safety frameworks, with Taiwan serving as an instructive case study.

Keywords

Flood risk management, Gumbel distribution, Log-Pearson Type III (LP3) distribution, return period analysis, typhoon-induced floods, Reservoir-triggered seismicity, Probabilistic seismic hazard analysis, Dam safety management, ICOLD guidelines.

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利用海嘯波型逆推探討2024年4月3日花蓮地震之斷層模型

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摘　要

2024年4月3日，台灣花蓮縣發生了一場規模Mw 7.4的地震，早先台灣中央氣象局為觀測台灣東部海域之海嘯所建設的海底電纜壓力計，其中的五個測站(EOS2,3,8,9,A)在本次事件中第一次接收到清晰的海嘯訊號，為海嘯逆推研究提供良好的數據。

為確保逆推的穩定性，我們針對逆推模式進行敏感度分析，分析結果顯示，測站的數量不會大幅度影響逆推結果，在確保訊號品質的前提下，即使只有一個測站也能使逆推結果維持穩定。本研究利用海底壓力計所觀測到的海嘯波訊號，針對可能的東傾及西傾斷層模型進行逆推，並對比及討論逆推波型與觀測波型上的差異，旨在以海嘯訊號的角度探討2024花蓮地震的斷層構造。

我們使用EOS2、EOS3的觀測資料進行逆推，所使用的資料長度為地震發生後四十分鐘內的資料，EOS8、EOS9、EOSA則不參與逆推，用於探討逆推結果之波型與觀測波型的吻合度。

最終結果顯示: 由於逆推的數值擬和作用，東傾模型及西傾模型的逆推結果在參與逆推的EOS2、EOS3測站均能很好的對齊觀測值；但是在未參與逆推的EOS8、EOS9、EOSA測站，西傾模型的逆推結果能夠更好的對齊觀測波型，說明西傾模型以及其滑移量分布所產生的海嘯源較符合現實，因此根據以上結果，本次事件引發海嘯的主震，較有可能是西傾構造。

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池上斷層滑移速率統計與初步分析

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摘　要

在執行機率式地震危害評估(PSHA)工作時，斷層滑移速率除了顯示斷層的活動度外，亦用來描述地震的發生率。斷層滑移速率的取得可分為兩大部分，1.地質長期滑移速率方面一般由階地或槽溝開挖取得指準層高差與定年計算而得抬升速率及應變計取得水平速率;2.測地短期滑移速率則以GPS或InSAr分析計算所得水平與垂直變化率。

我們蒐集池上斷層沿線的地質抬升速率、地質水平速率、測地抬升速率及測地水平速率(垂直斷層)，以池上斷層傾角60度計算斷層面上滑移速率，這四個的統計結果依序為 19 ± 10 公厘/年;46 ± 10公厘/年; 24 ± 7公厘/年;43 ± 11公厘/年。

在水平速率方面，地質與測地的結果呈高度吻合，顯見觀測期內斷層在的地表水平方向的壓應力傳遞較一致。而在垂直方向上，測地則略大於地質的結果(5 公厘/年)，推測垂直方向的壓應力傳遞可能受到岩層間變形與潛移的影響。

關鍵字:PSHA、斷層滑移速率、池上斷層

應用非連續雙黏性流模式探討歪型海膽於大滅絕事件中存活之謎

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摘 要

古生物歪型海膽(Claviaster libycus)在面臨造成大滅絕之洪水時，因其特殊外型，相較於一般形狀之正型海膽有更高之存活率。本文旨在透過模擬與分析歪型海膽的特殊外型對流場的影響，以及其減緩周圍海砂局部沖刷的機制，以借鑑於現今海事與橋梁工程之基礎局部沖刷問題。

鑑於歪型海膽周圍之三維流場與局部沖刷時產生之強烈紊流，本文於數值模式方面選擇 Splash3D 模式。該模式求解三維 Navier-Stokes 方程式，並以LES (Large Eddy Simulation)大渦模擬閉合紊流模型，此外，本模式還利用 VOF (Volume of Fluid Method) 流體體積法追蹤各流體之介面，以及考慮到海膽有潛沙之特性，使用了DBM (Discontinuous Bi-viscous model) 非連續雙黏性流模型以此描述底床泥沙之流變行為。

本研究採用潰壩方式模擬海膽所受之強烈水流，並僅專注於海膽的外形對流場的影響。考慮到歪型海膽的形狀不對稱，海膽面向水流和背部面向水流所受到的影響不盡相同，以及海膽埋沙深度和角度亦會影響周遭流場變化，因此本研究將海膽固定在同一位置，只探討其外形所帶來的影響。模擬結果顯示，當歪型海膽背部面向水流時，對流場及局部沖刷的干擾較少。相對於正型海膽，歪型海膽在流場中對於流場及底床的干擾較小，其下游處所產生的局部沖刷坑也較小，這使得歪型海膽更不易受到水流沖走。

透過定床沖刷模擬分析海膽周圍的流場及壓力變化，與動床沖刷模擬相互對應，分析了泥沙受流場影響之沖刷機制。本研究結果顯示，歪型海膽的特殊外型確實使其於面臨水流沖擊時具有較好的優勢，並可藉由此特殊外型機制開發為仿生拋石結構，減緩海事或橋梁工程所面臨的局部問題。

關鍵詞：歪型海膽、局部沖刷、DBM、Splash3D

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利用地表水與地下水耦合數值模型解析高屏溪流域水文循環與水文收支

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摘　要

高屏溪流域為臺灣重要之水資源供應區，地表水與地下水之交互作用對區域水資源管理具有關鍵影響。本研究以高屏溪流域為主要研究區，建立地表水與地下水整合模擬架構，解析該流域之水文循環與水文收支特性。數值模式選用SWAT 模式模擬河流流域的水文歷程，並以MODFLOW模式模擬地下水系統，最後再進一步將SWAT與MODFLOW進行耦合，進一步分析地表水與地下水之交互作用與時空分布特性。研究蒐集2011至2023年之降雨、氣象、水文與地下水位等資料作為模型輸入，並以分布於各子流域之主要流量測站資料進行河川流量率定與驗證。地表水模擬結果顯示，SWAT 模型能合理反映流量之年際與季節變化，但在豐水期模擬流量有低估的情形，顯示在山區之降雨事件下，部分高流量事件下之洪峰無法準確掌握。地下水模擬結果顯示，模型可掌握地下水位之長期變化趨勢。此外，耦合模擬結果顯示降雨為主要水源來源，水體於地表逕流、側向流、地表水與地下水交互作用及地下水儲存之間分配，呈現明顯之年際變動。進一步解析在不同氣候與用水需求情境下之水資源時空變化，結果顯示地下水可減緩水資源需求增加之衝擊，然而過度之抽水行將造成顯著的地下水位下降，影響整體地下水資源儲量。整體而言，本研究建立之耦合數值模擬可用於評估從山區至下游平原整體流域之地表水與地下水互動關係，並提供未來流域水資源管理與永續利用之參考依據。

關鍵字:高屏溪流域、數值模式、SWAT-MODFLOW、水文循環、水文收支

屏東平原北部區域之人工補注潛勢區位及開發潛勢區位評估

林燕初、賴慈華、石同生、張良正、陳祐誠

屏東平原、臺中盆地及嘉南平原等地區，雖然以往已有相當多水文地質及地下水相關的研究，包括地下水觀測站網建置及地下水補注敏感區劃設，及所需之水文地質調查評估及地下水相關的各種模擬分析等。然而，以往之調查分析多以區域地下水資源評估為目標,調查分析尺度相對較大，對支援地層下陷或擴大入滲補注、抗旱找水等相關分析，仍然有所不足，因此需要持續新增調查，以發展更精細的三維水文地質模型，並進一步搭配地理及水文資訊規劃之高補注及開發潛勢區域，作為地下水保育、補注及開發之依據。

本研究以屏東平原北部區域為例，整合地球物理探測資料推估區域三維電阻率模型，並搭配岩芯及水文地質剖面資訊，進一步推估三維水文地質模型，依模型之淺層岩性資訊，計算地表下 30 公尺內，礫石與中粗砂累積厚度，即為天然補注分級，將厚度由薄至厚分為 1 至 5 級，補注能力由低至高，以天然高補注分級(5 級)範圍為基礎，搭配土地利用及鄰近水源等地表資訊,於範圍內建議 3 處人工補注潛勢區位;依模型之淺層岩性資訊，計算地表下 100 公尺內，礫石與中粗砂累積厚度，搭配現地試驗之導水係數(T)，推估出開發潛勢分級，並於高開發潛勢(5 級)範圍內，建議 2 處開發潛勢區位。

關鍵詞：天然補注分級、人工補注潛勢區位、開發潛勢區位

Keyword : Classification of Natural Recharge, Potential for Artificial Recharge, Groundwater Development Potential

Oral Report H1-O-132

從山區到平原區之地下水流動路徑與補注機制探討 – 以高屏溪流域為例

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摘要

近年來受極端氣候影響，臺灣西南部地區出現缺水危機之問題日益嚴重。山區具有豐富的地下水儲量，但過去常低估其對平原地下水補注的貢獻，為有效利用水資源，必須深入了解山區地下水的來源及其資源分布情形，並進一步探討其補注機制。本研究透過解析地下水自山區補注下游平原區之形式區分為山前補注(Mountain Front Recharge, MFR)與山體補注(Mountain Block Recharge, MBR)，除了區分兩種補注之差異，並嘗試評估其分別對於平原區地下水補注量之貢獻程度。試驗地點位於高屏溪流域，透過結合長期的地下水位監測資料蒐集、水質資料分析（氯離子質量平衡法，chloride mass balance, CMB）及現地試驗（分散式光纖溫度感測器為基礎之主動式加熱試驗（active distributed temperature sensor, ADTS），嘗試推估 MFR 與 MBR 之流動路徑與補注量。初步結果顯示，新威地區同時具有 MFR 與 MBR 兩種地下水補注機制，分界約在井下 40 公尺深，且淺井及深井之氯離子濃度差異進一步佐證此推測；寶來、旗山及三地門地區，因井下特定深度受到剪裂的影響，具有較快的流速，氯離子濃度在試驗井之間存在著顯著之差異，推測有不同的補注機制；瓦阿系地區則在深度 40 公尺以上流速較快，深度 90 公尺以下的岩層較為完整緻密，呈現流速較慢的情形。後續將持續進行流速分析，並結合全流域的地表水與地下水氯離子濃度，研析其進行補注機制之研析及補注量之推估。本研究藉由長期資料解析及現地試驗佐證，完整地解析高屏溪流域從山區到平原區的地下水流動與補注特性，其結果可進一步提升對該區域地下水資源的掌握及未來的規劃與管理。

關鍵字: 高山水文地質、山前補注、山體補注、主動式加熱試驗、氯離子質量平衡法、地下水資源管理

Oral Report H1-O-133

整合機器學習與地理統計方法於三維岩性模型建置–以屏東平原為例

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摘　要

摘要內容在地下水模擬或地質災害的風險評估中，建立可靠的地質模型至關重要，然而由於鑽井成本高昂，研究區內能取得的鑽井資料往往相當有限。為了重建完整的地質模型，傳統地質統計方法（如 kriging）常被採用於進行空間推估，然而，此類方法多建立於高斯分佈與線性估計等假設上，實際之岩性場通常具有高度異質性，使得上述這些假設難以成立，導致三維岩性架構的建立具有相當大的不確定性。

為因應上述挑戰，本研究提出一套結合Extreme Gradient Boosting(XGBoost) 與貝氏最大熵法（Bayesian Maximum Entropy, BME）的混合式架構，嘗試在資料有限且考量地質異質性的情況下，推估三維水文地質機率分佈。XGboost為樹狀的機器學習模型而BME為一可考量資料不確定性之地質統計方法。首先，利用 XGBoost 學習專家詮釋之地質剖面與地形因子之間的關係，使用之地形因子包括空間座標、流域屬性、DEM與坡度等。透過所訓練的模型可建立研究區之初始岩性機率場，接著透過BME與現有鑽井觀測資料進行整合，產生最終的三維岩性機率模型與不確定性。

本研究以機器學習方法將專家知識與地形因子導入三維地質之推估中，以彌補鑽井資料稀少之限制，並結合BME考量資料之不確定性，進行三維岩性模型之建置。研究將以屏東平原為案例，展示此架構之應用潛力。結果顯示，混合式 XGBoost–BME 架構能有效融合多源資訊進行岩性建模，為資料稀少條件下之三維岩性模型建置提供一套具實用性的推估方法。

關鍵字：XGboost、最貝氏最大熵法、三維地質架構推估

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Typology-dependent distribution and spatial heterogeneity of coastal microplastics in Taiwan

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Abstract

Microplastic (MP) pollution is a widespread issue in coastal environments, yet its spatial variability and governing drivers remain insufficiently understood, particularly in island systems with diverse coastal settings. Taiwan provides an ideal natural laboratory due to its complex geomorphology and intensive human activities. In this study, 29 coastal sites representing six typologies including estuaries, aquaculture areas, fishing ports, harbors, protected areas, and open coasts were surveyed, and surface seawater samples were analyzed for MP abundance and characteristics. Results show significant variation in MP distribution across both coastal types and regions, with estuaries exhibiting the highest concentrations due to strong terrestrial inputs and hydrodynamic retention. Higher MP loads were also observed along the central coast, associated with population density and riverine transport. Fibers and fragments dominated across all sites, and compositional differences were more strongly linked to coastal typology than geographic distance. These findings highlight the importance of typology-dependent and multi-scale processes in shaping MP distribution, providing insights for targeted monitoring and coastal management.

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臺灣東部土壤層水力特性初探：結合地表入滲與三軸透水試驗之分析

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本研究以臺灣東部和平溪至立霧溪間可及道路沿線區域為採樣目標，透過地表入滲試驗與土壤三軸透水試驗，建立土壤層水力特性數據資料，並探討其空間分布與季節變異特性。地表入滲試驗主要係針對未飽和層入滲行為，採用近年發展之ETC-Pask入滲儀進行現地量測，共完成31組表土試驗，並於乾溼季節分別取樣，以評估氣候條件對入滲參數之影響。而土壤三軸透水試驗則模擬飽和與壓密條件下之水力行為，透過施加不同三軸應力，量測水力傳導係數變化，現階段已完成43組不同深度樣本之試驗，並同樣進行季節性取樣分析。試驗結果顯示，地表入滲試驗所得之飽和水力傳導係數在乾季之變異範圍略大於溼季，顯示土壤結構與含水狀態對入滲行為具有一定程度之影響；而三軸透水試驗結果指出，隨壓密應力增加，20 ℃條件下之水力傳導係數呈現遞減趨勢，反映孔隙結構受壓縮所導致之滲流能力降低。整體而言，本研究結合現地與室內試驗成果，有助於提升對區域土壤水力特性之掌握，並提供後續水文地質模型建構之重要參數依據。

中文關鍵字：臺灣東部土壤層、地表入滲試驗、土壤三軸透水試驗、水力傳導係數

Oral Report H1-O-136

應用井下訊號推估技術推估複雜地層之岩性—以臺中盆地為例

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井測為地質鑽探完成後除岩心判釋之外，最直接瞭解井下水文地質狀況之測量方法，此測量方法需要在井裸孔狀態下方能利用探測器量測代表性數值，而在平原區岩層相較於山區結構鬆散，雖然鑽探完成後即將鑽桿拉起進行井測，仍無法完全避免起管後井壁失去支撐，具一定坍孔之風險，經由洗井清除碎屑效果有限且易改變井況，導致井徑不均並使測錄獲得參數增加不確定性。

本技術主要係於孔壁不穩定造成坍孔時，部分無法取得井測訊號之區段，其標準化推估流程(S.O.P.)為(1)收集部分裸孔測錄值與受鑽桿保護獲得之測錄資料後，(2)將其建立迴歸關係，(3)進行目標孔位之裸孔量測值補遺(推估)等三大步驟。而在電井測獲得之物理量中，又以自然伽瑪射線值（Natural Gamma Radiation, NGAM）與電阻率對地層岩性較有區別性，故此技術首要推估目標參數即為自然伽瑪射線。在電阻率部分，由於電阻率量測受鑽桿屏蔽效果較自然伽瑪值顯著，因此電阻率之推估係間接利用量測之裸孔自然伽瑪值及電阻率進行迴歸分析，再透過挑選之最佳迴歸關係式與後續所推估之裸孔自然伽瑪值進行電阻率之推估。

基於自然伽瑪射線對岩性之高辨識度，本研究蒐集地礦中心113年於臺中盆地執行之水文地質鑽孔，並應用上述推估技術於臺中盆地之地層岩性推估。概略區分淺層(0至50公尺)及深部(50至150公尺)統計自然伽瑪射線之測錄值，於深度0至50公尺內統計之自然伽瑪射線統計範圍較廣，估計淺部係因地層結構較為鬆散，組成較為複雜，故於盒鬚統計25至75%之範圍區間，明顯高於深部50至100公尺之統計值，整體而言，泥>砂>礫，礫石層約介於40至65 API、砂層約介於55至80 API、泥層則顯著大於80 API，可透過有限資訊推估具有高度代表性之完整孔內水文地質調查資料，推估技術之應用在取得測錄值之前提下，除可減少重複洗井次數，推估結果可提升含水層判定之精度，作為井體設計之科學依據，並有效降低坍孔造成之儀器損壞風險。

中文關鍵字：電井測、自然伽瑪射線(NGAM)、電阻率

Oral Report M4-O-137

Secondary Weakening in dm-Scale Laboratory Earthquakes: Frictional Origin or Rigid-Body Artifact?

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中文標題：分米尺度實驗室地震中的次級弱化現象：摩擦成因抑或剛體效應假象？

中文關鍵字：實驗室地震、地震破裂過程、線性彈性斷裂力學、凝聚區模型、PMMA 斷層

Keywords: Laboratory Earthquakes, Earthquake Rupture Processes, LEFM, Cohesive zone model, PMMA fault

Abstract

Earthquakes involve rapid fault slip, well described by linear elastic fracture mechanics (LEFM). Extending LEFM to laboratory earthquakes bridges lab and field observations, but scale and boundary-condition differences complicate direct comparison.

We built a decimeter-scale (dm-scale) single-direct-shear PMMA fault system (stationary & moving blocks) with independently controlled normal and shear loading. Normal stresses of 12–32 MPa are applied over a 50 cm × 5 cm interface, while constant displacement-rate shear loading at the load point promotes spontaneous nucleation. A dense strain-gauge array within 10 mm of the fault records dynamic strain through nucleation, propagation, and arrest, enabling inference of on-fault weakening. Experiments show a secondary weakening stage after the initial friction drop, with larger amplitude that increases apparent breakdown work and alters source-time functions and far-field radiation.

To interpret these observations, we run finite-element simulations replicating the geometry, elastic properties, and boundary conditions. Comparing simulated and measured strain fields constrains rupture dynamics, energy localization, and partitioning between fault dissipation and apparatus unloading driven by rigid-body motion. This comparison also tests LEFM assumptions against finite-size effects.

Beyond constitutive complexity, we find that rigid-body motion and apparatus unloading (mechanisms lacking a clear natural analogue) can dominate energy release, such that energy is released from the bulk apparatus rather than localized near the rupture tip—violating the small-scale yielding (SSY) assumption underlying LEFM.

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Oral Report M4-O-138

Rupture Area Recovery from Finite-Fault Inversion and Its Implications for Stress-Drop Estimation

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Stress drop is among the most widely reported earthquake source parameters, yet its reliability depends critically on accurate rupture area estimation. In both spectral and finite-source frameworks, rupture area enters the stress-drop calculation directly, so systematic errors in area recovery propagate into inferred stress drop. Despite its importance, how finite-fault inversion recovers rupture area under varying source complexity remains poorly constrained.

We construct a suite of synthetic earthquake scenarios using dynamic rupture simulations with a linear slip-weakening friction law, in which rupture geometry and nucleation location are prescribed and therefore exactly known. Overstress patch shape and boundary conditions are varied to produce ruptures ranging from compact and symmetric to elongated and off-center. Synthetic seismic waveforms generated from these models serve as input for finite-fault inversion, and the inverted rupture areas are compared quantitatively against the true values from the forward models.

The comparison reveals how source complexity, including non-circular rupture geometry and asymmetric rupture propagation, biases inversion-based rupture area recovery and the resulting stress-drop estimates. These results establish a controlled benchmark linking dynamic rupture modeling, finite-fault inversion, and stress-drop interpretation, and identify the source conditions under which finite-fault inversion yields reliable area estimates versus conditions where rupture area uncertainty becomes a dominant source of stress-drop bias.

Keywords: stress drop, finite-fault inversion, rupture area, dynamic rupture simulation

Oral Report M4-O-139

Source Parameter Analysis of Near-Fault Laboratory Earthquakes Utilizing Broadband Calibrated Acoustic Emission Sensors

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Abstract

Quantitative recovery of source parameters from laboratory earthquakes is hindered by the narrow bandwidth of conventional acoustic emission (AE) sensors, whose resonance and frequency-dependent attenuation severely distort recorded spectra above ~100 kHz. We present a broadband calibration and attenuation-correction framework that enables reliable spectral source parameter retrieval from near-fault AE recordings.

The absolute amplitude response of the Olympus V103-RB transducer was characterized from 1 kHz to 1 MHz by combining generalized ray theory (GRT), finite element analysis (FEA), and laser Doppler vibrometry (LDV). Frequency-dependent attenuation in PMMA was quantified through OpenSWPC wavefield simulations and corrected via a frequency-domain quality-factor operator Q_p.

Confined stick-slip events were generated in a biaxial shear apparatus within a controlled seismogenic patch, enabling investigation of rupture behavior from quasi-one-dimensional ruptures on narrow faults (5 cm × 50 cm) to two-dimensional ruptures on square faults (50 cm × 50 cm). The calibrated spectra were fitted with the Brune model to extract corner frequency f_c and high-frequency decay exponent n. Spectra consistently decay faster than the Brune ω^{-2} prediction, indicating gradual rupture arrest and suppressed high-frequency radiation. Seismic moment M_0, stress drop $\Delta\sigma$, and rupture area were robustly estimated derived from these fits show good inter-station consistency across multiple near-fault receivers, validating the end-to-end

workflow. These results underscore the necessity of broadband-calibrated instrumentation for reliably interpreting high-frequency source radiation in laboratory earthquake experiments.

Keywords: laboratory earthquakes, spectral analysis, attenuation correction, corner frequency, source scaling, broadband calibration

Oral Report M4-O-140

Frictional properties of the Chungling Formation under hydrothermal conditions and its implications for fluid injection-induced seismicity

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Abstract

Fluid injection will lead to an increase in pore pressure in a fault/fracture, causing a decrease in effective stress and the associated fault instability. Fluid injection is demonstrated to induce seismicity during the operation of Enhanced Geothermal Systems (EGS). Therefore, understanding both the frictional and healing properties of faults/fractures is key to EGS operation. Here we perform slide-hold-slide experiments using a hydrothermal pressure vessel (HYPE) equipped with a rotary shear apparatus. We use pulverized Chungling (CL) rocks from the Yilan area as the starting materials. The experiments were conducted under effective normal stress of 10 MPa, pore pressure of 30 MPa, temperature range of 25 to 300 °C, and slip velocity of 1 μm/s. The gouges were compacted (healed) for 3 to 100,000 seconds before re-shearing. Results show that the friction coefficient ranged from 0.5 to 0.55, which is lower than Byerlee's friction coefficient (0.6-0.85). Frictional strength (μ_{ss}) decreased as the temperature increased. Frictional healing increases with holding time and temperature, except for the negative healing at 100 °C. The obtained healing rates are consistent with the reported values of natural and synthetic fault gouges. Microstructural observations reveal the formation of slip zones in experiments conducted at 25 °C and 100 °C. These results suggest that variations in hydrothermal conditions alter water viscosity and microstructure, thereby influencing frictional properties. Because negative healing implies that only a limited amount of stress can accumulate and be released, potentially generating small earthquakes, the temperature of injected fluids should be carefully considered during the operation of EGS.

Oral Report M4-O-141

Effects of Nucleation Location, Overstress Zone Geometry, and Bilinear Slip-Weakening on Earthquake Source Time Functions

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Abstract

The source time function (STF) describes the temporal evolution of seismic moment release during rupture and is a primary observable for inferring earthquake source dynamics. Classical dynamic rupture theory predicts quadratic STF growth during symmetric bilateral expansion, but natural earthquakes routinely deviate from this behavior. The physical controls on STF variability, particularly the coupled roles of nucleation asymmetry, fault geometry, and frictional weakening, remain poorly constrained.

We conduct dynamic rupture simulations using the spectral boundary integral method to investigate how these three factors govern STF evolution. Nucleation location is varied systematically relative to the fault boundary, and overstress zone geometry is varied across circular, rectangular, and tapered configurations to isolate geometric confinement effects. In addition to a standard linear slip-weakening law, we implement a bilinear slip-weakening law with a secondary weakening phase parameterized by δ_{c2}.

STF evolution decomposes naturally into three phases: growth, steady-state, and arrest. Nucleation location controls STF symmetry and peak moment rate timing, while elongated geometries produce plateau-like steady phases through geometric confinement. Increasing δ_{c2} prolongs frictional weakening and promotes distributed slip acceleration near the rupture front, producing super-quadratic moment rate growth and smoother arrest-phase decay. These results demonstrate that nucleation asymmetry, overstress geometry, and secondary weakening collectively shape STF character and must be considered jointly when interpreting observed moment rate functions.

Keywords: source time function, dynamic rupture, overstress geometry, rupture nucleation, bilinear slip-weakening

Oral Report M4-O-142

Healing behavior in sandstone-derived fault gouge across subcritical to supercritical regimes

砂岩源斷層泥在次臨界至超臨界狀態下的癒合行為

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Abstract

Natural and induced earthquakes often occur along faults at depths characterized by high-temperature and pressurized fluids. Hydrothermal fluids significantly influence the frictional healing of fault gouge during interseismic periods, thereby governing the seismic cycle. While experimental studies have reported fault healing and associated time-dependent mechanisms under hydrothermal conditions, there remains a knowledge gap regarding healing across the transition from liquid to vapor and supercritical states of water. In this study, we utilized a rotary shear apparatus equipped with a high-temperature pressure vessel to investigate the frictional healing behavior of sandstone-derived quartz gouge from the Tatun Volcano Group (TVG), a potential superhot geothermal system in northern Taiwan. We performed slide-hold-slide experiments at a sliding velocity of 10 μm/s, an effective normal stress of 20 MPa, water pressures of 5–30 MPa, and ambient temperatures of 250–500°C, spanning subcritical to supercritical conditions. Results demonstrate that the healing rate (β) of quartz gouge strongly depends on the physical state of water. In the liquid regime, β increases with temperature, whereas it decreases with temperature under supercritical conditions. For vapor conditions, β declines as conditions move further from the liquid-vapor saturation curve, highlighting the critical role of fluid density in facilitating healing. These trends suggest solution-transfer as the dominant time-dependent healing mechanism in hydrothermal quartz gouge. These experiments provide a mechanical basis for the observed correlation between micro-seismicity and subsurface fluids beneath the TVG.

Oral Report M4-O-143

Role of Seismogenic Patch Geometry in Stick-Slip Rupture Dynamics on PMMA Laboratory Faults

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Abstract

Natural seismogenic faults are often characterized by velocity-weakening (VW) patches embedded within velocity-strengthening (VS) surroundings, and rate-and-state friction theory predicts that the geometry of this heterogeneity governs rupture nucleation, propagation, and arrest. To investigate how seismogenic patch geometry controls rupture dynamics, we designed a direct-shear PMMA fault apparatus in which a bare-PMMA patch (VW) is surrounded by polyethylene film (VS). Patch geometry was varied systematically across 1D configurations (5 cm × 50 cm) under normal stresses of 8–32 MPa and 2D configurations (50 cm × 50 cm) under 1–9.6 MPa. Repetitive stick-slip cycles were driven by a servo-controlled hydraulic loading system.

Macroscopic fault response was recorded using hydraulic pressure gauges for normal and shear loading, LVDTs for load-point displacement, and eddy current sensors for fault slip. From load-point displacement and shear stress records, we extracted system stiffness k and compared it against the critical stiffness k_c to characterize the mechanical transition from stable sliding to unstable rupture. Spatiotemporal evolution of friction coefficient μ, slip δ, and slip rate was used to quantify stress drop $\Delta\tau$ and peak slip rate across patch geometries. Our results reveal how patch aspect ratio and VS boundary width modulate rupture style and source parameters, with implications for interpreting natural earthquake sequences on geometrically heterogeneous faults.

Keywords: rate-and-state friction, velocity-weakening patch, seismogenic zone, stick-slip, laboratory earthquakes

Oral Report EM1-O-144

黏土礦物吸附有機分子的機制及其產學研應用

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摘　要

本人主要從事天然和改性地質材料的黏土礦物對水環境污染物吸附及移除應用基礎研究，系統研究了醫學藥物、染料、介面活性劑等有機分子官能基團於固/液界面的陽離子交換化學反應、分子吸附動力學和熱力學、分子模擬表徵、分子吸附機制。提出了結構插層使有機分子不易脫附形成二次污染的新保護機制；分析了黏土礦物的移除率及相關吸附影響參數，將黏土礦物與有機分子作用機制的認識從宏觀的吸附量和吸附類型的探討，深入到礦物精細結構與有機物官能基團的超微觀層次的理解。具體揭示了天然黏土礦物影響地表環境中有機類污染物歸宿、遷移和轉化作用的過程，延伸礦物學領域應用在環境整治工程開發低成本、高效率防治污染物並提供了技術支撐與方法選擇，成果具理論指導作用與潛在應用價值。

開發新技術不如改善原材料或尋找新材料來得快。因為吸附材料最終其實追求的是實際應用，只有具有實際應用價值，才能說有突破，並最終實現從實驗室階段–模場階段（小試-中試-大試）–最終生產環節。

黏土礦物產量豐富、便宜易取得、陽離子交換容量高，不僅可達到高經濟實用性、快速吸附、高吸附量等目的，而且零溫室氣體排放、不產熱、無二次污染。符合零溫室氣體排放的碳中和目標。

Oral Report EM1-O-145

臺灣北部金瓜石金銅礦床矽化岩石新近發現五種富銅或富鐵砷酸鹽礦物之產狀特徵與生成作用

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摘　要

金瓜石淺溫高硫化型金銅礦床以硫砷銅礦－呂宋礦（enargite-luzonite, Cu_3AsS_4）為礦石礦物，後期生成之砷酸鹽礦物僅見報導臭蔥石（scorodite, $Fe^{3+}AsO_4{\cdot}2H_2O$）。金瓜石矽化岩石新近發現數種砷酸鹽礦物，本研究進行X光繞射、光學顯微鏡，掃描式電子顯微鏡及拉曼光譜分析，以依其組成、生成序列及共生產物，探討與礦化作用之關聯性。富銅或富鐵砷酸鹽礦物以細晶集合體生成於矽化岩石孔隙，不同標本上見有三種生成序列或共生產物：（1）含鋅綠砷銅礦（cornubite, $Cu_5(AsO_4)_2(OH)_4$）→含鋅橄欖銅礦（olivinite, $Cu_2(AsO_4)(OH)$）→富鈉毒鐵礦（pharmacosiderite, $KFe^{3+}_4(AsO_4)_3(OH)_4 6–7H_2O$）± 重晶石；（2）氯砷鈉銅石（lavendulan, $NaCaCu_5(AsO_4)_4Cl{\cdot}5H_2O$）± 銅氯礬（connellite, $Cu_{36}(SO_4)_2(OH)_{62}Cl_6 6–12H_2O$）± 毒鐵礦 ± 重晶石；（3）臭蔥石→含氯水砷鈣鐵礦（yukonite, $Ca_2Fe^{3+}_3(AsO_4)_3(OH)_4{\cdot}4H_2O$）± 毒鐵礦，這些砷酸鹽可形成前述生成序列、取代局部溶蝕硫砷銅礦或個別沉澱於石英表面或孔洞。綠砷銅礦片狀細晶（~10 μm）形成數毫米之藍綠色塊狀、葡萄球狀及縞狀膠質集合體；橄欖銅礦生成墨綠色自形板狀、柱狀、針狀或纖維狀晶簇，晶體長度數微米至數毫米，綠色色調深淺依晶體大小而異；毒鐵礦多以黃橙色立方體細晶或其晶簇生成於矽化岩孔洞中，或沾附於其他砷酸鹽礦物表面或孔隙；氯砷鈉銅石微米片狀晶體沉澱於石英晶體間隙，形成天藍色球狀集合體，另局部可見氯砷鈉銅石細晶環繞硫砷銅礦生長，或緊貼部份溶蝕硫砷銅礦，與細粒自然金、毒鐵礦、重晶石或銅氯礬交錯生長；銅氯礬微米六方柱狀晶體另局部沉澱於石英晶簇表面，形成鈷藍色葡萄球狀集合體。除了臭蔥石之外，本研究證實金瓜石矽化岩石另產出五種砷酸鹽礦物，其多樣性、生成序列或共生產物特徵，暗示這些富銅或鐵砷酸鹽為金瓜石成礦作用最末期近地表低溫、弱酸－弱鹼性及相對氧化之過渡性熱液沉澱產物，易受岩石組成與熱液條件局部變化影響。金瓜石砷酸鹽礦物種類與分布之更廣泛性調查，可提供討論晚期熱液作用影響範圍和環境評估之參考。

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GRDB 地質材料拉曼光譜庫與 Racolyte 軟體推廣計畫

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物質之拉曼光譜是近年來一種作為快速定性物質結構態與鑑別種類的工具，隨著國內外廠商的軟硬體趨於成熟，近年來在國內學術及公私立單位亦有越來越多的拉曼光譜儀實驗室建立及應用場域出現。然而受限於各硬體製造商的光譜儀性能及其隨機軟體功能的支援度不同，其對拉曼光譜在數據處理及比對工作的支援能力差異甚大，常見的問題例如: 可進行數據處理的場域及功能受限、儀器隨機購置資料庫價格高昂或隨附的資料庫數據量不足、數據品質良莠不齊，又或是無法延伸應用於第三方軟體進行數據後製處理及研究發表，此外各軟體獨有的光譜數據格式可能存在第三方軟體相容性不足或轉換限制，這些情況在許多應用情境下對於終端使用者，不論是研究人員或學生常造成諸多障礙，不利於工作效能及相關應用情境。本計畫參考了國內現有各大拉曼光譜儀製造(代理)商之產品，並考量了許多應用場域的使用情境後，設計了支援通用 XY 數據格式的光譜數據處理暨比對軟體 Racolyte。其並隨軟體搭載開放可供線上進階查詢的地質材料拉曼光譜庫 GRDB。GRDB 資料庫現階段含蓋數百種台灣本土及國外礦物的拉曼光譜資料，且持續增加建置中，其數據除了使用高解析度的光譜儀建置外，完全支援 XY 通用格式及涵蓋泛用的 150~4600^{cm-1} 波數範圍，可支持更廣泛的比對及數據應用情境。另外軟體在設計層面除了直覺化的圖形操作介面更是支援業界少有的數據批次處理功能及繁體中文介面及檔案格式，且預計的終端使用者授權 EULA 方式為自由與開源軟體 (Free & Open Source Software, FOSS) 無隨儀器綁定或連網註冊限制，支援於個人裝置中安裝並可離線使用，即使是新手亦友善。本計畫預計於今年第三季 Q3 起啟動對外招募國內有意合作之單位優先體驗本軟體及資料庫，共同強化軟體之功能及資料庫數量，盼未來能拓展軟體及資料庫的應用面，成為國內廣大的拉曼光譜使用者一個便利且實惠的選項。

關鍵字: 拉曼光譜、資料庫比對軟體、Racolyte、GRDB

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GRDB Geological Materials Raman Spectroscopy Library and Racolyte Application Software Project

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Raman spectroscopy has emerged as a rapid tool for qualitative analysis and identification of material structures in recent years. With the increasing maturity of hardware and software from domestic and international manufacturers, more and more Raman spectrometer laboratories have been established and applied in academic and public/private institutions in Taiwan. However, due to differences in the performance of spectrometers from various hardware manufacturers and the extent of support provided by their accompanying software, their capabilities for Raman spectroscopy data processing and comparison vary significantly. Common problems include: limited data processing areas and functions; high prices of accompanying databases or insufficient data volume; inconsistent data quality; inability to extend data processing and publication to third-party software; and potential compatibility issues or conversion limitations with third-party software due to the unique spectral data formats of various software programs. These issues often create obstacles for end-users, whether researchers or students, hindering work efficiency and related application scenarios. This project referenced products from major domestic Raman spectrometer manufacturers (and distributors) and considered various application scenarios to design Racolyte, a spectral data processing and comparison software supporting the universal XY data format. It also includes the GRDB (Geological Materials Raman Spectroscopy Database), an open online database for advanced queries. The GRDB database currently covers Raman spectral data for hundreds of minerals from Taiwan and the whole world and is continuously expanding. In addition to using high-resolution spectrometers, the data fully supports the universal XY format and covers a broad wavenumber range of 150–4600 cm^{-1}, enabling wider comparison and data application scenarios. Furthermore, the software features an intuitive graphical interface, supports batch processing (rare in the industry), Traditional Chinese interface, and file formats. The planned end-user licensing EULA of the software is Free & Open Source, with no instrument-binding or online registration restrictions, allowing installation on personal devices and offline use, making it user-friendly even for beginners. This project is expected to launch in Q3 of this year, recruiting interested domestic organizations to experience the software and database first, jointly enhancing the software's functionality and expanding the database's scope. The goal is to broaden the application of the software and database in the future, making it a convenient and affordable option for all Raman spectroscopy users in Taiwan.

Keywords: Raman spectroscopy, database matching software, Racolyte, GRDB

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利用同步輻射解析玻璃蛋白石之鈾醯中心結構與負熱淬滅發光動力學

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摘　要

產自墨西哥的玻璃蛋白石(Hyalite)具備獨特的紫外激發綠色螢光特性，其成因與微量鈾元素密切相關。為突破傳統光譜對深層發光機制探討之侷限，本研究利用同步輻射技術，整合X光吸收光譜(X-ray absorption spectroscopy, XAS)與真空紫外光光致發光/光致發光激發光譜(Synchrotron Radiation Vacuum Ultraviolet Photoluminescence Spectrum / Photoluminescence Excitation Spectrum, VUV PL / PLE)，從原子配位結構與能階動力學角度，全面解析其罕見的負熱淬滅(Negative Thermal Quenching)行為。

X光吸收近邊緣結構(X-Ray Absorption Near Edge Structure, XANES)分析顯示，鈾的吸收邊相對於金屬鈾產生了明顯的化學位移(Chemical Shift)，其能量位移量證實樣品中的鈾完全以六價鈾醯$(UO_2)^{2+}$形式存在，排除了低價態鈾或混合價態的可能性。在延伸X光吸收精細結構(Extended X-Ray Absorption Fine Structure, EXAFS)分析中，本研究利用多重散射理論重新定義了徑向分佈函數中位於3.8 Å的異常特徵峰。證實此峰源自線性鈾醯離子的軸向結構對光電子波產生的聚焦與多重散射效應，而非以往推測的U-U金屬鍵結或鈾團簇。證實鈾原子在非晶質基質中呈現高度均勻分散的孤立單核狀態，有效抑制濃度淬滅效應。

變溫光致發光實驗顯示罕見的非單調溫度依賴行為。螢光強度在100 K時降至最低谷，隨後在200 K時發生反常增強(負熱淬滅現象)，在300 K時因多聲子弛豫主導而再次回落。本研究提出「淺層陷阱－去陷阱輔助的負熱淬滅模型」來解釋此動力學過程。在低溫下，非晶質二氧化矽基質中的缺陷能階充當了電荷的捕獲中心，抑制輻射復合。當溫度升至200 K，環境熱能足以釋放陷阱中的電子使其逃逸，並重新注入鈾醯發光中心，進而補償並超越了熱淬滅造成的能量損失。

中文關鍵詞: 鈾醯發光中心、X光吸收光譜、光致發光光譜、發光動力學。

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臺灣東部海岸山脈烏石鼻安山岩多樣性沸石化作用之研究

Varied zeolitization in the Wushipi andesitic rocks, Coastal Range, eastern Taiwan

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摘要

光學及電子顯微鏡、X光繞射和拉曼光譜分析顯示海岸山脈烏石鼻海蝕平台安山岩依沸石及其他次生礦物產狀可分為三類區塊：(1) 多岩脈安山岩具有東北－西南走向貫穿性沸石岩脈，且廣泛分布蛛網狀沸石細脈，貫穿性岩脈邊緣沉澱皂石，繼之充填方沸石及鈉沸石，蛛網狀岩脈則結晶十字沸石、方沸石、鈉沸石、片沸石或魚眼石，尤其常見方沸石和鈉沸石晶簇；岩石基質及橄欖石斑晶多為皂石取代；(2) 富杏仁孔塊狀安山岩部份具有次毫米至厘米之不規則狀杏仁孔，偶見沸石細脈，較大杏仁孔多保有未填滿孔洞，自孔壁依序沉澱黏土礦物＋十字沸石＋方沸石＋鈉沸石±桿沸石±魚眼石±白色皂石；部份安山岩具有相對密集、長軸約略平行之橢球狀杏仁孔（長約數毫米），孔壁沉澱物富含十字沸石，繼之生長柱狀鈉沸石＋桿沸石±雙錐狀水鈣沸石晶體晶簇，局部鄰接鈣質沉積物；富杏仁孔安山岩之橄欖石及基質呈現程度不等黏土化，局部鄰接沸石膠結之安山岩角礫，角礫多半部份蝕變成黏土礦物，但部份基質保留板狀細晶集合體組織，且可見倍長石轉變為桿沸石或方沸石；(3) 部份具有柱狀節理之安山岩幾未見沸石岩脈和杏仁孔，蝕變程度相對較低，其橄欖石斑晶部份反應形成皂石，基質沸石（十字沸石、桿沸石、方沸石）及皂石比例相對較低。沸石種類及產狀分布多樣性暗示烏石鼻安山岩具有獨特熔岩及低溫熱水次生礦物形成過程之演化，相異於臺灣其他火成岩體。烏石鼻早期安山岩質熔岩冷卻時，可能因後續岩漿活動抬升擠壓或區域應力作用，產生廣泛分布之貫穿性與蛛網狀裂隙，並發生相對廣泛低溫熱水蝕變和沸石脈狀沉澱；後期局部形成多氣孔安山岩，低溫熱液隨之形成杏仁孔及基質次生礦物，次生礦物比例相對低之柱狀節理安山岩可能相對接近冷卻熔岩流核心。烏石鼻蝕變安山岩相對高含量富鈉沸石及皂石暗示其為高水岩比反應產物，次生礦物種類及產狀變化可能受階段性母岩組構、水岩比和鄰接岩性差異影響。

關鍵詞：海岸山脈、安山岩、沸石脈、杏仁孔、水鈣沸石、水岩比
Keywords: Coastal Range, andesite, zeolite vein, amygdule, gismondine, water-rock ratio

衝擊實驗石英－柯石英過渡拉曼訊號與結構演化

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摘　要

石英（SiO_2）為常見之衝擊變質礦物，其拉曼光譜常用於辨識高壓相。然而，在衝擊波（動態壓縮）條件下，由於快速卸壓與後衝擊加熱作用，高壓相常發生回轉（back-transformation）或非晶化，使得多數撞擊實驗中難以直接觀察到穩定之柯石英訊號。

本研究透過石英撞擊實驗，結合拉曼光譜深度剖面量測與 X 光奈米繞射分析，解析衝擊後樣品之結構演化。拉曼結果顯示，衝擊區域表面除了觀察到以約 ~500 cm^{-1} 之寬廣特徵峰為主，且伴隨非晶質相存在；隨距離衝擊中心增加，光譜逐漸轉為石英特徵峰為主的圖譜。進一步對該 ~500 cm^{-1} 訊號位置進行深度剖面分析，可見其拉曼振動模隨深度（約數十至百微米）由 ~488 cm^{-1} 連續偏移至 ~520 cm^{-1}，對應柯石英之特徵峰。

此一由卸壓後高度變形之柯石英結構向較穩定柯石英晶體訊號演化之連續拉曼變化，揭示石英於動態壓縮條件下形成柯石英，並於卸壓過程中經歷結構鬆弛與應變釋放之連續轉變路徑。此類石英－柯石英過渡拉曼訊號於既有撞擊實驗研究中尚未被系統性報導。X光奈米繞射結果進一步顯示，~500 cm^{-1} 訊號區域之晶體結構呈現接近柯石英晶格之低對稱變形（近三斜晶系），顯示該區域為具殘餘應變之柯石英微晶，反映其在快速載入與卸載過程下之非平衡相變機制。

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鋰輝石 C2/c–P2$_1$/c 高壓相變研究

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摘　要

單斜輝石族礦物為上地函自地表至約 400 公里深度的重要組成，在此深度範圍中體積含量約達 25%，其高壓相變被認為與約 225 公里深處深源地震的成因，以及上地函中地震波異常與不連續面之形成密切相關。鋰輝石（spodumene, $LiAlSi_2O_6$）除了主要產於地殼偉晶岩並為重要鋰礦來源，也成為研究地函單斜輝石族高壓相變的指標礦物。前人指出，鋰輝石於約 3.2 GPa 發生由低壓 C2/c 相轉變為高壓 $P2_1/c$ 相，伴隨體積下降與拉曼光譜振動模的顯著改變（Pommier et al., 2003）。

Arlt 與 Angel（2000）在鑽石高壓砧（DAC）實驗中，於偏光顯微鏡下觀察到單晶中出現兩種干涉色及清楚的貝克線（Becke line）；Nestola et al.（2008）亦在 $LiAlSi_2O_6$–$LiGaSi_2O_6$ 固溶體系統中觀察到相同現象。然而，僅憑偏光顯微鏡下的干涉色差異，缺乏 X 光繞射或拉曼光譜等直接結構證據，無法確定新出現的光學特徵是否對應於高壓相。過去研究在光譜與結構量測上受限於技術與壓力控制，未能成功捕捉兩相共存的瞬間。因此，本研究旨在突破此觀測限制，以拉曼光譜直接辨識鋰輝石相變區中的兩相共存，並檢驗相變過程中是否存在可辨識之中間相。

本研究以天然單晶鋰輝石為樣品，於 DAC 中進行高壓拉曼量測。由於此相變的壓力區間極為狹窄，精準捕捉兩相共存難度甚高，透過精細調控壓力，多次升降壓的反覆測試，並結合拉曼光譜面掃描（Raman mapping）技術，以在微小壓力範圍內鎖定相變區。結果顯示，樣品於約 3.33–3.35 GPa 進入相變區，且在同一單晶的拉曼面掃描中，可明確辨識低壓 C2/c 相、高壓 $P2_1/c$ 相及兩相共存區域。此結果顯示，鋰輝石之高壓相變並未經過度相，而是於有限壓力範圍內以兩相共存方式進行的一階相變（first-order phase transition），並首次以拉曼光譜提供兩相共存的直接光譜證據。

綜合本研究結果與前人文獻，鋰輝石之高壓相變可解釋為 C2/c 與 $P2_1/c$ 兩相之直接轉換，在本研究量測壓力範圍內未見可辨識之中間相。此一判讀與 Ullrich et al.（2009）之結果一致，該研究在 3.2–9.3 GPa 雖確認 C2/c–$P2_1/c$ 相變，但亦未發現中間相之證據。整體而言，本研究首次以拉曼光譜量測並證實鋰輝石兩相共存，並為後續探討相邊界特徵奠定基礎。

Oral Report G1-O-151

基於多變量統計架構之 GNSS 時空模式識別：以 2021 年花蓮群震為例

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摘　要

GNSS 時間序列中訊號常受有色雜訊（Colored Noise）與季節性訊號影響，瞬態訊號中低信噪比低時難以有效分離真實物理訊號。針對此一挑戰，本研究旨在建立一套基於多變量統計理論之時空模式識別架構，整合經驗正交函數（EOF）與擴充經驗正交函數（Extended EOF, ExEOF），改善傳統單變量分析在低信噪比環境下之局限性。本研究選定 2021 年花蓮地區群震作為方法論驗證之實例，旨在評估此統計架構於解析複雜群震與傳播波訊號之效能。

研究首先針對群震活躍期（2021 年 4 月至 8 月）執行標準的 EOF 分解。因EOF分解出之主要成分雖特徵向量彼此正交但受抽樣誤差而統計上不一定可分離，故本研究導入North's Rule of Thumb對各模態之特徵值進行統計顯著性檢定。經 North's Rule 檢定後，第一模態與第三模態為顯著可分離（separable）。其中，第三模態成功從背景雜訊中分離出與群震時空分佈高度一致之同震變形特徵。本研究同時針對群震發生前與初期設定 30 日延遲視窗，引入 ExEOF 架構後，成功印證出 30 日週期信號的傳播特徵。該模態於斷層兩側呈現相位相反的情況，與斷層走向與地殼變形方向相符，顯示斷層兩側之信號具潛在擴散行為。

本研究證實，透過整合 EOF 降低空間維度與 ExEOF 之時頻解析，能有效建立一套系統化之 GNSS 訊號識別流程，於低信噪比的背景中提取具物理意義。

Oral Report G1-O-152

Surface Deformation in the Tatun Volcano Group revealed by InSAR

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Abstract

The Tatun Volcano Group (TVG) is located near the Taipei metropolitan area. Monitoring the deformation of volcano's surface is crucial for volcanic early warnings. Although there is no historical record of an eruption, recent studies confirm the active nature of the TVG. A low V_P anomaly at 8-20 km beneath eastern TVG (Huang et al., 2021), rising seismicity from 2014 to 2021 particularly beneath Dayoukeng and Mt. Qixing, especially from 2019 to 2021 (Pu et al., 2025). Increasing SO_2/H_2S ratio indicates the potential ascent of magmatic fluids from deeper sources (GSMMA, 2024). The transient deformation cycle demonstrated by GNSS data at Dayoukeng between 2015 and 2020 (Huang et al., 2024). Our work aims to reveal the deformation pattern of TVG during the past eight years by using Interferometry Synthetic Aperture Radar (InSAR). We process ALOS-2/PALSAR-2 ScanSAR mode images from 2015 to 2023 across multiple orbits, employing the ISCE2 alosStack workflow. For better ionospheric correction, dispersive phases from split-spectrum method are further inverted for the phase at each acquisition date and recombined for correction phase. Our results demonstrate the line-of-sight (LOS) velocities are below 10 mm/yr, majority of the GNSS velocities yield a root mean square error of 1.51 mm/yr. Furthermore, a subtle increase in velocity towards the satellite is observed in northeast of Dayoukeng, possibly suggesting migration of fluid or magma toward the LOS direction.

Keywords: Tatun Volcano Group, Volcano surface deformation, InSAR, ALOS-2, Ionospheric correction

Oral Report GM-O-153

Rethinking uplift, emergence, and landscape evolution of the Hengchun Peninsula since the late Miocene, the southern tip of the Taiwan orogen

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Abstract

Given the southward-propagation model of the Taiwan orogen beginning in 5 – 6 Ma, the Hengchun Peninsula at the south tip is considered the part emerging latest. Our review of stratigraphic and geomorphic data, however, comes to different perspectives. The peninsula was in a deep-sea setting in the late Miocene and shallowed to a continental-shelf environment by the Pliocene. The time of this shallowing agrees with the known apatite fission-track ages as old as 5.5 Ma. These ages also suggest minimum crustal denudation of 2 – 4 km and yield denudation rates of ~1 – 2 mm/yr in the north (averaged over the last ~2 Ma) and < 1 mm/yr in the south (averaged over the last ~5 Ma). Lateritic low-relief terrains, stranded above steep slopes including sea cliffs, are widely preserved on/around drainage divides, particularly in the east. These terrains probably evolved from the hills developed since the emergence of the MPP when relatively unconsolidated sediments/rocks were exposed for erosion. The subsequent enhanced river incision that stranded the terrains was triggered jointly by the creation of sea cliffs (causing base-level fall) and acceleration of tectonic uplift; the latter includes the shift of the uplift center from the Dongyuan area in the northeast (headwaters of the major rivers) to the Lilong ridge in the west (600 – 700 m higher than the Dongyuan) perhaps starting as late as ~0.4 Ma. The Lilong ridge, with Holocene tectonic-uplift rates of 2 – 4 mm/yr, has been raised to an elevation of 1000 m and exhibited hillslopes steep enough to generate landslides; it may have approached the topographic steady state (yet many lateritic soils/colluviums remain left near the ridge tops).

Keywords: Lateritic low-relief terrain; Apatite fission-track thermochronology; Hengchun Peninsula; Taiwan orogen

由地形指標之時空變化解讀臺灣東北部地區不同時間尺度之地景演化特徵

Interpreting Multi-Timescale Landscape Evolution in Northeastern Taiwan from Spatiotemporal Variations in Terrain Metrics

張瓊文　李錫堤　吳禮浩　邱一夫　陳亮谷

本研究以四期地形資料為基礎，包括 1929 年日治時代五萬分之一地形圖及 3 期數值地形(1980 年、2006 年及 2015 年)，針對臺灣東北部地區，將不同年代、不同測製技術所產製之地形資料，透過高斯低通濾波及降階為統一網格尺度 40 公尺，建立可跨期比較的地形指標框架。跨期比對之核心原則為:以相對化取代絕對值、以統計摘要取代逐像元比較。並將地形指標依統計穩健度分級：以分位數、比例關係等相對量為核心者，較能在不同來源與精度的 DEM 間維持一致物理意義。

本研究希望透過四個時間點的地形資料，分析在時間與空間上的地形指標變化，以解讀出臺灣東北部地區在構造運動及侵蝕作用下，地形隨時間演化的趨勢。

各種地形指標變化所反應之時間尺度不同：水系形態、溪流縱剖面與集水區邊界，百年內整體形狀大致維持，但局部可因強震或極端降雨之崩塌，造成河道侵淤、一級河系或稜線的變動；地形坡度及粗糙度受到山崩影響，百年內坡面局部可能會有變動，本研究則以斜坡單元之平均值觀察區域性的變化。

與地表侵蝕有關的地形指數中，逕流強度指數(SPI)是利用 DEM 取得上游集水面積及坡度來近似模擬水流侵蝕能力，隨著坡面上侵蝕溝及坡度的變化，各點數值上會有微幅變動，但從整體斜坡單元觀察，除了發生深層滑動的坡面之外，區域性明顯變化的時間尺度應在百年以上；局部起伏量(local relief)是量測某一範圍內的高程振幅，可反映地形系統中構造抬升、侵蝕削切、岩性抗蝕與時間演化耦合的綜合量測，明顯變化的時間尺度在千年以上，在數十年的幾期資料間不易出現顯著差異，更適合用來呈現較長期的地形背景差異。

在臺灣東北部地區百年內地形演化的解讀上，由 1980 年至 2015 年間 3 期數值地形所產製之水系分布、水文指標、主流縱剖面及標準化河流陡峭度指標等可得知，35 年間差異很小，溪流坡度大趨勢一致，局部河段 3 期溪流坡度略有變化，主要可能因崩塌堆積導致嚴重淤積段坡度變緩，淤積段下游又加強下切導致坡度變陡。由 1929 年地形與現今地形差異亦可發現，部分河道會受到大量崩積物堆積而加寬。臺灣因特殊之地理位置，同時受到構造運動及太平洋熱帶低壓帶

影響，有較高的頻率遭受強震或颱風豪雨之侵襲，其所誘發的大規模崩塌，會在很短的時間造成局部坡地地形與河道長期上的變化，是主要的侵蝕與沉積作用之一。

百年內在坡地地形的變化上，除了受到大規模崩塌影響地區之外，由 2006 年及 2015 年兩期的斜坡單元平均坡度變化可以觀察到區域性的坡度減低情形，雖然減低的坡度值很小，不過因其呈現區域群聚性，仍值得觀察。經詳細地形圖及地質資料比對，其主要位於片岩或板岩分布區，並且有較為密集的褶皺通過。多褶皺片岩區，局部可能形成順坡之片理面，易在早期就發生滑移，且片岩較易沿片理風化、解體，形成厚度較大且可移動的崩積層和土層，促進土壤潛移、細小崩滑與或者在下雨時發生均勻的片狀沖刷，使坡面逐步變緩。

在萬年以上更長時間的地形演化解讀上，本研究主要是以空間代替時間(Space-for-time)進行觀察，將臺灣東北部放入板塊構造的區域框架中，數百萬年以來臺灣東北部歷經造山擠壓到山脈緩慢垮塌下陷的轉換。隨著菲律賓海板塊向西北西移動且向北隱沒，加上沖繩海槽的擴張，此一轉換界線仍在向南移動中，其位置可由菲律賓海板塊向北隱沒的西側邊界(WEP)#(Teng, 1996)觀察，水平投影位置目前大約位於花蓮至桃園蘆竹的連線上。WEP 兩側因來自板塊相對運動的大地應力作用不同，而在地形演化上留下了印記，可觀察到 WEP 兩側之地形指標分布呈現出系統性的差異。

由標準化河流陡峭度指標、局部起伏量及逕流強度指數等侵蝕指標的空間分布發現，在臺灣東北部地區由北至南有明顯不同的趨勢。WEP 以東因侵蝕深化、堆積填谷，呈現山坡坡度降低、地形顯現圓潤及溪流陡峭度較低的狀態，此現象顯示 WEP 以東因處於後造山時期，地殼趨於伸張沉降，而產生的地形回應。WEP 以西的地形，則呈現出更陡峭的河道與地形及更強的侵蝕指標，因仍受到板塊碰撞擠壓的造山活動影響。

整體而言，臺灣東北部地區百年至千年間的地形演化主要受到強震與降雨形塑，並受到岩性及構造的制約；長期地形演化則受控於構造運動的演進，隨著沖繩海槽持續擴張，未來萬年至百萬年間臺灣東北部地區可能會有更多區域進入後造山時期，地形上也將呈現出更加圓潤和緩的開闊樣貌。

關鍵詞：數值地形、地形指標、地景演化

Oral Report GM-O-155

Evaluating Global Satellite DEMs for Decadal-Scale Erosion Monitoring: Frequency-Domain Corrections in the Laonong River Basin, Taiwan

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High-relief, landslide-prone regions like Taiwan experience rapid topographic change driven by frequent typhoon-induced extreme events. Quantifying these changes at decadal scales requires both robust datasets and correction workflows capable of isolating true geomorphic signals from systematic errors. However, open-source satellite-derived DEMs suffer from vertical biases, vegetation artifacts, and datum inconsistencies that obscure the signals of interest, limiting their use for reliable long-term geomorphic change detection.

To address these limitations, we present targeted correction workflows for decadal-scale DEM differencing and evaluate seven underutilized satellite-derived DEMs (i.e., ASTER GDEM, ALOS World 3D, Copernicus DEM, FABDEM, TanDEM-X EDEM, SRTM, and NASADEM) against a high-resolution airborne LiDAR DEM in Taiwan's Laonong River Basin. Our methodology isolates vertical bias and mitigates high-frequency artifacts through frequency-domain correction and canopy-removal algorithms. We identify NASADEM as the most suitable dataset for long-term geomorphic change detection, characterized by low RMSE, limited void-filling requirements, and minimal high-frequency artifacts. Applying a DEM of Difference (DoD) between 2000 and 2020, we resolve a basin-wide erosion rate of 5.60 ± 1.60 mm/yr. Our results reveal a striking scaling effect: while the Laonong Basin as a whole reflects long-term geological averages modulated by sediment buffering, sub-catchments such as the Puntanpunas yield rates up to 55 cm/yr, highlighting the extreme geomorphic sensitivity of smaller drainages to stochastic landslide events. These findings demonstrate that with targeted error-correction workflows, global satellite DEMs can effectively bridge localized geohazard monitoring and regional sediment budget modeling in inaccessible mountainous terrain.

Oral Report GM-O-156

莫拉克颱風後荖濃溪河道沖淤變遷與地形回應：十年尺度與年尺度DoD分析

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摘　要

極端氣候事件常誘發大規模山崩，造成大量土砂輸入河川系統，進而引發河道淤積、排洪能力下降及災害風險升高。除事件當下之地形擾動外，受損坡地與鬆動地質條件亦可能於後續多年持續供應沉積物，促使河道發生長時間尺度之沖淤調整。因此，釐清極端事件後河道地形變遷及沉積物搬運行為，對山區河川演育與災害風險評估具有重要意義。為探討此類擾動對河道系統之影響，研究區域須兼具明確事件衝擊、可辨識沉積物來源與適合觀測河道變化之地形條件。高雄荖濃溪寶來至六龜河段於2009年莫拉克颱風期間受強降雨影響，大量土砂輸入主河道。區域分析顯示該河段受支流輸砂干擾相對較低。河道寬度有限故具備辨識垂向地形變化之條件，並可結合鄰近氣象站與下游水文站資料進行綜合分析，故選為本研究區域。本研究採用多期數值高程模型進行地形差異分析（DEM of Difference, DoD），探討該河段在極端事件後十年與年尺度下之變遷。十年尺度採用2003、2011、2016與2024年四期20公尺解析度開放DEM，建立三期DoD成果；年尺度則利用2022至2024年間乾季無人機光達測製之0.5公尺DEM，建立兩期DoD成果。資料處理流程包括以Nuth and Kääb方法，以穩定地表進行DEM對位，隨後執行DoD分析；另將研究河段由上游至下游等距劃分為125區，以呈現體積變化之縱向分布。DoD不確定性則依Hugonnet等人提出之架構估算系統誤差與空間相關誤差。由寶來至六龜的河段依DoD分析成果可自上游分為A至D四段。極端事件後，A與C段呈現明顯堆積，B段亦以堆積為主，D段則表現為侵蝕，研究河段淨體積變化約為20百萬立方公尺。後期成果顯示A與C段轉為侵蝕，B段持續呈現顯著堆積，D段則維持侵蝕訊號，顯示莫拉克事件造成沈積物之不均勻堆積，於後續持續經由河道調整逐步趨向較均勻之坡度。年尺度DoD結果進一步顯示，同一分區內側向侵蝕與堆積並存，可細緻反映主流擺動與局部河床調整過程。未來若進一步整合雨量與流量觀測資料，將有助於定量描述河道沉積物收支及其與水文事件之關聯，並提升地形變遷研究與防災評估之應用價值。

關鍵字：極端氣候事件、地形差異分析、河道地形變遷、荖濃溪

Oral Report GM-O-157

花東海岸沉積階地的地形演育及其環境變遷意義

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摘　要

臺灣東部海岸有許多沉積階地，其生成過程可分為兩種類型，第一型是更新世末期海水面上升，造成河口或小海灣被沉積物埋積，全新世中期海水面相對穩定之後，再因陸地抬升、河川下切或海岸侵蝕而成，如港口溪、金崙溪、馬武窟溪、牛山海灣、水璉溪的近海岸地帶均發育此類型的河階地。第二型是全新世中期海水面相對穩定之後，河川中、下游河谷又歷經埋積與河川再下切而形成，如港口溪、豐濱溪、水璉溪的近海岸地帶均屬於此類型的河階地。在港口溪研究中，第一型階地的發育歷經海水面上升過程的河谷、河口灣埋積期(前期)與海水面相對穩定後的陸地抬升、河川下切期(後期)，此過程中的海岸線後退與前進均記錄在近海岸地帶的階地沉積層剖面中。故由沉積層特徵的調查得以推測該地的陸地抬升速率。在大武溪、朝庸溪埋積谷岩芯的研究中，應用此概念亦推測該地區的陸地抬升速率特徵。

本研究於豐濱溪南側海岸的綠野、立春海岸及北段的牛山、水璉溪口海岸的沉積階地崖進行沉積相判識及沉積物採樣，再進行粒徑分析、X光螢光(X-ray Fluorescence) 分析及碳十四定年。得知綠野、立春和牛山海岸的階地均屬於更新世末期海水面上升，造成小海灣被沉積物埋積，至全新世中期海水面相對穩定後，再因陸地抬升、河川下切或海岸侵蝕而形成。綠野、立春附近的陸地抬升速率約為 3 mm/yr以上，牛山海岸地帶的陸地抬升速率則略低於 1 mm/yr。水璉溪口的階地則是屬於全新世中期海水面相對穩定之後，河川中、下游河谷又歷經埋積與河川再下切而形成，溪口加積的時間在距今一千多年，加積期之後則發生海岸侵蝕、海岸線後退。依據前人研究，水璉溪口亦發育第一型階地，依據階地特徵推測的陸地抬升速率約為 0.84-1.35 mm/yr。

Oral Report GM-O-157

Landscape Evolution and Environmental Significance of Alluvial Terraces along the Hualien-Taitung Coast, Taiwan

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Abstract

There are numerous alluvial terraces along the eastern coast of Taiwan, which can be categorized into two genetic types. Type I originated from the sea-level rise during the late Pleistocene, which led to the infilling of river mouths or small bays with sediments. Following the relative stabilization of the sea level in the mid-Holocene, these alluvial terraces were formed through tectonic uplift, fluvial incision, or coastal erosion. Such terraces are developed near the coastal zones of Gangkou River, Jinlun River, Mawuku River, Niushan, and Shuilian. Type II alluvial terraces formed after the mid-Holocene sea-level stabilization, characterized by cycles of aggradation and subsequent re-incision in the middle to lower reaches of river valleys; these are observed in the coastal areas of Gangkou River, Fengbin River, and Shuilian. In studies of the Gangkou River, Type I terrace development transitioned from an early phase of valley and estuary infilling during sea-level rise to a later phase of land uplift and fluvial incision after sea-level stabilization. The record of shoreline transgression and regression during this process is preserved within the sedimentary profiles of these coastal alluvial terraces. Consequently, land uplift rates can be inferred from the characteristics of these sedimentary layers. This conceptual framework has also been applied to analyze uplift rate characteristics using core samples from the buried valleys of Dawu River and Zhaoyong River.

This study conducted sedimentary facies identification and sampling at alluvial terrace cliffs along the southern (Luye and Lichun) and northern (Niushan and Shuilian river mouth) coasts of the Fengbin River. Analytical methods included grain size analysis, X-ray Fluorescence (XRF) analysis, and radiocarbon dating. Results indicate that the alluvial terraces at Luye, Lichun, and Niushan belong to Type I, formed by the late Pleistocene sea-level rise and subsequent infilling of bays, followed by land uplift, fluvial incision, or coastal erosion after the mid-Holocene sea-level stabilization. The land uplift rate near Luye and Lichun is estimated to be above 3 mm/yr, while the rate at Niushan is likely lower than 1 mm/yr. Conversely, the alluvial terraces at the Shuilian river mouth belong to Type II, formed through aggradation and re-incision after the mid-Holocene sea-level stabilization. Aggradation at the river mouth occurred approximately 1,000 years ago, followed by coastal erosion and shoreline retreat. However, according to previous research, Type I alluvial terraces also develop at the Shuilian river mouth, with inferred land uplift rates ranging from 0.84 to 1.35 mm/yr.

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Earthquake-modulated soil CO_2 degassing along the Central Range Fault, eastern Taiwan: Evidence for transient permeability enhancement and deep gas migration

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Abstract

Active faults act as conduits for deep fluid migration, yet the temporal evolution of fault-zone permeability during seismic cycles remains poorly constrained. In eastern Taiwan, degassing studies have largely focused on the Chihshang Fault, while the Central Range Fault (CRF) remains understudied. Here, we conducted repeated soil gas geochemical surveys in the CRF zone, where no clear surface rupture is exposed, to investigate earthquake-related degassing processes.

Soil CO_2 flux was measured using the accumulation chamber method, and gas samples were analyzed for composition, $\delta^{13}C$-CO_2, and radon. Results show pronounced temporal variations linked to seismic activity. Two days before an earthquake, CO_2 flux increased significantly, suggesting early fracture development and enhanced pathways for deep gas migration. Two weeks after the event, flux remained slightly elevated, accompanied by heavier $\delta^{13}C$ and higher radon, indicating increased deep-source contributions.

Following a subsequent earthquake in June 2025, CO_2 flux became higher and more widespread, reflecting further permeability enhancement. By March 2026, flux returned close to background levels, suggesting gradual recovery of the fracture network. These results indicate that earthquakes transiently enhance permeability, enabling deep gas ascent, while system recovery may require several months after clustered seismic events.

Oral Report M1-O-159

Mechanisms of block rotation and transrotational basin development in oblique convergent margins: Insights from the southern Longitudinal Valley, Taiwan

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ABSTRACT

The oblique plate boundary in Taiwan provides a premier setting to investigate the mechanical evolution of localized transtensional basins within active convergent orogens. Integrating geodetic measurements, seismic reflection profiles, and structural analyses, this study proposes a transrotational tectonic model to elucidate the structural evolution of Mount Pinan in the southern Longitudinal Valley. While plate convergence initially drove folding and tilting, current deformation is dominated by a complex interplay between the north-south-striking Luyeh and Lichi Faults. Reinterpreted seismic profiles reveal synclinorium-like basins characterized by high-amplitude interwoven reflections and syndepositional normal faults, consistent with interseismic subsidence observed via GNSS and PSInSAR. These extensional features, alongside documented counterclockwise block rotation, suggest that Mount Pinan operates as a transrotational system. Positioned between the Central Range and the westward-thrusting Coastal Range, the indurated Pinanshan Conglomerate undergoes persistent shearing. This triggers rotation along a basal detachment, segmenting the massif into structural blocks and forming triangular overlap and gap zones. The overlap zones manifest as topographic highs, while gap zones evolve into rotational basins. This kinematic behavior, analogous to "bookshelf-faulting" in Tibet or the Los Angeles Basin, indicates that the Luyeh and Lichi Faults are mechanically coupled at depth via a common detachment. Consequently, Mount Pinan represents a key component of a regional deformation system where lateral shear is accommodated through systematic block rotation and localized extension.

Keywords: block rotation, transrotational basin, Longitudinal Valley, Mount Pinan, Luyeh and Lichi Faults

Oral Report M1-O-160

整合光纖地震儀與常規地震儀測網建立高解析度地震目錄：以池上光纖地震儀為例

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分散式聲波感測儀（又稱光纖地震儀，Distributed Acoustic Sensor, DAS）具備高密度陣列特性，在微震監測上深具潛力。本研究利用台東池上多維尺度觀測計畫中多口穿越斷層的井下光纖連續資料，建立一套高解析度的地震偵測工作流程。我們發揮 DAS 的密集陣列優勢，先以 PhaseNet-DAS 深度學習模型自動挑選潛在的地震訊號，再整合區域地震儀測網波形進行精確定位。經分析 2025 年 3 月至 7 月共五個月的連續紀錄，本研究成功建置包含 541 起事件的地震目錄。與現有基於深度學習的常規地震目錄相比，本流程不僅完整收錄了規模較大的區域地震，更額外捕捉到約 10% 的微小地震。特別是在光纖井周圍 5 公里的範圍內，我們偵測到數個因傳統測站分布稀疏而遺漏的微震。此結果顯示，DAS 資料能有效補足傳統測網的限制，大幅提升微震偵測能力，藉由整合 DAS 與現有地震測網所建立的完整地震目錄，將為後續的斷層活動性分析提供更詳盡的基礎資料。

中文關鍵詞：光纖地震儀（DAS）、PhaseNet-DAS、地震定位、微震偵測、池上斷層

Oral Report M1-O-161

Complex Fault Geometry and Structural Control in the Southern Longitudinal Valley: Evidence from the 2022 Chihshang Earthquake Sequence

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Abstract

The 2022 M_W 6.9 Chihshang earthquake sequence provides critical constraints on the seismogenic mechanisms and fault architectures in the southern Longitudinal Valley (LV), Taiwan. This study utilizes a dataset from 45 broadband stations—including CSN (MAGIC-Chihshang), BATS (IES), and SANTA (NCREE) networks—to monitor the sequence via the SeisBlue deep-learning (DL) platform. We employed the NonLinLoc (NLL)-SSST-coherence relocation method, incorporating 3D velocity models, station corrections, and waveform cross-correlation. SeisBlue identified 14,276 earthquakes from two months of continuous data, of which 11,247 were relocated. Compared to the 1D-hypoDD-selected catalog, the 3D relocated catalog showed improvements in location precision: the root-mean-square (RMS) travel-time residuals decreased from 0.32 s to 0.10 s, while horizontal (ERH) and vertical (ERZ) errors were reduced from 3.32 km to 1.25 km and 4.14 km to 1.42 km, respectively. By integrating the relocated catalog, focal mechanism solutions, and P-wave velocity models, we identified a high-V_P anomaly beneath the LV that extends westward under the Central Range (CeR). Seismicity is primarily concentrated along the upper boundary of this high-V_P body at depths of 0–30 km, suggesting that the development of primary fault systems is strongly controlled by this structural feature. To the east, the eastward-dipping LV fault system (LVFS) lies beneath the Coast Range (CoR) near Luyeh and Chihshang, shifting westward beneath the LV and CeR further north near Yuli. To the west, the CeR fault system (CeRFS) exhibits complex geometry: between Luyeh and Chihshang, the CeRFS dips eastward at depths of 10–25 km but shifts to a westward dip with branching faults at shallower levels. Conversely, near Yuli, the system primarily dips westward at depth and eastward near the surface. Our results highlight the northward structural transition of the CeRFS as it migrates from beneath the CeR toward the LV.

Keywords: 2022 Chihshang earthquake sequence, southern Longitudinal Valley, Seismotectonics, Deep learning, 3D earthquake relocation, Central Range Fault System

Oral Report M1-O-162

2026 地質地物年會
投稿議程：M1 多維尺度孕震過程觀測/Multidimensional Observations for the Earthquake Generation Processes

池上即時微震監測系統地震定位方法探討

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完整且定位準確的地震目錄，是各項地震地體構造研究的關鍵基礎資料。池上多維度觀測計畫（Multidimensional Active fault of Geo Inclusive observatory Chihshang, MAGIC）已陸續完成池上寬頻地震網（CSN）及池上即時微震監測系統（2022CSN-RT-MEMS）的建置，結合中研院臺灣寬頻地震觀測網（BATS）及國震中心全台地震陣列（SANTA）共45個寬頻站資料，進行聯合定位，大幅提升偵測微震活動的測站覆蓋率與地震事件解析度。目前自動化即時系統所產出的地震目錄（自2021年11月中旬迄今），仍基於氣象署一維速度模型進行定位，為了提高地震定位精度以利後續相關研究分析，我們使用2022年關山-池上餘震序列進行各種重新定位比較。一維及三維HypoDD 定位法（Waldhauser & Ellsworth, 2000），雖能提升相對位置精度，但容易受到初始定位品質影響，且未產生走時聯結的事件會遭剔除，導致定位後保留的地震數量大幅減少（自 14,276 筆減至 5,691 筆，40%）；此外，相對定位亦可能造成地震群絕對位置偏移。為克服此限制，本研究測試NonLinLoc（NLL）-SSST-coherence （Lomax et al., 2022）處理流程，包括三維地震定位（NLL）、測站修正（SSST），並輔以波形交相關（coherence）提升相對位置精度。結果顯示，此流程不僅能保留多數地震事件（11,358 筆，80%），提高地震目錄的完整性，更有效避免絕對位置的偏移。本研究建立的自動化高精度三維定位流程，能提供更完整且精確的地震目錄，為後續發震構造與斷層活動特性解釋提供重要基礎。

關鍵字：池上多維度觀測計畫、池上即時微震監測系統、三維地震定位、池上寬頻地震網

Oral Report M1-O-163

池上斷層淺層構造探測：井中 DAS 小尺度折射震測與震源測試

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摘　要

井下DAS（Distributed Acoustic Sensing）技術具備全井段且高密度之波場觀測能力，對於淺層構造解析具有潛在優勢。於台東池上多維尺度觀測計畫（MAGIC）中，已鑽鑿多口穿越池上斷層之觀測井，並於井內佈設光纖以進行DAS資料收錄。

本研究利用井中DAS所提供之垂直觀測幾何，結合地表地震儀陣列進行小尺度折射震測實驗。透過人工敲擊（hammer）與可攜式主動小型震盪器（PASS）作為震源，建立包含水平與垂直方向之走時資料分布，並進行折射震測走時分析以推估淺層速度構造。進一步探討井下的池上斷層在材質與震波速度構造之關聯性。此外，本研究亦檢視不同震源型式於此類觀測幾何下所產生之訊號特徵，作為評估可攜式主動震源於小尺度折射震測應用之參考。

Oral Report M2-O-164

Thermal Characteristics of the Milun Fault Using Borehole Optical Fiber Sensing

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Abstract

Understanding the thermal characteristics of fault zones provides critical insights into earthquake dynamics, fluid transport, and fault mechanics, as temperature anomalies may reflect frictional heating, fluid migration, or variations in lithology. The Milun Fault, an active east-dipping, left-lateral reverse fault, is located in the northern section of Taiwan's Longitudinal Valley. This fault has been responsible for multiple major earthquakes over the past decades. Due to its frequent slip behavior, the Milun Fault Drilling and All-inclusive Sensing Project (MiDAS) initiated a scientific drilling program in 2021 to monitor the fault's thermal and mechanical properties. The MiDAS Hole-A borehole directly intersects the fault zone and is equipped with a distributed temperature sensing (DTS) system, enabling high-resolution and continuous temperature monitoring along its depth.

Since September 2022, long-term DTS monitoring has identified a long-lived but decaying temperature anomaly at depths of 540–580 m beneath the fault zone, persisting through August 2025. The origin of this thermal anomaly remained unclear until a recent analysis of DTS data acquired during cementing operations in January 2022, which reveals that the observed anomaly was primarily caused by heat released during the cementing process. However, this finding raises further questions regarding the depth-dependent variation in thermal decay rates, particularly the slower cooling observed below the fault zone. To address these issues, we evaluate the thermal properties of the fault zone using cementing related DTS data and compare the inferred thermal diffusivity with laboratory measurements obtained from retrieved fault core. This approach allows us to map detailed thermal characteristics along the Hole-A. After removing cementing induced thermal effects, the results will help in understanding the mechanisms controlling temperature variations near active fault zones.

Oral Report V1-O-165

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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摘要

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。根據 Ar-Ar 定年結果，獲得兩個七星山熔岩流的噴發年代，分別為 11.6 ± 3.6 ka 與 14.0 ± 2.2 ka。薄片觀察結果：東西兩側爆裂口樣本礦物組成相當類似。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 micro-texture 和 reation rims，其可能為岩漿上升過程中的減壓速率不同、在岩漿通道停滯時間不同、增溫、或有不同的岩漿成分摻入或上述機制的組合造成，並表示斑晶所承受之非平衡狀態的相對程度不一致。根據全岩地球化學、鍶釹同位素分析和 Ar-Ar 定年結果得知，東西側樣本為中鉀鈣鹼性安山岩；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（Nb、Ta 和 Ti）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。

關鍵字：岩象學、岩心、地球化學、七星山火山、大屯火山群

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Geomorphological mapping, $^{40}Ar/^{39}Ar$ geochronology, and geochemistry of the Huangzuei complex (Tatun Volcanic Group, Taiwan): Implications for volcanic architecture and magma generation

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Abstract

The Huangzuei complex is a volcanic complex within the 25 km-wide Tatun Volcanic Group, which is situated on the northern tip of Taiwan and poses significant potential hazards to the Taipei metropolitan area. The Huangzuei complex consists of three principal lava flows with well-preserved landforms, radiating northwestward, northeastward and southeastward up to several kilometers from Mt. Huangzuei, the 250-m-high cratered summit of the complex.

High-resolution topography from a LiDAR-based bare-earth DEM enables detailed demarcation and characterization of individual flows of the Huangzuei complex including volume, thickness, and profile. Detailed geomorphological mapping and newly obtained $^{40}Ar/^{39}Ar$ ages reveal that eruption began at ~139 ka, was most vigorous from ~129 ka to ~133 ka followed by a quiescence, and resumed at ~116 ka. The southeastern lavas are capped by a lahar containing blocks that are ~85 ka, but they partially overlap much older lavas (~264-298 ka) that might have erupted from Dajianhou, a neighboring volcanic complex. It is likely that the Huangzuei volcanism ended in the formation of domes and a summit crater at 85 ka or later.

Disequilibrium textures, including oscillatory zoning, reverse zoning, partial resorption, and development of reaction rims, are common in samples from the Huangzuei complex. These textures, together with the wide ranges of differentiation indices of major minerals (Fo of olivine, Mg# of pyroxenes and An of plagioclase), indicate that the magma that formed the Huangzuei complex underwent intense magma hybridization, involving periodic replenishment by more primitive magmas during crystallization differentiation. We propose that the ~129-133 ka eruptive episode was likely triggered by a major event of magma recharge.

Keywords: LiDAR, lava flow, olivine, magma recharge, disequilibrium texture

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重出「漿」湖：大屯火山群下部凝灰角礫岩的前世今生-以磺嘴山地區為例

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摘要

大屯火山群位於臺灣北部，是由一群地形保存良好的火山所構成的活火山群。大屯火山群以廣泛分佈的熔岩流與數座熔岩穹丘為主。相較之下，火山碎屑則相當罕見。因此，大屯火山群長久以來被認為是以寧靜式的噴發為主。然而，有一層被稱作「下部火山角礫岩」的地層，廣泛分佈於各地的熔岩流之下。這層下部火山角礫岩對於大屯火山群的演化歷史、噴發型態、災害潛勢都至關重要。可惜的是，受限於相當稀缺的露頭、露頭嚴重風化等限制下，我們對於這層角礫岩的產狀、形成機制與年代的認知都相當有限。

在 2024 年 10 月初旬，受到山陀兒颱風挾帶的驚人雨勢，在陽金公路 5.3K 處發生了大規模的山崩，出露了相當有趣的露頭。此露頭包含一層上覆、約 30 公尺厚的熔岩流，以及一層下伏、約 10 公尺厚的火山碎屑。在 Chen and Wu(1971) 繪製的地質圖中指示磺嘴山區域的下部火山角礫岩出露於此。因此，我們好奇這新出露的火山碎屑，是否就是 Chen and Wu（1971）所指的下部火山角礫岩呢？

為了解決我們的疑問，我們先透過野外的觀察去建立初步的產狀分析。我們的觀察指示露頭呈現基質支撐以及極差的淘選度。均質、紅棕色的火山碎屑主要呈現次角礫狀。我們再透過掃描式電子顯微鏡、X 光繞射儀去分析火山碎屑中基質的成分。經過初步的研究，我們認為在磺嘴山區域出露的火山碎屑露頭很有可能就是前人所稱的下部火山角礫岩，源自於噴發或基體垮塌所沉積的火山碎屑流。但未來下部火山角礫岩仍需要更多深入的分析去釐清其成因與沉積的機制。

關鍵字：大屯火山群、下部凝灰角礫岩、火山碎屑

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臺灣東北部龜山島海底火山熱液氣體組成之時間演化（2020–2025）

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摘　要

自2020年至2025年，對臺灣東北部龜山島海底淺層熱液系統進行連續氣體監測，結果顯示氣體組成具有顯著時間變異性。然而，氦同位素比值（$^{3}He/^{4}He$ ~ 6.2–7.7 R_A）於整個觀測期間內維持相對穩定，顯示岩漿來源持續存在且未發生明顯改變。

2020–2021年間，熱液排放以CO_2為主，組成變化幅度有限，代表一穩定背景狀態。2022–2023年間，S_{total}/CO_2比值升高且$^{4}He/^{20}Ne$值降低，並伴隨頻繁之局部地震群與海底地形擾動，顯示氣液交互作用增強及淺層流體傳輸通道受到擾動。

自2024年下半年至2025年間，系統出現進一步轉變，特徵包括顯著的CO_2下降（最低至26.2%）、N_2/Ar（>120）與CH_4/CO_2比值增加，以及氦濃度升高。值得注意的是，這些地球化學異常並未隨地方地震頻率呈比例變化，顯示流體組成變化並非單純受地震活動直接控制，而可能反映流體傳輸與揮發分分配機制之轉變。

最新一階段之組成變化發生於2025年12月27日龜山島東方M_L 7.0地震之前，顯示淺層熱液系統對區域構造條件演化具有高度敏感性。

本研究顯示，長期地球化學監測可解析火山熱液系統之多階段演化，並提供火山–構造交互作用之重要觀察證據，即使在岩漿來源未顯著改變之情況下亦然。

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Temporal Evolution of Hydrothermal Gas Compositions at the Kueishantao Submarine Volcano, NE Taiwan (2020–2025)

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Abstract

Continuous gas monitoring at the shallow submarine hydrothermal system of the Kueishantao volcano, northeastern Taiwan, from 2020 to 2025 reveals pronounced temporal variability in gas compositions despite relatively stable helium isotopic ratios ($^3He/^4He$ ~ 6.2–7.7 R_A), indicating a persistent magmatic source.

During 2020-2021, hydrothermal emissions were dominated by CO_2 with limited compositional variability, representing a stable baseline state. In contrast, the 2022-2023 period was characterized by elevated sulfur-to-carbon ratios (S_{total}/CO_2) and reduced $^4He/^{20}Ne$ values, coinciding with frequent local seismic swarms and documented seafloor disturbances, suggesting enhanced gas-water interaction and perturbation of shallow transport pathways.

A further transition was identified from the second half of 2024 to 2025, marked by pronounced CO_2 depletion (down to 26.2%), increased N_2/Ar (>120) and CH_4/CO_2 ratios, and elevated helium concentrations. Notably, these geochemical anomalies do not scale with local earthquake frequency, implying a shift in gas transport and volatile partitioning processes rather than direct control by seismic activity.

The latest compositional changes occurred prior to the M_L 7.0 earthquake east of Kueishantao on 27 December 2025, highlighting the sensitivity of shallow hydrothermal systems to evolving regional tectonic conditions. These results demonstrate that long-term geochemical monitoring can resolve multi-stage evolution of hydrothermal transport processes independent of changes in magmatic source characteristics.

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大屯火山地區微震孕震機制的時變特性

Temporary Variations of Triggering Mechanisms underlying Earthquakes at the Tatun Volcano Group in Northern Taiwan

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摘　要

關於微震的孕震機制探討，對於地震研究來說一直是個挑戰。主因不外乎微震的破裂頻率高，與背景雜訊的頻帶重疊性高，且高頻地震訊號的模擬不易。在非火山地區，地震的孕震機制多半與區域的構造應力環境有十分高的相關性；但在火山地區，地震的孕震機制就相對複雜，除了區域應力場作用外，火山流體與氣體也可能形成微震活動。因此，在火山研究與監測作業中，如何能分析微震的孕震機制，並瞭解其與火山流體間的關係，就顯得有其重要性。

由於大屯火山位在大臺北都會區內，是政府重點監測的火山，故在當地布設大量地震觀測站。基於這些觀測資料，大屯火山地區淺層的地下速度構造已可被清楚解析。近期，甚至已有關於火山的四維速度構造資訊。根據這些資料，本研究試著分析大屯火山地區地震的行為模式（*b*-value）與孕震帶的構造特徵（V_P/V_S ratio），並藉由這些觀測資料，探討當地主要孕震機制隨時間的變化。研究結果發現*b*-value與孕震帶的V_P/V_S ratio在時間上出現一致且富含意義的變化。進一步的討論與分析之後，本研究指出，在2016以前，大屯火山地區地震的發生主要受應力擾動與氣體充填影響；在2017年時，多數的地震發生可能與氣體的充填有關；2018年時，水的填則變成是地震主要發生的機制；2019以後，多數地震的孕震機制轉而為區域應力作用或擾動。

關鍵字：大屯火山、孕震機制、時間變化、*b* 值、波速比（V_P/V_S）
Key words: Tatun Volcano Group, triggering mechanism underlying earthquake, *b*-value, V_P/V_S ratio.

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Petrographic and Mineral Chemistry Constraints on the Magma Plumbing System of the Tatun Volcano Group, Northern Taiwan

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Multiple lines of evidence indicate that the Tatun Volcano Group (TVG), northern Taiwan, hosts an active volcanic system. Given its proximity to the Taipei metropolitan area, improving constraints on eruption timing and pre-eruptive conditions is critical for hazard assessment. Achieving this requires a clear understanding of the magma plumbing system, which governs magma storage, transport, and eventual eruption.

The crystal rich andesites of the TVG provide key insights into these subsurface processes. These rocks are predominantly porphyritic hornblende andesites composed of plagioclase, amphibole, minor pyroxene, and rare biotite. Plagioclase phenocrysts commonly exhibit disequilibrium textures, including sieve structures, resorption surfaces, complex zoning, large anorthite spikes (>10 mol%), and melt inclusion rich zones, and occur as single crystals, synneusis clusters, and glomerocrysts. Amphiboles define two main populations: (1) large composite crystals dominated by magnesiohornblende with pargasitic rims or internal domains, and (2) smaller, single crystal pargasites. Pyroxenes are dominated by orthopyroxene with clinopyroxene rims, although clinopyroxene also occurs as discrete crystals. Collectively, these features record repeated mafic recharge, reheating, and partial re equilibration of crystals with the surrounding magma, likely reflecting reactive flow within a crystal mush dominated plumbing system.

Multi mineral thermobarometry further constrains the architecture of this system, indicating overlapping crystallization depths that define a vertically extensive, transcrustal reservoir, broadly consistent with geophysical evidence for low velocity zones beneath the TVG. In addition, shallow crystallization depths (~5 km), recorded by large magnesiohornblende crystals and not resolved by current geophysical models, suggest the presence of a transient or volumetrically limited, water rich upper crustal reservoir.

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Tracing Slab Contributions and Mantle Domains in the Solomon Island Arc Using Sr-Nd-Hf-Pb Isotope Systematics

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ABSTRACT

The Solomon Island Arc (SIA) serves as a natural laboratory to investigate unique geological phenomena, including subduction polarity reversal (SPR), arc-plateau collision and their specific impact on magma source characteristics. This study presents integrated whole-rock major and trace element geochemistry, Sr–Nd–Hf–Pb isotopes, and zircon U–Pb geochronology from volcanic and plutonic rocks across Choiseul, Santa Isabel and New Georgia. Discrete magmatic episodes at ~ 46 Ma, ~35, ~20, and ~12 Ma indicate long-lived, intermittent activity, continuing until the late Pleistocene. Rare earth element (REE) and trace element patterns combined with isotopic ratios, record a temporal shift from Pacific-like depleted mantle at ~46 Ma towards an Indian-type signatures at ~35 Ma in εNd(t) versus εHft space. This transition indicates a change in magma mantle domain, likely driven by SPR. The Miocene (~20 Ma) to Pleistocene samples show typical arc signatures and isotopically identical to Indian-type mantle domain and lie close to OJP-basalt field on εNd(t) versus εHft diagram which we interpret the timing of another SPR. The overlap of isotopic ratios suggesting arrival timing of OJP at North Solomon trench. However, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ isotopic ratios of ~46 Ma samples indicate involvement of volcaniclastic and pelagic sediments suggestive of mixing between mantle-derived melts and slab derived inputs, with several samples plotting near the Northern Hemisphere Reference Line,

suggesting limited involvement of highly radiogenic components. Two-component mixing models will be used to further quantify the relative contributions of these sources.

Keywords: Solomon Islands arc, Subduction polarity reversals, arc-plateau collision, Sr-Nd-Hf-Pb isotopes, mantle domain.

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結合現地入滲試驗與土壤排水特性資料之地下水補注區入滲特性分析：臺灣中南部案例研究

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由於氣候變遷與降雨時空分布不均，地下水補注機制日益受到重視，而地表土壤之入滲能力為影響補注效率之關鍵因子。然而，過往研究多仰賴地層資料或間接推估方法，缺乏現地量測與土壤性質之整合分析，致使入滲特性之評估仍存在不確定性。

本研究以臺灣中部及南部地下水補注區為研究對象，探討其水文特性，並結合現地土壤入滲試驗與土壤排水特性資料，分析其入滲行為及其控制因子。研究採用符合ASTM標準之加拿大 ETC -PASK現地入滲儀，進行地表淺層(30~60 cm)土壤之入滲特性試驗，並整合土壤詳測資料與既有地層資訊進行分析。試驗點位係依據土壤類型與區域分布規劃，選取原狀土壤進行試驗，以確保具代表性；其中中部地下水補注區共完成48處現地試驗，南部屏東平原則完成13處。結果顯示，中部地下水補注區多位於沖積扇上游至中游區段以及臺地地區，土壤以砂質及礫質材料為主，粒徑較粗、孔隙連通性佳，入滲能力強，其土壤飽和透水係數約介於1.08×10^{-7}至3.35×10^{-5} m/s；南部屏東平原則受細粒沉積影響，入滲能力呈現較大空間變異，其土壤飽和透水係數約介於3.4×10^{-7}至8.05×10^{-6} m/s，整體趨勢偏低。進一步分析顯示，土壤飽和透水係數與粒徑分布及排水特性之間具顯著相關性。本研究據此建立現地入滲行為與土壤性質之整合分析架構，可作為地下水補注潛勢評估與水文地質研究之重要依據。

中文關鍵字：地表入滲試驗、土壤排水特性、土壤飽和透水係數

Oral Report H1-O-173

臺灣水文地質資訊系統之建置與應用

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摘　要

因應極端氣候導致之旱澇不均與水資源調配壓力，地下水已成為臺灣重要且具備即時應變能力之關鍵水源。經濟部地質調查及礦業管理中心長期累積近四十年水文地質鑽探、地球物理調查等資料，建構完整之地下三維水文地質架構模型，並據以發展「臺灣水文地質資訊系統」，作為整合資料、分析應用與決策支援之核心平臺。

秉持地質資料公共財精神，系統採開放式 WebGIS 架構，整合多元圖資與外部系統，提供免登入之資料查詢、三維視覺化展示及 API 服務，落實地質資料公共化與跨域應用。同時透過資料視覺化與互動分析工具，將抽象地質資訊轉化為可操作之決策資訊。為因應抗旱找水之急迫性與解旱目標，整合三維水文地質模型，建立「抗旱地下水找水潛力圖」以蛋黃圖(紅、黃、綠網格分布圖)視覺化潛能分級，直觀呈現極低、低、中、高地下水蘊藏潛勢區，可快速掌握平面空間中富水層之分布位置與厚度，作為抗旱井選址及地下水保育規劃之參考依據，並於 110 年及 112 年乾旱年度，提供水利署等單位鑽鑿抗旱地下水井之依據，其成果豐碩。

為因應實務需求，系統新增並優化了多項核心功能，包含：岩性比例分布圖、電阻率三維模型建置、實體岩心館藏管理系統、三維地層採樣模組開發、岩心轉繪功能擴建及行動版介面優化。大幅提升了機關行政管理與地質研究之應用效能。

未來，隨著水文地質資料持續更新與整合，並結合三維技術與數位孿生應用之深化，本系統將持續精進分析與決策支援能力，持續服務產、官、學、研各界，強化地下水資源之有效管理與調度，維護臺灣地下水資源之永續。

Oral Report H1-O-174

應用多尺度電阻率探測技術探討臺中北部之水文地質架構

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摘　要

本研究旨在系統性地解析臺灣中部苗栗丘陵南段、后里臺地及大肚臺地之地下水補注環境與深部地質構造。隨著氣候變遷導致水資源調度難度增加，精確掌握地下水補注區之邊界特性與導水路徑已成為水資源永續管理的關鍵。由於調查區之地質條件複雜，單一地球物理方法往往受限於探測深度或空間解析度的權衡，難以同時兼顧淺層含水層細節與深部地質構造位態。

為克服上述限制，本計畫採用垂直電阻探測（VES）進行點狀的高垂直解析度地層劃分；地電阻影像剖面法（RIP）進行橫向連續觀測，藉此捕捉淺層地質的不均質性；結合聲頻大地電磁探測（AMT），將探測深度延伸至地表下千公尺，建構出完整的立體電性架構模型。

研究結果顯示，在淺層（地表至百公尺深度）解析方面，VES 與 RIP 探測展現了優異的對比能力。調查區內之表層通常由巨厚的乾燥礫石層組成，在電性上呈現極高電阻特徵（數千歐姆-公尺）；而其下伏之飽和含水層則呈現顯著的中低電阻反應（約 50 至 200 歐姆-公尺）。透過電阻率界面的分析，定位出受古河道下切控制之局部導水路徑，顯示古河道礫石層為該區淺層地下水之主要儲留與輸送空間。

在深部構造（數百至一千公尺深度）方面，AMT 探測成功揭示了三義斷層及魚藤坪斷層向深部延伸之電性特徵。研究發現，三義斷層兩側具有顯著的電性對比，東側之砂頁岩互層呈現低電阻特徵，對地下水運移具有阻隔作用。值得注意的是，於大湖向斜軸部附近觀測到一條隨深度向西側延伸之顯著低電阻帶，根據其與區域位態之空間關聯，研判該帶為山區地下水向西側平原補注之深層優勢通道，此發現證實了褶皺與斷層構造對於中部地區地下水系統的控制作用。

多尺度整合技術不僅提升了地下水區邊界判認的準確性，提升過去僅依賴點狀鑽井資料所產生的解釋盲區。除釐清區域補注機制外，更可直接應用於未來中部地區伏流水開發選址、抗旱水井佈設及地下水資源長期的永續管理與保育，具備高度的科學意義與實務應用價值。

關鍵字：多尺度電阻率探測技術；水文地質架構；地下水補注

Oral Report H1-O-175

利用水文地質鑽井探討后里臺地區域之地層分布特徵

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自工業革命以來，全球氣候變遷加劇了極端乾旱事件的頻率與強度，已成為當代水資源管理的首要挑戰。臺灣中部位於冬季季風之背風側，乾濕季分明之特性在遭遇極端乾旱事件時更為脆弱，使地下水資源成為民生、農業及工業用水不可或缺的關鍵來源。為了評估可用的地下水資源並規劃穩健的管理計畫，經濟部地質調查及礦業管理中心於111年提出「地下水補注區調查與水資源評估－臺灣中部地下水區」計畫，其中針對具較高地下水資源潛能之礫石與礫岩，希望進一步釐清其分布、厚度與邊界等特性。

后里臺地位處西部麓山帶前緣，此區域地層分布區域主要受控於地質構造。在鐵砧山背斜、月眉背斜、大甲斷層系統與屯子腳斷層的先後作用下，后里臺地之地層大致為河道礫石不整合接觸於頭嵙山層之上。然而，頭嵙山層中火炎山段礫岩與香山段砂岩地下的幾何形貌，則尚待更多工作釐清。在地礦中心的支持與指導下，本研究透過新增四孔地質鑽探取樣與蒐集既有鑽井及露頭資料，建立了本區域的地質剖面，結果顯示后里臺地礫石與礫岩分布的厚度與深度並不均勻，推測頭嵙山層於本區域先受鐵砧山背斜褶皺並向南傾沒，臺地西側地區局部又受大甲斷層作用而變形。

中文關鍵字：后里臺地、頭嵙山層、地下水資源

Oral Report H2-O-176

三維離散裂隙網路與等效連續介質模型於裂隙岩體流場與功能測度之應用

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在放射性廢棄物深層地質處置之安全評估中，結晶岩體因具備低滲透率特性，被視為具潛力之處置母岩。然而，岩體內部複雜之裂隙網路及高度異向性，往往主導地下水流徑與核種傳輸路徑。傳統定率式方法難以描述裂隙空間分布之隨機特性，因此本研究導入序率式方法(stochastic approach)，結合三維離散裂隙網路(DFN)與等效孔隙連續介質(ECPM)模型，量化評估天然地質障壁之遲滯功能。本研究以離島結晶岩參考案例之現地鑽孔資料為基礎，建構具深度相依性(depth-dependent)之DFN模型；淺層(深度0-70 m)之裂隙體積強度P_{32}約為2.4 m^{-1}，深層緻密母岩區則遞減至0.3 m^{-1}。數值模型整合導水構造與低透水之岩脈，並透過升尺度(upscaling)技術將DFN之透水特性轉化為等效滲透度張量，以反映岩體之空間異向性。此外，本研究使用功能測度值，量化評估地下水傳輸過程的各項參數。模擬結果顯示，深部岩體呈現顯著之流動傳輸阻力(F)，中位數可達10^7 yr/m。此高流動傳輸阻力特徵源自於深層岩體完整，且流動潤濕面積較大與地下水流速緩慢，而核種在此傳輸條件下，主要以基質擴散(matrix diffusion)方式進行傳輸。敏感度分析結果亦指出，區域水力梯度變異將導致傳輸流徑(L)縮短，並透過比較不同裂隙隨機實現值案例，探討裂隙岩體中優勢水流路徑之變異與不確定性，研究成果顯示所獲取之功能測度值可作為後續反應傳輸模擬之可靠輸入參數。

中文關鍵字：深層地質處置、離散裂隙網路(DFN)、流動傳輸阻力、功能測度值、安全評估

Oral Report H3-O-177

濁水溪沖積扇地層下陷機制探討

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摘　要

濁水溪沖積扇的地層下陷問題已經持續數十年，近年來的持續沉陷對高鐵安全造成風險。為緩解濁水溪沖積扇的地層下陷情勢，首要任務是了解其下陷機制。本研究整合了研究團隊過去針對濁水溪沖積扇地層下陷的研究成果，揭示了該地區地層下陷的可能機制與因素。台灣花東地區發生地震規模五以上的地震，會在濁水溪沖積扇造成數毫米的壓縮量。以該區域地震頻繁的特性，累積造成的沉陷量或可達到每年一公分。透過山區到平原區的水力耦合數值模式研究，原本地下水從山區向平原地區的補注循環降低，可能導致地表下沉數公分。觀測資料顯示，季節性地下水位變化不僅對淺層變形產生影響，甚至在濕季對深部地層產生壓密作用。透過異質場模擬研究，淺層抽水不僅造成淺地層的壓縮，也貢獻了6%至35%的深層壓縮。更重要的是，水文地質材料的空間分佈，在濁水溪沖積扇的地層下陷分佈中扮演了關鍵角色。複雜地質模型的水-力耦合數值模式研究顯示，地層下陷分佈從沿海地區向內陸區域的轉換，可能與黏土層厚度的空間分佈有關。透過數千個鑽探資料建置的異質水文地質分佈的評估結果顯示，濁水溪沖積扇南岸的扇央地區黏土含量較高，與該區域顯著下陷的觀測吻合。透過地下水位與土壤壓縮量的觀測進行計算與評估，扇央的土體比扇頂與扇尾區更容易因為水位下降而壓縮。綜合以上相關研究研究結果顯示，濁水溪沖積扇的地層下陷分佈，與細粒物質的分佈高度相關，顯示水文地質特性的重要性與異質場水文地質模型的必要性。然而，早期的地下水位下降是地表持續下沉的主要驅動力。因此，僅停抽地下水無法解決目前地層下陷問題，須提高扇央區的地下水位，並增加扇頂區的地下水補注，才能在短時間內緩解濁水溪沖積扇地層下陷問題。

關鍵詞：地層下陷機制、水文地質材料分布、數值模擬、山區塊體補注、地下水循環、地震。

Oral Report H3-O-178

Decadal evolution of ground subsidence in Yangon inferred from multi-sensor InSAR time series analysis

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Abstract

Yangon, Myanmar's largest metropolitan center, has undergone rapid urban expansion and economic development over the last decade, placing significant demands on groundwater resources. Due to insufficient public water supply infrastructure, the city faces an escalating risk of land subsidence, particularly within its low-lying floodplains. To investigate the long-term evolution of ground subsidence in the Yangon metropolitan area, this study uses Multi-Temporal Interferometric Synthetic Aperture Radar (MTInSAR) techniques across multiple satellite missions to estimate ground deformation. Displacement derived from L-band ALOS data (2007–2009), C-band RADARSAT-2 data (2012–2014), and C-band Sentinel-1 data (2015–2025) indicates that cumulative ground subsidence reached up to ~50 cm between 2007 and 2025 in eastern Yangon's floodplain, associated with groundwater extraction from the deep aquifer system. The cumulative subsidence on the floodplain west of the Yangon River is less significant, totaling ~18 cm, resulting from groundwater extraction from the shallow aquifer. A noticeable reduction in deformation rates after 2022 is likely associated with decreased groundwater extraction during the COVID-19 pandemic and subsequent socio-political disruptions. In contrast, the urban core situated atop the Shwegondaing-Mingalardon anticline is relatively stable, owing to the limited sediment compaction of the Pleistocene sedimentary rocks exposed along the anticline. Our findings provide a clear basis for zoning and management of groundwater usage in the region, facilitating a more sustainable urban development within the Yangon metropolitan area.

Oral Report M4-O-179

Seismic Slip Indicators of the Milun Fault and Their Implications for Mechanoradical Hydrogen Generation

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Abstract

Shearing in fault zones has been proposed as a mechanism for natural hydrogen generation, including mechanoradical reactions in which freshly comminuted silicates react with water to produce hydrogen. Although such reactions have been well documented in laboratory experiments and fault-zone gas monitoring, geological evidence from natural fault zones remains scarce. Here we characterize fault gouge of the Milun fault retrieved at the depth of 522 m in the Milun fault Drilling and All-inclusive Sensing (MiDAS) project. The black gouge contains coexisting lime (CaO) and carbonaceous material (CM), accompanied by melt-origin injection vein. Grain size reduction and the occurrence of melt-origin pseudotachylyte indicate comminution and frictional heating associated with seismic slip within the black gouge. Lime and CM are products of thermal decomposition of calcite and the subsequent reduction of CO_2 produced during the decomposition process under H_2-rich atmosphere. Because both lime and pseudotachylyte are highly susceptible to alteration in the presence of fluids, their preservation suggests that the slip zone is in a relatively dry condition. Although hydrogen generation is not directly observed, we propose that mechanoradical reactions occurred within the black gouge, providing a plausible mechanism for water depletion and hydrogen production that may have facilitated reducing conditions. Our findings provide the first direct geological evidence of seismic slip in the Milun fault and possible mechanoradical hydrogen generation during rapid shearing in natural faults.

Oral Report M4-O-180

Frictional Behavior of the Milun Fault Zone Rocks Determined in Experimental Multiple Seismic Slip Pulses

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Abstract

The Milun Fault in Hualien City is an active fault associated with several destructive earthquakes. Borehole cores retrieved by the Milun Fault Drilling and All-inclusive Sensing project reveal that a foliated yellow-black gouge layer was observed within loose and porous yellow gouges. This foliated gouge layer was interpreted as a slip zone, which may imply repeated strain localization during multiple coseismic events. However, the frictional behavior of this fault and the mechanism responsible for the formation of the foliated gouge remain poorly constrained. To address this issue, we conducted high-velocity rotary shear experiments on yellow gouge samples mainly composed of quartz and clay minerals under multiple identical seismic slip pulses (1 m/s). Under drained conditions, the apparent friction coefficient (μ_{app} = shear stress/normal stress) increased to a peak value of $\mu_p \sim 0.55$, gradually decreased to $\mu_{app} \sim 0.37$, then increased again to ~ 0.65, and finally showed an oscillatory manner toward the end of the slip. The peak friction (μ_p) becomes sharper with increasing number of pulses, indicating an energy reduction in breakdown work. Microstructural observations reveal that the yellow gouge on the rotary side was transformed into a black shear zone, accompanied by grain-size reduction and the presence of amorphous materials. The reduced breakdown work suggests the development of a mechanically efficient, localized slip zone that facilitates subsequent slip within the pre-existing slip zone. Our results suggest that the foliated gouge within the active fault zone of the Milun Fault may have formed through repeated coseismic slip under fluid-drained conditions.

Oral Report M4-O-181

Numerical investigation on dynamic weakening mechanisms triggered during experimental seismic slip on synthetic gouge

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Abstract

Dynamic weakening is a crucial process governing coseismic fault slip during earthquake rupture propagation. Frictional heating triggered by seismic slip can activate various processes by raising temperature (T) and pore fluid pressure (Pf) of saturated gouge-filled fault and reduce fault resistance. Therefore, understand the evolution of T and Pf is of paramount importance for determining dynamic weakening mechanisms during earthquake slip. To this aim, we built a thermo-hydro-mechanical-chemical (THMC) modeling using COMSOL Multiphysics. We utilize mechanical and measured T data obtained from kaolinite-illite-quartz gouges sheared at seismic slip rates under both undrained and drained conditions. Results show that under drainage conditions, the apparent friction coefficient (μ_{app}) increases to a peak friction (μ_p) followed by abrupt decrease with displacement, ultimately reaches a steady-state low-friction (μ_s), with μ_{app} being lower under undrained conditions. This behavior corresponds to a measured T at 100–150°C and at 250–300°C, the simulated Pf at ~1.8 MPa and ~2.4 MPa, respectively. Under undrained conditions, Pf is sustained at a high-level during shearing, whereas under drained conditions, Pf exhibits a transient spike followed by an immediate decay due to fluid drainage after 1 s. These results indicate that frictional heat triggered pore fluid pressurization/thermal pressurization/water vaporization accounting for the observed weakening. In addition, we suggest that fluid drainage conditions affect frictional behavior through the variation of Pf.

Keywords: Dynamic weakening, Seismic slip, fluid drainage, fluid pressurization, THMC modeling

Oral Report M4-O-182

Effect of mineralogy and fluid drainage on gouge friction at seismic slip rates

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Both minerology and fluid drainage are known to influence fault behavior, yet their combined effects during seismic slip remain unclear. To address this, we conducted experiments on water-saturated gouges composed of mixtures of quartz, illite, and kaolinite, the minerals commonly found within natural fault zones. Experiments were performed at 10 MPa normal stress and 1 m/s velocity under undrained and drained conditions. All samples exhibited slip weakening behavior. The apparent friction coefficient decreased from peak values of 0.16–0.6 to steady-state values of 0.03–0.45, generally decreasing with increasing clay content, except for steady-state friction under undrained condition. Restrengthening behavior occurred in clay-bearing gouges under drained conditions. Microanalytical results and thermo-mechanical modeling indicate that fluid drainage controls dynamic weakening mechanisms. Under undrained condition, thermal pressurization governs weakening, as pore pressure (P_p) increases outpace temperature rise, with grain size reduction and grain segration within the principal slip zone. Under drained condition, vaporization dominanates in the weakening stage. As slip progresses, P_p diminishes, drying the slip zone and promoting thermal decomposition of clay minerals, leading to strength recovery. We suggest that thermal decomposition of clays can noly be triggered under fluid drainage conditions, which may explain obervation from natural fault zones (e.g., Chelungpu fault). Our study provides a reference dataset for frictional coefficient in complex mineralogical compositions and highlights the effect of fluid drainage during coseismic faulting.

Oral Report M4-O-183

Effects of Asperity Aspect Ratio on Seismic Moment, Corner Frequency, and Double-Corner Spectra in 2D In-Plane Stick-Slip Ruptures With a Free Surface

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Recent studies suggest that source spectra are not controlled solely by rupture area. Whether rupture propagates in a crack-like or pulse-like manner, and the geometric asymmetry of the fault, can also significantly influence spectral characteristics. In particular, double-corner frequency spectra may arise from multiple mechanisms, including slip-pulse width, rupture directivity, gradual arrest, heterogeneous length scales, and supershear-related effects, with the second corner frequency most prominently expressed at small take-off angles (Kano et al., 2025). These findings motivate a focused question: for fixed rupture area, can high-aspect-ratio asperity geometry fundamentally modify source parameters such as seismic moment M_0 and corner frequency f_c, and give rise to double-corner spectral behavior?

To investigate this problem, we perform 2D in-plane dynamic rupture simulations under free-surface boundary conditions with a linear slip-weakening (LSW) friction law. Rupture area is held constant across models while asperity geometry is varied systematically, spanning square, rectangular, and elliptical patches across a range of aspect ratios. We analyze rupture kinematics, source time functions (STFs), M_0, and f_c to assess whether the short fault dimension becomes the dominant scale controlling source radiation as aspect ratio increases, and under what conditions double-corner spectral features emerge. We anticipate that high-aspect-ratio models will exhibit reduced average slip and M_0, elevated f_c, and stronger rupture directivity compared with compact geometries.

Keywords: dynamic rupture simulation, asperity geometry, corner frequency, double-corner spectrum, seismic moment, slip-weakening friction, rupture directivity, source time function

(1) National Taiwan University/Chun-Yu Ke
(2) Master's degree/First grade

Oral Report M4-O-184

Influence of Interface Roughness on Stick-Slip Rupture Dynamics in PMMA Laboratory Faults

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Abstract

Interface roughness is a primary control on fault frictional properties, yet its effect on stick-slip recurrence and dynamic rupture characteristics remains incompletely understood at the laboratory scale. We investigate this relationship using a direct-shear PMMA fault apparatus under constant normal stress, in which a 120 mm wide rectangular seismogenic patch was prepared at controlled surface roughness levels while peripheral regions were lined with low-friction polyethylene film to suppress edge effects and confine slip to the target zone.

Shear loading was applied at a constant displacement rate using a servo-controlled hydraulic system. Fault slip was monitored in real time by eddy current sensors distributed along the sliding interface, and PZT sensors positioned near the fault plane recorded acoustic emissions associated with each rupture event.

Results show that surface roughness governs the frictional energy budget of stick-slip cycles. Increasing roughness systematically modifies recurrence interval, coseismic slip amplitude, and acoustic emission characteristics, reflecting changes in contact asperity strength and the spatial distribution of stress concentration. These results constrain how microscale interface properties control macroscopic rupture dynamics and have implications for understanding the role of fault surface morphology in natural seismicity.

Keywords: interface roughness, stick-slip, laboratory earthquakes, rate-and-state friction

(1) National Taiwan University
(2) Master's degree /First grade

Oral Report M4-O-185

Seismological Source Localization of Acoustic Emissions for Internal Damage Mapping in Reinforced Concrete Members

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Abstract

Acoustic emission (AE) monitoring captures internal damage in loaded structures, but conventional AE source location methods lack the precision to resolve crack propagation paths and damage clustering. We adapt seismological hypocenter relocation techniques, originally developed for resolving microseismic event clusters, to improve AE source location accuracy in reinforced concrete beam-column joints under cyclic loading.

AE waveforms were recorded by four sensors while the specimen was subjected to cyclic lateral loading. P-wave arrival times were picked automatically and used in a grid-search initialization followed by nonlinear least-squares refinement. Multi-event double-difference relocation was then applied to sharpen relative source positions by minimizing differential travel-time residuals between event pairs.

The relocated AE catalogs reveal the spatiotemporal progression of internal cracking through successive loading cycles, which surface observation and conventional single-event location cannot capture. These results demonstrate that seismological relocation methods substantially improve the spatial resolution of AE monitoring and offer a practical framework for quantitative internal damage assessment in reinforced concrete structures.

Keywords: acoustic emission, source localization, reinforced concrete, structural health monitoring, damage evolution, double-difference relocation

(1) National Taiwan University/ Chun-Yu Ke
(2) Master's degree/First grade

Oral Report G1-O-186

Crop Field Monitoring by PolSAR Variable Decomposition

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Abstract

Polarimetric Synthetic aperture radar (PolSAR) must be an essential tool for a long-term monitoring of earth environment due to its high sensitivity to scattering mechanisms with flexible operability. To realize quantitative remote sensing using time-series satellite based PolSAR data, a variable decomposition technique utilizing a general volume scattering model has been proposed.

In this report, sensitivity study of the variable decomposition technique was applied to time-series real PolSAR data for crop fields where various changes for each inferred parameter could be expected. The technique was applied to time-series ALOS-2 data observing corn and soybean fields in Iowa state in U.S. showing considerable variation of growth status. Through the systematic comparison of derived parameters such as isotropy, a degree of double-bounce scattering, helicity, randomness, and mean orientation angle with time-series optical images obtained by Sentinel-2, each proposed variable was qualitatively validated.

Particularly, isotropy and a degree of double-bounce were quantitatively analyzed in this report. A significant correlation of the isotropy to soil moisture of bare surfaces before vegetated season was explicitly recognized. On the other hand, the degree of double-bounce scattering during vegetated season showed distinct differences of the growth status between corn and soybeans where time-series fully polarimetric SAR data would not only automatically classify the crops, but also understand growth conditions.

Oral Report G1-O-187

Topographically Informed Regression for InSAR Tropospheric Correction: Taiwan Tropospheric Delay Model

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Abstract

Differential synthetic aperture radar interferometry (DInSAR) technique is widely applied to geodetic analysis, while the accuracy of the measurement is often jeopardized by tropospheric delay. The effectiveness of popular correction methods such as using global numerical weather models (NWMs) is limited due to the heterogeneous distribution of water vapor, especially in Taiwan. One way to mitigate this issue is to develop a localized Taiwan Tropospheric Delay (TTD) model by using the delay data from the densely distributed continuous GNSS stations. For this purpose, we compute zenith total delay (ZTD) data from more than 400 GNSS stations and apply the Topographically InformEd Regression (TIER) model to estimate the spatially-varying transfer functions between elevation and delays. On each grid, an anisotropic station selection scheme is adopted to account for the uneven distribution of GNSS stations. Stations are weighted based on the distance from the grid to the stations, the elevation difference between the grid and the stations, and the sparsity of the stations. The transfer functions are then estimated using weighted least-square regression. To evaluate the performance of TTD model, we process 184 interferograms with 60 ALOS-2/PALSAR-2 acquisitions. Tropospheric correction is done by using the delays derived from ECMWF ERA-5 model and the TTD model, respectively. Result shows that the average reduction of displacement standard deviation reaches 11% with the TTD model and only 0.5% with the ERA-5 delay model. These numbers indicate that the TTD model can perform more effective tropospheric correction for the DInSAR processing in Taiwan.

Keywords: Taiwan Tropospheric Delay Model, Tropospheric Delay Correction, Differential Interferometric Synthetic Aperture Radar (DInSAR)

Oral Report G1-O-188

A Generalized Clairaut's theory for Celestial Bodies in the Clairaut Coordinate System

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Abstract

Clairaut's theory describes the deformation of a spherically symmetric body that reaches hydrostatic equilibrium under Newtonian gravity and relatively small perturbing forces, such as centrifugal or tidal forces. It remains a classical and fundamental theory in the field of geodesy.

In the traditional derivation, the equipotential surfaces of the total potential in integral form are required to coincide with the isodensity surfaces, and the result is then transformed into a differential form (Chao & Shih, 2024). This procedure is often laborious. In this study, we instead attempt a direct derivation in the Clairaut coordinate system using the differential form of the potential. Although the derivation is more involved than the classical approach, it allows us, at first-order accuracy in deformation, to derive the differential equation satisfied by deformations induced by any external potential that satisfies Laplace's equation, namely the generalized Clairaut equation.

This formulation also provides a clearer interpretation of (1) the physical meaning of the Clairaut differential equation, (2) the origin of its coefficients, and (3) the mathematical meaning of the boundary conditions. Unlike the traditional approach (Poisson & Will, 2014), the present method avoids the use of density perturbations $\delta\rho$ near discontinuities.

Using the same framework, the second-order form of Clairaut's theory, i.e., the Darwin equation, as well as rotational deformation up to third-order accuracy, can also be derived. We further derive the governing differential equation, up to second-order accuracy, for tidally locked bodies subject to both centrifugal and tidal forces, and compare the results with celestial bodies in the Solar System. Finally, we outline other applications of Clairaut's theory.

PS-InSAR 技術在離岸風機基樁穩定性監測之應用

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隨著全球推動能源轉型與淨零碳排政策，台灣也正積極開發台灣海峽的離岸風電。然而，由於台灣海峽內富含流體的沉積層，加上頻繁的地震與颱風，該區域可能存在地質不穩定之條件。在此背景下，台電一期示範風場（TPC-p1D）施工期間發生的「溜樁（pile run）」事件，凸顯了基樁穩定性的隱憂，以及對基樁進行長期監測的必要性。鑑於多數離岸風機缺乏現地監測數據（台電一期示範風場亦然），本研究開發了一套新的衛星永久散射體雷達干涉（Persistent Scatterer Interferometry Synthetic Aperture Radar, PS-InSAR）流程，進行以基樁為單位的形變分析，旨在避免相位解纏混疊（unwrapping aliasing）問題並允許傾斜估算。針對每一支基樁，此流程依據振幅離散度（amplitude dispersion）篩選 PS 點，並侷限於單一基樁的範圍內執行三維相位解纏。在取得各 PS 點的視線向（LOS）位移時間序列後，我們建立了一套傾斜模型，以估算各基樁之傾斜速率與傾斜方向。為驗證模型可靠性，我們先進行了合成測試以證明此概念的可行性。接著以義大利亞得里亞海的離岸鑽油平台為案例，利用該處同時具備的 SAR 與 GNSS 數據進行比對。結果顯示傾斜模型預測的位移速度與GNSS位移速度在LOS方向上有高度吻合。在確認模型有效性後，我們利用 Sentinel-1A（升軌與降軌）及 TerraSAR-X，（降軌）影像，計算台電一期示範風場內基樁的傾斜速率。最終反演結果顯示，pile 2 與 pile 9 具有相對大的傾斜速率，皆大於 0.025 deg/yr，可能在風場服役年限內出現結構安全疑慮，需多加留意。

Oral Report G2-O-190

Developing a Taiwan-Specific Tropospheric Model for InSAR: Integrating GNSS and ERA5 Delay Estimates

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Tropospheric delays present substantial challenges for accurate interferometric synthetic aperture radar (InSAR) measurements, particularly in Taiwan where complex topography and dynamic meteorological conditions create highly variable atmospheric effects. This study evaluates the uncertainty and accuracy of delay components from Global Navigation Satellite System (GNSS) observations and ERA5 reanalysis data to develop an optimized region-specific correction model for precise InSAR-based deformation estimates. GNSS-derived delay estimates were obtained at high temporal resolution (5-minute intervals) from stations distributed across Taiwan, while ERA5 provided spatially continuous hourly estimates. Initial comparison between GNSS and ERA5 delays revealed spatially consistent bias patterns for zenith total delay (ZTD) and zenith hydrostatic delay (ZHD), while zenith wet delay (ZWD) exhibited minimal bias (~1 cm). IQR-based outlier detection indicates that the debiased RMSD between GNSS and ERA5 ZWD reduces at higher elevations. As GNSS ZTD is the only observable, the accuracy of ZWD values (and hence the corresponding precipitable water vapor, PWV) differs depending on what model-based ZHD value is adopted. This study proposes the integration of GNSS-based ZWD with ERA5-based ZHD for constructing regional tropospheric delay correction model in Taiwan as compared to a model using purely GNSS ZTD (=ZHD+ZWD). By separating ZWD and ZHD into separate components, other sources such as PWV from the Himawari 8/9 geostationary satellites can be easily integrated. Both types of delays will be interpolated individually using the topographically informed regression (TIER) method and then summed to form the final ZTD model. Interferograms generated from the L-band ALOS-2 SAR

data will be used to validate the accuracy of the proposed correction method.

透過多年冰面高程變化在加拿大北極識別活躍冰下湖

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摘　要

冰下湖影響冰河的水文、流動與質量平衡，然而除了極地冰蓋之外，冰下湖的相關研究卻十分匱乏。本研究利用 2011 至 2021 年間的高解析數值高程模型（DEM），結合迴歸分析方法，在加拿大北極地區共識別出 37 個冰下湖，其中 35 個爲本研究新發現之湖泊。這些冰下湖面積介於 0.3 至 48.5 平方公里，在注水與排水時，可使冰面高程變化幅度達 10 至 150 公尺，對應到 0.003 至 4.5 立方公里的水體體積。這些活躍冰下湖可分成三種類型：（1）傳統冰下湖；（2）終端冰下湖（位於兩條冰河末端匯聚處）；（3）部分冰下湖（冰下湖與冰河邊緣的開放水域連通）。第 2 類與第 3 類爲本研究新提出之概念，而且本研究描述的冰下湖分別有 11 座與 15 座歸屬於此兩類。這些湖泊活動與區域冰河質量平衡呈負相關（r = -0.69，p-value = 0.039），意味著在冰河加速消融的時代，需要對冰下湖活動進行更密集的監測。

Oral Report G2-O-192

CARBONSAR: 透過合成孔徑雷達進行樹高推測

謝秉皓[1]、郭昱廷[1、2]、林玉儂[3]、衛強[4]、陳嘉俞[1、2]

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摘　要

森林冠層高度為描述森林垂直結構的重要參數，也是估算地上生物量與森林碳儲量的重要基礎資訊。在全球氣候變遷與淨零排放政策推動下，如何精確且大範圍地監測森林結構，對碳循環研究與森林資源管理具有關鍵意義。傳統上，光達可提供高精度的三維森林結構資料，並已廣泛應用於森林高度與生物量估算。然而，光達資料取得成本較高，在大尺度區域監測上仍受限於空間覆蓋率與資料更新頻率。相較之下，合成孔徑雷達具有全天候、全天時觀測能力，且可提供大範圍且連續的觀測資料，因此逐漸成為森林結構反演的重要工具。其中，利用干涉式合成孔徑雷達結合高解析度光達資料與物理散射模型估算森林冠層高度的方法，近年來受到廣泛關注。

在多種干涉式合成孔徑雷達森林高度反演方法中，Random Volume over Ground（RVoG）模型被視為描述森林雷達散射機制的重要理論模型。此模型假設森林由隨機分布的體積散射層與地表散射組成，並藉由選用HV極化（Horizontal-Vertical Polarization）雷達影像以降低地表散射的影響，再透過干涉相關性結合局部光達資訊進行模型參數反演。此外，模型假設由植被含水量變化所造成的介電常數波動參數，以及由風引起之樹木隨機運動參數，在雷達影像範圍內為均勻分布，據以推估衛星影像範圍內的森林冠層高度。

本研究預期利用日本ALOS-2 衛星影像，結合我國內政部高解析度空載光達資料，在特定的試驗林區，先建立地面到低空（光達）的森林樹高驗證，再透過低空到高空（SAR）的結合，建立大範圍森林冠層高度地圖，並進一步分析地形高程、局部入射角及不同森林類型對反演誤差之影響，期望提升森林結構監測方法之穩健性，並為未來大規模森林地上生物量估算提供科學依據。

【學生壁報比賽】參與者於摘要尾端註記

(1) 就讀學校/指導教授：國立中正大學/郭昱廷、林玉儂、陳嘉俞

(2) 學位/年級: 碩士/一年級

Oral Report M2-O-193

Linking remote typhoon forcing to coastal boundary dynamics using distributed acoustic sensing

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Abstract

Surface gravity waves generated by tropical cyclones can propagate across ocean basins and affect coastlines far from their source, yet direct observations linking offshore forcing to nearshore boundary response remain limited. Here we analyze distributed acoustic sensing (DAS) data recorded along a nearshore fibre-optic cable to resolve both remote wave generation and coastal boundary dynamics during a typhoon event. The source region of incoming swell is constrained from the temporal evolution of peak frequency using linear wave dispersion, together with directional wind forcing derived from reanalysis data. The results indicate that the dominant wave energy originates from the right-front quadrant of the storm at distances exceeding 1000 km, consistent with established asymmetry in tropical cyclone wave fields. Near the coast, DAS records a coherent high-frequency (0.5–1 Hz) energy front that migrates along the cable in phase with tidal variations and shifts landward during storm conditions. This signal is consistent with wave-breaking processes in the swash zone, which are known to generate broadband high-frequency ground motion. Satellite imagery shows a shoreline retreat of approximately 40 m over the same period, consistent with the displacement inferred from DAS measurements. These observations provide a direct link between remote storm forcing and nearshore boundary change, and indicate that DAS can provide continuous measurements of shoreline dynamics.

Keywords: distributed acoustic sensing; tropical cyclones; Surface gravity waves; wave-breaking processes; Satellite imagery

Oral Report M2-O-194

Distributed Acoustic Sensing Data from the MiDAS site: 2024-04-02 Mw7.4 Hualien Earthquake Sequence

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Abstract

The seismic response at the MiDAS site to the 2 April 2024 Mw 7.4 Hualien, Taiwan earthquake was comprehensively recorded by the distributed acoustic sensing (DAS) system, which has been operational since 2022. The DAS installation along the Milun fault employs optical fiber sensors that measure strain rate over a 10 m gauge length, sampled at 4 m intervals along the entire fiber. The system spans approximately 6.7 km, yielding 1,666 channels at a sampling frequency of 1000 Hz.

To facilitate further seismological investigations using this unique dataset, we have established an online repository that provides DAS recordings in daily MiniSEED format. The archive covers the period from one week prior to the mainshock through 30 days afterward (27 March–3 May 2024). All traces were down-sampled from 1000 Hz to 100 Hz following the application of a 40 Hz high-cut filter. Despite compression, each daily MiniSEED tarball remains sizable, with a file volume of approximately 22 GB. In addition, the repository includes the fiber route map, borehole coordinates, and associated metadata.

This data release serves as a valuable test case for understanding how to share a comprehensive DAS dataset with the broader community. It is now publicly accessible worldwide through the link at https://midas.earth.sinica.edu.tw.

Oral Report M2-O-195

以分散式聲學感測被動提取鐵路鋼軌千赫茲導波之初步研究

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摘　要

鋼軌作為鐵路系統的核心承載構件，其結構狀態的連續監測對行車安全至關重要。現有監測方法在頻率分布上存在一個尚未被探索的空白頻段，現有分散式聲學感測(Distributed Acoustic Sensing, DAS)鐵路應用多集中於500 Hz以下，而傳統超音波非破壞檢測則操作於50 kHz以上，介於兩者之間的千赫茲頻段至今缺乏被動量測方法的系統性探討。本研究於一鐵路鋼軌上黏貼100公尺光纖，採用20公分空間取樣率與20 kHz時間取樣率進行連續兩小時的被動量測，並透過互相關疊加提取虛擬震源響應，成功提取具建設性干涉特徵之虛擬震源訊號。頻率-波數(f-k)分析結果顯示，所提取訊號之主頻約為1100 Hz，傳播速度約為5180 m/s，與 UIC60鋼軌縱向導波理論值(5189 m/s)高度吻合，可明確識別為鋼軌縱向導波模態。此外，共偏移距剖面(Common Offset Section)分析結果於40公尺處呈現局部繞射特徵，並觀測到與現場錄影記錄之異常動態響應位置空間吻合的反向傳播訊號，顯示該量測方法對軌道支撐條件之局部擾動具有潛在敏感性。本研究為首次以被動式技術於鐵道營運條件下提取鋼軌千赫茲縱向導波之初步示範，驗證此方法應用於鐵路結構連續被動監測之可行性。

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Resolving the Active Milun Fault Structure at Hualien, Taiwan using 3-D DAS Array with Local Earthquake Data

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Abstract

Distributed Acoustic Sensing (DAS) converts an optical fiber into a densely spaced sensor array, enabling high-resolution near-surface structural investigations. Utilizing a 3-D DAS array from the Milun fault Drilling and All-inclusive Sensing project (MiDAS) at Hualien, Taiwan, we analyze earthquake waveforms from local events (ML > 4.0) to investigate the fine-scale structure of the active Milun fault, which ruptured during the damaging 2018 Hualien earthquake. We perform waveform simulations that incorporate different fault geometries and near-surface structural complexities, and iteratively adjust the model to reproduce the observed DAS waveforms. The surface fiber recordings clearly capture secondary wave phases generated by wavefield interactions with the fault zone, and these derived phases are consistently reproduced in the simulations when appropriate fault geometries are implemented. This agreement between observations and simulations demonstrates the capability of surface DAS arrays near fault zones to constrain fault geometry and provide new insights into near-surface fault structures, with important implications for seismic hazard assessment.

Keywords: Distributed Acoustic Sensing, MiDAS, shallow P wave velocity structure, Phasenet_DAS, borehole DAS array

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利用跨斷層井下光纖地震儀偵測微震事件-以池上斷層為例

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摘要

小規模微震事件在地震活動中佔多數，然而傳統地震儀為達空間上的均勻分布，測站間距通常較大，導致能量較弱之微震訊號難以被多個測站同時偵測。近二十年來，分佈式聲學感測（Distributed Acoustic Sensing, DAS）技術（又稱光纖地震儀）因具備空間上的高取樣密度，可形成類似地震儀陣列的觀測系統，於偵測相較弱之微震訊號方面展現優勢。在臺灣東部地區，池上斷層因頻繁的地震活動與獨特的斷層潛移特性，為研究花東縱谷沿線斷層變形之重要區域。在本篇研究中，我們開發一套應用於跨斷層光纖地震儀之地震事件偵測流程，結合垂直井下光纖纜線與深度學習自動挑波模型PhaseNet，在事件判定上設定在一秒的時間窗，當有超過 75%的通道偵測到S 波；或 S 波於超過 50%通道且 P 波於超過 30%通道同時被偵測時，即判定為一次地震事件。針對 2025 年 3 月至 7 月的資料進行分析，並與僅使用地表測站資料結合深度學習方法所建立的地震目錄做比較，結果顯示本研究所建立之流程可額外偵測約一成的地震事件數量，反映井下光纖地震儀對地震波列之偵測能夠提供有效的補充資訊，而透過將本研究所提出之流程應用於長時間光纖觀測資料中，預期可提升偵測微震事件之能力，進而為其他相關研究提供更完整的地震目錄，並有助於解析斷層構造的細部特徵。

關鍵字：分佈式聲學感測技術、光纖地震儀、微震事件、自動化地震事件偵測、PhaseNet

Oral Report M2-O-198

Borehole Distributed Acoustic Sensing Reveals Stick-Slip Dynamics in Deep-Seated Landslides

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Abstract

Deep-seated landslides pose major hazards to infrastructure and public safety, making it essential to better understand their internal deformation processes for effective risk assessment. In this study, we use Distributed Acoustic Sensing (DAS) to monitor subsurface deformation within a deep-seated landslide in Lantai, northern Taiwan. By installing a fiber-optic cable across multiple slip zones in a borehole, we turn the cable into a dense array of seismic sensors capable of resolving ground motion at high spatial resolution. Our results reveal that DAS successfully captures accelerated landslide movements and recurring stick-slip events at the soil-bedrock interface approximately 20 meters deep. Our results show that DAS captures abundant recurring stick-slip events primarily near the soil-bedrock interface at around 20-m depth and occasionally at deeper depths. The temporal clustering and recurrence intervals of these events are strongly influenced by typhoon-driven rainfall and intense earthquake shaking. These periodic stick-slip signals, which are not detected by conventional surface geophones, suggest velocity-weakening frictional behavior and reveal the high spatiotemporal complexity of slip within landslide shear zones. Our findings provide new insight into landslide mechanics and demonstrate the potential of borehole DAS as a powerful tool for real-time monitoring and hazard mitigation.

Oral Report M2-O-199

Field-scale artificial channel experiments for fluvial DAS observations

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Abstract

Understanding river sediment transport, and bedrock incision remains a major challenge in fluvial geomorphology Capturing their full temporal dynamics requires long-term monitoring of experimental catchments. This study explores the potential of Distributed Acoustic Sensing (DAS) technology to advance our understanding of fluvial sediment transport and riverbed evolution. Two experiments were conducted in meandering and straight artificial channels, with boundaries lined by waterproof membranes and stone protections, allowing for systematic effects of boundary and meandering shape. The experimental channels had a trapezoidal cross section, with widths ranging from approximately 2 to 4 m and bed slopes of 4–5°. During the experiments, the maximum flow depth reached about 0.3–0.4 m, the discharge ranged between 0.2 and 1.5 $m^3 s^{-1}$, and the median grain size (D50) was approximately 10–20 mm. The experiments were monitored using a synchronized multi-sensor framework that combined UAV- and ground-based photogrammetry, particle tracking velocimetry, water-level gauges, stand-alone hydroacoustic sensor, riverine seismic dense array and DAS monitoring. Two fiber-optic burial configurations were examined for strain-rate sensing: (1) burial within a 30 cm thick sediment layer, and (2) installation beneath the armored riverbed (riprap) layer, allowing assessment of coupling conditions. Two-gauge lengths (2 m and 10 m) were also tested to evaluate their influence on strain-rate measurements. In our artificial channel experiments, the DAS measurements

successfully captured high–spatiotemporal-resolution riverbed erosion and deposition dynamics. Fibers buried beneath the armored riverbed layer exhibited less sensitivity to riverbed morphological changes compared to those embedded within the sediment layer. This study demonstrated that fluvial DAS enables continuous, high–spatiotemporal-resolution monitoring of sediment transport and riverbed evolution.

Keywords: Fluvial distributed acoustic sensing (DAS), Stand-alone hydrophone, Field-scale artificial channel experiments

Oral Report S4-O-200

Multi-scale and Multi-step Tomographic Imaging –The Final Chapter Serving As Initial Model for Full Waveform Inversion

多尺度、多步驟層析成像－最終章：全波形反演的初始模型探討

ABSTRACT

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Through travel-time and waveform arrival simulations to verify various tomographic models proposed by several authors and methods, there are many pros and cons on the proposed models. This study emphases: (1) Deep learning-based seismic denoise data processing to preserve accurate picks on amplitude and first arrived p- and s-wave travel-time information. (2) Design semi-automatic picking strategy by hybrid DNN, STFT, EMD and STA/LTA methods. (3) Estimate the separate effects on scattering and intrinsic attenuation. (4) Establish empirical Vp-Vs relationships from local and regional velocity model studies. Assimilating 1D (mostly well-logs), 2D (mostly active surveys) and 3D (mostly passive earthquake monitoring studies) velocity models is not a trivial work. The inferred near-surface velocity model is determined from spatially distributed 1D well-logs and mostly 2D active source surveys/studies. The regional 3D velocity model is obtained from 3D and 2D models determined by travel-time tomography studies from passive source earthquake monitoring networks and active source long-offset TAIGER experiment. The goal is to remove over-estimated near-surface velocity perturbation and distribution. Thus, velocity structure for regional tectonic features can be better and clear revealed. (5) Multi-staged reference velocity model refinement via classical ray tracing, wavefield plus travel-time inversions and through fairly elaborated spatial interpolation of available sparse 2D/3D models. (6) Construct structured/unstructured 2D triangular, and 3D tetrahedral rectilinear grids and mesh system for building model. The mesh system tightly collocated with the lithological/geological boundary, surface fault traces, recording sensor locations and topography and bathymetry changes based on the well-defined geographic information database. (7) Implemented frequency-dependent Fresnel volume ray tracing (FVR) scheme to account for 3D propagation effects. (8) Implement FVR tomography. The powerful nonlinear Markov chain Monte Carlo (MCMC) and Generalized Gauss Newton (GGN) inversion techniques to estimate velocity model in Taiwan. MCMC methods provide ensemble solutions characterizes the uncertainty and non-uniqueness of the solution. An optimized single solution is determined by posterior distribution samples to find the maximum a posteriori (MAP) estimate (highest probability density)

or the posterior men/median. The selected “best” model fits the data while quantifying uncertainty/confidence interval surround the best estimate. GGN utilized Conjugate Gradient Least Square (CGLS) scheme. Three tomographic schemes (2D with initial model of 1D; pure 2D model profile; localized 3D FVRT) are used to accommodate irregular crooked-line survey geometry. For TAIGER-T6 Line case study, FVRT used separated 5, 10, 15 Hz frequency. For 2D inversion case study, high and skewed travel-time residual is within -0.5-+0.25 S. A noticeable improvement of more symmetric residual distribution around 0 S and within ±0.25 S.

Keywords: 多尺度、多階段、非結構化、四面體和三角形網格、菲涅耳體積波線追跡、非線性反演、馬可夫鏈蒙特卡羅（MCMC）、廣義高斯牛頓（GGN）、本體固有衰減和散射衰減
Keywords: Multi-scale, Multi-stage, Unstructured mesh, Tetrahedral and triangular grid, Fresnel volume ray tracing, Nonlinear Inversion, Markov chain Monte Carlo (MCMC), Generalized Gauss Newton (GGN), Intrinsic and Scattering Attenuation

Earthquake Early Warning and Real-Time Shakemap Development Using Low-Cost Sensors in Taiwan

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Abstract

This study synthesizes the development and operational performance of Taiwan's high-density, low-cost P-Alert earthquake early warning (EEW) network by integrating a system-level review with two recent large-earthquake case studies. Based on MEMS-based sensors, the P-Alert network complements the official regional EEW system by providing rapid onsite warnings within near-source blind zones and by generating real-time shakemaps of peak ground acceleration (PGA), peak ground velocity (PGV), spectral acceleration, and seismic intensity. The 2024 Mw 7.4 Hualien, Taiwan earthquake illustrates how rupture directivity can challenge point-source regional EEW approaches, leading to underestimated ground shaking in distant metropolitan areas. In contrast, the dense P-Alert network successfully delivered timely onsite warnings and high-resolution shakemaps that captured the directivity effect and mitigated missed alerts. The 2025 M_L 6.4 Dapu, Taiwan earthquake further demonstrates the system's capability to issue onsite alerts earlier than regional public warnings within approximately 30 km of the epicenter and to generate stable shakemaps within tens of seconds, with PGV distributions closely matching observed damage patterns. Together, these results demonstrate that dense, low-cost sensor networks substantially enhance EEW performance, improve rapid damage assessment through PGV-based products, and strengthen societal resilience to complex earthquake rupture processes.

Keywords: Earthquake, Earthquake Early Warning, Shakemap, P-Alert

Oral Report S4-O-202

Lithospheric Structure and Deformation Beneath Southern Taiwan Revealed by the SALUTE Array and a Deep Learning–Enhanced Earthquake Catalog

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Abstract

Southern Taiwan marks a critical segment of the Eurasian–Philippine Sea plate (PSP) boundary, where Eurasian continental subduction transitions northward into collision between the Luzon Arc and the Eurasian continental margin. However, the lithospheric structure in this region remains incompletely resolved due to limited data coverage in offshore and mountainous areas. To better constrain the lithospheric architecture across this transition zone, we integrate permanent seismic networks with the dense amphibious Southern Array for Lithosphere and Uplift of Taiwan Experiment (SALUTE) deployed since October 2021. A deep learning–based workflow applied to continuous three-component waveform data provides reliable P- and S-phase picks and construct a high-quality earthquake catalog for P- and S-wave velocity (Vp and Vs) tomography.

The models reveal a shallow (< 10 km) high-velocity, low Vp/Vs body beneath the Central Range (CR), contrasting with low-velocity and high-Vp/Vs anomalies in surrounding regions. This contrast reflects the compact metamorphic basement of the CR and sedimentary and volcaniclastic deposits elsewhere. At depths >10 km, a laterally extensive high-velocity structure beneath the eastern offshore region delineates the PSP mantle lithosphere, while an east-dipping low-velocity anomaly represents the subducted Eurasian lithosphere. North-south trending velocity bands subparallel to the eastern coast likely correspond to the Luzon forearc basement and basin deformed and deflected during arc-continent collision. These results provide new constraints on lithospheric structure and deformation across the subduction–collision transition in southern Taiwan.

Oral Report S4-O-203

Investigating Crustal Discontinuities beneath Southern Taiwan Subduction-Collision Transition Zone from CCP stacking of Receiver Functions

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Abstract

Southern Taiwan, situated at the transition between subduction and arc-continent collision, provides a natural laboratory for investigating lithospheric evolution and orogenic processes. In this study, we utilize common-conversion point (CCP) stacking of teleseismic receiver functions (RFs) to image crustal discontinuities in this complex tectonic setting.

We analyze over 3000 P receiver functions from 42 broadband stations across land and offshore regions, incorporating data from the BATS, CWASN, and our amphibious SALUTE array. To achieve the most ideal result, we establish a slightly different workflow for land and OBS stations.

The resulting CCP images highlight pronounced lateral variations in crustal structure across the orogen. In the western coastal plain, we observe two major discontinuities indicative of compositional layering in the continental crust. These features deepen and lose coherence toward the eastern offshore region, potentially reflecting steep subduction geometry or artifacts from water reverberations. Beneath the Central Range, a series of complex signals emerge that may be related to lower crustal accretion or inherited heterogeneities. On the eastern edge of the study area, the N-S profile reveals a northward-deepening trend of the Moho, indicating the graduate collision of the orogeny. Also, a distinct west-dipping feature likely corresponds to the subducting oceanic forearc crust. These patterns suggest significant structural variations across the arc-continent boundary.

This study demonstrates the effectiveness of RF-CCP imaging in capturing fine-scale crustal features and provides new insights into the tectonic architecture underlying southern Taiwan.

Oral Report S4-O-204

Revealing a Shear-Low-Velocity Structures beneath South-Western Taiwan by Using Rayleigh-Wave Tomography with SALUTE Array

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With the establishment of the Southern Array for the Lithosphere and Uplift of Taiwan Experiment (SALUTE) seismic array, we retrieved Rayleigh wave dispersion curves from 10–70 s using ambient noise and teleseismic data. For shorter periods, we selected station pairs with interstation distances ≥ 100 km and applied Bessel function fitting via a nonlinear least-squares algorithm, with initial model from Linear Radon Transform (LRT) analysis. After the first inversion, the resulting dispersion curves for each station pair were weighted by their Bessel function misfit, and an average dispersion curve was computed for a second inversion iteration, significantly reducing cycle-skipping in the final Bessel function fits. After carefully reviewing the fitting results, conducting verification tests confirming the absence of cycle-skipping at shorter periods, and discarding poor-quality station pairs, we constructed a shear wave velocity model beneath southern Taiwan. Our profiles reveal the subducted slab geometry and continental crustal deformation. Resolution tests confirm a low-velocity anomaly below 50 km in western Taiwan, likely reflecting remnant thermal material from Cenozoic continental margin rifting. Preliminary azimuthal anisotropy results show that the overall anisotropy strength remains ~1% across 20–70 s, with southwest Taiwan exhibiting weaker anisotropy at shorter periods that strengthens toward longer periods, while in southeast Taiwan the fast-axis direction evolves from N-S at shorter periods to NW-SE at longer periods. The SALUTE array provides key insights into the geodynamic evolution of the subduction-to-collision transition beneath southern Taiwan.

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

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Multi-Mode Ambient Noise Shear Velocity Tomography in Southern Taiwan Using Frequency-Bessel Transform and Voronoi Partitioning

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Abstract

Phase velocity dispersion derived from cross-correlation functions (CCFs) of ambient seismic noise has become a powerful tool for imaging subsurface structures. However, most conventional studies focus only on the fundamental mode of surface waves, which often yields poor depth resolution and non-unique shear velocity models. To address this, we implement a multimode surface wave tomography approach in southern Taiwan, utilizing data from the CWA, TSMIP, BATS, and the dense SALUTE array deployed since October 2021.

We apply the Frequency-Bessel (F-J) transform to extract multimode dispersion information from ambient noise CCFs. To improve the clarity of higher modes, a multi-component F-J approach is used to enhance signal quality. A major challenge in array-based surface wave analysis is balancing resolution and data quality when selecting subarrays. We address this by adopting a Voronoi partitioning strategy combined with wavelet parameterized inversion to construct period-dependent phase velocity maps.

Following the generation of phase velocity maps, we extract dispersion curves at each grid point and perform independent 1D inversions based on automatic differentiation to efficiently reconstruct the final 3D shear-wave velocity model. Results suggest a prominent low-velocity zone in the shallow crust beneath the Coastal Plain, clearly corresponding to thick, unconsolidated sedimentary sequences. Furthermore, a distinct high-velocity anomaly is observed at depths of 5–8 km beneath the Central Range (CR). This study contributes to a better understanding of the crustal structure in the complex tectonic region of southern Taiwan.

Oral Report M3-O-206

梅山地震 120 週年之再探：梅山斷層區淺層構造與斷層特徵

Revisiting the Meishan Earthquake After 120 Years: Shallow Structure and Fault Characteristics of the Meishan Fault Zone

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摘要

雲嘉南地區長期被視為臺灣西南部地震活動與災害風險較高之區域，近百年來曾發生多起具代表性之地震事件，包括 1906 年梅山地震、1941 年中埔地震、1964 年白河地震、1998 年瑞里地震、1999 年嘉義地震，以及近期之 2025 年大埔地震，顯示本區構造活動頻繁，且其孕震環境與淺部地質條件具有重要研究意義。尤其今年適逢 1906 年梅山地震 120 週年，更凸顯重新檢視梅山斷層構造特徵、近地表速度構造及其與地震災害關聯性之重要性。梅山斷層為區內重要活動構造之一，1906 年梅山地震曾造成顯著地表破裂與災害，顯示其斷層幾何、淺部構造值得深入探討。本研究以梅山斷層及其周邊區域為研究對象，整合不同時期建置之密集地震陣列、線性陣列與臨時性地震網資料，並針對研究區淺層速度構造、斷層帶幾何特徵及構造分段性進行分析與討論。藉由不同尺度與不同時

期觀測資料之整合，可望更完整描繪梅山斷層及其周邊構造於山麓至平原區之側向變化，並進一步探討斷層構造、近地表地質條件與歷史地震災害分布之空間關聯。研究成果除可增進對梅山斷層區孕震環境與淺部構造特徵之理解外，亦可作為後續地震危害評估與場址效應分析之基礎。

Oral Report M3-O-207

2026 年地物地質年會

預計投稿議程：M3 梅山地震 120 周年：區域孕震構造與科學新視野/Meishan 120: Regional Seismogenic Structures and New Scientific Perspectives

嘉南即時微震監測系統與近期地震活動概況

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根據歷史地震統計，嘉南地區已進入百年大地震週期高風險期，因此，能提供完整地震活動資訊且穩定運作的即時地震監測系統至關重要，而即時及長期地震目錄，能為不同面向的地震防救災工作提供關鍵資訊。自 2024 年四月至今，嘉南地區各地陸續發生數十起規模大於五（M5+）地震事件，尤其 2025 年 1 月 20 日 M6.4 大埔地震，造成不少災情。為更有效監測嘉南地區即時地震活動，我們在 2024 年底建置針對嘉南地區的即時微震監測系統（RT-MEMS），命名為 2025CN-RT-MEMS（Sun et al., 2025）。該系統是一個全自動化地震資料處理平台，搭載由台灣地震資料集訓練而成的深度學習模型，以臺灣西南部為中心，選取半徑 85 公里內近三十個寬頻地震站，所屬單位包括中正地震所及中正台灣南部地震研究中心、中研院臺灣寬頻地震觀測網（BATS）、與國研院國震中心全台地震陣列（SANTA），平均測站距離約在 15-25 公里，用於持續監測嘉南地區的地震活動，並透過電子郵件提供研究人員每日地震報告。截至 2026 年三月中旬，系統監測到的地震活動主要在大埔地震序列範圍內(Kuo-Chen et al., 2025) ，可觀察到嘉南地區的 M5+地震餘震數量，多依循餘震衰減特性逐時下降。有鑑於嘉南即時微震監測系統在過去 15 個月的穩定運作經驗，我們除了維持目前的測網及系統架構，持續進行即時監測及地震目錄累積，同時利用相同資料處理標準回朔過往地震目錄，以其獲取更完整的嘉南地震活動特性。

關鍵字：嘉南即時微震監測系統、深度學習、地震潛勢

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主震前的「徵兆」：大埔地震前震序列時空特徵解析

Foreshock Time-Spatial Characteristics of the 2025 Dapu Earthquake

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前震活動常被視為主震發生前的重要徵兆，其時空演化可反映孕震過程中的斷層幾何、應力調整與構造控制。本研究利用設置於嘉義、臺南與高雄交界、位於麓山帶邊緣之那瑪夏密集地震網，共 39 個測站，建立 2025 年大埔地震前 7 日之前震序列，並探討其時空分布特徵及構造意涵。本研究於密集網周圍共定位出 345 筆地震事件，整體地震活動度雖無明顯變化，但在不同時段可觀察到地震分布型態具有顯著差異。初期前震活動在南剖面及北剖面上分別呈現向東傾與向西傾的分布型態；自主震前 5 日起，各區域前震分布則逐漸轉為一致的向西傾特徵，且傾角較破裂模型為小。部分前震分布於主震主要破裂面周圍，顯示震源區鄰近構造可能已在主震前經歷應力調整與破裂準備。主震前約 20 小時起，地震活動度有所降低，顯示該區域之應力累積可能已接近臨界狀態，進入高度鎖定階段。本研究顯示，高密度地震觀測可有效揭露前震序列的細部時空演化，並為理解大地震之孕震過程與主震初始破裂機制提供關鍵觀測依據。

關鍵字：大埔地震，前震序列
Key words: Dapu Earthquake, Foreshock Series

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新一代地磁儀的研發、測試與初步觀測成果

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台灣的地球磁場觀測始於 1965 年 5 月，並隨即加入國際地磁及高空物理協會（IAGA）。初期觀測重點為磁偏角、水平分力及垂直分力之每小時平均值（黃胤年，1966；Huang, 1990）。隨後，中央研究院地球科學研究所（IESAS）於 1979 年在桃園崙坪與台南曾文設置 G826 全磁場磁力儀，達成每 5 分鐘一次的連續觀測；1988 年進一步更新為 G856 質子磁力儀，並將全台觀測站擴增至 8 站。2002 年起，藉由教育部「地震預兆觀測」卓越計畫，研究團隊全面更新觀測儀器（加拿大 GEM 公司 GSM90F 型），並增設 4 個站點，將採樣率提升至每 5 秒一次（陳界宏，2005）。此類數據不僅能分析地磁在寧靜期的狀態，亦能監測磁暴引發的劇烈變動，以評估感應電流對電力設施的影響；此外，也能用於觀察火山地區因岩漿侵入與火山作用導致的岩石磁化強度變化（Isabel et al., 2024）。

然而，過去台灣所使用的儀器多依賴進口，不僅價格昂貴且維護不易，最高每秒 10 點的採樣率已難以滿足現今精密觀測的需求。為此，本研究應用海底電磁觀測（OBEM）開發技術，自主設計 8 通道磁力儀資料記錄器，整合三分量磁通量（Fluxgate）、二軸傾斜、氣壓及氣溫感測器，構建每秒 100 點取樣率的高精密地磁觀測系統。目前已在大屯火山地區完成 5 處測站佈建，本文將深入探討該系統的運作穩定性，並分析火山活動之初步觀測結果。關鍵字： 地球磁場, 地磁儀, 傾斜應變, 磁通量, 火山

關鍵字；地球磁場, 地磁觀測, 磁通量, 火山活動

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地質探勘資料之雲端湖倉儲存架構初探

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摘　要

隨著我國推動「2050淨零轉型」與再生能源發展政策，地熱能源逐漸成為重要再生能源之一。而地熱資源的評估與開發高度依賴地下地質探勘資料，包括鑽井資料、測井紀錄、地球物理探測、地球化學分析、岩性與岩心分析以及影像資料等多來源資料。然而，現行地熱探勘資料係由不同單位產製，資料型態涵蓋結構化、半結構化及非結構化資料，普遍存在資料格式不一致、資料分散及整合困難等問題，缺乏一致性的資料標準與建檔方式，亦限制了地熱研究與資源評估的應用深度。

本研究探討地質探勘資料於雲端環境下導入資料湖倉（Data Lakehouse）之儲存架構設計與規劃。資料湖倉結合資料湖（Data Lake）之高彈性儲存能力與資料倉儲（Data Warehouse）之結構化管理特性，規劃分層式資料處理機制，包含原始資料層、整理轉換層及應用服務層，設計資料接入與轉換流程，以提升不同來源資料之整合效率與一致性。透過分析地熱探勘資料之來源與特性，建立具擴充性之資料儲存與處理架構，期望提升地質探勘資料之整合深度與分析能力，有效保存高價值之地熱地質鑽探資料，支援地熱潛能評估、地下構造分析及開發風險評估，提供多型態資料於單一平台之管理與應用基礎，同時於系統設計中預留人工智慧擴充能力，可作為後續系統擴充與智慧化服務發展之參考依據。

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An Agentic AI Research Loop for Geoscience

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Geoscience problems such as landslides, earthquakes, and slope hazards evolve continuously as monitoring conditions, engineering disturbances, and geological settings change through time, making it difficult to rely on fixed interpretation or warning criteria. This study proposes an agentic AI-assisted research loop that integrates knowledge updating, hypothesis generation, analytical testing, and iterative feedback into a repeatable workflow for geoscience research. The framework includes three core steps. First, dynamic literature collection and synthesis are used to continuously update prior knowledge, unresolved questions, and the scientific context for model revision. Second, a structured comparative reasoning process is applied to develop and evaluate multiple competing hypotheses for the same observations across disciplinary and spatial scales. Third, data analysis workflows are used to rapidly build testable models, assess alternative interpretations, and identify the most promising directions for the next round of investigation. This closed-loop design shortens the time between data acquisition and scientific interpretation while preserving geological judgment as the basis for evaluation and decision-making. Using environmental seismology of landslide as the main application context, this study shows how agentic AI can support adaptive scientific inference rather than act solely as a computational tool. The framework also has broader potential for large-scale data comparison and for building geological data archives from legacy materials such as field sketches, photographs, and other unstructured records. These results suggest that agentic AI can serve as a research collaborator that connects literature, hypotheses, data, and validation within a continuous scientific workflow, offering a scalable approach for hazard assessment, intelligent monitoring, and knowledge preservation in geoscience.

Keywords: Agentic AI; Geoscience; Research workflow

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應用人工智慧於台灣地熱探勘井之鑽進率預測與異常偵測

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摘　要

近年國際鑽井智慧化已從基礎演算法轉向結合物理特性與數據驅動的「混合模型(Hybrid Models)」。此趨勢旨在克服純數據模型的黑箱局限，確保系統決策未偏離工程實務法則，大幅提升預測準確度與可解釋性。我國為了因應能源轉型，積極推動具基載特性的地熱能源為國家重要戰略。然而，台灣地質構造複雜，鑽井常遇堅硬且破碎的岩層，致使開發成本高昂。導入智慧技術以預測鑽進率 (ROP) 並偵測扭力與泵壓異常，相當具工程實務應用價值。鑒於國內少有針對本土探勘井的人工智慧應用研究，本研究為首次結合台灣地質特性的鑽進率預測及異常偵測混合模型，期望在鑽井效率、成本與安全間取得最佳平衡。

本研究蒐集我國四口地熱井（H-1、H-2號、NY-1號、Y-1號）的小時級鑽探紀錄，經資料清洗與正規化後，取得 1,597 筆鑽進數據。模型架構主要可分為兩階段：第一階段為特徵萃取，採主成分分析 (PCA/PCAs) 從鑽頭加重、轉速、衝次等 14 項變數中，降維萃取出代表地層應力與鑽進機械力的關鍵特徵；第二階段為監督式學習，將特徵輸入隨機森林 (RF)、XGBoost、決策樹、SVM 與 GRU 等演算法建模。為了反映地質分層特性差異，本模型依據沖積層、乾溝層、四稜砂岩層及西村層等四種相異的地質類型各自建模。

結果顯示，各地質層的預測績效各有差異，在鑽進率預測任務中，沖積層的測試準確度達 61.38%，乾溝層為 36.59%，四稜砂岩層為 51.31%，西村層則為 20.64% 。在涵蓋正常、扭力異常與泵壓異常的三元分類任務中，異常偵測率分別為沖積層 100%、乾溝層 75%、四稜砂岩層 88%、西村層 60% 。綜合而言，本系統在各地質層之鑽進率預測能力約介於 20% 至 60%，異常偵測能力則穩定達 60% 以上 。此結果顯示混合模型能有效捕捉基礎鑽井趨勢，但受限於目前採樣頻率（每日數筆至小時級），尚難以完美映射分鐘級的非線性物理變化（如鑽頭磨損或瞬間井下震動）。未來建議導入泥漿錄井與 MWD/LWD 等高頻數據，以增進智慧鑽井之實務應用價值。

中文關鍵字：地熱探勘、機器學習、鑽進率、異常偵測

Application of Artificial Intelligence for Rate of Penetration Prediction and Anomaly Detection in Taiwan Geothermal Exploration Wells

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Abstract

In recent years, the intelligentization of global drilling operations has shifted from basic algorithms toward "Hybrid Models" that integrate physical characteristics with data-driven approaches. This trend aims to overcome the inherent black-box limitations of purely data-driven models, ensuring that system decisions strictly adhere to practical engineering principles while significantly enhancing prediction accuracy and interpretability. In response to the imperative of energy transition, Taiwan has actively promoted geothermal energy—characterized by its baseload power generation capability—as a crucial national strategy. However, due to Taiwan's highly complex geological structures, drilling operations frequently encounter extremely hard and highly fractured rock formations, leading to exorbitant development costs. Consequently, the introduction of intelligent technologies to predict the Rate of Penetration (ROP) and detect anomalies in operational parameters such as torque and standpipe pressure (SPP) holds substantial practical engineering value. Given the current scarcity of artificial intelligence application research tailored to domestic exploration wells, this study proposes a pioneering hybrid model for ROP prediction and anomaly detection specifically integrated with Taiwan's unique geological characteristics. The ultimate objective is to achieve an optimal balance among drilling efficiency, operational cost, and safety.

This study collected hourly drilling records from four domestic exploration wells (H-1、H-2、NY-1、Y-1). Following rigorous data cleaning and normalization, a total of 1,597 valid drilling data points were obtained. The proposed model architecture is primarily divided into two stages. The first stage involves feature extraction, utilizing Principal Component Analysis (PCA) to reduce the dimensionality of 14 operational variables—including Weight on Bit (WOB), Revolutions Per Minute (RPM), and pump Strokes Per Minute (SPM). This process extracts critical latent features representative of formation stress and mechanical drilling dynamics. The second stage employs supervised learning, wherein the extracted features are fed into various algorithms, namely Random Forest (RF), XGBoost, Decision Tree (DT), Support Vector Machine (SVM), and Gated Recurrent Unit (GRU), for predictive modeling. Furthermore, to accurately

capture the heterogeneity of distinct geological strata, the models were developed independently for four different geological formations: the Alluvium, the Kankou Formation, the Szeleng Sandstone, and the Hsitsun Formation.

The results indicate that predictive performance varies across different geological formations. In the Rate of Penetration (ROP) prediction task, the testing accuracy reached 61.38% for the Alluvium, 36.59% for the Kankou Formation, 51.31% for the Szeleng Sandstone, and 20.64% for the Hsitsun Formation. In the ternary classification task—encompassing normal operations, torque anomalies, and standpipe pressure (SPP) anomalies—the anomaly detection rates were 100% for the Alluvium, 75% for the Kankou Formation, 88% for the Szeleng Sandstone, and 60% for the Hsitsun Formation, respectively. Overall, the system's ROP predictive capability across various formations ranges approximately from 20% to 60%, while its anomaly detection capability consistently exceeds 60%. These findings demonstrate that the hybrid model can effectively capture fundamental drilling trends. However, constrained by the current sampling frequency (ranging from a few records per day to hourly intervals), it remains challenging to perfectly map minute-level, non-linear physical variations, such as bit wear or instantaneous downhole vibrations. For future research, it is highly recommended to integrate high-frequency data, including Mud Logging and Measurement/Logging While Drilling (MWD/LWD), to further enhance the practical engineering value of intelligent drilling

Keywords: Geothermal Exploration、Machine Learning、Rate of Penetration、Anomaly Detection

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從東北亞延伸至臺灣的西太平洋隱沒系統岩漿演化一致性

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摘　要

西太平洋自白堊紀至新生代之隱沒系統，在東北亞（日本、韓國及俄羅斯遠東）保留了連續且相對完整的岩漿活動紀錄。整合區域地質觀測與板塊重建結果顯示，約100–50 Ma期間該區出現顯著岩漿旺盛期（magmatic flare-up），沿超過約2200公里之陸弧展現一致的酸性岩漿組成與高岩漿通量特徵。此一時期對應伊邪那岐（Izanagi）板塊之隱沒，其聚合速率可能高達約12–24 cm/yr。相較之下，約50 Ma之後東北亞轉為太平洋海板塊隱沒，聚合速率降低至約2–10 cm/yr，並伴隨岩漿通量減弱及岩漿組成轉為以中性岩為主。上述時空對應關係顯示，東北亞陸弧岩漿特徵變化與西太平洋板塊運動歷史具有高度關聯。

然而，此一適用於東北亞／西北太平洋之板塊重建框架，是否可延伸至更南方之臺灣與中國華南地區，仍具顯著不確定性。相較於東北亞長期且相對單一的隱沒系統，臺灣與華南地區於白堊紀至新生代經歷更為複雜之構造演化。中國華南廣泛分布之中生代燕山期岩漿作用（約180–80 Ma），多被解釋為古太平洋板塊隱沒與板塊回撤相關的岩漿成因；其後於南中國海張裂（約32–15 Ma）背景下，發育一系列玄武質火成活動，涵蓋澎湖與臺灣西部麓山帶。透過對比東北亞與臺灣—華南地區之岩漿活動時序、空間分布及地球化學特徵，本研究評估東亞南段的隱沒系統是否呈現不同於東北亞之演化模式，並探討建立具區域差異性之板塊重建模型的必要性。

Oral Report TT2-O-214

台灣造山帶的岩石歷史、與其所隱示之山脈構造時空演變

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山脈核心區域之變質岩出露、與淺部地殼伸張變形是碰撞造山帶演化至成熟至晚期時常見的構造現象，然而其特性與大地構造意涵仍尚待厘清。臺灣島上源因于進行中亞歐-菲律賓海板塊聚合的中央山脈提供了一個優良的天然實驗室，探討造山帶晚期淺部伸張與地殼增厚、山脈地形形成與抬升、變質岩掘升、前陸盆地沉積等大尺度作用間的關聯。取得山脈帶出露變質岩的變質度、變質年代、脆性張裂礦脈與正斷層古地震形成年代，以及前緣盆地磨拉石碎屑變質度等關鍵資料與約制後，可知山脈地形抬升及變質岩掘升(始於~2.5 Ma，於~1.5 Ma 旺盛)是與淺部地殼脆性伸張變形(不遲於~1.6 Ma)高度相關聯，而顯著滯後於大陸邊緣俯衝及岩石進度變質的時間(始於~10 – 6 Ma)。而由同造山之磨拉石沉積物分析可得知，在最近 1.5 Ma 以內雖然山脈地形地貌已大致成熟如今，岩石掘升程度仍在持續增高。以上所得指示臺灣島的造山運動持續處於動態演變之中，其中相當於造山垮塌的淺部地殼伸張作用可能是變質岩快速擠出掘升、以及山脈地形隆升的關鍵推手。

岩石歷史、地殼增厚、岩石掘升、造山垮塌、時空演變
Rock history, crustal thickening, rock exhumation, orogenic collapse, secular change

Oral Report TT2-O-215

A petrological tale of two metamorphic belts in eastern Taiwan

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Abstract

The eastern Central Range of Taiwan is traditionally divided into two elongated metamorphic terranes, the Tailuko belt and the Yuli belt. Differences between the two belts are mainly in rock type, age, and peak pressure-temperature (P-T) condition. Both belts are dominated by pelitic-psammitic schists with minor greenschists. Metacarbonates and metagranitoids are abundant in the Tailuko belt, but absent from the Yuli belt. By contrast, metaserpentinites and associated metasomatic rocks are characteristic of the Yuli belt, but rare or absent in the Tailuko belt. Metabasites occur in both belts and vary in metamorphic grade. Metaplagiogranites occur exclusively in the Yuli belt. Sillimanite and andalusite have been identified in the Tailuko belt, but not in the Yuli belt. The Tailuko belt is subjected to polymetamorphism, with metamorphic records in Jurassic, Cretaceous, and late Cenozoic. The Yuli belt is essentially late Cenozoic. Amphibole compositions of representative rock types from the Tailuko belt are all calcic, whereas those from the Yuli belt are in the range of calcic, sodic-calcic, and sodic. Calculated amphibole formulas from analyzed compositions in meta-mafic and intermediate rocks from the two belts show distinct trends and complexities in [B]Na vs. [IV]Al plots and represent a good petrological indicator. Mineral assemblages and amphibole compositions indicate that metamorphism of the Tailuko belt includes intermediate and low P/T types, and metamorphism of the Yuli belt is high P/T type. The tectono-metamorphic processes and histories of the two belts are not paired in time and space.

Oral Report TT2-O-216

「蓬萊造山運動」的起始時代?

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摘　要

傳統觀點將蓬萊造山運動定義為由《弧陸碰撞》觸發的過程。早期研究依據關鍵指標：前陸與前淵盆地中出現造山帶變質岩岩屑（Teng, 1979）、中央山脈最早的抬升冷卻年代（Liu *et al*., 2001），及前陸盆地的形成（Lin *et al*., 2003）。基於上述證據，傳統界定的造山起始年代約 6.5–4 Ma。

然而，山脈形成不限於阿爾卑斯型碰撞模式，隱沒作用引起的安地斯型造山同樣關鍵。兩個板塊在進入碰撞階段前，必先經歷隱沒以達成聚合。因此，在北呂宋火山弧與歐亞大陸碰撞前，南中國海海殼的隱沒伴隨了火山弧萌發、增積岩體發育以及新生弧前地殼（SSZ；Chung *et al*., 2025）的形成，進而引發變質作用與地殼抬升。

陳文山等（Chen *et al*., 2019）首先主張應以「隱沒作用起始」作為造山運動的新定義，並得到鋯石 U-Pb 定年數據的支持：（1）利吉層與玉里帶中具 SSZ 特徵蛇綠岩塊，玉里帶變質輝長岩最老年代達 17.8±0.4 Ma（羅允傑等 Lo *et al*., 2020），變質斜長花崗岩年代為 17.4±0.1 Ma（羅文翰等 Lo *et al*., 2022）。利吉混同層輝長岩年代為 17.4±0.2 Ma（Shao *et al*., 2018）。（2）火山島弧萌發：北呂宋火山弧最老火成岩年代約 16.8±1.3 Ma（Lin *et al*., 2019），顯示早中新世即有岩漿活動。（3）早期變質事件：玉里帶最高變質度的石榴子石 Lu-Hf 年代為 13.1±0.5 Ma（陳采薇，未發表）與~14 Ma（羅文翰，東華博士論文，2026），角閃石 $^{40}Ar/^{39}Ar$ 定年為 12.2±0.5 Ma（Lo and Yui, 1996）。綜上所述，臺灣造山演化史可從傳統認知的 6.5 Ma 大幅提前至約 18 Ma。

然而，《弧陸碰撞》究竟始於何時？當火山弧與大陸接觸時，之間的弧前地殼會因強烈壓縮而消失，進而導致隱沒作用停止與岩漿活動停息。根據北呂宋火山弧岩漿活動由北向南陸續停息的年代顯示：海岸山脈北段火山弧最早於 5.3±0.2 Ma 停止活動、中段為 4.3±0.3 Ma（Chen *et al*., 2023）、綠島為 1.24±0.04 Ma（Shao *et al*., 2014）、小蘭嶼為 0.5±0.1 Ma（Lo *et al*., 1994）。由上述火山活動停止的時空分布，顯示《弧陸碰撞》在臺灣北端約始於 6–5 百萬年前。

近年透過鋯石 U-Pb 定年研究，讓我們能更深入探索臺灣各岩層的形成年代，完整呈現出從「隱沒造山（~18 Ma）」轉變至「碰撞造山（~6 Ma）」的時空演化過程。

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Oral Report TT2-O-217

Mountain Building Mechanism of the Taiwan orogen - along-Strike variability

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Abstract

Taiwan is situated within an active arc–continent collision zone and represents one of the most rapidly exhuming orogens on Earth, characterized by complex structural architecture. In our previous work, we developed a comprehensive thermomechanical model that incorporates the depth-dependent transition from brittle to ductile deformation, lithology-controlled erosion, and observed geometries of the basal decollement and backstop. The model successfully reproduces the key structural features of the northern Taiwan orogen and is consistent with metamorphic temperature profiles, thermochronological constraints, spatial patterns of strain, and the observed rates of exhumation and cooling. The results further demonstrate the critical roles of ductile deformation and ramp structures in the formation of the Hsuehshan Range and the Western fold-and-thrust belt. Structural styles, however, vary systematically from north to south across the Taiwan orogen. Notably, the Hsuehshan Range is absent in southern Taiwan, and total crustal shortening decreases significantly toward the southern tip of the island. Here, we apply the same thermomechanical framework under varying boundary conditions to reconstruct the along-strike evolution of mountain building across Taiwan. Our results indicate that the timing of orogenic onset is comparable along strike, whereas the rate of shortening decreases progressively from north to south. The basal decollement extends to approximately 20 km depth and exhibits variable ramp–flat geometries, leading to distinct structural styles along the orogen. The model successfully captures the development of the Pingtung Basin and the structural evolution of the Hengchun Peninsula, providing a unified framework for understanding the along-strike variability of Taiwan’s orogeny.

Oral Report TT2-O-218

A common provenance of Miocene-Pliocene sediments in western and eastern Taiwan as evidenced by the presence of ~1.8 Ga detrital monazites

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Abstract

Miocene-Pliocene sediments in western Taiwan have long been advocated to be sourced from the Cathaysia continent, although different views focused on the dominance of various drainage systems exist. However, recent observations on washouts from these sediments reveal that there are high percentage (43-27%) of ~1.8 Ga detrital monazites, which have never been found through the monazite age reconnaissance in the Cathaysian basements and drainage systems. Thus, the provenance of a now-concealed microcontinent was proposed. As paragenesis of monazite is often marked by a peraluminous environment, this particular peak in the age spectrum then records the time of an ancient orogeny (formation of S-type granite) or high-grade metamorphic event caused by crustal processes. We present here new monazite age determinations on detrital grains from some late Miocene/Pliocene sedimentary strata in the East Coastal Range, including Lichi Fm., Fugang Sandstone and Fanshuliao Fm., from which high percentage (46-33 %) for the age of ~1.8 Ga is likewise obtained. Assuming the East Coastal Range has moved northwestwardly at a rate of ~70 km/myr for the past 8 myrs, such monazites were originally deposited in places roughly 500 km southeast to Taiwan. This reconfirms the existence of an ancient microcontinent which supplied washouts not only to construct the Foothill unit for western Taiwan under the on-going arc-continent collision, but also to cover the sea floor of the northwestern margin of the Philippine Sea plate at the time when the North Luzon Arc initiated. The Palawan continental terrain in the Philippines may represent the relict of this microcontinent drifted to the south as aided by the opening of the South China Sea on the basis of the fact that it also contains such a particular group of monazite populations.

台灣地震構造之回顧

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摘　要

臺灣地震構造之研究可追溯至日據時代結束之後。徐明同教授率先系統性整理臺灣地震紀錄，並於1971年發表「臺灣地震活動及相關問題」，首次提出隱沒帶等重要地震構造概念。1972年，臺灣遙記式地震網（TTSN）開始建置，設有約25個即時地震站，大幅提升微震事件之觀測能力與資料完整性。隨著觀測資料的累積，蔡義本教授等人於1986年進一步提出臺灣地震構造模型。其後，Roecker等學者利用TTSN資料建立臺灣三維震波速度構造模型，使臺灣地震構造之整體輪廓得以初步掌握。1990年，TTSN併入中央氣象署地震觀測系統並進行升級，三分量即時地震站數量增加至約75站。至1993年底，中央氣象署地震網全面採用連續記錄系統，並配合人工判讀，使規模2.0以上之地震得以完整記錄。隨著氣象署、中央研究院及TAIGER（TAiwan Integrated GEodynamics Research）等觀測網資料累積，地震觀測空間密度與資料品質均顯著提升，顯著促進臺灣地震構造研究之發展，包括更精細之三維震波速度構造模型與更高精度之地震定位結果。此外，結合豐富之震源機制解與衛星大地測量資料，研究人員得以更清楚描繪臺灣造山帶與隱沒帶之構造特徵。中央山脈下方之地殼加厚現象（山根）及莫荷不連續面之形貌亦逐漸明朗，進一步深化對臺灣造山作用機制與地震孕震過程之理解。

關鍵詞: 地震、地震構造、震波成像、地震網

Oral Report TT2-O-220

New Geophysical Perspectives on the Structure and Evolution of the Taiwan Orogen

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Abstract

The Taiwan orogen is one of the most active and complex mountain belts in the world. The convergence between the Eurasian Plate and the Philippine Sea Plate gives rise to enigmatic deep slab interactions and intricate fault structures within the accretionary wedge that have not yet been clearly resolved. Recent advances in machine learning, imaging techniques, and dense array experiments have improved geophysical observations in both quality and quantity, providing new opportunities to revisit some long-standing tectonic questions. In this presentation, I will highlight recent progress from new seismic imaging and ML-enhanced earthquake catalog that reveal detailed intersecting fault structures along the Longitudinal Valley, eastern Taiwan and illuminate 3-D slab geometry and detachment from the crust to the deep mantle. These new results refine our understanding of the structure and evolution of Taiwan's arc-continent collision system.

Oral Report TT2-O-221

Tomographic Constraints on a Mid-Crustal High-Velocity Body Beneath West-Central Taiwan: Implications for Passive-Margin Mafic Additions

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Using dense seismic datasets, we present a new 3D velocity model of Taiwan that images a prominent mid-crustal (~20–30 km) high-velocity body beneath west-central Taiwan. The inclusion of high-quality post-2012 recordings from the Central Weather Administration Seismic Network (CWASN) ensures the elimination of uncorrectable timing errors. In addition, a machine learning–based phase picker was applied to the entire dataset to improve the consistency and accuracy of phase arrival identification. The resulting model generally aligns with previous tomographic studies. Structures inferred from velocity gradients in the tomographic profiles largely correspond to mapped faults and geological unit boundaries in Taiwan. The model also images a pronounced mid-crustal (~20–30 km) high-velocity anomaly beneath west-central Taiwan. Under representative P–T conditions, Vp–Vs–density comparisons

indicate the best match with mafic compositions, though the interpretation is not unique. This mafic interpretation is compatible with passive-margin mafic additions (underplating and/or intrusions). The anomaly coincides with reduced seismicity below ~20 km and depth-dependent stress orientations, consistent with a relatively competent mid-crustal volume. Geological and geophysical similarities with the Dongsha Rise further suggest a possible shared tectonic and magmatic origin, likely linked to mafic underplating during South China Sea rifting. These findings improve our understanding of structural highs along passive continental margins and their role in influencing crustal deformation in the Taiwan orogen. The new model also provides a robust framework for future waveform-based seismic imaging.

Oral Report TT2-O-222

Numerical thermo-mechanical models on the arc-continent collision in eastern Taiwan

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Abstract

This study employs 2D numerical thermo-mechanical models to simulate the arc-continent collision and elucidate the fault geometries in this region. The time progression of the model can be understood as the structure evolution from south to north. Following the subduction initiation at the Manila Trench, the oceanic crust of the South China Sea (SCS) is subducted eastward under the Philippian Sea plate, leading to the formation of the Luzon Arc (LA). As the SCS transition crust, which resists deep subduction due to its buoyancy, approaches the trench, it causes horizontal shortening to be transferred to the upper plate. Subsequent deformation results in the buckling of the forearc basin into a syncline and the formation of the east-dipping Taitung Trough fault, which facilitates overthrusting of the LA over the basin sediment and its basement. As the collision progresses, the North Luzon Backthrust's dip becomes nearly vertical, while the Taitung Trough fault sinks to 15 km depth, coinciding with the emergence of the Longitudinal Valley fault (LVF). A new backthrust develops parallel to the North Luzon Backthrust but further east, matching the observed Central Range fault (CRF) and extending shallowly eastward towards the Coastal Range, possibly aligning with the Chimei Canyon thrust. This evolution results in a complex #-shaped fault system beneath the Longitudinal Valley, profoundly affecting the region's seismotectonic structure. The correlation of shear zones in the model with the aftershock distribution validates our forward model's accuracy in capturing the essential tectonic blocks.

臺灣中央山脈變質雜岩核心的構造特性與變形意涵－以南橫為例

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摘　要

造山帶變質雜岩核心之地質構造特性與脆塑性變形特徵，提供造山歷史與資源評估之資訊。為釐清過去地質問題與提供未來環境管理策略，本研究選擇前人文獻多樣、交通有利發展、仍有未調查路線與待釐清問題之南橫地區，沿各溪流進行野外地質調查，輔以岩相觀察與鋯石鈾鉛定年，測製成比例尺五萬分之一地質圖。

研究結果指出，壽豐斷層與嘉寶斷層分隔三個地體單元，分別是新武片岩(玉里層)與初來層、佳保片岩（太魯閣層）、霧鹿片岩與利稻層。

在新武片岩與初來層，過去根據兩岩體劈理期數不同，解釋其為斷層接觸，即清水斷層，但一直沒有明確的野外證據。野外調查發現兩岩體實為片岩至板岩之漸變關係，形成武陵複向斜，地熱探勘井下資料亦支持此模式。

霧鹿片岩與利稻層形成霧鹿複背斜。兩岩體為整合接觸，接觸面可見後期疊加之斷層。複背斜軸部為大崙變質花崗岩，形貌東陡西緩，圍岩夾有串腸狀變質花崗岩條帶。本研究預測的變質花崗岩頂部高度與特徵，業經井下資料證實，與野外觀察相符。此外，碳物質拉曼光譜顯示變質花崗岩與圍岩接觸帶之變質溫度比周遭地區更高，支持侵入接觸關係。

地質構造方面，南橫地區普遍可見約北北東走向、向西傾斜之劈理。本研究調查出後期開放-閉合褶皺，伴隨西北西走向、高傾角之夾皺劈理與破劈理。霧鹿片岩西側存在坑頭斷層，由一系列北北東走向、近垂直之斷層所組成。霧鹿至初來之井下資料與電阻率特徵，與上述現象不謀而合。

結果顯示，有效的野外地質調查，不僅發現新事實，也釐清既有地質爭議。經由地表地質與地下地物兩種不同途徑，若得到相同結論，或限縮地質模型的可能性，代表具有探勘可信度，有助提升投資信心，促進在地經濟活力。

Oral Report TT2-O-224

Miocene ophiolitic serpentinite in eastern Taiwan: Affinity to the South China Sea or the Philippine Sea?

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Abstract

Xenolithic and ophiolitic peridotites/serpentinites in the eastern Taiwan are geochemically investigated to provide constraints on clarification of the boundary between Eurasia and Philippine Sea Plate. Major-element contents show Eastern Taiwan ophiolitic (ETO) peridotites fit to global ophiolitic and abyssal peridotites. But Qing-Shui River (QSR) ophiolitic serpentinites from the Yuli belt is similar with orogenic peridotites. Tsunkuanshan (TSU) ophiolitic serpentinites from the Yuli belt 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 mantle wedge characteristics. Both QSR and TSU ophiolitic serpentinites 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. ETO ophiolitic peridotites show both LREE-depleted and U-shaped REE patterns. In terms of PGE concentrations, most ophiolitic peridotites/serpentinites are mantle residues which can directly reflect source mantle characteristics. Therefore, mantle source where ETO peridotites formed is LREE-depleted, whereas LREE-enriched mantle source is where Lanyu and QSR 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 serpentinites are supra-subduction zone (SSZ) affinities. Some TSU serpentinites are suggested their intermediate feature between the abyssal and SSZ affinities. Os isotope results further show ETO, Lutan, Lanyu, QSR and TSU peridotites/serpentinites are definite Philippine Sea plate affinity, but parts of TSU serpentinites might be involved with South China Sea affinity.

Keywords:
lithospheric mantle, ophiolitic peridotite and xenolithic peridotite

Oral Report TT2-O-225

Paleo-subduction in the Taiwan orogen: insights from Lu–Hf garnet geochronology and petrological modelling

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Abstract

Exhumed high-pressure (*HP*) metamorphic rocks are direct petrological records of paleo-subduction. In the Yuli belt of the Taiwan orogen, evidence of *HP* metamorphism has been reported within several serpentinite-bearing subunits, yet the timing remains poorly constrained. This study presents the first Lu–Hf garnet ages for metabasaltic and metapelitic lithotypes within the subunits, integrated with thermobarometric constraints from phase equilibrium modelling. The estimated peak pressure–temperature (*P–T*) conditions of 1.3–1.5 GPa, 575–585 °C for the metabasites and 1.4–1.7 GPa, 500–575 °C for the metapelites indicate subduction-zone *HP* metamorphism. Lu–Hf dating yields bulk garnet crystallization ages of 13.5–12.6 Ma (four metabasites; ±0.4–0.8 Ma; ±2σ) and 12.0–10.2 Ma (three metapelites; ±0.2–0.3 Ma; ±2σ), interpreted as the timing of (near-)peak metamorphism. These Lu–Hf garnet ages (*c.* 13.5–10 Ma) predate or partially overlap with previously published $^{40}Ar/^{39}Ar$ white mica dates (*c.* 11–9 Ma) from the so-called glaucophane schists. We find no geochronological support for previously proposed Late Cretaceous or Early Pliocene (*c.* 5 Ma) timing of *HP* metamorphism in the belt. The small but resolvable Lu–Hf age offset between the two investigated lithotypes, together with apparent differences in peak conditions and prograde *P–T* paths, suggests juxtaposition along the paleo-subduction interface. We conclude that *HP* metamorphism in the Yuli belt reflects short-lived intra-oceanic subduction during the Miocene prior to the transition to arc–continent collision.

Keywords: intra-oceanic subduction, subduction interface, high-pressure metamorphism, pseudosection modelling, Yuli belt

Oral Report TT2-O-226

Potassium isotopic variability in the Northern Taiwan Volcanic Zone and its implications for the origin of K in subcontinental lithospheric mantle

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Abstract

Magmatism occurred in the Northern Taiwan Volcanic Zone was associated with extensional collapse of an active mountain belt formed by oblique collision between northern Luzon arc with the Asian continental margin. Earlier work demonstrated substantial geochemical variability in terms of elements and radiogenic isotopes in volcanic rocks that is linked to the combined influence of melts derived from subducted sediments and fluids released from subducted slab in generating precursor, metasomatized mantle sources to the magmas. This view is tested with newly obtained high-precision K isotopic data for a set of well-characterized samples of volcanic rocks from different eruptive centers in the volcanic zone, yielding the following isotopic ranges: Tsaolinshan, ($\delta^{41}K$ = −0.62 to −0.28‰), Mienhuayu ($\delta^{41}K$ = −0.62 to −0.39‰), Kobisho ($\delta^{41}K$ = −0.44 to −0.41‰), and Sekibisho ($\delta^{41}K$ = −0.13 to −0.09‰). The lack of trends between $\delta^{41}K$ and [K_2O] indicates that the isotopic variation has nothing to do with the process giving rise to the wide range in [K_2O], which varies from ~0.36 to ~5.5 wt.%. Two samples from Tsaolinshan with variable degrees of K loss (sample TLS-3 and T20) show deviations from the narrow range in $\delta^{41}K$ among four other samples ($\delta^{41}K$ = −0.47 to −0.44‰). As subducting sediments of the Ryukyu trench are characterized by extremely low $\delta^{41}K$ of −1.4 to −0.8‰, the heavier K isotopes seen in most samples could only be explained by the influence by altered oceanic crust or fluids derived from it, unless there is substantial K isotopic fractionation during sediment melting. The altered oceanic crust component is manifested in the Sekibisho samples that have relatively high and resolvable $\delta^{41}K$ compared with the mantle range ($\delta^{41}K$ = −0.42 ± 0.08‰). Future work targeted at Tatun Volcanic Group and Kueishantao will result in a more complete picture of K isotopic variability among the Northern Taiwan Volcanic Zone.

Oral Report TT2-O-227

Hsiaolanyu island: An Active Volcano!

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Abstract

Hsiaolanyu island (HLY) is a volcanic island located off the southeastern coast of Taiwan. It is part of the northern North Luzon Arc. HLY belongs to the Eastern Volcanic Chain (EVC) of the arc, and shares the same lineage as Lutao island. Lanyu island, situated approximately 5.6 km to the northwest, belongs to the Western Volcanic Chain (WVC). The EVC formed within the last 2 My, making it geologically younger than the WVC. Due to its proximity to the Eurasian continental margin, it was previously widely believed that volcanic activity in the Taiwan segment of the EVC ceased due to the arc-continent collision approximately 0.02 Ma, based on the youngest available dating result from HLY.

HLY is roughly quadrangular in shape. Along its southern coast, a series of horizontal volcaniclastic deposits containing embedded driftwood is exposed. After tree-ring calibration, carbon-14 dating of a wood sample yields an age of 1270–1180 BP (approximately 680–770 CE). Crucially, volcanic breccia and lava flows at the southeastern corner of the island overlie these deposits locally, indicating that volcanic eruptions occurred more recently.

This study analyzed a fresh lava flow sample of biotite-hornblende andesite, collected from the southeastern corner of the island. Although Ar-Ar dating failed to determine a significant age, suggesting an extremely recent formation, this study employed a zircon double-dating technique. This method combines U-Th disequilibrium and (U-Th)/He dating of zircon. The analysis yielded a geological age of 1.08±0.22 ka, the youngest age yet recorded using this method. Field observations and geochronological data confirm that HLY is an active volcano. Consequently, the volcanic hazard potential of this region must be reassessed urgently.

Oral Report TT2-O-228

Detrital zircon and monazite U-Pb ages of Well TL-1 in Penghu Islands, Taiwan: Implication for exotic basement of Peikang High

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Abstract

The Peikang High (PK), a well-preserved pre-Cenozoic basement beneath Taiwan, remains poorly understood due to limited sub-surface investigation. This study examines core samples from Well TL-1 in the Penghu Islands—a 900-meter-deep borehole at the westernmost extent of the PK—using coupled detrital zircon and monazite U-Pb dating to elucidate its crustal characteristics and reassess the tectonic framework of the Cathaysia Block continental margin. Below a major unconformity at 503 meters, five Early Cretaceous (Aptian) sandstones and siltstones consistently exhibit a prominent zircon age cluster at approximately 120 Ma, indicating syn-volcanic deposition. The positive ƐHf(t) values of these Cretaceous zircons suggest a mantle-derived magmatic origin. In contrast, two Early Miocene littoral-to-neritic sedimentary units (depths of 403 m and 500 m) are characterized by a high abundance of ~1.8 Ga ages (30–45%) in both zircon and monazite populations. The large grain sizes (>200 microns) and euhedral morphology of these ~1.8 Ga grains suggest a proximal source-to-sink relationship for the Miocene sediments. The composition of the uppermost PK, dominated by ~120 Ma juvenile magmatic zircons, aligns with magmatic episodes in the East China Sea but contrasts sharply with the Mesozoic crustal-assimilation magmatic systems typical of the Cathaysia Block. Furthermore, the ~1.8 Ga monazite signature is entirely absent from the Cathaysia Block, suggesting an exotic provenance potentially associated with the lower crustal components of the PK. Collectively, the unique geochronological and isotopic features of the Well TL-1 deposits suggest a tectonic disconnection between the PK and the Cathaysia Block, supporting the interpretation of the Peikang High as an allochthonous terrane.

General Poster GP001

Heavy Metals Dynamics Across Coastal Waters and Mangrove Sediments: Insights into Plant–Microbe Co-mitigation

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Abstract

Mangrove wetlands are coastal buffers but are increasingly burdened by heavy metals (HMs) delivered from rivers, estuaries and nearshore waters. We assessed HMs sources, mobility, ecological risk and nature-based attenuation in Taiwan's Xinfeng mangrove using coupled water-sediment geochemistry, mangrove bioaccumulation and rhizosphere metagenomics. Waters (coastal sea, estuary, river and mangrove overlying water) and rhizosphere sediments (0–20 cm) were sampled with roots, branches and leaves of *Kandelia obovata* and *Avicennia marina*. Water-quality indices indicated moderate contamination in river/estuary/overlying waters relative to coastal seawater. Sediment indices showed contamination by Bi and Pb and moderate enrichment of Zn, Sr, Cu and Cd. Partitioning suggested higher mobility of Bi, Pb, Co and Sr at the sediment-water interface, increasing potential for aqueous transport and exposure. Ecological risk was low to moderate, with Cd as the main contributor. Both mangroves showed strong phytoremediation potential (Bi, Cd, Mn, Sr and Co), indicating vegetation can lower bioavailable HMs. Metagenomics revealed diverse rhizosphere communities with predicted plant-growth functions (N fixation, P solubilization, IAA-related pathways) and HM-resistance traits, highlighting plant-microbe synergy. These results support management that couples upstream input control with monitoring of sediment-water exchange and nature-based mitigation to strengthen mangrove resilience.

Key Words: Heavy metals, Rhizosphere, Ecological risk, Microbes, Heavy metals resistant

General Poster GP002

Utilization of pig urine as a sustainable urea substitute in microbially induced cerium carbonate precipitation for heavy metal remediation from water

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ABSTRACT

Heavy metal (HM) contamination represents a persistent and globally distributed environmental challenge, necessitating the development of effective, sustainable, and resource-efficient remediation technologies. In this study, microbially mediated cerium carbonate precipitation (MICCP) was investigated as an integrated approach for the simultaneous removal of Cr, Pb, and Cu from aqueous systems. The process employed varying cell concentrations of *Sporosarcina pasteurii* and pig urine (PU), a urea-rich agricultural waste, as a sustainable substitute for commercial urea typically used in microbially induced carbonate precipitation (MICP). Morphological characterization by scanning electron microscopy revealed the formation of nanoscale spherical and rod-like structures with an average size of ~112 nm. Phase identification and functional group analyses using X-ray diffraction and Fourier-transform infrared spectroscopy confirmed the formation of high-purity crystalline $CeCO_3OH$, characterized by surface-associated hydroxyl groups and carbonate (CO_3^{2-}) species, indicating successful cerium incorporation and carbonate mineralization. Batch adsorption experiments demonstrated rapid and efficient HM removal, achieving maximum removal efficiencies of 99% for Cr, 99% for Pb, and 68% for Cu within 80 min at an initial metal concentration of 6 mg L^{-1} and an adsorbent dosage of 0.05 g. Adsorption behavior was well described by the Langmuir isotherm model ($R^2 \approx 0.9$) and pseudo-second-order kinetics, suggesting monolayer adsorption dominated by chemisorption mechanisms. Thermodynamic analyses revealed that the adsorption process was spontaneous and exothermic ($\Delta G < 0$, $\Delta H < 0$, $\Delta S > 0$). Overall, the results highlight MICCP coupled with waste-derived urea as a promising,

environmentally benign, and sustainable strategy for heavy metal remediation in contaminated water.

Keywords

Heavy metal remediation, Microbially induced mineralization, Cerium carbonate precipitation, Sustainable bioremediation, Agricultural waste valorization, Water treatment.

General Poster GP003

臺灣海百合化石：板塊運動主導的新生代擴散

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自一百多年前韋格納提出大陸漂移學說以來，板塊運動已被證明在陸生生物的擴散中扮演關鍵角色，透過大陸之間的連通與分離影響生物地理分布。然而，在海洋生態系中，儘管有更大比例的海洋生物仰賴被動擴散，其生物地理分布的變化多被認為主要由洋流所主導，板塊運動的影響仍不清楚。新生代西太平洋的有柄海百合擴散史在過去被認為可能與板塊運動相關，但由於新生代有柄海百合棲息於深海環境，而深海相沉積岩往往僅在構造活躍且快速造山的地區出露，導致晚新生代的化石紀錄極為稀少。在本研究中，我們報導來自花蓮上新統港口石灰岩與臺南更新統古亭坑層的等節海百合（Metacrininae）化石，為目前全亞洲最年輕的海百合化石紀錄，也補足了晚新生代化石紀錄的缺口。結合既有化石資料，我們利用全球板塊模型（Global Plate Models）重建高解析度的古地理座標與擴散軌跡。結果顯示，等節海百合在新生代期間由南極洲與澳大拉西亞向西北方向，經由馬來群島逐步擴展至臺灣。早中新世之前的擴散速率與澳洲板塊向北漂移速率一致，顯示當時的擴散主要受板塊運動所主導，反映固著的海百合成體隨板塊漂移而移動。相對地，早中新世之後的擴散速率遠大於板塊漂移速度，顯示擴散主要受澳洲與東南亞碰撞後所形成的北太平洋西邊界流所驅動，帶動浮游的海百合幼體進行長距離擴散。透過新化石的發現與量化的古地理座標重建，本研究證明板塊運動及其所導致的海洋環流變化，是在地質時間尺度上控制海洋底棲生物擴散的重要機制。

General Poster GP004

利用土壤細菌去除電鍍廢水中的重金屬

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摘　要

本研究探討利用土壤細菌進行電鍍廢水中重金屬去除的可行性，並以微生物誘導碳酸鈣沉澱（MICP）技術作為核心處理方法。電鍍廢水中常含有鋅、鎳、鉻、鎘等重金屬，若未妥善處理，將對環境、水體生態及人類健康造成危害。因此，發展高效率且環保的處理技術具有重要意義。

本研究自牧場土壤中分離出具脲酶活性的陰溝腸桿菌（Enterobacter cloacae），利用其分解尿素產生碳酸根，進而形成碳酸鈣沉澱，並藉由共沉澱作用固定廢水中的重金屬。實驗中以掃描式電子顯微鏡（SEM）、能量散射光譜（EDS）及X光繞射分析（XRD）觀察沉澱物特性，並以ICP-OES分析重金屬去除效率。

研究結果顯示，此方法對電鍍廢水中的鋅具有良好的去除效果，證明MICP在重金屬污染處理上具有應用潛力。此外，本研究也進一步探討沉澱物經高溫氧化後的金屬回收可能性。整體而言，MICP是一項兼具環保、永續與資源回收潛力的創新技術，可作為未來重金屬廢水處理的重要發展方向。

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General Poster GP005

臺灣鹿科動物化石研究之回顧與展望

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鹿科動物(Cervidae)自中新世於東亞起源以來，演化出極高的多樣性。臺灣位處歐亞大陸東緣，除了現生種外，亦留下豐富的鹿科動物化石記錄。臺灣鹿科化石的研究最早可追溯至日治時期，並已經顯示具有高度的研究潛力。然而，受限於化石保存破碎、特徵鑑定未臻完善，且多數標本為私人採集和收藏，致使近年來相關研究進展有限。本研究乃重新檢視臺灣鹿科化石的研究歷史脈絡、梳理與統整全臺灣鹿科化石的分佈，並進一步評估其研究潛能。透過結合已知紀錄及本研究所新發現的化石顯示，臺灣從最北之臺北盆地至最南之屏東墾丁皆有鹿科化石的紀錄，地層涵蓋從中新世晚期至更新世晚期，堪稱是臺灣分佈最廣泛、多樣性最高的陸相脊椎動物化石類群。初步調查結果亦反映臺灣鹿科動物化石的快速多樣化，高度具備了生物地層的指標潛力，若進一步結合歐亞大陸的化石紀錄，將有助於釐清時間尺度上生物地理的變化及其成因。另一方面，目前所發現的鹿科動物化石之所屬地層，涵蓋多樣的沈積環境面貌，亦可推斷鹿科動物可能具有極佳的環境適應力。同時，鹿科動物作為臺灣目前發現最古老的哺乳動物成員，除了分佈廣泛之外，體型多為中小型鹿科類群，印證其作為先驅物種的演化優勢，小型鹿科動物因資源需求較低而能更有效適應新興與破碎化棲地之假說，將可由臺灣鹿科動物化石的分析研究而得到印證。

General Poster GP006

臺灣周邊海域表層沉積物 VIS-NIR 光譜之主成分提取與跨海域光譜特徵比較

Extraction of Spectral Components from Surface Sediments around Taiwan Using VIS–NIR Spectroscopy and Varimax-Rotated PCA

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Abstract

Sediment composition provides important information for understanding sediment provenance and environmental conditions. This study aims to establish a reproducible workflow for sediment reflectance spectroscopy that is rapid and non-destructive. Surface sediment samples from the East China Sea, the Taiwan Strait, and the northern South China Sea were measured using an ASD FieldSpec visible–near infrared (VIS–NIR) spectrometer (350–2500 nm). Each sample was measured multiple times to ensure data quality. The spectral data were processed through band selection, first-derivative transformation, and normalization. Subsequently, Varimax-Rotated Principal Component Analysis (VPCA) was applied to extract the dominant spectral components of the sediments. These components were further compared with international spectral databases, such as the United States Geological Survey (USGS) Spectral Library, to interpret their mineralogical characteristics. By comparing the spectral-based component composition of the samples from different regions, this study aims to reveal the spatial distribution patterns of sediment mineral components around Taiwan and the surrounding marginal seas of the Western Pacific.

Keywords: Sediment Composition, Reflectance Spectroscopy, Varimax-Rotated Principal Component Analysis (VPCA), Spatial Distribution, Western Pacifc

General Poster GP007

Optimization of Furfural Removal from Water by Bioremediation Using Indigenous Pseudomonas putida (OSBH3) and Pseudomonas aeruginosa (OSBH4) with Novel Suphala Media for Field Application

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ABSTRACT

The furfural released from industrial effluents poses a serious environmental concern due to its toxicity and persistence in aquatic systems. Biological treatment using indigenous microorganisms offers a cost-effective and environmentally sustainable approach for its removal. This study investigated the potential of native bacterial strains for furfural degradation and optimized operational conditions for practical application. Two indigenous isolates (OSBH3 and OSBH4) were obtained from furfural-contaminated oily sludge and identified via 16S rRNA sequencing as *Pseudomonas putida* (OSBH3; Acc. No. GU329915) and *Pseudomonas aeruginosa* (OSBH4; Acc. No. GU329916), each showing over 99% sequence similarity. Batch degradation experiments were conducted under different nutrient conditions, including Suphala (a nitrogen-phosphorus fertilizer), glucose supplementation, and carbohydrate-free medium (CFM). Among the strains, *P. putida* exhibited superior degradation performance, while both strains showed reduced efficiency in CFM compared to nutrient-amended systems. Complete degradation (100%) of 500 mg L^{-1} furfural was achieved by *P. putida* within 12 h in the presence of 1 mg L^{-1} Suphala. Process optimization using a Taguchi L9 orthogonal array revealed that Suphala concentration was the most influential factor, followed by pH and glucose, with optimal performance observed at 1 mg L^{-1} Suphala, 2 mg L^{-1} glucose, and pH 7.2. Under these conditions, furfural served effectively as the sole carbon source supporting bacterial growth and degradation activity. The findings demonstrate that the indigenous strain *P. putida* (OSBH3) combined with a modified nitrogen-phosphorus fertilizer medium provides a promising and environmentally friendly strategy for furfural removal from industrial wastewater, with strong potential for field-scale application.

Keywords: Furfural; Microbial treatment; Nitrogen-phosphorous fertilizer media; *P. putida* and *P. aeruginosa*; Orthogonal study.

General Poster GP008

Late Quaternary deep hydrography and deep-water circulation of the Indo-Pacific warm pool

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Abstract

Changes in the magnitude of oceanic circulations among the IPWP are fundamental to modulate regional energy transfers and therefore global climate. Detailed insight into past deep-water circulation and associated deep hydrography of the Indo-Pacific warm pool (IPWP) is, however, limited by the spatiotemporal coverage of paleo-climatic archives. In particular, long-term thermohaline circulation of the central IPWP, a key site in the Banda Sea under the influence of modern pathways of the Indonesian Throughflow and Circumpolar Deep Water (CDW), are poorly understood. A continuous, high-resolution late Quaternary benthic foraminiferal oxygen isotope record of the Banda Sea core MD01-2380 (5°42'S, 126°54'E, 3232 m water depth) was reconstructed to investigate ventilation of late Quaternary IPWP deep circulation in response to thermohaline circulation adjustments. An orbitally-tuned benthic foraminiferal $\delta^{18}O$ stratigraphy of MD01-2380 was generated by mapping the benthic $\delta^{18}O$ record to the target of LR04 global benthic stack using the Match protocol. Estimates of bottom water salinity was obtained from the IPWP benthic $\delta^{18}O$ results by correcting glacial-interglacial changes of ice volume and deep-water temperature. During the late Quaternary deep-water salinity at the central IPWP was punctuated by a prolonged increasing ~0.5‰ in $\delta^{18}O$ that were more saline from MIS 13, while similarly saline conditions may have also existed at southern South China Sea (SCS) at ~400 ka. The prolonged "plateau-like" saline condition at the southern SCS bottom water coincident with the carbonate dissolution event MBT are preluded by the co-occurrence of $\delta^{13}C_{max}$ episodes and a similar salinity pattern at the heart of the IPWP at ~500 ka. We suggest that deep hydrography at the core of the WP was bathed by the shallower CDW water mass until the onset of the MBT/MIS 13, when colder, well-ventilated Lower CDW (LCDW) production possibly increased and may have spread into the WP since MIS 13.

General Poster GP009

嘉南地區地質調查成果應用於地球科學教育

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摘　要

臺灣嘉南（嘉義縣、嘉義市、臺南市）地區涵括許多不同地質元素，在地質分區屬於西部麓山帶地質區及海岸平原地質區，受蓬萊造山運動影響，目前臺灣西南部仍處於造山環境，地殼變動活躍，亦孕育相當豐富的地質地形景觀與地質資源。該地區地質調查成果，包括經濟部中央地質調查所/地質調查及礦業管理中心公告的各類地質敏感區、各類地質圖、活動斷層分布圖、溫泉露頭、創意地質旅遊路線等，以及其他部會所劃設地景保育登錄點、自然地景（包含自然保留區、地質公園）、自然保護區、國家公園等地質地景相關保育成果，皆是地質知識推動素材。透過與普通型高級中等學校地球科學學科中心合作，整合地質調查成果，協助地科教師強化專業知能與教學應用能力，課程中融入地礦中心之地質業務成果與典藏資料，更為地科教師提供可直接運用的教學資源，將地質知識向下扎根。

關鍵字：嘉南地區、地質調查、地球科學教育、自然保育
Key words: Chiayi-Tainan Area, Geological Survey, Earth Science Education, Nature Conservation

General Poster GP010

活動斷層地質敏感區（F0016木屐寮斷層）劃定

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摘　要

木屐寮斷層位於臺南市白河區，斷層呈北北東走向，北起崎內，向南南西經木屐寮延伸至莿桐崎一帶，長約 8.3 公里。地形上，斷層位於平原與丘陵交界處，具顯著的線形特徵。斷層東側丘陵以北北東走向之單面山地形為主，西側則為隆起之沖積平原，線形處可見斷層小崖、三角切面或撓曲崖等構造地形特徵。

鑽井資料顯示斷層上盤岩層撓曲與破裂程度明顯大於下盤，斷層活動性證據來自虎子墓附近之鑽井岩心，顯示距今35,310 ± 560年之晚更新世岩層已被錯動。在地表變形觀測方面，2002至2024年GNSS觀測資料指出該區存在明顯水平壓縮特徵，InSAR資料亦顯示跨斷層兩側之視線方向抬升速率差約達5mm/yr，推測木屐寮斷層仍具相當的活動性。

基於上述調查成果，經濟部依據《地質法》劃定「活動斷層（F0016木屐寮斷層）地質敏感區」，期望藉由地質敏感區的劃定與公告，以及辦理基地地質調查與地質安全評估，提升國土規劃與開發的安全性。

關鍵字： 木屐寮斷層、地質敏感區、活動斷層、晚更新世、地表變形監觀測

General Poster GP011

活動斷層地質敏感區（F0028大茅埔－雙冬斷層）劃定

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摘　要

大茅埔－雙冬斷層是臺灣中部重要的活動斷層之一，為逆移斷層。大甲溪以北稱為大茅埔斷層，長約14公里；大甲溪以南稱為雙冬斷層，長約55公里，斷層總長度約69公里。位於仙洞指坑的斷層露頭顯示斷層距今3,120±30年以來曾活動。

1999年集集地震時斷層本身並無錯移，但沿線多處地方發生地表破裂並伴隨噴砂與噴泥現象，中寮地區平林溪的溪床除了呈階梯式落差斷裂，累積移距超過30公分外，隆起的砂脊斷裂及噴砂之排列與斷層方位一致，顯示本斷層仍有再活動趨勢。過去報導的斷層露頭，南華莊的崩塌地出露高角度向西傾斜的岩層，頁岩內出現斷層泥，砂岩內可見剪切帶。馬鄰坑出露的斷層帶厚度超過50公尺，其下方的斷層泥帶厚約10公尺，斷層泥直接與下盤頭嵙山礫岩接觸。哮貓的粗坑溪可見十四股層逆衝至頭嵙山層之上，上盤斷層帶中有剪碎的砂岩岩塊。

大茅埔-雙冬斷層活動斷層地質敏感區位於臺灣中部區域，通過臺中和平區、東勢區、新社區、太平區，南投縣國姓鄉、草屯鎮、中寮鄉、集集鎮、水里鄉以及鹿谷鄉等10處行政區，地質敏感區總面積約20.7平方公里。

General Poster GP012

土壤液化調查與風險評估計畫
Investigation and risk assessment of soil liquefaction

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摘要

為強化國土防災基礎並回應社會對地震災害風險的關注，行政院於109年核定推動「土壤液化調查與風險評估計畫」，由經濟部統籌執行，作為內政部「安家固園計畫」的延續與深化。此計畫在既有成果與資料基礎上，進一步從全國整體防災與永續發展角度出發，針對地質調查不足區域進行系統性盤整與風險檢討。透過中央與地方分工合作與資源整合，逐步提升地質資料的精細度與實務應用效益，厚植防災決策基礎。

在實際推動層面，自110年起，經濟部地質調查及礦業管理中心與18個縣市政府協力辦理都會區地質補充調查工作，已完成階段性成果。補充鑽探依目的區分為全取樣岩心之地質井與工程井，目前累計完成共約5,000孔鑽孔；另建置自記式水位監測井約500孔，以及人工地下水位監測井約4,500孔，相關資料均已彙整納入地質資料庫，形成系統化的大數據成果。同時，計畫亦完成超過32處老舊建築物與地下管線之液化風險評估，並透過地方說明會與教育宣導活動，提升民眾對居住環境地質風險的認識與理解。

未來將持續提升鑽探作業品質與空間密度，逐步擴充國土防災圖資建置範圍至約8,000平方公里，並同步優化三維地質資料庫內容，對外開放查詢與加值應用。該資料庫除可作為工程開發與規劃設計的重要參考依據，降低前期調查成本與時間，也將成為政府推動重大建設與防災政策時的重要決策支撐工具。

中文關鍵字：土壤液化、風險評估

General Poster GP013

淺談變電所用地選址規劃—以南崁及民雄變電所選址為例

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摘　要

摘要內容台灣的輸變電設施密佈，早年已開發及設立許多輸電設施，很多設施最初選址時，並沒有考量到所在地區的地質環境等，近年隨著知識及技術進展，變電所及高壓鐵塔選址時，也會考慮多變的地質因子影響，如：地質敏感區等，以期在輸變電設施設立後，減低地質災害發生之停電機率。

本計畫以兩個變電所選址案例為例，變電所選址及開發時常常先考慮實用性，如：該區要開發一個產業園區，需要極大的用電量，而近年綠電及園區蓬勃發展，西南部亦因此規劃了不少太陽能光電的變電所。我們再根據變電所預定地的位置，套疊活動斷層與山崩與地滑地質敏感區、易淹水潛勢區、地質圖、土壤液化、地層下陷等地質災害圖資，了解該場址潛在地質災害特性，並作為未來施工所需設計參數之參考。

本案以位於桃園的南崁都市計畫區變電所A、B及嘉義民雄的一次配電變電所為例，變電所選址經常受限於用地取得、線路規劃、線路佈設所需範圍等因素，經選定一場址後，才得以查詢及套疊圖資。南崁變電所A、B位於全新世沖積層，又查詢國家災害防救中心圖資，一日暴雨累積雨量650 mm 後之淹水潛勢深度為0.5~2.0 m，淹水潛勢較低。而嘉義民雄的一次配電變電所則位於更新世紅壤化台地礫石層，且其未位於土壤液化潛勢區、地質敏感區及易淹水潛勢區等範圍內。

中文關鍵字：變電所，地質災害，地質敏感區，淹水潛勢
Keywords：Substation site, Geological hazard, Geological sensitive area, Potential flooding area

General Poster GP014

土壤液化圖資創新與防治技術發展計畫
Innovation of susceptibility maps and development of prevention technology for soil liquefication

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摘要

地質環境潛藏的風險已成為公共安全治理的重要基礎課題，因此必須落實強化國土安全與都市防災體系的政策。特別是臺灣的大型都會區多發展於沖積層與軟弱地盤之上，當地震發生時，土壤液化可能導致地盤沉陷、建築傾斜與基礎設施受損，對民眾生活與城市運作造成衝擊。本計畫即透過系統化資料整合、分析模型建構與實務工法驗證，提升我國對土壤液化風險之辨識能力與應對策略，使地質調查成果更能實質應用於都市安全與公共建設規劃。

本計畫分四項關鍵計畫進行：1.在「圖資製作與防治技術精進」方面，分別整合工程環境地質圖（非震時期地質災害）與土壤液化潛勢圖（地震時期災害）之製作與更新工作，納入最新鑽探資料、長期水位觀測資訊與設計地震參數，優化圖資精度與可信度，使成果能作為國土規劃與震時防災決策之參考。2.在「土壤液化風險地圖產製與監測場址建置」部分，依危害度、暴露量與脆弱度整合分析成果，完成區域性液化風險圖資製作；同時建置土壤液化監測場址，即時監測震時地盤反應與孔隙水壓變化，進一步提供災害預警及震後液化災害評估等層面應用。3.在「淺層地下水位動態模式評估」部分，統合淺層三維水文地質架構模型分析與代表性地下水位精進研析兩項核心工作，透過鑽井、水文與地質資料整合，建置淺層三維水文地質架構模型，掌握含水層空間分布與補注特性；並進一步以統計分析方法建構地下水位機率分布模型，推估不同超越機率條件下之代表性地下水位，使液化潛勢評估更具風險導向之科學基準。4.在「低樓層建築物抗液化地質改善工法評估」方面，透過三維動態有效應力分析，系統評估不同液化層厚度與改良配置條件下之基礎沉陷行為，量化並比較各類地質改善工法之效益與成本合理性，並提出兼顧安全性與經濟性的設計建議，強化民宅等一般建築面對液化風險之實務應變能力。

中文關鍵字：土壤液化、工程環境地質圖、風險地圖、淺層三維水文地質架構、三維動態有效應力分析

順向坡之地質模型調查：陽明交大為例

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摘　要

順向坡在特定地質條件下，加上外在因素(如：降雨或地震)可能產生滑動破壞。在台灣，過往有大型順向坡破壞的案例，邊坡的特徵，其地層組成常包含砂岩、頁岩或砂頁互層，且地層傾角不陡。陽明交通大學陽明校區部分邊坡即具有類似的地形與地質特徵，此場址之地層屬木山層，是山崩與地滑地質敏感區。本研究以陽明交通大學陽明校區之順向坡邊坡為研究對象，本研究試圖利用地表地質調查、岩心調查、岩象、礦物相和化學分析等，將整合BH1至BH7鑽井、M7和M8各式資料，根據地質、礦物及地球化學特徵，建立從地表到地底的二維地質模型。岩心觀察顯示研究區主要為木山層砂岩，與部分砂頁互層所組成，根據層理構造、生痕構造、生物擾動、鏽染及裂隙等特徵，顯示沉積環境具有能量變化，且岩心對比能側向連接，同時顯示地下水活動明顯。XRD分析結果顯示以石英為主要礦物，代表沉積成熟度高，並含伊萊石等黏土礦物。XRF分析顯示Si為主要元素，對應石英礦物，而Al與K反映黏土礦物存在，Fe元素則廣泛出現在岩心中，並與鏽染現象密切相關。Fe主要來源為地下水中Fe^{2+}氧化為Fe^{3+}後形成氧化鐵沉澱，顯示地下水滲流為重要地球化學作用。特別是在BH2與BH5中，Fe呈現集中分布，反映裂隙控制的流體活動，而BH6則同時具備構造破碎與化學改變，顯示構造與地下水具有耦合關係。綜合各鑽井分析結果：（1）岩性特徵：砂頁互層提供潛在滑動面，根據地質模型結果，研究區地層傾角約為 26°，且與坡面傾向大致一致，形成典型順向坡幾何條件，使層面成為潛在滑動控制面；（2）礦物組成：黏土礦物具有較低剪切強度，將進一步降低岩體強度並促進滑動發生；（3）地下水與構造作用：地下水沿層面與高角度節理流動，不僅造成氧化鐵沉澱，降雨時亦會造成孔隙水壓，降低有效應力，進而影響岩體的強度。BH6鑽井顯示可能是斷層帶特徵，包含破裂帶與斷層核心。本研究最終將整合岩心資料、地表地質調查及GIS分析，建立研究區之二維地質模型，並探討區域地層與地質構造對邊坡破壞的影響。

中文關鍵詞：地質模型、順向坡、岩心調查

General Poster GP016

澳洲西北海域 A 區塊井測岩石物理分析

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摘要

本研究研究區塊位於澳洲西北海域 Roebuck 盆地中的 Bedout 次盆地，離岸約 110 公里，水深 60 到 150 公尺。主要探勘標的為三疊系（L. Keraudren 與 Archer Formation）斷層-地層封閉儲油氣構造。主要儲集層位於 Archer 層中的 Caley、Baxter、Crespin 與 Milne 段之海侵-三角洲淺水砂岩。本研究首先蒐集礦區內及周遭相關之井下資料並輸入至解釋系統。整備各井的井程、分層與測錄曲線，針對密度與聲波走時曲線進行質控與修整，隨後完成 13 口井的合成震波比對工作，除可提供三維震測層面解釋參考之用外，對於三維震測資料時深轉換所需之速度體也提供重要參考依據。本研究選定 15 口井下儲集層段（Cossigny、L. Keraudren 與 Archer 層）完成岩石物理的參數計算，包含頁岩含量、孔隙率含水飽和率及岩相分類。根據實際井測岩石物理分析結果，完成震波逆推可行性分析。其結果顯示震波逆推工作須倚靠聲波阻抗與縱橫波速比之雙參數，搭配二維機率密度函數進行岩相預測，可有效針對儲層段各岩相進行分類與辨識。藉由實際鑽遇油氣之井測數據，建立岩石物理模型，除提供儲集層段縱波、密度與橫波模擬外，同時檢驗岩石物理參數計算之合理性。依據目前岩石物理模型搭配虛擬井可建立岩石物理模板，提供岩石物理參數如頁岩含量、孔隙率、含水飽和率與岩相在不同變量上之量化分布。結果顯示主要具有油氣之儲層屬於低縱波阻抗、低縱橫波速比與較低密度之特徵，提供震波逆推或岩石物理參數與各岩相之關聯性。

General Poster GP017

澳洲西北海域油氣盆地生油岩特性研究

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摘　要

澳洲西北海域賦存有豐富的油氣資源，是台灣中油公司長期關注的國外重點探勘區域，而生油岩特性是進行探勘區域石油系統評估時最根本的關鍵，除了關係到探勘區域內有無產生油氣的來源外，亦關係到探勘區域內可發現的碳氫化合物類型(油或氣)與石油系統關鍵時刻(Critical Moment)的決定。因此，本研究藉由蒐集澳洲西北海域四個油氣盆地(即 Roebuck、Offshore Canning、Browse 與 Bonaparte 盆地)的有機地球化學數據(包含有總有機碳含量、岩石熱解烴含量與鏡煤素反射率等)，並對蒐集到的數據進行梳理與彙整，以勾繪出澳洲西北海域有效生油岩(即總有機碳含量為良好等級以上、油母質非屬 IV 型且成熟度達到成熟階段以上的岩石)的分布及生油岩形成的概念模式，期能幫助台灣中油公司聚焦澳洲西北海域具油氣潛能的礦區、降低探勘風險。

結果顯示，Roebuck 盆地的有效生油岩多屬於三疊系，主要存在於盆地的西南部與東北部；西南部生油岩層可產氣與油，而東北部則以產氣為主。Offshore Canning 盆地的有效生油岩多屬於石炭系、二疊系與侏羅系，主要存在於相應時期的沉積中心，以產氣為主。Browse 盆地的有效生油岩除了侏羅系與白堊系外，亦可能有二疊系與三疊系，主要分佈在 Barcoo 次盆地與 Caswell 次盆地中；其中，二疊系與三疊系的生油岩以產氣為主，侏羅系與白堊系中的生油岩則可產氣與油。Bonaparte 盆地的有效生油岩除了石炭系、二疊系、侏羅系與白堊系外，三疊系亦有機會；石炭系與二疊系的有效生油岩主要分佈在 Petrel 次盆地與 Londondery 高地，以產氣為主；而三疊系、侏羅系與白堊系的有效生油岩層則主要分佈在 Ashmore 高台、Vulcan 次盆地、Sahul 向斜與 Malita 地塹中，可產氣與油。進一步將前述有效生油岩層的化學特性、沉積環境及古氣候資料進行彙整，可發現到澳洲西北海域的生油岩多形成於海陸過渡帶沉積環境，可能以沼澤、三角洲前緣、前三角洲或瀉湖的沉積物為主要，且在寒冷時期(如石炭紀、二疊紀)堆積的生油岩，其油母質類型多屬於 Type III(產氣)，而在溫暖時期(如三疊紀、侏羅紀與白堊紀)堆積的生油岩，其油母質類型則多屬於 Type II(產油)至 Type II/III(產氣與油)。

移棲油氣對生油岩地球化學判釋之影響

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摘　要

在生油岩地球化學研究中，常透過總有機碳含量分析與傳統熱裂分析評估岩石中有機物富集度及其生油氣潛能。然而，在實際探勘研究中，部分岩樣可能受到移棲油氣滲入影響，使游離性碳氫化合物含量增加，進而造成熱裂分析結果出現異常，如S_1值偏高或氫指數異常，增加生油岩判釋之不確定性。本研究探討岩樣受移棲油氣影響時，在不同地球化學分析方法中所呈現之特徵差異。研究首先比較岩樣在傳統熱裂分析中的異常現象，並透過HAWK石油評估方法與熱裂解評估方法，分析游離性與裂解性碳氫化合物釋出特徵之差異。其次，比對岩樣與油母質樣品之分析結果，以評估游離性碳氫化合物之來源；並透過變溫熱處理氣相層析分析岩樣釋出碳氫化合物之組成特徵，以輔助判識移棲油氣之影響。

研究結果顯示，部分岩樣雖在傳統熱裂分析中呈現較高S_1值與異常氫指數，但不同分析方法所得結果存在明顯差異，顯示該類樣品之游離性碳氫化合物可能來自移棲油氣，而非現地岩石有機物生成之產物。整合多種地球化學分析方法之結果，可建立辨識移棲油氣干擾之判釋依據，有助於提升生油岩評估與地球化學判釋之可靠度，並為探勘研究中生油岩潛能評估與地球化學資料解釋提供重要參考。

General Poster GP019

澳洲 D 油田及周邊探勘礦區震測解釋

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摘要

澳洲 D 油田及周邊探勘礦區主要位於 Roebuck 盆地南邊之 Bedout 次盆地，屬於西澳外海西北陸棚區域的一部分，整體水深介於 80 至 150 公尺；根據前人研究，該次盆地由 7 公里厚之中、新生代沉積覆蓋於 2.5 公里厚之古生代地層；研究礦區的探勘活動在早年較不活躍，然而隨著礦區近幾年的多個重點發現，皆指出研究區域在未來深具探勘前景。

本研究採用兩個三維震測資料體作為震測解釋基礎，分別為 A3D（約 7,500 平方公里）及 B3D（約 2,200 平方公里），震測範圍合計可達 Bedout 次盆地約 80%的面積，依序進行震測斷層解釋與層面解釋，其中層面解釋部分，針對研究區內之三疊紀中期泥質碳酸鹽岩層頂部及二疊系頂部，逐一進行反射訊號檢視、追蹤和摘取，並描述各層面之震測特徵；震測剖面顯示，二疊系頂部於特定範圍內具有強振幅和中等連續性特徵，對應於 Roebuck 盆地的年代地層表中，該面為火山岩與頁岩或砂岩層之岩性界面，故具有明顯的聲波阻抗差異，使二疊系頂部呈現較強而連續的反射訊號，可作為類比至深部基盤面的參考。

本研究藉由連井剖面解釋與時間域地下構造圖，發現二疊系頂部走時大致由東南往西北加深的變化趨勢，且局部構造高區位於礦區東北及東南方，相對構造低區位於礦區西北方，綜合描繪出 Bedout 次盆地的構造形貌，初步對探勘礦區之構造框架有所認識。

關鍵字：澳洲西北海域、Bedout 次盆地、震測解釋
Keywords：Offshore Northwest Australia, Bedout Sub-Basin, Seismic Interpretation

General Poster GP020

澳洲西北海域 Bedout 次盆地探勘標的解釋

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摘要

本研究蒐集並取得澳洲 Bedout 次盆地相關之三維震測資料以進行盆地東南側之探勘標的解釋。根據 Bedout 次盆地內之地下鑽探結果，三疊紀 Lower Keraudren 層與 Archer 層為次盆地之儲油氣構造，本研究探勘標的針對中三疊紀 Archer 層之河流-三角洲沉積物進行解釋，結果顯示， 原鑽探井和解釋之好景區有相同之構造趨勢，但高區應仍受到後期侵蝕截切作用影響， Archr 層內之小層段分布不連續，內部存在不連續的小侵蝕面為此探勘標的。海水面上升期間之外伸和填積作用和下切谷系統是此區塊之層序特徵，震測解釋結果可作為後續儲層分布之參考。

關鍵詞: Bedout 次盆地、探勘標的、侵蝕截切

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General Poster GP021

台西盆地南部邊緣原油可能來源

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摘　要

過去國內油氣探勘活動曾在台西盆地南部邊緣進行鑽探，並於埋深較淺的地層鑽獲受生物降解影響的原油，對該原油生物指標(biomarker)化合物的研究指出其為源自高等植物有機質之成熟原油。本研究分析取自台西盆地南部邊緣，涵蓋古近系與下部中新統之鑽井與露頭岩石樣品的生物指標化合物組成，並嘗試推論台西盆地南緣原油可能來源。分析結果指出始新統、漸新統與部分木山層樣品與該原油同樣有較多源自高等植物來源化合物，其中三環類萜烷(tricyclic terpanes)組成分布指示這些地層屬陸相沉積環境，與該原油來源相近。過去推論該原油可能來自於後分離期，沉積環境偏陸相的地層。然而台西盆地南緣後分離期地層埋深淺，且成熟度較原油低，盆地模擬結果顯示後分離期地層油氣生成時間較晚，尚未能在生成後經長距離移棲至盆地南緣高區。因此除了後分離期地層外，靠近盆地南緣，形成於同張裂時期，且具備偏陸相沉積環境之始新統，若埋深夠深也可能為油氣來源；然而仍需進一步對台西盆地南部邊緣沉積與構造活動探討方能印證。

關鍵字：台西盆地、生物指標、三環類萜烷

Keywords: Taihsi Basin, biomarker, tricyclic terpane

General Poster GP022

高解析無人機空中磁力探測：以臺東紅葉地熱區為例

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摘　要

本研究利用無人機（UAV）進行高精度空中磁力探測，探討臺東縣紅葉地熱潛能區之地下地質構造特徵。相較傳統以直升機為載具之空中磁測，UAV 具低空、低速與高解析度之優勢，能提供更細緻之地球物理資訊，有助於地熱潛能評估。

研究範圍涵蓋紅葉地區三口探勘井（YP01、YP02、YP03），透過磁力資料反演建構三維磁感率模型，並整合地表地質、大地電磁（MT）與井下溫度資料，綜合分析地熱構造特徵與其空間分布。

結果顯示，研究區磁力分布具明顯空間非均質性：西側為高磁力異常區，推測與脊樑山脈高感磁率岩體相關；東側則以低磁力異常為主，局部區域受人為干擾影響。剖面分析指出，YP01 與 YP02 位於磁化向量高低值交界帶及感應磁場高值區，淺部（約 200 公尺）即鑽遇約 120°C 高溫流體；YP03 雖位於磁感率交界處，但處於低磁場區，井下溫度未見顯著異常，高磁場區與磁化向量梯度帶可能為地熱流體運移之有利構造位置。

無人機磁力探測結合多種地球物理資料，能有效提升地熱構造判釋能力，並可作為地熱資源探勘與鑽井選址之重要依據。

關鍵字：無人機、空中磁力、紅葉地熱

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Perth 盆地位於澳洲西部，為一南北向狹長型盆地，可以南緯 31°30’為界分為南、北 Perth 盆地。過去研究結果顯示北 Perth 盆地多數具經濟價值的油氣田主要位於陸域，海域部分僅於南側的 Cliff Head 油田較具代表性。緣此，為進一步評估海域其他的油氣探勘潛能，本研究針對北 Perth 盆地海域 Cliff Head 油田以北之區域，由南至北挑選 5 口井，藉由電測相特徵及鑽井岩屑與井壁岩心樣本觀察結果完成連井剖面對比。同時，結合總有機碳 (TOC)、總無機碳 (TIC) 及硫含量等地球化學分析數據，藉以推測研究區域內的潛在生油岩層，並藉由生油岩層與儲集岩厚度的側向變化來探討研究區域的油氣探勘潛力。

研究結果顯示，有機質富集度較佳（TOC >1.0%，有機質富集度為良好以上）的地層包含：下二疊統 Irwin River Coal Measures 與 Carynginia Formation 及下三疊統 Hovea Member。透過連井剖面對比發現，Irwin River Coal Measures 僅在南側井位鑽遇，北側鑽深不足無法向北完成對比；Carynginia Formation 則是僅在北側井位鑽遇，南側井位缺失；Hovea Member 則在全區井位均有鑽遇，惟地層厚度與有機富集度皆呈現向北減小的趨勢。此外，研究區域潛在的儲集層(即上二疊統 Dongara Sandstone)的地層厚度則顯示「南薄北厚」的特徵。綜上所述，在北 Perth 盆地海域的南北兩側雖受地層分布差異影響，導致石油系統的生儲條件相異，但整體皆具備一定程度的油氣探勘潛力，遂將本研究成果作為後續研究及繪製有效生油岩分布圖之參考依據。

中文關鍵詞：澳洲、Perth 盆地、地層對比、潛在生油岩、油氣探勘潛力

General Poster GP024

Bedout 次盆地反剝模擬與分析

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摘　要

Bedout 次盆地位於澳洲西北海域的 Roebuck 盆地南側，為 Roebuck 盆地中的陸棚區域，澳洲西北海域為重要的油氣產區，其中 Roebuck 盆地的探勘熱度雖較低，然近十數年來有數個重大的油氣藏發現，例如 Dorado、Phoenix South 等，皆位於 Bedout 次盆地，顯示其確實具備探勘潛力。已發現的油氣藏顯示區域石油系統的關鍵層位為三疊紀地層，但由於盆地的探勘活動較少，相關資料稀缺，因此對 Bedout 次盆地的地質理解仍有待進一步提升，以增進對區域石油系統的掌握。

本研究以 Bedout 次盆地的六條震測解釋剖面與五口鑽井井測數據為材料，利用孔隙率井測、密度井測與井徑井測計算深度與孔隙率關係以擬合地層壓密曲線，參考並修正前人之震測剖面解釋，結合前人研究之古地理資料後進行盆地反剝模擬，建立二疊紀以來總共八個時期的的反剝模擬與盆地沉積厚度圖。結果顯示於二疊紀時期盆地受正斷層構造影響，形成西北-東南向之構造低區與沉積中心，至三疊紀早期 Bedout 高區隆起，導致高區沉積中斷，沉積物被侷限於區域西南側，直到侏羅紀 Bedout 高區活動漸止，對沉積地層的影響減弱，沉積模式便轉為由東南向西北堆積的被動大陸邊緣模式，反剝模擬之結果顯示 Bedout 高區對區域石油系統的關鍵層位三疊紀地層的分布與厚度具有極大的影響力。

關鍵字：澳洲西北海域、反剝模擬

General Poster GP025

澳洲 Bedout 次盆地演化研究

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摘　要

本研究根據 Bedout 次盆地鑽井及震測資料，使用盆地反剝技術以建立此次盆地的盆地演化歷程。研究結果顯示在二疊紀之前，Bedout 次盆地主要構造大致呈西北-東南方向。此架構符合 Canning 盆地主要構造的走向，暗示此時 Bedout 次盆地受陸域大地構造影響。二疊紀晚期至三疊紀早期，位於盆地東北部的 Bedout 高區因火成作用而隆升，改變盆地形貌，且影響三疊紀沉積物輸送方向、分布及厚度。三疊紀沉積物被侷限在一往西開口的沉積中心內，並往周圍高區減薄。至三疊紀晚期，此沉積中心已逐漸被填滿，使 Bedout 高區與沉積中心之間的起伏差異不再顯著，故侏羅紀以來的沉積物可逐漸蓋過高區並堆積其上。Bedout 高區對三疊紀沉積物的影響，很可能也決定了此次盆地三疊紀石油系統發育的時間及位置。若未來能詳細瞭解高區成因，或有助於預測油氣高潛區。

關鍵字：油氣探勘、井下地層、大地構造

General Poster GP026

具地質一致性的地下地質建模流程探討

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摘　要

地下地質模型建立為傳統油氣評估流程中，用以進行靜態蘊藏量評估的重要環節。除傳統油氣評估外，地下地質建模亦廣泛應用於近年來蓬勃發展的碳封存場址評估。然而，在建模流程中，如何整併已知之震測解釋、井測資料與地質概念以得到符合地質統計結果及各地層特性趨勢的地質模型，為接續計算蘊藏量或碳封存量是否可信的關鍵。

應用於靜態模擬的地下地質模型基本可包含岩性與孔隙率模型等兩種屬性模型。其中，岩性模型內的岩性差異及分布特性與油氣的流動路徑或二氧化碳的封阻高度相關；孔隙率模型則進一步地展現出各岩性內可供流體移動或聚集的難易程度。然而，模型建置流程執行的差異，將可能造成建模成果的失真並影響接續評估量體的不確定性。除了模型建置流程可能導致地質模型失真外，建模過程中的參數設定亦須謹慎擬定，以使地質模型能盡量如實地描繪地下地質形貌。此些參數的求取，均基於已知資料分析而得到。但在地下資訊不如分析人員預期的完備時，如何在有限之稀疏分布資料中，分析並擬定出可接受之參數，實是建模過程的一大挑戰。

本研究基於台灣中油公司近年來執行油氣探勘與碳封存場址研究之經驗，彙整建模流程中各屬性模型建立時可能面臨之地質不一致性問題與參數擬定情境，並以流程化之方式說明地下地質建模過程中可供參考的建模流程與參數決定依據，以提升模型建立之合理性與可靠性，作為後續相關研究與實務應用之基礎。

General Poster GP027

澳洲西北海域B盆地西部下部三疊系構造與封閉研究

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摘　要

澳洲西北海域 B 盆地為一中生代張裂盆地。在盆地西部下部三疊系中，已發現了數個具有油氣徵象或油氣儲集潛能的區段，其中在盆地南邊的 D 區域內現在已有較顯著的油氣發現，並且已開始進行油氣田開發。本研究使用位在 B 盆地西部的 2 個 3D 震測資料體，並根據已取得的井下資料與震測資料比對出重要層面的時深關係，進行下部三疊系頂面(Cossigny 層)與底面(二疊系頂面) 2 個目標面與構造解釋，同時也對研究區域內可能具有油氣潛能的重點區域，進行較細部的解釋，解析 B 盆地西部下部三疊系的構造與封閉。

本研究以 inline 方向每 25 條間格，crossline 方向每 100 條間格進行解釋。在研究區域下部三疊系中共辨識出 289 條斷層，走向以東北-西南向為主，斷層分布密度有由西北向東南減少的現象，在研究區域的東南部，部分地區甚至沒有觀察到斷層錯動。區域內斷層的型態也與斷層密度有類似的變化趨勢，西北部的斷層錯動量與延伸長度普遍較東南部的斷層大。分析結果認為，這種變化趨勢與二疊系頂面位置的深淺及中下部三疊系厚度有關，研究區域南部二疊系頂面整體而言往東南變淺，同時中下部三疊系厚度也往東南減薄，斷層錯動量與規模也逐漸變小。此外，觀察斷層的形貌，認為研究區域中有部分斷層以接力(relay)的方式延伸其錯動，形成一系列的接力斷層，此現象為導致區域內斷層數量較多的原因。

研究區域內有數個已有鑽井的區域，細部解析這些區域的資料，能夠更加了解區域內的儲蓋層分布。細部解釋結果顯示，在下部三疊系較深處的 Archer 層中，有可供油氣儲集的構造圈合或高區，這些圈合或高區搭配鑽井資料，可進行更進一步的分析工作，解析區域內的儲蓋系統，提供未來油氣探勘決策參考。

中文關鍵字：澳洲西北海域、震測資料解釋、構造與封閉

Keywords: offshore Northwest Australia, Seismic interpretation, Structure and trap

General Poster GP028

澳洲西北海域 Budout 次盆地盆地架構研究

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摘 要

澳洲西北海域為澳洲主要油氣產區，亦為台灣中油公司國外油氣探勘之核心地區，近年來在澳洲西北海域仍持續有新的發現，尤其是 2014 年至 2022 年在 Roebuck 盆地中之 Bedout 次盆地中的諸多油氣藏重大發現，根據這些發現的蘊藏地層及可能生油岩層，推測其石油系統年代屬於三疊紀早至中期。然而，雖已有顯著發現，在此次盆地中的探勘活動仍處於不成熟階段，因此對於該次盆地中大部分區域的地質認識仍相當粗淺。

本研究利用 6 條二維震測，將地層根據年代劃分出 8 個關鍵層面，並繪製出構造圖，藉此了解 Budout 次盆地不同時期的盆地形貌。結果顯示 Bedout 次盆地於二疊紀時期為一向西開口的構造低區。到了三疊紀時期，沉積物之分布受到盆地北邊的 Bedout 高區顯著影響，導致靠近 Bedout 高區之沉積物較薄，遠離高區之沉積物較厚。侏羅紀時期構造低區已被沉積物填滿。白堊紀後逐漸轉變為由東南向西北變深之被動邊緣樣貌。

關鍵字：油氣探勘、Bedout 次盆地

General Poster GP029

澳洲 Bedout 次盆地之地層架構與電測特徵判識研究

Stratigraphic Framework and Well Log Response Characteristics in the Bedout Sub-basin, Offshore NW Australia

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摘 要

澳洲西北海域為該國核心油氣產區，近年持續的探勘實績證實其具備長期開發展望。本研究聚焦澳洲西北海域 Roebuck 盆地之 Bedout 次盆地，整合 5 口井之岩屑描述、生物地層及電測資料，依照區域地質標準建立精確的地層架構。

本研究關鍵技術為開發 Excel 巨集(VBA，Visual Basic for Application)一鍵式自動化流程，整合從 PDF 文字擷取、資料品質檢視、岩性百分比計算及各項地層資訊格式化處理；並透過批次化作業自動輸出與井下資料應用軟體相容之 ASCII 格式文件，大幅提升後續地層判斷與劃分之正確性及效率。

在地層劃分成果方面，本研究針對該 5 口井井下資料釐清二疊系至白堊系之層面特徵。分析結果顯示大部分層面皆可從 Gamma Ray (GR)數值大幅度轉變加以辨識。針對岩性較均質之白堊/侏羅系交界，則可額外以密度/中子孔隙率曲線趨近後分離的特徵作為劃分依據。各地層皆依照上述標準進行詳細劃分，亦參考井下報告將重要儲層進一步細分至岩段(member)。本研究詳實整合各井地層頂部深度，可提供區域地質模型建立的關鍵數據。

關鍵字：Bedout 次盆地、地層劃分、VBA 巨集應用、電測

General Poster GP030

墨西哥 B 礦區油氣探勘綜合討論

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本研究彙整墨西哥 B 礦區探勘資料，透過區域構造發育文獻蒐集、震測剖面特徵分析、斷層解釋與層面追蹤，釐清本區的地質架構；並分析電測資料、井下報告所提供的儲集層資料、鄰近產油氣礦區的相關資料，進行石油系統的比較與鑽後討論。綜合研究成果，推測墨西哥 Macuspana 次盆地形成年代應為中~晚中新世，因 Sureste 盆地內大量沉積物堆積於岩鹽上方，因無法承受荷重、向西北方流動而形成 Macuspana 次盆地；故推測 Macuspana 次盆地內底部滑脫面以上地層可能僅限於漸新統/中新統以上，Macuspana 次盆地內應不存在中生代地層，若存在也僅限於底部的殘餘分布。根據震測解釋結果，B 礦區之範圍大部分落在 Macuspana 次盆地左右兩側邊界斷層之內，底部可銜接至同一滑脫面，鑽井結果亦無鑽遇中生代地層，亦可以支持上述論點。另外鄰近礦區存在世界超級油田 Cantarell 油田，經分析後推測類似該油田優良品質的中生代石油系統，應不存在於 Macuspana 次盆地內，而最新鑽井的成熟度分析結果顯示中新統的生油岩成熟度不足，且 B 礦區內歷史井岩心亦鮮少有油氣浸漬痕跡，故可推測缺乏優良品質的生油岩應為本次鑽探結果不如預期的關鍵因素，亦為 B 礦區內其他井之 DST 油氣偵測結果不理想的主因。

關鍵字：Macuspana 次盆地、鹽構造、墨西哥

General Poster GP031

澳洲 Bedout 次盆地南部古水道分布研究

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摘　要

澳洲西北海域 Bedout 次盆地因近年油氣發現而探勘活動頻繁，研究此區域的沉積環境與古水道分布有助於此區域的油氣探勘。海相沉積環境通常會有從陸緣或淺海的陸源沉積物，因重力流形成海底水道或海底扇，並在深海形成濁流沉積物，其中含粗顆粒的水道砂或濁流砂為可能的儲集岩，尋找強振幅的反射訊號或古水道的訊號可瞭解水道砂或濁流砂的分布。本研究利用 Bedout 次盆地南部的三維震測資料，透過頻譜分解屬性分析古水道砂體的分布。結合頻譜分解方法與三原色融合技術分別將 20 Hz、30 Hz 與 40 Hz 三個不同頻率的資料體套用不同顏色，並將資料體顏色疊加得到三原色融合展示頻譜分解資料體。切面圖可清楚展示古水道的空間分布，由於三維資料體的時間切面通常只會水平切過古水道的一部分，因此用地層切面較能展示古水道的分布。透過三原色融合頻譜分解結果可發現 Bedout 次盆地南部震測資料體範圍在晚三疊紀的 Bedout 層有明顯之古水道分布，且廣布於此三維資料體的範圍，古水道多為由東往西，由南往北流向，與地層傾斜方向一致。此外，由 Permian 頂部層面上方地層切面的頻譜分解結果可以觀察到 Dorado 峽谷的形貌，並確認 Dorado 峽谷的範圍。此研究結果可瞭解研究區域的古水道分布，助益於此區域之油氣探勘。

中文關鍵字：Bedout次盆地、震波屬性、頻譜分解、三原色融合、古水道

General Poster GP032

井測資料異常值篩選與地層參數重建：澳洲西北海域油氣井實例研究

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摘要

本研究旨在修正由井崩及岩層結晶水等因素所導致的井測資料異常，以獲得準確的地層密度與孔隙率數據。研究針對 D-1、D-2、R-1、P-1 及 A-1 等五口井之井測資料進行重新評估。在研究方法上，首先利用井徑（caliper）數據判定並剔除因鑽井井崩所造成的密度失真值；其次，針對易受頁岩與黏土岩結晶水影響而高估的中子孔隙率，採取移除大於 50% 數值的標準進行校正。分析結果顯示，經修正後的各井地層特性普遍符合「深度越深，密度越大、孔隙率越小」的正常壓密趨勢；唯有如 Cossigny Member 等特定地層，因其泥質石灰岩的岩性特徵，呈現高密度與低孔隙率的合理偏離。本研究所建立的修正後密度—深度及孔隙率—深度關係，將可作為後續盆地反剝及地層解壓密分析的可靠輸入參數。

關鍵詞：井測資料、異常值篩選

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利用無人載具熱影像進行地熱勘探—大屯火山群大油坑火山口之應用

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摘要

台灣大屯火山群(Tatun Volcanic Group; TVG)是從構造壓縮區過渡到地殼延伸區之活躍構造區；是一個有利於地殼岩漿侵入的地殼減薄構造區(即地塹)。此地質環境為火山及地熱系統的發展提供了熱源，因此呈現大量與火山活動相關的地表熱特徵，是極具潛力的火山研究及地熱勘探點。在大屯火山群中，大油坑火山口(Dayoukeng crater; DYK)是面積最大的硫磺噴氣口，為非常活躍的地熱區，其硫磺噴氣孔溫度甚至高達 120 ˚C。本研究採用無人載具(Unmanned Aerial Vehicle; UAV)熱影像進行 DYK 地熱勘探，同時利用大地衛星(Landsat)地球觀測衛星的熱影像進行比較分析，以評估 DYK 地熱資源儲量。首要結果為 UAV 熱像儀與 Landsat 衛星熱傳感器所擷取之地表溫度(Land surface temperature; LST); 標示為 UAV LST 與 Landsat LST。本研究使用 UgCS (Universal ground Control Software for unmanned vehicles)無人機軟體來規劃與控制無人機飛行任務; 於黎明時分在 DYK 火山口區域執行約 20 分鐘的無人載具飛行勘測任務，以盡量減少太陽輻射對熱影像的影響。UAV 測量飛行任務完成後，利用 Pix4Dmapper 軟體依據 UAV 搭載之 Workswell Pro Sc (WWP)熱像儀所擷取之 782 張影像(地面取樣距離為 13 cm)，製作完成 UAV LST 鑲嵌影像。其次，從大地衛星(Landsat) 影像資料庫中選取最接近 UAV 拍攝日期的衛星熱影像進行交叉比對，即進行 UAV 與 Landsat 熱影像的比較分析。再依據斯特凡-波茲曼定律（Stefan-Boltzmann law）由地表溫度、發射率、大氣透射率與環境溫度，估算出地熱輻射熱通量(Radiative heat flux ; RHF)與輻射熱散逸(Radiative heat loss ; RHL)。結果顯示，UAV LST 與 Landsat LST 在 DYK 呈現一致的地熱異常形態。UAV LST 熱影像提供了詳細的地表溫度分佈，最高值為 79.2 ˚C，Landsat LST 熱影像最高值則為 44.2 ˚C。UAV 與 Landsat 所計算的 DYK 最大輻射熱通量(RHF)分別為 191 W/m^2 與 62.5 W/m^2。地熱輻射熱散逸(RHL)為 UAV 與 Landsat 熱影像所計算之地熱輻射熱通量總和，分別為 200 MW 及 217 MW。此估測值與前人研究利用傳統地球化學體積法所得估測值(514 MW)數量級相近。本研究為首次嘗試利用無人載具熱影像探勘評估 DYK 地熱潛能，顯示運用無人載具熱影像進行地熱與火山研究的效益與優勢。

關鍵字：大屯火山群(TVG)、大油坑(DYK) 、無人機熱成像(UAV thermal imaging)、地表溫度(LST)、輻射熱通量(RHF)、輻射熱逸散(RHL)

Land surface thermal imaging with UAV and Landsat: comparison analysis and application at Dayoukeng crater of Tatun Volcano Group

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Abstract

The Tatun Volcanic Group (TVG) of Taiwan is an active tectonic region that transitioned from zones of tectonic compression to crustal extension. It's an area of crustal thinning structure (i.e., a graben) conducive to the crustal magmatic intrusion. This geologic setting provides a source of heat for the development of volcanic and geothermal systems, plus, owing to occurrences of the large number of surface thermal features related to young volcanic rocks, TVG is a promising spot for volcanic study and geothermal exploration. Among various volcanoes in TVG, The Dayoukeng (DYK) crater is the largest area of sulfur vents and is expected to be the primary site for lava flow during a volcanic eruption. It's the most active geothermal field featured with fumaroles of temperature up to 120 °C. Here we evaluate the geothermal resource reservoir of DYK by conducting a land surface heat survey with unmanned aerial vehicle (UAV) thermal imaging, and at the same time, utilizing Landsat Earth-observing satellite's thermal image for comparison and cross validation. Primary results are the land surface temperatures (LST) retrieved from thermal camera of UAV and Landsat satellite thermal sensor. First, a 20-minute UAV survey mission is carried out in the dawn in DYK crater area for maximum depletion of solar radiation effect on thermal images. The UgCS drone software is used for the planning and flight control of UAV missions with terrain following. After the UAV survey flight mission, the UAV LST mosaic image is made by Pix4Dmapper software based on the 782 images (with a ground sample distance of 13 cm) acquired from the UAV onboard Workswell Pro Sc (WWP) thermal camera. Second, the satellite thermal image is selected from the Landsat archive for the nearest image acquisition date to the UAV for cross validation. The comparison analysis between the UAV and Landsat thermal images is conducted. Then, the geothermal radiative heat flux and heat loss is estimated from LST, emissivity, atmospheric transmittance, and ambient temperature. Results indicate that both UAV LST and Landsat LST show a consistent geothermal anomaly pattern at DYK. UAV derived LST image gives the detailed surface temperature distribution with the highest value of 84.4 °C compared with that of 44.2 °C from Landsat derived LST. The calculated maximum radiative heat flux (RHF) at DYK is 214 W/m^2 and 62.5 W/m^2 from UAV and Landsat, respectively. The geothermal radiative heat loss (RHL) are estimated as 210 MW and 217 MW at DYK by the summing of geothermal radiative heat flux form UAV and Landsat thermal image, respectively. The estimation of DYK geothermal heat loss from the UAV survey is obtained and is in the same order as that from the conventional geochemistry method in previous studies. The similarity in the estimation of geothermal heat loss from UAV and Landsat (210 MW vs. 217 MW) indicates that the Landsat thermal imaging is a valid and reliable way to survey the geothermal field when UAV is unavailable. This research represents the first attempt to evaluate DYK's geothermal potential using UAV thermal observations, demonstrating the benefits and advantages of utilizing UAV thermal imaging in geothermal and volcanic studies.

Keywords: Tatun Volcanic Group (TVG), Dayoukeng (DYK), UAV thermal imaging, Land surface temperature (LST), Radiative heat flux (RHF), Radiative heat loss (RHL)

General Poster GP034

整合多源數據建構萬榮地區三維地熱地質概念模型之研究

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摘　要

三維地下地質模型（3D Subsurface Geological Model）為當代地熱探勘之核心技術，其整合地球科學、構造地質學、地球物理探勘及工程地質學等多領域研究成果，透過高精度數據融合與空間建模，突破傳統二維地質圖表於垂直向度解釋之局限性。相較於平面剖面，三維模型具備卓越的空間定位精度與動態模擬能力，能更精確地刻劃地下複雜的地質幾何特徵，為專家學者提供直觀且科學化的視覺化平台，進而提升對深部熱儲系統與資源分布的認知。

本研究針對花蓮萬里溪流域之萬榮溫泉區進行系統性探勘，採用紐西蘭 Seequent 公司研發之 Leapfrog Geothermal 專業建模軟體作為技術核心。研究流程系統性地整合地表地質調查、大地電磁法（MT）三維逆推結果、流體地球化學分析及遙測線型分析等探勘成果，據以推估地熱系統中熱源（Heat Source）、儲集層（Reservoir）等三維空間分布特性。

萬榮地區地熱徵兆顯著，主要分布於萬里溪流域之摩里沙卡洞穴溫泉、鴛鴦谷溫泉及萬榮峽谷溫泉三處熱液湧出點。為釐清熱液上湧通（Hydrothermal Conduits）與地質構造之內在關聯，本計畫深入野外露頭進行地質隨跡調查與應力場分析，探究導水裂隙之張裂性質與區域應力張量之交互作用。研究結果顯示，熱水上湧路徑與局部斷裂構造及構造裂隙發育帶具有高度空間一致性。最後，本研究整合各分項探勘數據，建立兩條貫穿關鍵熱點之代表性地質剖面，並建構完整地熱地質概念模型。本模型不僅明確呈現萬榮地區關鍵地下空間之

分布特性，更為後續地熱鑽探選址與產能評估提供具科學實證之決策支持。

關鍵字：三維地下地質模型，地熱概念模型，儲集層，熱液上湧通道，萬榮溫泉。

Keywords: 3D Subsurface Geological Model, Geothermal Conceptual Model, Reservoir, Hydrothermal Conduits, Wanrong Hot Spring.

General Poster GP035

金山-萬里地區地熱潛能探勘研究

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摘　要

金山-萬里地區位於大屯火山群東北側且為地熱潛能區之一，研究區域內地表出露地層組成單元包含漸新世五指山層、中新世沉積地層(木山層、大寮層和石底層)、更新世火山熔岩流/火山碎屑岩和全新世沖積層，其中東北側靠海岸已出露沖積層或是沉積地層，而西南側靠大屯火山區則為安山岩質火成岩。本研究主要藉由過往鑽井溫度資料、地質資料和地球物理測勘資料建立地下三維地質概念模型，包含上述所提及之地層分布、地下構造分布和地下等溫面，並於研究區域內採集30個岩樣進行礦物組成分析，其中13個為地表露頭岩樣、10個CPC-CSN-1T井下岩樣和7個CPC-SHP-1T井下岩樣，分析結果探討地表受熱液換質帶之範圍、地下是否有火成岩體侵入和造成高地溫異常區之原因。此外，建立3條地下構造及溫度剖面示意圖，深度皆推估至海平面下5 km，分別為X1-X1’ 、X2-X2’ 和Y-Y’ ，3條剖面根據鑽井溫度資料向下推估100°C、150°C和200°C等溫線分布，其中X1-X1’ 和X2-X2’ 為西北-東南向，Y-Y’ 則為東北-西南向，示意地下溫度分布與斷層或是裂隙帶之關聯性。地熱探勘標的建議考量鄰近主要道路且為公有地，並且於海平面下2公里溫度高於200°C的條件下，本研究提出2個建議區塊，地點分別位於磺嘴山和金山市區周圍，預估能在研究區域內相對淺層便鑽遇200°C之地下溫度。

應用三維幾何演算法於變質岩區地熱探勘：以花蓮富源地區裂隙系統為例

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摘　要

花蓮富源地區位於中央山脈東南翼，屬變質岩地熱潛能區。由於現地植被覆蓋且地勢陡峭，傳統地質調查難以全面掌握地下構造。本研究利用高精度數值高程模型（DEM），配合多向日照陰影圖與坡度圖，於富源地區判釋出 422 條地表線型（Lineaments），經位態可信度篩選後獲得 390 條高可信度裂隙資料。統計顯示該區裂隙長度主要集中於 98 至 228 公尺（Q1~Q3），且以東北-西南及西北-東南走向之高傾角裂隙為優勢組。

為進一步評估地下導水潛能，本研究開發一套基於 Python 的自動化三維幾何演算法。該算法透過坐標中心化與向量代數，計算裂隙面在地下深處的實體交會線（Intersection Lines），並針對深度 1,000 公尺以內之範圍進行空間裁切。研究結果顯示，地表高密度裂隙區與計算出的地下多重交會帶在空間上具有高度關聯性，特別是東北-西南向主裂隙與西北-東南向次要裂隙的立體交會處，極可能為富源地區地熱流體之優勢上湧通道。本技術成功將二維地表線型轉化為三維構造模型，為後續地熱鑽探井位規劃提供科學依據。

General Poster GP037

Integrated Remote Sensing and Fracture Reactivation Analysis for Geothermal Exploration: a case study from the Guguan hot spring, Taichung

整合遙測與裂隙活化分析於區域地熱探勘之應用：以臺中谷關溫泉為例

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摘要

在我國 2050 淨零碳排政策中，地熱資源因可作為基載電量，在我國能源政策中擔任關鍵要角。近年來，整合遙測技術與區域應力之分析技術已投入至我國多個地熱案場，以達到於大範圍標定潛在導水裂隙分布之目的。而在地熱裂隙探勘中，裂隙之空間分布與位態(方向)為主要評估項目，其中裂隙密度圖能量化地表破碎程度，然而其純量特性並無法指示各方向上之密度變化。因此本研究將使用一維碎形分析探討裂隙碎形異向性，在由應力資料得知導水裂隙方向後，相以結合，提升標定地熱好景區之精確性。

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(DEM)，以肉眼判釋地表裂隙線型，並以三角網格法計算位態。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。進一步將裂隙位態整合區域應力資料，繪製臺中谷關地區潛在導水裂隙空間分布圖。關於一維碎形分析部分，以判釋之地表線型特徵點擬合空間裂隙圓盤面，並繪製水平高程面與裂隙圓盤的交線分布，後續使用多方向平行線以康托集(Cantor Set)方法對交線分布評估各方向之碎形維度，其結果將以碎形橢圓呈現。此外，本研究亦將碎形分析應用至高活化趨勢之裂隙，探討碎形特性與導水裂隙之間的關聯。

初步結果指出，地表線型於 6 公尺解析度 DEM 套疊 1 公尺解析度衍生圖資下判釋出 2348 條。區域應力反演結果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-東南方向之近鉛直裂隙面具有高潛能，而導水裂隙分布圖指出谷關及馬陵兩處溫泉區皆為高潛能區。碎形結果顯示橢圓長短軸及長軸方向可分別對應裂隙密度及方向，在整體裂隙及導水裂隙之碎形橢圓皆表明谷關區域具有較高的導水特徵，此敘述可經由谷關地區擁有較高的溫泉流量得到論證。

本研究提供一種評估區域裂隙異向性的方法，後續若結合其他地熱探勘方法，將能大幅提高我國地熱開發競爭力。

關鍵字：地熱、谷關溫泉、地表線型判釋、裂隙活化分析、一維碎形分析

General Poster GP038

廬山地熱區三維熱-水耦合數值模擬與熱傳機制探討

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摘 要

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。本研究選擇台灣前四大地熱潛能區的廬山地熱區作為研究對象，以建立符合廬山地熱區三口地熱井井溫分布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，其井深介於五百至一千兩百米之間，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。研究區域內地質為廬山層，又可將其由上而下分為昆陽板岩段、鳶峰砂岩段、春陽板岩段。Bertrand (2009)對台灣中部的大地電磁調查結果指出，有一低電阻從梨山斷層淺部往東延伸至春陽-廬山地熱區，且地礦中心的調查亦顯示廬山地熱區的熱源來自西南部地下。有別於過去的材料參數設定，本研究參考大地電磁探測結果，將低電阻區視為是含水量多的區域，其滲透率高；高電阻區則反之。

目前研究結果顯示 CPC-LS-1T 井淺部模擬與觀測溫度相近，深部模擬溫度則高估，此井深部方向往西北方低電阻區前進，可推測為深部模擬溫度高估之原因；CPC-LS-2T 淺部模擬與觀測溫度相近，深部模擬溫度則低估，其原因可能是深部遠離低電阻區，高電阻區可視為熱水難以穿過之構造；CPC-LS-3T 則是全井模擬溫度低估觀測值 40 度以上，推測是該井位處於板岩帶，因其滲透率低，從西南方來的熱源難以傳遞至此。

基於目前的結果，後續研究將嘗試更多種情境模擬，並使用 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，並結合參數最佳化，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。

關鍵字：廬山地熱區、三維熱-水耦合數值模擬、地熱概念模型、熱傳機制

【一般壁報展示】

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General Poster GP039

板岩區 EGS 水岩反應後之熱液重金屬濃度探討

Heavy Metal Concentrations in Hydrothermal Fluids during Water–Rock Interactions in Slate EGS

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摘要

地熱發電具備穩定供電的基載電力特性，而臺灣位於板塊交界的造山帶，地熱資源相當豐富。由於部分深層地熱儲集層具有高溫但滲透率不足的特性，未來加強型地熱系統（Enhanced Geothermal System, EGS）技術之成熟，將成為開發深層地熱資源之關鍵路徑。臺灣多數主要地熱區如清水地熱、土場仁澤地熱、廬山溫泉、知本溫泉及紅葉溫泉等地皆位於板岩地質環境，於 EGS 開發過程中，地表水或地下水回注至高溫岩層後可能與含黃鐵礦與黏土礦物之板岩產生水岩反應，進而促使岩石中重金屬元素溶出並改變循環流體化學組成，這過程是否會產生重金屬汙染是本研究關注的焦點。

本研究以臺灣重要板岩區地熱場址為研究對象，採集三星、清水、土場、廬山與知本的板岩岩樣與純水及溪水。首先分析地熱流體、地表水、岩礦組成，建立流體與岩樣之背景值，隨後利用水熱高壓釜分別在 175℃與 195℃條件下進行一天、三天、三十天之水岩反應實驗，並透過水質化學分析結合 SEM、

XRD 鑑定岩石元素與礦物組成之演變。結果顯示:反應後的流體會在短時間內達到或超過飲用水標準，其中以砷（As）最容易在高溫與高氧化還原條件下被促進釋出，是整體反應中最需要高度關注的重金屬；其他如銅、鉛、鎳、鉻、鋅等亦有超標風險。機制分析顯示，因注入氧化態地表水使黃鐵礦分解產生硫酸根，進一步將黏土礦物內的離子溶出，使得循環流體化學性質發生變化。

若循環水體未完全回注至儲集層，而透過裂隙進入周圍地下水系統，則可能增加地下水受到重金屬污染的風險。因此，在未來評估 EGS 開發對環境的影響時，水岩反應造成的重金屬溶出與地下水污染潛勢，是未來評估 EGS 對環境衝擊時必須考量的核心議題。

中文關鍵字: *地熱發電、加強型地熱系統、水岩反應、重金屬、砷、地下水污染。*

英文關鍵字: *Geothermal power generation, Enhanced geothermal system (EGS), water–rock interaction, heavy metals, arsenic, groundwater contamination.*

General Poster GP040

地熱井靜態地層平衡溫度評估之應用比較

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摘　要

在鑽鑿地熱井時，鑽井泥漿循環產生的冷卻效應會掩蓋真實儲集層熱狀態，導致鑽井期間難以即時獲取地層原始溫度（T_i）。為此，鑽井作業中通常於特定深度停泵進行靜態地層溫度測試（Static Formation Temperature Test, SFTT）（也稱作溫度恢復試驗），藉由短期量測數據推估熱平衡溫度，作為立即之完井決策或區域開發策略之關鍵依據。

為求資料一致性，本公司以往多沿用傳統之Horner法。該方法假設井孔為一無限長線熱源，透過關井後2至3次的暫態測溫數據進行半對數座標外推。然而，Rangel-Arista等人（2024）年發表於Geothermics，針對各種靜態地層溫度測試方法比較的論文指出，Horner Plot法在停泵時間較短時易產生偏差，並傾向低估真實地層溫度（Jorge Alberto Rangel-Arista et al, 2024）。

本研究參考Rangel-Arista等人之研究建議，採用Brennand法針對宜蘭縣土場地熱區七口地熱井數據進行分析（A至G井），將兩方法計算之井下最高溫與產能測試階段之實測值進行對比。此方法基於熱擴散方程式之圓柱熱源解，考慮循環時間與關井時間之間的線性相關性，且與Horner Plot法同樣具備計算簡便且無需複雜地層熱特性資訊之優勢。研究結果顯示，Brennand法之推算結果普遍較Horner法更貼近實際產測所得之最高溫；而Horner法皆呈現負偏差，驗證了其會低估真實地溫之特性。於A井至E井，兩方法之偏差率均控制於10%以內。G井Horner法偏差率為-16%，較Brennand法（偏差率為+3.95%）呈現較大之溫度低估。另外，D、F、G井僅進行2次靜態地層溫度測試（其他井皆為3次），三口井的Horner法偏差率較高，D、F井的Brennand法偏差率亦較高。此現象主因為兩點量測僅能推導唯一線性解，任何量測誤差均會於外推過程中被放大。

綜合研究結果，本研究建議未來在土場或相似地質條件區域，可優先採納Brennand法推估地層溫度，並以Horner Plot法輔助比較。實務上建議應做到至少3次的靜態地層溫度測試，可有效將最高溫預測偏差率降低至10%內。若因時程考量，僅採用2次溫度測量時，Brennand法仍較Horner 法展現出較佳的溫度推估能力。此外需特別注意，兩方法的公式中皆有關鍵數據「測溫前循環總時間（t_c）」，若此數據代入錯誤可能造成推測之地層溫度嚴重高估，故務必仔細查閱現場資料，透過作圖對比來檢視靜態地層溫度測試參數之正確性，進而提升地熱資源評估之可靠度。

關鍵字：溫度恢復試驗、靜態地層溫度測試（SFTT）、Horner法、Brennand法、土場地熱區

General Poster GP041

酸性地熱流體產氫

Hydrogen production from acidic geothermal fluids

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摘　要

地熱酸性流體長期造成設備與管道的嚴重損耗，增加維護成本；同時，鋁渣等廢棄金屬回收價值低，極需新技術以促進循環經濟。本研究聚焦於地熱酸性流體與廢棄金屬的再利用，旨在解決地熱設備腐蝕與廢金屬處理的雙重問題，將環境挑戰轉化為能源契機，探索能源發展的新方向。

本研究採用改質澱粉造孔技術，成功合成高比表面積多孔性複合材料，以提升反應界面並抑制金屬表面鈍化現象，進而加速酸性流體與金屬的非均相反應，提升產氫效率。實驗結果顯示，溫度提升能促進反應進行，而多孔材料的使用則能顯著增強產氫效率。此外，本研究也發現金屬的添加量與材料的投放量亦對產氫量有明顯影響，進一步證實雖然材料本身不直接參與產氫，但作為高效能催化載體，能顯著改善金屬與酸性流體間的反應環境。

本研究成功證實了地熱酸性流體與廢金屬產氫的可行性，並透過多孔複合材料顯著提升反應效率。此研究成果不僅提供了廢棄資源再利用的新途徑，也為地熱與氫能技術的發展開啟了新的可能性，充分展現環境治理與能源開發的雙重價值。

關鍵字：地熱酸性流體、多孔複合材料、廢金屬再利用、氫能
Keywords：Acidic geothermal fluids, porous composite material, Waste metal recycling, Hydrogen generation

台灣東北部地區尺度地震觀測網與地熱分布之探討

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摘　要

在全球氣候變遷與減碳壓力持續升高的背景下，能源轉型已成為各國重要施政方向。我國亦積極回應國際淨零排放趨勢，行政院於近年推動多項再生能源政策，其中包含以地熱能為核心之一的旗艦型行動方案，期望透過強化地熱資源探勘與開發，提升國內穩定型再生能源占比，作為邁向 2050年淨零排放的重要支柱。同時，國家科學及技術委員會於「臺灣2050 淨零轉型—前瞻能源」關鍵戰略中，亦明確指出需結合地球科學、地球物理探測與監測技術，強化對地下構造與熱流分布之認識，以降低地熱探勘風險並提升開發效率。

台灣位處環太平洋地震帶與板塊交界，具備豐富的地熱潛能，其形成與地下構造活動、斷層分布及流體運移關係密切。近年研究顯示，微震活動可作為解析地下裂隙系統、熱流通道與構造活動的重要指標，因此地震觀測與定位分析已成為地熱探勘中不可或缺的工具之一。透過高解析度的地震資料處理與事件定位，可有效補足傳統地質與地球化學調查於地下深部資訊之不足。

本研究以台灣東北部地區為研究區域，利用地區尺度之地震觀測網共五個測站所記錄之2023年3月地震資料，進行地震波形處理與震源定位分析，來探討地震事件分布與地表地熱熱點之關聯性。研究成果期望能建立東北部地區地下構造與地熱系統之初步概念，並作為未來地熱資源評估與永續開發規劃之參考基礎。

中文關鍵字：地震定位、微震監測、地熱
英文關鍵字：Earthquake Location、Microseismic、Geothermal

General Poster GP043

應用水—二氧化碳狀態方程式建立地熱流體相態預測模型：與現場量測之對比分析

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摘　要

在台灣 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。台灣中油公司在宜蘭縣變質岩區建立地熱電廠，在開發過程中發現本地熱區之地熱流體有碳酸鹽結垢現象，在瞭解碳酸鹽結垢機制的情況下，搭配 Pritchett et al.(1981)所建立的水-二氧化碳混合物狀態方程式，可根據儲層溫度及二氧化碳含量快速計算出該地熱流體的閃發點和沸騰點，並以現場溫度-壓力量測進行擬合，最後進行敏感度分析，確認閃發深度。

碳酸鹽結垢機制為地熱流體溶解二氧化碳，在壓力降低的情況下，會析出碳酸鹽結垢，依據化學反應式: Ca2+ + 2HCO3- => CaCO3+H2O+CO2 向右移動 (Brown, 2013)，主要驅動原因有兩項，其一是在壓力降低過程中，水中的二氧化碳會汽化，開始條件也可以稱為汽化點或閃發點，使化學反應式向右移動，造成結垢。其二為水在沸騰情況下，會有大量的水氣離開液態，也是方程式向右移動 (工研院，2008；黃怡華等，2015；朱正文，2023)。因此，本研究所參考的狀態方程式即是根據溫度和二氧化碳濃度作為變數，計算出在地熱流體的汽化壓力和沸騰壓力。

根據該模組計算結果，在 166.3℃、二氧化碳比例 0.67wt%情況下，汽化壓力為 23.68 Bar，沸騰壓力為 7.15 Bar，該情況與 C-2 井之井下溫度量測最高溫為 166.3℃，依據壓力梯度判斷之閃發點深度對應壓力約為 25 Bar，依據轉子轉速判斷沸騰點約為 152℃，壓力 6.2 Bar(朱正文，2023)，以 166.3℃計算的閃發點與現場量測之結果極為類似，顯示該計算模組在獲得儲層溫度和二氧化碳比例的情況下，可以快速計算出閃發點，但沸騰點因地熱流體在上升中可能的因氣體膨脹產生的降溫行為導致判斷可能會高估其沸騰壓力，但因結垢抑制劑之注入需求為閃發點下約 100 公尺，因此本模擬模組可做為結垢抑制設計的快速參考，可以節省決策時間。

關鍵詞 : 碳酸鹽結垢、變質岩地熱、閃發點、狀態方程式
Keyword : Carbonate scaling, Metamorphic rock geothermal, Flash point, Equation of state

General Poster GP044

Characterization of the In-Situ Stress State and Geological Structures in a Deviated Well for Geothermal Exploration, Yilan, Taiwan

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Abstract

With increasing global concerns over climate change and carbon emissions, Taiwan pursues renewable energy to meet its net-zero goals by 2050. Geothermal energy stands out due to its baseload capacity, minimal carbon footprint, and continuous availability. Identifying productive fracture zones is essential, as these control fluid pathways and determine production efficiency and drilling risks. Characterizing in-situ stress is critical because it controls fracture permeability and wellbore stability. This study supports Taiwan's geothermal development through an integrated workflow characterizing geological structures and stress conditions at the well YS-1T in Yilan, identifying critically stressed fractures, and optimizing well targeting to reduce uncertainty in geothermal reservoir models.

We interpret geological structures, including natural fractures, bedding, cleavage, and drilling-induced tensile fractures (DITFs) from FMI logs, while composite logs provide lithological and petrophysical context. Acoustic logging and stress magnitude estimation will be conducted to characterize in-situ stress. Fracture stability and slip potential will be assessed under the present stress conditions. Preliminary results show DITF orientations rotating across depth intervals in YS-1T, trending from NE in shallow sections to NNE in the deepest section. Over 1,119 bedding planes and 323 cleavage planes show varying orientations across depth intervals, reflecting lithological transitions and structural deformations. This approach will identify critically stressed, potentially conductive fractures and provide stress estimates to optimize drilling strategies and improve efficiency.

Keywords: Geothermal reservoir, Drilling-induced tensile fractures, In-situ stress, Fracture reactivation, Well logging

地熱井內結垢潛勢分析流程建立

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摘　要

因應世界局勢快速變動，為提升我國能源供應穩定與自主性，配合淨零排放等政策，地熱能源開發議題為國內產官學研關注焦點。成功的地熱案場必須兼具適合開發之地質條件、探勘與生產方案通盤規劃、法規與經濟面可行、工程技術成熟與掌握度等條件。宜蘭清水案場因生產過程壓力下降，地熱流體閃發(flashing)產生碳酸鹽結垢，未能有效事先預防與控制，導致我國首座地熱發電廠最終於西元1993年底被迫關閉。有鑑於此，若忽視結垢控制且未納入電廠營運計畫，則日後必將付出更多成本處理結垢問題，甚至提前關廠。結垢控制為地熱電廠穩健營運的關鍵要素。

本研究以實場案例試建立地熱井內結垢潛勢分析流程，透過井口採樣的流體物化特性數據，搭配PTS井測資料，模擬井內結垢的情境。第一步為蒐集井資訊，包括產能測試期間井頭溫度與壓力、液體與蒸汽流量、液相與氣相採樣(陰陽離子與氣體組成、導電度、pH值、TDS、鹼度)、不凝結氣體佔比、PTS井測等資料。以宜蘭某地熱開發案場地熱井A井為例，為求生產條件其穩定性及代表性，井頭流體資料選用A井進行產能測試之長期噴流數據(井頭壓力3.35 barG、井頭溫度141.2℃、液體流量69.49 TPH)；模擬深度節點選擇A井開篩段的頂端深度。第二步為計算二氧化碳莫耳分率，並以此作為調和條件。第三步使用結垢潛勢模式模擬關鍵結垢物(例如碳酸鈣)濃度達飽和，開始產生結垢(Pre-Scale Tendency≧1.0)的情境，亦可依需求評估其他可能產生的結垢物之結垢潛勢。假設地表為常溫常壓的條件(25℃、1 atm)，在井內各深度的主要的生成物(碳酸鈣)結垢潛勢(Pre-scaling tendencies)。以A井模擬結果為例，在接近地表區段因壓力急遽下降，使得碳酸鹽(方解石、霰石、碳鈉鎂石)、矽酸鹽(水鎂石)等礦物結垢潛勢大幅提升。搭配現場情況，可提供開發與生產規劃產能最佳化方案，例如生產壓力調控、阻垢劑添加位置，有望降低結垢相關事件與維護成本，提升地熱發電系統穩定性與安全性。

關鍵字：結垢潛勢、地熱流體、碳酸鹽結垢、地熱發電

General Poster GP046

苗栗地區地熱潛能探勘初步成果

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摘　要

本研究針對苗栗泰安與梅園兩區域所進行的地熱探勘，結合地質、地物、地化分析，初步簡述如下：

由泰安區域的地下地質來看，此區具備明確的深淺雙層儲集層。在司馬限斷層以西，流體沿著斷層下盤的破碎帶向上遷移，受阻於上方低滲透率的打鹿頁岩，在深度約 1000~3000 公尺處聚積，形成體積龐大的深部儲集層。而在司馬限斷層以東的地區，受近期構造作用影響，部分深部流體可能沿裂隙進一步向上移棲，與天水混合後，形成供應現今虎山、錦水、甚或警光山莊等地的淺層溫泉儲集層。

在梅園區域地表地質雖無太多現生地熱特徵，但地物資料顯示此區具備深部流體上湧特徵的大尺度低電阻區，可能與北方司馬限斷層西側的熱儲集構造相關。此外，以天狗溫泉為核心，其地熱流體的上湧受控於東北–西南向的褶皺逆衝系統（如大安斷層、天狗斷層）以及近東西向的橫移斷層系統交會處的裂隙，溫泉水化學與同位素分析顯示天水補注且循環快速的特徵。

總結來說，苗栗地區的地熱潛能受控於良好的深部熱源與斷層裂隙通道，該區的熱源應來自 3 公里以下的深部高地溫，這與造山運動快速抬升的基盤餘熱及東西向推覆構造有關，屬於非火山成因的斷層型地熱。溫泉水源來自東側雪山山脈高海拔區域的天水補注，這些天水向下循環至深部受熱後，再沿著斷層兩側的破裂帶通道向上遷移。泰安地區打鹿頁岩下方的儲集層為尚需要核實的開發目標，而梅園地區也展現出深部熱液上湧的強烈地球物理徵兆，這種深部導電、淺部高阻的電性特徵，暗示地下對應著熱液滲流或高溫含水層系統，且被上覆的乾燥緻密岩層所封蓋，這些深部低電阻異常體展現了作為潛在地熱資源的開發潛力，建議可由至少 1500 公尺以上的探勘深井來進一步驗證。而調查區域東側山區之淺層熱水儲集層，可能受控於近期走滑斷層相關的裂隙發育，未來仍需更精細的現地調查來確認。

先進型地熱案場盤點及應用

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摘　要

隨著全球對於綠色能源的需求及重視，臺灣目前積極開展能源轉型的工作。臺灣擁有極其豐富的地熱資源，然而傳統地熱技術因選址條件嚴苛(如熱流體供應不足、需要特定地質結構)造成開發潛力較低，先進型地熱系統則因具有不依賴地層流體、封閉迴路對環境影響小、不需要使用水力液裂方法建立人造的裂隙儲集層而不會有誘發地震的風險等優勢，讓此地熱技術在發展上更有操作彈性並可適用於更廣泛的區域。

本研究主要進行臺灣先進型地熱閉迴路水平跨孔工法之可行性評估。研究中使用數值模擬方法，進行先進型地熱閉迴路水平跨孔工法的單井產能(發電能力)的計算；再結合技術經濟分析，計算此技術工法的發電均化成本(LCOE)，藉此判斷應用此地熱工法可能之經濟效益，以供未來進行相關技術應用和工程決策的參考。

大屯山場域的模擬案例結果顯示(循環注入率300 ton/hr)，在水平井段設定為8000m的情況下的出口溫度為88.1°C，LCOE為18.18元/度電。若採用多分支先進型地熱系統設計，雖然鑽井成本增加，但產能大幅提升且出口溫度提升，LCOE降至10.8元/每度。在未來鑽井技術提升，成本下降後，可以預想到LCOE下降的程度。

依照研究所得成果，建議未來進行先行地熱專案時，可以仿照德國引進EAVOR技術的策略，在台灣的合適場域進行規模化的複數井的先進型地熱專案，除了可以協助引進及建立台灣先進鑽井的產業鏈之外，也可建立低探勘風險的地熱開發事業。

關鍵字：前瞻能源、深層地熱、先進型地熱(AGS)、儲集層模擬、技術經濟分析

General Poster GP047

Sites Screening and Technology Application of Advanced Geothermal Systems (AGS)

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Abstract

In response to the global demand for and emphasis on green energy, Taiwan is currently actively advancing its energy transition. Taiwan possesses abundant geothermal resources; however, traditional geothermal technologies exhibit low development potential due to stringent site selection requirements (e.g., insufficient hydrothermal fluid supply and the necessity for specific geological structures). Conversely, Advanced Geothermal Systems (AGS) offer significant advantages, including independence from formation fluids, minimal environmental impact due to their closed-loop design, and the absence of induced seismicity risks, as they do not require hydraulic fracturing to create artificial fracture reservoirs. These advantages endow this geothermal technology with greater operational flexibility and broader regional applicability.

This study primarily conducts a feasibility assessment of the AGS closed-loop horizontal cross-hole method in Taiwan. Numerical simulation methods are employed to calculate the single-well productivity (power generation capacity) of this advanced geothermal technique. This is subsequently integrated with a techno-economic analysis to calculate the Levelized Cost of Energy (LCOE), thereby evaluating the potential economic benefits of applying this geothermal method to serve as a reference for future technology applications and engineering decisions.

Simulation case study results for the Tatun Volcano Group site (with a circulation injection rate of 300 ton/hr) indicate that under the configuration of an 8,000-meter horizontal well section, the outlet temperature reaches 88.1°C, and the LCOE is 18.18 NTD/kWh. If a multilateral AGS design is adopted, despite the increase in drilling costs, both productivity and outlet temperature are significantly enhanced, reducing the LCOE to 10.8 NTD/kWh. It is anticipated that as future drilling technologies advance and costs decrease, the LCOE will experience a corresponding decline.

Based on the research findings, it is recommended that future pioneering geothermal projects in Taiwan emulate Germany's strategy of introducing Eavor technology. Implementing large-scale, multi-well AGS projects in suitable sites across Taiwan will not only facilitate the introduction and establishment of an advanced drilling industry

supply chain domestically but also foster a geothermal development enterprise characterized by low exploration risks.

Keywords：Foresight Energy、Deep Geothermal、Advanced Geothermal Systems(AGS)、Reservoir Similation、Techno-economic Analysis

General Poster GP048

利用盆地模擬初探鹽水層碳封存潛力-以澳洲 Roebuck 盆地為例

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摘 要

隨著溫室效應加劇，尋找合適的地質封存場址已成為全球關注焦點。鑒於澳洲碳封存政策開放及我國於澳洲礦區取得探勘權之現況，本研究針對澳洲 Roebuck 盆地進行鹽水層碳封存之盆地模擬研究。透過鄰近盆地的儲集層類比，選定中侏羅紀三角洲沉積之 Depuch Formation 為儲集層，其中南側 Bedout 次盆地具理想封存深度，並由早白堊紀泥岩層作為區域性蓋層。

本研究利用 7 條二維地質剖面透過 PetroMod 進行盆地模擬，由於缺乏足夠的岩石物理資料，本研究以鑽井岩性將 Depuch Formation 初步細分為 20 個子層。預測結果顯示，扣除深度大於 3200 公尺區域後，儲層平均厚度為 442.4 m、平均孔隙率 22.6 %、平均溫度 72.7 °C、平均壓力 21.1 MPa。以 2 % (P50) 儲存效率因子進行靜態體積法的資源量計算，儲存資源量可達 361.3 億噸，不過需更進一步考慮遠離斷層區域。在注入模擬方面，針對 JN87-20 剖面之儲層進行單井注入情境分析，結果顯示在每年注入 25 萬、50 萬及 100 萬噸二氧化碳且持續 50 年的情境下，超壓及羽流最終均未觸及儲層頂部。然而，當年注入量達 100 萬噸時，局部壓力增加可能導致岩石破裂，進而影響儲層穩定性，且大部分二氧化碳仍處於自由態，危險性較高。此結果可能與模擬的滲透率結果有關，推估每年 50 萬噸為目前該模型之安全極限，但尚須以更精確的岩石物理資料進行校正。另外，雙井模擬結果證實井距越近壓力疊加效應越顯著，當井距達 15 公里以上時方能有效降低壓力干擾。本研究以初步探勘資訊建立盆地尺度模型，評估盆地是否有潛力進行碳封存，尚可透過新的探勘資料來持續調整模型、甚至以三維模型獲得更符合實際狀況的結果。

關鍵詞: 澳洲西北海域、Roebuck 盆地、碳封存、儲存量評估、注入模擬

General Poster GP049

北台灣碳封存潛在場址之陸域地下地質概述

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摘　要

為達成台灣2050年淨零排放之政策，碳捕捉、再利用與封存（CCUS）已成為關鍵的減碳技術。在眾多地質封存選項中，深部鹽水層因具備較佳的封存潛力與較高的安全性，在國際上被視為現階段主要的開發目標。台灣中油公司憑藉豐富的油氣探勘經驗與地質、地球物理資料，評估台灣西部陸域沿海從桃園、新竹、苗栗至彰化、雲林一帶的碳封存潛力。本研究整合10口鑽井之井下地質與井測資料，及多條二維震測剖面。首先針對不同年代的二維震測資料(以南北向為主，搭配少數東西向)進行閉合差校正，以確保資料解釋的一致性；接著利用聲波井測數據、密度井測數據及小波製作井下合成震波，再與震測剖面進對比，透過對井震主要反射訊號進行校準，來得到時間-深度關係。如此一來便可在震測資料上對碳封存潛在儲集層及蓋層進行層位追蹤，以瞭解地層在空間上的變化。

研究成果描繪出兩套延伸廣泛的潛在儲蓋組合，地層深度皆由北往南漸深，由東往西漸淺。第一套以錦水頁岩作為蓋層，其厚度普遍介於 100 至 200 公尺之間，側向連續性高，具備良好的封阻性；其下方的桂竹林層與南莊層則含有多段厚度佳且連續性高的砂岩段，是理想的二氧化碳儲集層。第二套則以打鹿頁岩為潛在蓋層，其厚度變化較大，從桃園沿海的 400 公尺向南至新竹一帶減薄至 200 公尺；其下方的打鹿砂岩、北寮層與石底層，同樣具備優良的孔隙發育，可作為潛在儲集層。

考量碳封存之最佳深度介於 800 至 3,000 公尺之間，此區間的地層溫壓條件能使二氧化碳維持在超臨界態，增加封存效率。本研究顯示於北部沿海區域，兩套儲蓋組合深度介於較佳封存區間，具備開發潛力；往中部沿海區域，因地層深度向南加深，封存效率恐受影響，惟區域構造呈現向西淺化，因此中部海域不失為另一碳封存潛力區。

General Poster GP050

苗栗鐵砧山碳封存場址之三維地質模型建構與儲層特性評估

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摘　要

隨著全球氣候變遷議題日益受到關注，二氧化碳捕集與封存（CCS）技術已被視為達成淨零碳排的重要技術之一。苗栗鐵砧山構造因具備良好的背斜與封存條件，被選為二氧化碳灌注試驗之示範場址。為評估場址之地下地質特性及二氧化碳移棲路徑，建立可靠的三維地質模型為後續評估封存潛能與灌注安全性的關鍵。

本研究整合三維震測資料與井測資料分析建構鐵砧山場址之地質模型。首先透過三維震測解釋場址之層位及構造分布，並結合灌注井之井測資料，包含伽瑪射線（GR）、電阻成像（FMI）、聲波（Sonic Scanner）及核磁共振（CMR）等井測成果，同時整合舊有油氣井之歷史井測資料，進行綜合分析，藉此釐清鐵場址內之岩性分佈及儲層特性。分析結果顯示，目標層位之砂岩具有良好的儲集空間，且上覆頁岩層則具有較低滲透率，顯示適當之儲蓋組合條件。

在三維建模過程中，本研究將綜合分析後之井測資料進行粗化處理，將數據分布於三維構造模型網格中，以確保地下特性在尺度轉換過程中之代表性。隨後運用地質統計方法，將井測資料拓展至各模型網格中，分別建構岩相模型、孔隙率模型及滲透率模型。此方法能有效表現儲層內部空間之非均質性，並描繪出儲蓋層於三維空間中的連續性與分布特徵。建構完成之三維地質模型後續可進一步應用於流動模擬，定量化評估二氧化碳於灌注後的移棲路徑及壓力影響範圍。相關成果可作為後續灌注設計與監測規劃的重要參考，並有助於提升鐵砧山場址進行二氧化碳地質封存之安全性與可行性。

關鍵字：碳封存、鐵砧山、地質模型、地下特性、井測

General Poster GP051

應用物理資訊圖神經網路代理模型進行多相多成分二氧化碳封存注儲之預測

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摘要

二氧化碳地質封存多相多成分數值模擬具強非線性、高維度與高計算成本，限制了大規模情境分析與不確定性評估之效率。為此，本研究以挪威北海案例之TOUGH3 模擬結果建立圖式資料庫，目的在結合物理神經網路（Physics-Informed Neural Networks）及圖神經網路（Graph Neural Network）以提出一個物理資訊圖神經網路（Physics-Informed Graph Neural Network, PIGNN）代理模型，以預測二氧化碳團之時空分布。各案例之非結構網格被轉換為圖結構，而研究資料則以案例為單位進行訓練、驗證及測試，以避免資訊洩漏。

PIGNN 模型直接預測六個主變數（primary variables），包括氣液相壓力、氣固相飽和度、以及 CO2 及 NaCl 的液相質量分量。之後再根據主變數計算次變數（secondary variables），包括各相密度、動黏度、各成分組成（phase compositions），以及液相飽和度，使預測結果符合多相多成分熱力學關係。模型以 GNN 處理非結構網格鄰接關係，GNN 輸入端將空間座標與時間經傅立葉特徵（Fourier features）映射，以提升對尖銳前緣與非平滑時空變化之特徵表現。此外，為了避免極端值影響訓練而將輸入進行標準化，而 GNN 輸出端同樣經過標準化處理。

訓練流程以監督式資料損失（data loss）進行先期訓練，之後則加入物理損失（physics loss）以加強訓練，後者則包含局部及全域的質量守恆，並考慮面通量淨值及涵/源項。初步結果顯示，模型可重現層狀地層之主要壓力梯度，並捕捉二氧化碳團的主要遷移路徑與空間分布。誤差主要集中於尖銳前緣、蓋層界面與低飽和度過渡帶，而相組成場於局部界面附近之偏差較為明顯，顯示跨層前緣銳化與多相組成耦合仍為後續改進重點。整體而言，本研究所提出之 PIGNN 架構已展現作為高保真多相多成分模擬代理模型之可行性，後續研究仍需透過完整測試集統計分析，進一步驗證其泛化能力與守恆表現。

General Poster GP052

Active-Source Validation and Ambient Noise Wavefield Characterization in Guanyin Littoral Zone Using the PASS System

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Abstract

The littoral zone—the dynamic interface between land and sea—presents significant challenges for seismic surveys due to strong tidal forcing and nearshore noise variability and has remained relatively under-explored owing to the lack of suitable instrumentation. In this study, we analyze approximately 12 hours of continuous recordings from a 34-station ocean bottom node (OBN) array deployed in the Guanyin littoral zone, including both active-source time windows with the Portable Active Seismic Source (PASS) system from the University of Tokyo and ambient-noise time windows. For the active-source data, progressive shot stacking evaluated using Hilbert envelope misfit indicates that ~50 shots are sufficient to produce stable waveforms. Cross-correlation functions (CCFs) computed between station pairs reveal a systematic moveout corresponding to a propagation velocity of ~1.485 km/s, consistent with acoustic wave propagation in the water column, and f-k beamforming of the CCFs yields a back-azimuth of ~309°, validating our workflow against the known PASS source direction. For the ambient-noise data, CCFs are computed by stacking short overlapping time windows across all station pairs in the 80–150 Hz band. The resulting CCF section reveals a systematic moveout with a group velocity of ~2.14 km/s, consistent with shallow seismic wave propagation through the coralline algal reef and sandy substrate. The f-k beamforming is further applied to characterize the dominant ambient noise source directions. These results demonstrate that robust seismic signals can be extracted from the challenging littoral environment using both active-source and ambient-noise approaches.

General Poster GP053

CO_2 Baseline Study of the CCS Pilot Storage Site in Taiwan, Prior to CO_2 Injection

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Carbon capture and storage (CCS) is an industrial scale mitigation strategy for reducing anthropogenic CO_2 emissions from entering the atmosphere. However, for CCS to be routinely deployed, it is critical that the safety and security of the stored CO_2 can be verified and that unexpected escapement from a storage site can be identified. This study uses a newly developed isotope ratio laser spectrometer for CO_2 analysis being tested during a tracer experiment at a certain CCS pilot storage site in Taiwan.

This study conducted a characteristic survey of the environmental CO_2 baseline in this CCS pilot storage site area in Taiwan, including CO_2 concentrations and their carbon isotopes for soil at 40 survey points every season as well as ambient atmospheric analyses for CO_2 concentrations and their carbon isotopes. For continuous and long-term monitoring, four monitoring stations for ambient atmospheric CO_2 concentration have been set up in the existing facilities on this pilot storage site for real-time measurements equipped with weather station, including temperature, relative humidity, pressure, wind speed, wind direction, rainfall, etc., to assist charting the dynamic range of natural fluctuations of CO_2 concentration.

For ambient atmospheric CO_2 concentration, the measurements with an average value of *ca.* 440 ppm. The relatively higher average atmospheric CO_2 concentration might be the reflection of the emissions from local industries. The measurements of carbon stable isotopic composition of CO_2 showed an average value of -20.7 ‰ for soil samples and -9.7 ‰ for ambient atmospheric samples. The relatively lower $\delta^{13}C$ composition of soil suggested that it is derived from biological processes and obviously distinct with atmospheric $\delta^{13}C$ composition. The slightly enriched $\delta^{13}C$ composition of ambient atmosphere should be the result of heavy reliance on fossil fuels as power source in Taiwan.

General Poster GP054

地質碳封存之環境衝擊監測方法學先期研究

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摘　要

碳捕捉與封存是我國為達成「2050 淨零轉型」12 項關鍵策略之一，為推動我國淨零排放政策、地質碳封存環境管理及二氧化碳洩漏監測方法學研究，環境部氣候變遷署已於 2025 年 12 月正式預告了「二氧化碳捕捉後封存管理辦法」草案，草案內容包含於封存期間及封井後監測期間，須定期申報監測資料，並即時上傳地層壓力、二氧化碳濃度與地震等資訊，以確保封存場址安全，維護環境品質與落實國家減碳目標。而我國目前碳封存仍處在起步階段，缺乏實際正式運作的碳封存場域，以致各項監測方法與技術尚未完備，急需盤點國內外之監測技術方法學與參考國際碳封存場址之環境監測經驗以作為後續政策、法規、示範計畫與研究推動的重要基礎。

本研究將系統性整理國際地質碳封存環境衝擊監測之方法與經驗，分析其環境衝擊辨識、監測指標與管理作法，辨識並分類地質碳封存環境衝擊與監測需求，研析不同監測技術之適用性，並以 MMV（監測、測量與驗證）框架建構監測方法學選擇邏輯與原則，作為支援我國碳封存監測相關技術指引之參考，並建立適合我國政策與地質條件之環境監測方法學架構，以供後續碳封存監測制度研訂與示範計畫之參考。

關鍵字：地質碳封存、監測方法學、政策制定

General Poster GP055

利用光譜學探討礦化封存液相環境中的金屬離子

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摘　要

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金屬離子溶出反應時的化學行為。

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、離子釋出等反應機制。此外，也設定不同的岩石-反應溶液比例，了解不同岩石量在定量去離子水中的金屬元素溶出現象。

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等金屬離子濃度，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。

【學生壁報比賽】參與者於摘要尾端註記

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General Poster GP056

建構 CCS 整合研究之多尺度數值模擬流程：探討異質性地層中的二氧化碳封存演化

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摘　要

目前台灣之二氧化碳封存技術（CCS）正處於由TRL 4邁向5的關鍵階段，實地灌注試驗之選址、計畫制定及長期監測亟需可靠的數值模擬協助資源分配與效能預測。然而在數值模擬的工作流程中，地質模型建置常面臨跨單位軟體判釋不一與資料整合困難之挑戰，因此發展一套規格化的數據整合框架與高解析度模擬技術至關重要。

本研究建構了一套適用於CCS整合計畫之多尺度模擬建置流程，能有效整合多方來源的調查資料與地質概念模型。在數值模擬方面，採用 TOUGHREACT 數值模式深入探討異質地層中的水力-化學耦合（H-C coupling）過程。透過考慮地層滲透性、連通性及孔隙分布之空間變異，模擬多相流二氧化碳之遷移、溶解與礦物沉澱反應，藉此分析非線性流體行為、地球化學動力與孔隙率-滲透性演化對各類封存機制之相互作用。

研究首先由二維簡化模型出發，系統性釐清滲透性與孔隙連通性如何主導二氧化碳羽流（Plume）擴散範圍及礦化沉澱之空間分布；隨後擴展至三維現地場址模型，評估地層異質性對於構造封存、殘留封存、溶解封存與礦物封存間比例分配轉換之影響。結果顯示，地層異質性顯著改變了停注後的二氧化碳穩定化行為與大尺度壓力累積效應，以及封存類型的空間樣態。本研究成果可為國內場址尺度之長期封存安全性評估提供重要之科學基礎與技術支撐。

General Poster GP057

鐵砧山碳封存地震觀測網之微震定位分析

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摘要

為了瞭解鐵砧山碳封存場址在灌注二氧化碳前的背景微震，台灣中油公司探採事業部委託台大新碳勘中心於該場址附近架設鐵砧山地震觀測網（TCSSN）進行微震監測。本研究分析 TCSSN 資料期間為 2024 年 4 月 16 日至 12 月 31 日，共 260 日。

TCSSN 連續地震紀錄透過資料前處理轉換成 SAC 格式並合併成每日地震資料；將此四個地震站的地震資料中 P 波與 S 波到時拾取出來，彙整成地震事件文字檔；透過地震定位，將研究區域內的地震彙整成地震事件目錄，本研究也依照既有的（中央氣象署及台大新碳勘中心）地震目錄重新檢視地震波形，並彙整至本研究的地震事件目錄當中；最後繪製地震事件分布圖。

微震定位結果，並未在封存場址內發現地震。而在區域尺度內共定位 26 筆地震，其中 6 筆深度 10 公里以上的淺層地震可能與疊瓦狀地層有關。

關鍵字：鐵砧山、二氧化碳封存、微震監測、地震定位

Tieh-Chen-Shan, CO_2 Storage, Microseismic Monitoring, Earthquake Location

苗栗碳封存場址之背景訊號分析

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摘要

微震監測是碳封存場址環境監測的一環，然而地震儀設置的位置往往因土地取得不易及是否有電力供應等因素而受到限制，不可避免的接收許多背景訊號，如交通工具、地面設施產生的人為訊號。除了人為訊號之外，還有天然背景訊號也會影響微震監測，像是在場址區域之外發生的地震也不是碳封存監測的目標，但只要震度夠大，地震儀仍會記錄下來，因此需要在地震定位流程之中加以排除；還有颱風強力風吹造成的振動，也會被地震儀紀錄下來。因此瞭解背景訊號為訊號分析的首要工作，這些背景訊號需要在微震定位流程之中加以排除。

本研究整理了鐵砧山地震觀測網（TCSSN）所記錄周圍的人為訊號，如高鐵經過、振盪震源車採集三維反射震測資料、注產氣行為、地震站周遭工作所產生的訊號，透過比對既有之高鐵時刻表、振盪震源車震源目錄、TCS-I1 井鑽井日誌、注儲工程處之輸氣日報等資訊與地震紀錄的波形，在微震監測流程中排除這些人為訊號。

天然背景訊號則包含區域尺度外的地震及颱風，透過分析比對既有之中央氣象署、美國地質調查所等地震目錄資訊與地震紀錄之波形，將其標為地區尺度外之地震，在微震監測流程中排除。為了釐清颱風對訊號觸發之影響，本研究也參考中央氣象署颱風資料庫襲台時間，檢視分析該期間之地震紀錄。

透過已知的人為活動、地震目錄和颱風路徑等觀測紀錄，辨認地震儀紀錄之波形，以明瞭鐵砧山場址背景訊號對微震監測之影響，可提供後續分析之參考，期能增進儀器微震監測之能力。

關鍵字：苗栗、二氧化碳封存、微震監測、背景訊號分析

Miaoli, CO_2 Storage, Microseismic Monitoring, Background Signal Analysis

General Poster GP059

地質碳封存開發計畫範圍劃設之探討–以中部濱海開發為例

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摘　要

在2050淨零碳排政策下，雖然許多產業可以仰賴製程改善與使用模式改變來減少碳排放，但仍有難以減排的產業需要大規模碳移除技術來進行減碳。根據研究顯示臺灣具有豐富地質封存潛能，因此難減排產業可將地質碳封存做為去碳選項。然在大規模開發下，對於地質碳封存開發計畫的可能影響範圍與開發前的調查範圍之界定仍未有定論。本研究參考歐美的商轉案場之範圍劃設方法與案場經實務考量下的許可面積，以中部地區大規模商轉開發注入情境為假設案例，探討(1)僅考慮團塊、(2)考慮壓力與(3)考慮地質風險影響的三種觀點，對影響範圍劃設與事前調查範圍進行探討。情境假設以台中火力發電廠為案例，進行(a)濱海單井注入與(b)濱海及海域多井注入下的兩個對比情境之模擬。假設注入率每年100萬噸二氧化碳，受安全操作壓力限制，多井注入假設六口井群注入，間距為五公里，分兩排井自電廠往海域延伸10公里之區域。二氧化碳注入期三十年，觀察期兩百年。

模擬結果顯示，在單井注入情境下，觀察期200年之二氧化碳團塊分布範圍約直徑6公里。壓力前緣採用美國EPA方法估計，在10年內壓力前緣可達主要彰化斷層，壓力影響範圍至關井時最大約為直徑20公里；此單井注入不會到達安全操作壓力上限，能維持在每年100萬噸注入直至停止。地質風險上因壓力增量較小，對彰化斷層的滑移潛勢與區域內的假設深井洩漏量皆小。在海域多井注入情境下，會產生明顯的注入井交互影響，六口井於觀察期200年之二氧化碳團塊總範圍約16公里乘11公里。壓力前緣約在注入10年內可達彰化斷層，壓力影響範圍至關井時最大，超過直徑30公里；此多井注入下之注入率於初期即達安全操作上限，故以每年86萬噸注入直至停止。地質風險上因壓力增量較高，然而往海域開發對主要斷層影響小，區域內假設深井洩漏量明顯增加，需加強注入壓力管理以降低洩漏風險。由於壓力為地質風險基本驅力，建議以壓力前緣範圍作為影響範圍劃設的主要考量。

General Poster GP060

勵進研究船2024年三款科儀風速計資料差異分析

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摘　要

即時風速資料是船舶航行與作業安全的重要依據之一。然而，電子儀器在海上長期暴露於高鹽分與高溫濕的環境中，容易產生故障，例如電子訊號隨時間產生飄移，或螺旋槳式風速計因風葉與旋轉軸的物理磨損而影響數據精度。本文亦同步以PyQt開發氣象資料接收、即時處理與數據展示介面，於船端實驗室內之終端機螢幕上顯示，後續將持續優化數據展示介面。本文針對2024年間勵進研究船在港及航行期間，船上所安裝三種不同型式風速計的測量數據資料，進行差異性比較與相關性分析，提出影響精度的原因及改善建議，作為船載氣象監測系統維護與優化的參考依據。

分析結果顯示，三款風速計的風速資料具高度相關性，相關係數介於0.89至0.99，風速差值平均在0.4至2.1節之間，顯示三者測量的風速數值相當接近。風向方面，三款風速計的風向值相關性高，經適當修正後，風向差異明顯縮小，因此，藉由3款風速儀的同步紀錄資料，後續可比對與校正，以確保觀測數據準確性。

關鍵字 :風速計、勵進研究船、Python

General Poster GP061

地質資料蒐集填報作業智慧化發展之研究

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摘　要

隨著地質資料應用逐步朝向智慧化與決策支援發展，資料品質與檢核機制之完善性已成為影響後續分析應用之關鍵因素。然而現行地質資料填報檢核流程仍多依賴人工判斷、缺乏系統性，難以支援後續智慧化應用需求。

本研究以地質資料蒐集填報及工程地質探勘資料庫建檔流程為基礎，探討檢核流程制度化與智慧化發展之方法。經盤點現行檢核流程，將人工檢核經驗轉化為明確規則，並建立檢核清單與分類架構。透過資料模型設計，將檢核規則結構化，並定義錯誤等級與修正建議，使檢核結果具備可讀性與可分析性。搭配GEO2020鑽探資料輸入系統防呆設計之智慧化檢核機制，使原本分散且依賴經驗之檢核作業轉化為具一致性與可重複性之標準化機制，作為工程地質資料品質控管之參考。未來可進一步透過實務資料測試與系統整合，驗證檢核規則之適用性，發展智慧化檢核與資料應用服務，提升資料可信度，支援工程地質判釋與防災應用，奠定地質資料人工智慧服務與自動決策支援系統之關鍵基礎。

General Poster GP062

臺灣宜蘭平原西側之岩屑溫度分析與隱示

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摘　要

隨著全球能源轉型趨勢與國家綠能政策推動，宜蘭地區因受於沖繩海槽北段張裂作用影響，具備極佳之熱流儲集潛力，蘭陽平原西側之地熱開發成為關鍵研究之一。本研究針對「員山一號」深層地熱探測井，進行系統性岩屑取樣以及溫度分析，旨在精確掌握該區域之深部地溫架構。

在溫度分析技術上，本研究利用碳質物拉曼光譜分析儀（Raman Spectroscopy of Carbonaceous Material , RSCM），針對薄片中受透明礦物（方解石、石英）覆蓋之碳質物進行多點取樣。每組樣本選取28－30 個分析點的平均值，以確保有足夠資料因同個岩石樣本內的碳質物的石墨化程度存在微小差異的現象，所產生10－15℃ 的誤差值，並導入地溫計模型，藉此推算出該岩石所經歷之最高變質溫度（Tmax）。選取不同岩屑薄片，為確保實驗準確，本研究根據宜蘭地區地溫梯度約每公里上升45~60℃，估算出具代表性之採樣間距。

最後，本研究將整合員山一號井之RSCM 實驗數據結合岩屑地溫梯度，對比蘭陽平原既有之地溫梯度，預期分析資料為線性關係，以評估員山地區深部是否具開發價值。本研究結果不僅提供了員山一號井關鍵的地熱資訊，亦為宜蘭地區未來深層地熱電廠之選址與產能預估提供科學支撐。

【一般壁報展示】

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General Poster GP063

基於資料湖倉(Data Lakehouse)架構之地質資料治理可行性研究
—以工程地質探勘資料庫為例

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摘　要

為響應我國「2050 淨零轉型」目標，地熱能因其基載電力特性，被視為前瞻能源發展的關鍵「第三支箭」。經濟部地質調查及礦業管理中心長期推動之「工程地質探勘資料庫系統」為國內最完整之地下空間知識資產，奠定了穩固的資料共享基礎。然而，隨著地熱探勘活動日益蓬勃，產生了大量且高維度的新型態資料，包含地球物理探測（如大地電磁法 MT、震測 SEG-Y）、地球化學分析及孔內地球物理井測等半結構化與非結構化數據。為妥善保存並極大化這些科學數據的應用價值，傳統關聯式資料庫在收納與治理上已面臨極限，底層資訊架構之擴建勢在必行。

本研究旨在探討將既有系統架構躍升為「資料湖倉（Data Lakehouse）」之可行性。該架構兼具「資料湖」收納海量原始檔案的擴展彈性，以及「資料倉儲」之嚴謹分析效能。技術上核心評估導入開放表格格式（Open Table Format），確保系統具備 ACID 特性與版本控制功能，以維持數據一致性。為落實此架構，本研究研擬四項核心推動策略：首先，增修開放式資料作業規範，針對複雜格式資料研訂標準檔案與詮釋資料（Metadata）；其次，辦理逾 10,000 公尺地熱鑽探資料之規模化電子建檔測試以驗證架構承載力；第三，導入 UI/UX 設計並擴充三維空間（如多孔柱狀圖、定向井）調閱與動態視覺資訊圖表功能；最後，依循資安 C 級防護，導入隱私工程（Privacy by Design）與零信任架構確保系統韌性。此外，新架構亦為未來導入人工智慧預鋪管線，規劃實作資料治理框架以精煉金層資料市集，並萃取「知識向量（Vector DB）」支援檢索增強生成（RAG）技術，實現自然語言高精度探勘檢索。

藉由既有資料庫基礎推動湖倉轉型，預期將大幅提升國家地質資料治理層級，促成跨機關地熱探勘資料標準化與流通，奠定大數據永續發展根基。透過即時供應高精度科學數據，將實質協助產業界掌握關鍵地下熱源特徵，降低前期探勘不確定性與開發風險。展望未來，靜態歸檔數據將轉型為動態的地質知識大腦，做為三維至四維國土實體模型之基礎，將探勘成果轉化為國家級大數據戰略資產，直接支援政府空間規劃與前瞻能源決策，加速達成淨零碳排願景。

關鍵詞：工程地質探勘資料庫、資料湖倉、地熱能、資料治理、淨零轉型

General Poster GP064

基於微調策略訓練AI地震波相拾取模型與關聯器優化

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摘　要

近年來，為因應氣候變遷挑戰，台灣中油公司積極投入地熱能源開發與碳封存技術研發，作為能源轉型與減碳的雙重策略。由於地熱開發及二氧化碳封存皆涉及流體與地下地層的交互作用，過程中可能產生微震事件。透過微震事件的時空分布，有助於掌握地下流體移動、裂隙發展及背景地震活動特性等情形，並作為評估地層穩定性與誘發地震風險的重要依據，因此建立有效的地震資料處理流程及進行長期背景地震監測至關重要。

本研究之地震資料處理流程可分為資料讀取與前處理、AI模型拾取波相到時、關聯器(associator)及Hypo71地震定位。由於長期監測將累積大量的連續地震資料，若僅依賴人工進行波相到時拾取，不僅曠日廢時，亦難以因應大量資料的處理需求。因此，可透過自動化拾取的方法提升效率，應用AI模型已成為目前主流的自動化方法之一，其中EQTransformer(簡稱EQT)為近年廣泛應用的開源波相拾取模型。由於EQT的訓練資料包含全球的地震資料，因此EQT雖具良好的泛化能力，但在區域微震辨識上仍有改善空間，為了提升模型的拾取能力，本研究透過微調(fine-tuning)改善模型的表現。本研究同時也改良前人提出的關聯器演算法，利用AI模型輸出的地震波偵測時窗作為約束，使關聯器與AI模型輸出的波相到時拾取之間有更佳的相容性，降低過往關聯器錯誤配對的情況，提升整合地震事件的能力。

本研究使用約300個地震事件之波相到時拾取資料，並以約2小時完成AI模型微調。經過測試，地震事件的召回率(recall)提升51%，顯示微調策略及關聯器的優化有助於提升區域微震監測品質。綜上所述，本研究導入AI模型辨識地震波及拾取波相到時，並改良波相到時關聯的演算法，驗證本研究之地震資料處理流程可以較低資料量與較短開發時間成本下開發，並應用於未來長期背景地震監測中處理大量資料之自動化流程。

General Poster GP065

基於深度學習的震測資料降噪方法

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摘　要

在全球氣候變遷壓力與淨零碳排趨勢下，二氧化碳地質封存已被視為達成減碳目標之關鍵技術，而震波測勘技術可透過分析地下震波傳遞特性，追蹤二氧化碳團塊在地層中的分布與移棲狀況。然而，台灣地區地狹人稠，人為活動頻繁，震測資料常受到多種人因雜訊干擾，資料品質不佳。傳統降噪方法依賴人工參數調整，較難有效處理低訊噪比與複雜雜訊環境，限制監測精度與應用性。本研究旨在開發基於深度學習之震測資料降噪方法，藉由類神經網路模型自動辨識並去除雜訊，提升震測資料品質與成像解析度，進而強化二氧化碳地質封存過程中的地層分析能力與長期監測可靠性。

本研究首先建立簡單地層之合成震測資料，加入不同強度之現地雜訊，並透過反射事件到時誤差與重合後振幅兩項指標，分析資料品質隨訊噪比變化之影響，結果顯示當輸入資料訊噪比低於4 dB時資料品質顯著惡化，故以此作為需進行降噪之訊噪比門檻。本研究提出可用於震測資料降噪之神經網路模型DnUnet，模型結合DnCNN之殘差學習概念與U-Net之編碼器－解碼器架構，以提升對空間相關訊號的重建能力。本研究使用合成資料並加入高斯、粉紅與泊松雜訊，搭配資料增強與MSE損失函數進行模型訓練，提升模型泛化能力與穩定性。

實驗結果顯示DnUnet於不同雜訊強度下降噪表現皆優於DnCNN，可大幅提升資料訊噪比。在儲集層合成資料與現地資料測試中，DnUnet不僅能有效去除雜訊，亦能保留深部地層反射訊號連續性。此外，透過模型微調，可進一步改善深層弱訊號的重建效果。

本研究成功開發DnUnet震測資料降噪模型，其具備良好的空間訊號重建能力與泛化能力，可有效提升低訊噪比震測資料品質，避免破壞真實地層訊號，並可應用於碳封存場域之監測與地層成像，以利提升震波測勘監測精度及封存安全性。

General Poster GP066

Integrating Baseline Conditions and Long-Term Trends from Remote Sensing for Annual Wildfire Risk Assessment in Jambi Province, Indonesia

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Abstract

Wildfires are a persistent concern for ecosystem integrity, making reliable risk assessment important for identifying key drivers and accounting for multi-year environmental change. Many studies rely mainly on contemporaneous predictors and retain overlapping variables, which can obscure interpretation and limit sensitivity to longer-term change. This study develops an annual wildfire risk assessment approach for Jambi Province, Indonesia, by combining baseline conditions with long-term trends derived from remote-sensing time series. Multi-source datasets for 2010–2024 will be assembled, including satellite-based indicators, meteorological variables, topography, proxies of human activity, and historical burned-area records. Wildfire occurrence labels will be obtained from the MODIS burned-area product, and non-wildfire samples will be selected outside buffers around burned-area detections to construct a balanced dataset. Key predictors will be screened using Geodetector and Recursive Feature Elimination (RFE), then organized into baseline indicators (annual background conditions) and trend indicators (multi-year change). Trends will be estimated using the Mann–Kendall test and Sen's slope within a fixed time window. Random Forest (RF) and Long Short-Term Memory (LSTM) models will be trained to generate annual wildfire risk probability maps. The study will report (i) dominant predictors, (ii) comparative model performance using accuracy, F1-score, and the area under the receiver operating characteristic curve (ROC-AUC), and (iii) the incremental contribution of trend information relative to a baseline-only model. These outputs are intended to support risk zoning and inform early warning for wildfire management in Jambi.

Keywords: Wildfire; Jambi; MODIS; RandomForest; LSTM

General Poster GP067

利用天氣及空氣品質數據預測每日心血管急症：台灣23年機器學習分析

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摘 要

我們利用台灣地區2000-2022年的全國性數據，評估了天氣和空品狀況如何影響各區域的心血管疾病(CVD)急診就診量。首先，我們應用包括UMAP和K均值聚類在內的無監督學習方法，對184個環境特徵進行分析，並評估高風險CVD就診日在這些模式中的分佈。然後，我們訓練了8個監督學習模型來預測每日CVD急診就診量，並使用SHAP值來解釋關鍵預測因子。無監督分析揭示了一致的季節性和污染相關模式。高風險就診日往往集中在氣溫低且空污嚴重的時期，這些時期通常比冬季氣溫更高，但污染程度也更高，尤其是在65歲以上老年人和台灣北部地區。與僅使用氣象變數相比，空氣污染能夠更清晰地劃分高風險區，顯示污染對急性CVD的影響更為顯著。在監督學習框架下，基於樹模型表現最佳，R^2 值高達 0.67，MAPE接近 7-8%，且對老年人群和北部地區的預測能力最高。SHAP分析確定NOx相關指標是心血管疾病急診就診的主要預測因子。綜上所述結果，利用機器學習方法可有效預測CVD急症，並支持以空氣污染監測為中心的區域性早期預警系統。

General Poster GP068

利用宜花地區GNSS每日觀測資料 分析2018年2月6日花蓮地震之同震變形

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摘　要

宜蘭及花蓮地區位於臺灣地區板塊的碰撞帶，菲律賓海板塊以每年平均約8公分的速度朝西北方向移動，主要隱沒於歐亞大陸板塊之下。該地區因板塊交互作用，地震活動頻繁，地質構造複雜。為了推動地震前兆、斷層活動及火山活動監測等的研究，氣象署在2012年開始在全台灣以高精度GNSS(全球導航衛星系統)儀器，進行多星系統連續觀測，以提供全台灣地區的高精度地殼變動數據。

2018年花蓮地震發生在當地時間2月6日23時50分41.6秒，震央位於花蓮東北方立霧溪口的海上，規模為ML 6.2、MW 6.4，震源深度6.3公里。本文蒐集氣象署在宜花地區於震央附近所建置之13處GNSS觀測站資料(時間期距2018/1/30至2018/2/11)，利用Bernese資料後處理軟體(版本5.2)，進行各站三維坐標之計算，該軟體對於相對定位或絕對定位均可進行解算處理，分析各站地震前7日及後5日的平均三維坐標變化，來評估該地震的同震變形量。

為驗證13處GNSS連續站在地震前後之水平位移量分析，本研究使用（Caspary，1987）所提出之變形理論，針對GNSS連續站水平位移量進行統計檢定，其結果顯示在99%信心水準下，經統計檢定結果有12處GNSS連續站在地震前後產生顯著水平位移之趨勢。

依據2018年花蓮地震前後GNSS連續站之地形變動分析結果，顯示利用相對定位法與絕對定位法求得的水平方向與垂直方向的位移量具一致性，同時也與氣象署分析的結果一致。且由調查區域內分析結果可知，本次地震米崙斷層呈左移運動型態，區內水平同震位移量約為1.9至46.4公分。米崙斷層的上盤與下盤均呈抬升的趨勢，而嶺頂斷層北段同震變形的水平方向與垂直方向也有明顯的變化。

關鍵字：全球導航衛星系統;地震;同震變形

General Poster GP069

利用 GNSS 時間序列解析後甲里斷層的震間潛移與觸發滑移特性

Unraveling Interseismic Creep and Triggered Slip of the Houchiali Fault Using GNSS Time Series

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摘要

活動斷層的長期滑移速率是機率式地震危害度評估（PSHA）的關鍵參數。在臺灣西南部，藉由地質與地形紀錄估算的後甲里斷層長期滑移速率高達約 11.8 mm/yr，藉此推估的大地震再現週期僅約 55 年。然而，該區域的歷史紀錄中卻缺乏與此週期相符的災害性地震，此現象可能指示斷層所累積的構造應力，部分已藉由無震（aseismic）的滑移機制釋放。若未釐清這些無震滑移的實際貢獻，將高估以地質滑移速率推算的 PSHA 結果。

為釐清上述滑移機制，本研究分析橫跨後甲里斷層近 20 年的連續 GNSS 測站相對位移時間序列。初步結果顯示，在震間期跨斷層測站呈現穩定相對運動，指示斷層可能存在無震潛移或應變累積。此外，在 2016 年美濃地震與 2022 年池上地震發生時，跨斷層測站皆出現上盤相對下盤更顯著的同震位移，顯示外部地震也可能透過應力轉移觸發後甲里斷層的額外滑移。基於上述觀測，本研究將進一步量化震間潛移與觸發滑移（induced slip）這兩項機制的總滑移貢獻，藉此估計斷層面上的地震耦合比例（coupling ratio）。本研究期望能為未來的 PSHA 提供更合理的斷層滑移速率折減參數，避免危害度被過度高估，並將此分析框架延伸至臺灣西南部其他活動構造的地震潛勢再評估。

關鍵字：
後甲里斷層、GNSS 時間序列、無震滑移、觸發滑移、地震危害度評估 (PSHA)
Houchiali fault, GNSS time series, Aseismic creeping, Induced slip, Probabilistic seismic hazard assessment (PSHA)

General Poster GP070

以岩象影像分析作為量化安山岩礦物組合的工具之研究

Petrography Image Analysis as a Tool for Quantify Mineral Assemblages of Andesite

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摘　要

一般而言，岩象能呈現岩石的礦物組合及組織，且藉由岩象分析可推測組成礦物的來源及其轉變關係。傳統上，岩象分析以定性描述為主，但隨著影像數位化技術的進步及程式語言的普及，倘若能善用這些工具將得以解析更精確的岩象資訊，並以提供給其他領域使用。

本研究以安山岩為分析的標的物，利用python程式語言作為量化礦物組合、顆粒大小的工具。本研究初步成果顯示，安山岩中的礦物有斜長石、普通輝石、紫蘇輝石、不透光礦物。人工圈繪出來的斜長石占比24%、普通輝石9%、紫蘇輝石2%、基質65%。Python量化出來的斜長石占比33.84%、普通輝石3.2%、紫蘇輝石7.17%、不透光礦物1.91%、基質53.88%。兩者間的差異有待進一步釐清。

關鍵字：岩象、影像、量化、安山岩

Keywords: Petrography, Image, Quantify, andesite

General Poster GP071

棉花火山礦產潛能區地質精查成果與礦產資源潛能評估

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摘　要

為精確掌握我國海域金屬礦產之賦存類型及蘊藏範圍，經濟部地質調查及礦業管理中心自 113 年起推動「臺灣東北海域南沖繩海槽礦產潛能區地質精查」四年期科技發展計畫。計畫執行兩年以來，已完成棉花火山東、南及西熱液區之底拖聲納探測，成功辨識出煙囪構造、聲波反白帶及斷層等淺部地層熱液活動特徵。反射震測分析顯示，棉花火山周圍淺部地層具有反極性訊號特徵，主要分布於火山體西側，推測為熱液流體於地層中累積的界面。整合地球物理探測成果，判釋棉花火山最近海床聲波反白帶為熱液礦床富集潛能最高之區域，其整體面積約 20 平方公里，體積約 0.4 立方公里。

目前熱液礦石之採樣主要集中於棉花火山東熱液區，包含魔王煙囪、鬼馬煙囪及女巫隆堆等場址。礦石經分析具有早期低度硫化型，以及成礦中、晚期中度或高度硫化型熱液沈澱特徵，硫化物及富銀磺酸鹽礦物種類多。礦石全樣分析顯示金、銀濃度分別可達 9,800 ppb 與 1,987 ppm，攜銀礦物包括含銀膠狀組織黃鐵礦、含銀方鉛礦和富銀磺酸鹽，金元素可能賦存於富銀磺酸鹽和含銀膠狀組織黃鐵礦及方鉛礦。礦石除了金和銀兩種貴金屬外，還包括鋅、鉛、銅三種具有經濟價值之金屬，且含量可達 0.3 至 9.6(wt.%)。顯示棉花火山具有 Cu、Pb、Zn、As、Cd、Au、Ag 之多金屬礦產潛能。

勵進研究船海洋重力觀測系統建置

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摘　要

根據國土測繪法規範內容，國家測量基準涵蓋大地基準、高程基準、深度基準及重力基準；其中，基本測量工作包含測量基準之建立與基本控制測量。重力測量作為國家基礎建設之關鍵環節，其數據不僅支撐高精度大地水準面模型之推算，更在海洋資源開發、海床地殼變動監測、板塊構造活動研究及海洋潮汐演化等地球科學領域扮演核心角色。

為完備臺灣周遭海域之重力場資料蒐集，於勵進研究船（R/V Legend）建立海洋重力觀測平台。詳實紀錄自民國111年起之需求規劃、規格擬定與請購作業；並彙整113年第四季於勵進研究船聲納間進行之儀器安裝、系統整合、靜態測試及專業教育訓練等圖文紀錄，建立完整的建置歷程檔案。

針對系統核心設備SEA-III船載重力儀與CG-6可攜式重力儀，制定標準化作業程序。內容涵蓋系統規格參數設定、啟動作業流程、動態資料蒐集邏輯及長期維護保養方案，並藉由114年之實際隨航測試，驗證系統在不同海象下之運作效能與資料穩定性。

為確保觀測數據之可用性，於安平港碼頭建立AP10重力基站，透過CG-6進行引測，將船載儀器觀測值精確引測至國家重力基準體系，確保海域重力資料能有效銜接陸域測量成果。

透過勵進研究船科學服務平台，提供學界高品質之海洋重力調查數據，為我國海洋科學研究貢獻穩定的觀測能量。

關鍵字:重力儀、重力測量、SEA-III、CG-6、勵進研究船

General Poster GP073

臺灣東部花蓮海域斷層構造與地形特徵
Structural and Bathymetric Characteristics Offshore of Hualien, Eastern Taiwan

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摘要

花東縱谷被認為是菲律賓海板塊與歐亞板塊之間的碰撞縫合帶，產生了一系列的斷層系統，其北端為縫合帶與琉球隱沒系統西端的交會處，其中米崙台地位於縱谷北端，最主要的活動斷層為米崙斷層，而花蓮海脊則被多被認為是米崙台地的延伸，也是臺灣東部地震好發區域之一，然而過去受限於資料分布及儀器限制，對於花蓮近海尚未有系統性的地質與地形調查。2024 年 0403 花蓮地震後，針對花蓮海脊與新城海脊區域，透過多個不同研究船航次，利用不同配置的多頻道反射震測系統，進行了震測調查系統評估與測試，藉由新收集之高解析震測資料，並搭配進階震測資料處理流程，大幅提升震測成像品質，對於花蓮海脊、米崙斷層、新城海脊南緣斷層有了進一步掌握。結果顯示花蓮海脊應可視為一個基盤高區，在海脊西南側基盤頂部發育多個斷層構造，部分落差出露於海床，並可與海床線形特徵相互對應。在海脊西南側，部分基盤頂部未受沈積物覆蓋，展現出數公尺起伏的粗糙、不規則突起海床特徵，沈積物組成以中砂為主。隨著花蓮海脊向東北方向延伸，基盤深度漸增，沈積物厚度也持續增厚，且層理連續，未受構造活動變形。部分區域的沈積物頂部有侵蝕而成的溝狀特徵，可能為此區域海流造成的沈積作用影響，沈積物組成則以粉砂為主。針對米崙斷層向外海的延伸，於花蓮海脊西北側可觀察到一東北-西南向、且被近代沈積物覆蓋的逆衝斷層，此斷層面向東南傾，可能終止於花蓮峽谷，但尚不能排除其可能於深部繼續延伸至新城海脊，然而在新城海脊南側之淺部地層，亦觀察到一東南-西北走向的逆衝斷層，此斷層部分區段受沈積物覆蓋，斷層面則朝東北，顯示此區地質構造的複雜性。本研究測試了不同的反射震測系統，同時發展進階資料處理技術，對花蓮海域斷層構造與地形特徵進行了新的分析，不僅進一步掌握了臺灣東部海域斷層資訊，也可做為後續地震風險與地質災害潛勢評估之參考。

關鍵字：臺灣東部海域、花蓮海脊、新城海脊、米崙斷層、震測成像

Keywords: Offshore Eastern Taiwan, Hualien Ridge, Hsincheng Ridge, Milun Fault, Seismic Imaging

General Poster GP074

台東外海地質構造韌性分析

Toughness Analysis for Geological Structure offshore Taitung

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摘　要

臺灣位處於板塊活動劇烈區域，地震發生頻率高，然而為配合政府淨零排放目標，海域建設工程需求 (如: 海洋能等)日益增加，為瞭解海床穩定性與韌性，國家實驗研究院台灣海洋科技研究中心 (海洋中心)使用勵進研究船搭載之各種海洋探測設備，先選擇可能有黑潮經過之台東成功外海近岸進行先期基礎調查。其中，所蒐集的資料包含長支距多頻道震測 (Long-offset Multi-Channel Seismic， LMCS)、底質剖面儀 (Sub-Bottom Profiler，SBP)影像、水深與流速等。此外，可利用海洋中心發展SBP影像幾何定位技術等，更準確定位出海床活動斷層位置與畫分出地質脆弱區，藉以提高未來於海域進行相關工程選址的安全性。從SBP影像分析結果，得知此區域海床為砂質底質不易穿透，且有海底峽谷向陸延伸，研判可能為濁流侵蝕，且越往下游切蝕越深，同時發現有陷落的正斷層產生，且出露於海床，代表此區域構造可能仍在活動。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，可能發生約5次的崩塌事件。進而，本研究逐步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。

General Poster GP075

震測影像解析桃園外海之碳封存構造

Seismic Imaging of Carbon-Storage Structure offshore Taoyuan

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摘　要

碳封存是減緩氣候變遷的重要策略之一，透過將二氧化碳封存於深部地層孔隙內，以降低溫室效應。然而，地質碳封存潛勢區域的評估需瞭解地層結構，以及模擬二氧化碳移棲與儲存過程等相關資訊調查。因此，本研究結合國家實驗研究院台灣海洋科技研究中心 (海洋中心)與國家高速網路與計算中心 (國網中心)之合作，利用海洋中心勵進研究船搭載「長支距多頻道震測 (Long-offset Multi-Channel Seismic，LMCS)系統」，蒐集震測地層影像資料，提供國網中心進行三維地質建模，希望進一步提高選址精準度，加速海域碳封存場址選擇與安全性評估。目前海洋中心已於桃園觀音外海實測蒐集 LMCS等相關資料，經過LMCS資料解析後之影像，可清楚觀察到海床下方0-3公里深度之沉積層構造，已達預定之深度目標。從震測影像結果得知，大部分符合西北-東南走向之前陸盆地系統構造，且沉積層同時往東北方向增厚，其斷層構造集中於西南區域。此外，結合國網中心插值與三維建模整合流程，模擬建構地層層序，逐步建立二氧化碳移棲模型與估算移棲路徑等。未來將繼續結合既有的LMCS資料，持續補足缺乏的範圍，以優化目標區域之碳封存模擬與沉積層影像判釋，並提供更準確之儲存量評估與安全性數據，以及未來監測場域之環境資訊等。

General Poster GP076

南沖繩海槽棉花海底火山之地層構造與熱液活動特徵

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摘 要

南沖繩海槽因弧後張裂所伴隨火成活動，讓海水及沉積物產生熱液換質作用，進而形成具經濟價值之金屬硫化礦床，其中棉花海底火山位於南沖繩海槽北側斜坡邊緣水深約1,370 公尺處，鄰近棉花海底峽谷於陸坡出口之西側，並已證明具有相當熱液礦產潛能。為了解南沖繩海槽之海底火山與熱液系統，本研究透過新海研 1 號新收集的反射震測資料，輔以底質剖面、多音束聲納等地物資料進行分析。棉花火山體寬度約 2.2 公里，高出海床約220 公尺，震測分析顯示，棉花火山體於海床及近海床的淺部地層當中呈現廣泛強振幅並有混亂相的訊號特徵，而深部地層則呈現為無反射、反白相之訊號特徵，顯示棉花海底火山已有火成岩體出露海床，且尚未被沉積物掩埋，此外火山體外圍地層中，普遍存在一連續的反極性、強振幅訊號特徵，其呈現近水平向分布，主要位於海床下 25 – 145 公尺間，且此訊號特徵的分布深度大致是由火山體中心向邊緣處逐漸變淺，最後中斷於近海床處。透過底質剖面資料比對，顯示此訊號特徵可以對應至淺部地層中呈現為混亂相、無反射之區域；而進一步透過多音束聲納及背散射海床影像分析，顯示這些反極性訊號特徵於海床中斷處都具有較高背散射強度，並與海床冒氣特徵分布區相符合，而於此區域的岩心採樣分析也證實沉積物溫度變化大，且具有較低 pH 值及較高的金屬富集程度，明顯受到熱液影響。本研究認為這些反極性震測訊號可反映熱液流體於地層中填充、累積的界面，且應為熱液成礦富集，並具有相當資源潛能的區域，特別在棉花海底火山西側；這些反極性訊號漸淺趨近於海床並中斷，能對應至黑煙囪、海床礦物隆堆特徵，而目前活躍的熱液活動則主要分布於棉花火山東南側。本研究整合不同尺度的地物資料，綜合分析棉花火山的地層構造與熱液活動特徵，透過對目標層位追跡，不僅對此區域熱液流體的分布範圍、深度等關鍵資訊有更進一步掌握，也有助於預測未來較易開採的淺層熱液礦產資源分布，也可用來量化可能的熱液礦產潛能，並做為後續資源開發之依據。

關鍵字 ： 南沖繩海槽、棉花海底火山、火成活動、熱液礦床

General Poster GP077

台灣海峽黏土礦物來源之研究：EMMA 之端元混合模型應用

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摘　要

台灣海峽是連接東海與南海的重要通道，其沉積物的來源與傳輸機制一直是海洋地質學研究的重要議題。本研究旨在精確量化主要河流端元對台灣海峽表層沉積物的相對貢獻比例，並探討黏土礦物從源到匯的過程。選定台灣河流 (TW)、呂宋河流 (LZ) 以及閩/珠江 (ZM) 為三個主要端元，模型運算使用Thompson et al.(2025) 提出的 EMMALAB 軟體，基於示蹤劑空間 (Tracer space) 進行端元混和分析 (EMMA)，研究台灣海峽黏土礦物來源。

黏土礦物空間分佈結果顯示，台灣端元主導了除台灣西部沿岸及大部分海峽區域；閩/珠江端元主要分佈於大陸沿海；而呂宋端元的膨潤石則受洋流長距離搬運影響，少量進入於海峽南部。為評估模型準確度，本研究將計算得出的端元比例反推計算預測濃度，並與實際測量值進行對比。線性迴歸分析所得的四種礦物判定係數 (R^2) 分別為：膨潤石0.98、伊萊石0.80、高嶺石0.98、綠泥石0.69，其中膨潤石、高嶺石、伊萊石的預測值與實際值高度吻合，展現模型極佳的適配度，研究結果亦與Li et al.(2021) 相符。本研究成功結合了傳統 U-space 幾何模型的邊界限制與新式 EMMALAB 演算法的最佳化計算優勢，可提高了沉積物溯源品質，也為台灣海峽的從源到匯研究提供可靠的依據。

關鍵詞: 台灣海峽、黏土礦物、端元混和分析、從源到匯

General Poster GP078

臺灣海峽北部離岸風電潛力場址之地質風險潛勢評估

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摘　要

臺灣海峽為全球離岸風電開發高潛力海域，除中部海域外，臺灣海峽自臺北至苗栗外海等區域，亦為未來可能的潛力場址，相較於中部已開發場址，臺灣海峽北部地質構造亦相當複雜，且與臺灣海峽中部相當不同。新竹與苗栗外海構造主要受始新世後伸張作用所形成的正斷層系統以及中新世晚期造山作用形成之淺層逆斷層活動影響；而臺北及桃園外海則被認為未有明顯的淺部斷層活動特徵。然而在其外海，由於過去缺乏系統性高解析海洋地質與地球物理資料，使該區地質條件，特別是淺部地層與構造認識仍相對有限，故在離岸風電建設前取得完整之海域地質資料顯得格外關鍵。本研究整合臺灣海峽北部，特別是臺北至苗栗外海近海區域之多重尺度地球物理資料，包括多頻道反射震測、海床底質及多音束水深資料等，透過震測地層學分析，辨識前陸基底不整合面與末次冰期不整合面（LGMU），輔以近海床的地層與地貌分析，評估此區地質構造活動，並歸納出四類可能影響離岸風電開發的地質風險因子，包括：（1）斷層構造、（2）堅硬地層、（3）流體活動與軟質沉積物變形，及（4）海床基準面變動與沙波遷移。結果顯示，臺灣海峽北部廣泛分布多條斷層，多數深埋或未切穿LGMU之地層，對工程影響有限；然而近岸區之逆斷層及其伴隨之褶皺構造仍具活動性，需特別關注。堅硬地層方面，除中部海域常見之玄武岩或基盤岩外，桃園及竹苗外海亦辨識出礫石層或生物礁體，此類地層可能影響基樁施工效率與設計。此外北部海域亦觀察到流體移棲構造及沉積物變形特徵，不僅與淺層氣體分布有關，也可能存有土壤液化風險。調查區亦辨識出波高約1至10公尺之沙波分布，參考中部離岸風場開發之經驗，其可能造成海床基準面變動，亦可能增加風機基礎不穩定性及海纜裸露與受損風險。本研究整合海洋地質與地球物理資料，釐清臺灣海峽北部地質概況與可能之地質風險潛勢，其成果可作為離岸風電工程設計前期判釋與風險評估之依據，也有助降低開發與營運過程中的地質風險。

關鍵字：離岸風電、地質風險因子、多頻道反射震測

General Poster GP079

南海北部大陸邊緣之非均質岩漿作用：結合折射與反射震測之聯合逆推與地函熔融模型之啟示

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摘　要

南海北部大陸邊緣廣布的下部地殼高速帶（high-velocity layer, HVL）常被解釋為與岩漿活動及地函作用有關，並可能反應高溫與活躍的地函對流事件，故對於理解大陸張裂至海底擴張之過程及其構造演化至關重要。為探討其空間分佈特徵與地球動力學成因，本研究使用一條跨越大陸—海洋過渡帶之 OR1-999-6 測線的多頻道反射震測與海底地震儀資料，利用 TOMO2D 進行折射與反射震測層析成像聯合逆推，並結合自適應重要性取樣法之蒙地卡羅不確定性分析，以建構可靠的地殼速度構造。研究發現，剖面之下部地殼高速帶呈不連續之塊狀分布，而非側向連續之均勻層狀構造。我們彙整本研究結果與已發表文獻之速度構造剖面，所編繪之南海北部高速帶厚度與分布圖顯示，北緣西北部發育明顯條帶狀高速帶、東北部則出現較厚的高速帶、而東南部則呈現較零散之分布型態。為了解本測線地殼構造與熔融模型在地函動力學之關聯性，本研究進一步將觀測結果與二維穩態地函熔融模型進行對比，並基於岩石地球化學的觀測結果，採用更符合南海北部張裂演化之岩石圈特徵，包含岩石圈預存蓋層厚度與地殼混染程度的差異、以及富集或虧損地函等不同地函來源，以評估其對熔融生成之影響。模擬結果顯示本測線所觀察到之高速帶與異常高的地函溫度或極端的地函上湧速率無必要之關聯，係較支持南海北部在張裂初期具有僅略高於典型被動張裂之地函上湧速率，以及相對較高（約 1370℃）、隨後伴隨約 50℃冷卻的地函溫度；同時，地函源區受大陸下部地殼混染程度，亦隨時空推移由 5%逐漸降低，並被虧損地函所稀釋。本研究指出地殼構造觀測不僅有助於理解南海北部大陸邊緣地函熔融過程，亦顯示如納入更合適的區域地質背景之熔融模型，將進一步揭示地函動力學與源區異質性在被動陸緣構造演化及下部地殼高速帶形成中的作用。

General Poster GP080

利用單音束水深聲納資料解析台灣西南外海逸氣活動之三維分佈與動態特徵

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摘　要

本研究利用2011至2019年間於台灣西南外海高屏峽谷與澎湖水道蒐集之單音束水深聲納資料，探討海床逸氣活動之三維分佈與動態特徵。透過分析共555條聲納剖面，其中87條顯示明顯聲學異常，辨識出主要羽流（flare）活動集中於高屏斜坡與手掌海脊兩大區域。研究方法上，首先根據體積散射強度（Sv）隨深度變化之背景值設定閾值，進行半自動化羽流辨識，並結合訊號相關性分析以去除隨機雜訊；進一步利用聲納所提供之垂直與平行船軸角度資訊，將二維剖面轉換為三維點雲分佈，以重建羽流在水體中的空間結構與動態行為。

結果顯示，高屏斜坡區域之羽流呈近垂直上升，在約250公尺水深處出現明顯收縮現象，反映水體分層或環境條件對氣泡上升的控制；手掌海脊區域則顯示羽流形態與擴散範圍明顯受潮汐與海流影響，具有時間上的變動特性。三維點雲分析亦可有效降低因船速變化造成的判讀誤差，提升羽流定位與規模估計的準確性。整體而言，本研究證實將單音束聲納資料由傳統二維解析延伸至三維點雲表示，可更完整掌握海底流體排放之空間分佈與時間演化，並有助於理解不同地質環境（如甲烷水合物區與熱液活動區）下逸氣機制的差異，對海洋地質資源調查與海底災害評估具有重要應用價值。

General Poster GP081

東海陸棚至臺灣海峽北部沉積紀錄所揭示全新世晚期以來西太平洋邊緣海之源匯系統動態演變

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為瞭解晚全新世氣候轉型下西太平洋邊緣海源匯系統的動態演變，本研究挑選東海至臺灣海峽北部海域的箱型及重力岩心進行沉積物分析，應可用以晚全新世氣候以來沈積物傳輸的時空演化及其動力機制探討。於東海陸棚大範圍的空間調查，利用多重感應元岩心記錄器（MSCL）建立非破壞性分析指紋圖譜，確立長江來源具備高密度、高磁感率，而臺灣來源具備低磁感率之特徵，進而精準鎖定水動力交鋒的關鍵點位 G2（OR5-0032: 120.184°E、24.667°N；69.9m）。此關鍵站位 G2 岩心的分析資料可發現於西元 1800 年前後發生決定性的物源機制轉變（regime shift）。在西元 1500–1800 年（即小冰期後期），沉積物組成主要由臺灣來源主導；然而自西元 1800 年起，長江來源轉而佔據主導地位。從古海洋研究及溫度重建紀錄來看，小冰期期間東亞冬季季風的增強，應可有效驅動中國沿岸流南下，促使更多長江來源沉積物輸送至臺灣海峽。然而，整合最新的紅外光譜分析與歷史氣候紀錄顯示，小冰期期間東亞地區頻繁發生極端降雨與洪泛事件，此現象可能大幅增強了臺灣來源的輸出；同時，侵襲華南地區的颱風所引發之強烈水動力擾動，亦可能限制了細顆粒長江懸浮物質在臺灣海峽北部的有效沉降。據此，本研究提出之機制，合理地解釋了在沿岸流動力最為強勁的氣候階段，為何岩心紀錄反而呈現以臺灣物源為主導的沉積特徵。整體而言，此紀錄反映了西太平洋邊緣海源匯系統在晚全新世氣候轉折期的行為，實則受控於「水動力搬運效率」與「極端事件擾動」之間的動態平衡。此一研究策略成功將既有古氣候研究成果與非破壞性分析所建構的空間指紋標定加以整合，為解析全球變遷如何調控邊緣海沉積動力，提出了一套具高度可轉移性的分析架構。

General Poster GP082

臺灣北方海域正斷層構造自晚上新世以來之活動性探討 :基於斷層滑移量分析

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摘要

臺灣北方海域因造山帶垮塌使區域應力轉換，構造環境由擠壓轉變為拉張，促使廣泛的東北-西南向正斷層系統開始發育。為探討這些正斷層自晚上新世以來的發育歷史，本研究藉由歷史剖面、重新處理與新收集的多頻道反射震測資料，辨識出三個層序邊界（基盤面 P0 及上覆層序中的 P1、P2），並針對研究區內 11 條主要的正斷層進行滑移量構造分析，斷層構造分析主要是利用斷層滑移量與斷層跡線距離關係圖（T-x plot）和斷層滑移量與深度關係圖（T-z plot）將斷層活動進行量化討論。其中斷層滑移量與跡線距離關係圖之分析顯示，長度逾 30 公里之長斷層，其發育中心未隨時間產生顯著之側向遷移，呈原位（in situ）生長之特徵，本研究推測該區正斷層系統之演化模式符合協同生長（Coherent growth）模型。而斷層滑移量與深度關係圖則顯示各期活動速率與其變化，斷層近岸段在三個時期皆維持穩定活動速率；斷層離岸段則普遍呈現活動速率減緩之特徵。再進一步觀察數值分布將斷層發育趨勢劃分為三類：(1) 每一區段皆維持較一致的活動速率的「持續型」（外山腳 1、外山腳 2 斷層）；(2) 活動速率呈現各時期皆沿走向由近岸向離岸漸減的「漸減型」（外崁腳、外基隆、外龍洞、外蚊子坑及外三貂角斷層）；(3)斷層在不同區段皆出現活動速率顯著衰減，整體發育趨勢較為複雜的「趨緩型」（外山腳 3、外台北及外基北斷層）。綜合上述分析可知，各斷層的活動速率不盡相同，且各斷層活動速率亦有走向上的差異，此活動速率的差異，或反映臺灣北方海域於造山帶垮塌之大尺度構造特徵。未來將進一步探討正斷層各期活動速率在時空上的關聯，討論各構造區塊的相對沉降趨勢及其可能的控制因素，以進一步分析臺灣北方海域造山垮塌的構造演化史。

General Poster GP083

新版鹿野斷層與利吉斷層條帶地質圖

Strip Geologic Map of the Luyeh and Lichi faults

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摘要

鹿野斷層與利吉斷層位於臺灣花東縱谷南端，為南北走向逆移斷層，亦是歐亞板塊與菲律賓海板塊碰撞縫合帶之關鍵邊界構造。早期關於此區域之地質研究，主要彙整於 2009 年出版之《臺灣東部與南部的活動斷層》。然而，隨著地質調查資料累積與長期觀測大地測量數據，經濟部已分別於 2015 年與 2024 年，將鹿野斷層與利吉斷層劃設為「活動斷層地質敏感區」，成為國土安全規劃與開發規範之重要依據。

近年來，配合政府資料開放政策，地礦中心積極推動條帶地質圖之更新工作，納入多項關鍵調查成果。在地形方面，透過高精度光達（LiDAR）判釋，標識出斷層位置。地質調查顯示，兩斷層均截切全新世沉積層，鹿野斷層最近一次活動約在距今 1,890 至 2,110 年前，而利吉斷層亦展現出顯著的構造活動性。

在地下構造與地殼變形部分，本更新版整合了多口深層地質鑽探、淺層震測與地電阻探勘資料，並結合 GNSS 與 PSInSAR 觀測數據，證實此區域現今仍具備高度變形速率，且受近年重大地震事件（如 2022 年關山與池上地震）應力調整之影響顯著。此次改版旨在重組最新地質事證，提供產官學研各界在重大工程規劃、防災評估及構造地質研究上，具備時效性與精確性之基礎地質資訊。

關鍵字：鹿野斷層、利吉斷層、條帶地質圖、活動斷層地質敏感區

Keywords: Luyeh Fault, Lichi Fault, strip geologic map, Geologically Sensitive Areas for Active Faults

潛在活動斷層的評估與調查-以烏山頭等斷層為例

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摘要

依美國原子能委員會（1973）所提出「能動斷層」定義第 3 項：與認定的活動斷層有構造上的關聯，且能推測為可能會發生錯移之斷層為活動斷層；過去中央地質調查所曾列有「存疑性活動斷層」，但隨《地質法》公告，因應法規對土地管理，需具備更明確且可驗證之科學證據。在整理既有調查資料後，暫將缺乏明確活動證據存疑性斷層移出活動斷層定義，但在此前取得活動證據的旗山斷層（陳文山等，2005），仍列於 2012 年版的 33 條活動斷層，顯示存疑性活動斷層經調查仍具有取得活動證據的可能性。

在此基礎上，依據能動斷層的概念與學界提出的陸域活動斷層，篩選具構造關聯性與構造地形特徵者，作為優先調查對象，暫稱為「潛在活動斷層」。此類斷層若能透過露頭、鑽探、槽溝等調查取得活動證據，並釐清其區域尺度的斷層位置，即可納入新版活動斷層分布圖。

目前已列入評估之潛在活動斷層數量眾多，包括烏山頭（崙後）、口宵里、初鄉、車瓜林、龍船、鼓山、木柵（平溪）、仁武–鳳山、右昌、嘉義（盲）、新營（盲）、臺南（盲）、內英、鹿廚坑、桐樹湖、古坑...等斷層，均與已知活動相關。透過鑽探與露頭調查，口宵里斷層、初鄉斷層及車瓜林斷層已確認截切階地沉積層並取得年代證據，證實其活動性，並納入最新公布之活動斷層（林啟文等，2021）。

然而，臺灣地處高抬升速率且高降雨的環境，導致地表侵蝕作用強烈、植被覆蓋密集，潛在活動斷層上的階地堆積層或崩積層往往保存不良，增加以斷層截切沉積物確認活動證據的難度，往往需長時間野外與鑽探調查，方能發現局部保留的證據。未來潛在活動斷層之調查將更仰賴多源觀測技術之整合，包括 PS-InSAR 等多時序面狀變形監測，配合高精度 GNSS 點位資料以及精密水準測量成果，以提升平原區至麓山帶斷層活動的辨識能力。

關鍵字：潛在活動斷層、烏山頭斷層、階地堆積層、放射性碳定年、永久散射體雷達干涉技術

General Poster GP085

The Variation of Stress State Inferred from Veins During Seismic Cycles

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Abstract

Earthquake is a devasting, unpredictable, natural hazard in the world. The strength and/or stress state in a seismogenic fault are usually variated with time, making it difficulties to characterized the aspects of a seismogenic fault. Assessment of stress state variation during seismic cycles will shed the lights into evaluating possible earthquake mechanisms and furthermore recognizing the characterization of earthquake faults. Previous studies of veins developed in the Shimanto belt of Japan delivered us the stress states with different stages in the content of earthquake cycles. It provides us a unique chance to study the variation of stress state during seismic cycles and place constraints on earthquake faulting mechanisms.

In this study, a methodology of stress state determined from veins is developed. The complete stress tensors of reverse faulting and normal faulting stress regimes from the Mugi mélange are determined from vein attitudes, P and T conditions from fluid inclusion study, and rock failure envelop. Once the complete stress tensors are assessed, the depths of vein formation with different stages of earthquake cycles can be evaluated. Due to the cross-cutting relationship of veins in terms of earthquake cycles, the depths of veins from different stress regimes should be overlapped. Vein stress results from our study show that the reverse faulting regime is dominated by NNW compression, which is consistent with the current motion of the Philippine Sea Plate. The normal faulting stress regime is noticed by NEE extension, which stress configuration is similar with the stress stage after the 2011 Tohoku-Oki Earthquake. The most important outcome is that the depths (~4km) of both stress regimes are overlapped statistically, indicating the methodology of vein stress determination is validated. The mechanisms of earthquake faulting can be further studied based on the constraints of complete stress state on the pre- and post-earthquakes.

General Poster GP086

Geodynamic Modeling of Slab–Slab Interactions in the Manila–Taiwan–Ryukyu Subduction System

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Abstract

The Manila–Taiwan–Ryukyu subduction system provides a natural laboratory for investigating the transition from active oceanic subduction to mature arc–continent collision at a complex plate junction. While dense geophysical observations across Taiwan are commonly interpreted in terms of arc–continent collision and crustal-scale orogenic processes, the contributions of underlying mantle circulation and interacting slabs remains poorly quantified. This deficiency is critical because subduction-driven mantle flow can influence regional stress and deformation over distances of up to ~600 km, the ~500-km-long Taiwan orogen—particularly where neighboring slabs interact through slab edges, slab gaps, and potential tearing or detachment. Here, we investigate these processes using three-dimensional finite-element geodynamic models ASPECT. Starting from an simplified double-subduction configuration, we isolate the first-order signatures of slab–slab interactions from the complexity of regional tectonics. Systematic sensitivity tests varying inter-trench distance and convergence geometry are conducted to quantify their effects on mantle flow and regional stress–strain patterns. To connect model dynamics to seismological observables, we further predict seismic anisotropy by tracking the development of crystal preferred orientation within the modeled mantle flow. Model prediction of stress, strain, and seismic anisotropy are compared with earthquake focal mechanisms, island-wide GNSS-derived strain rates and SKS splitting observations. These comparisons constrain the extent to which double-subduction–driven mantle flow contributes to geophysical observables, and they identify which observables are most sensitive to specific subduction parameters and slab–slab interaction geometries.

以光達地形解析桃園褶皺逆衝帶中構造幾何與斷塊旋轉

Structural Geometry and Rotation of a Fault-Bounded Block Revealed by LiDAR Topography in the Taoyuan Fold-and-Thrust Belt

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This study uses Light Detection and Ranging (LiDAR)-derived topography to reinterpret the structural geometry, including salient structural patterns and a fault-bounded block with a non-typical orientation relative to the regional orogen, in the Taoyuan fold-and-thrust belt. LiDAR can removes vegetation cover, allowing identification of bedding-related lineaments formed by differential erosion, and enabling macroscopic interpretation of folds and faults. Multi-directional hillshade images, slope maps and digital elevation models (DEM) are together analyzed in a GIS-based 3D environment. Although previous maps have delineated the orientation of the block and a salient structure to its north, its deformation mechanisms and structural relationships with surrounding units remain unclear. Our results further quantified stratigraphic thickness variations within the salient region, and revealed that strata within the block extend eastward and connect to a previously unmapped southwest-plunging anticline. The fold axis is oblique to the regional structural trend by ~55°. We propose that the salient geometry and thickness variations might reflect basement control and along-strike variations in shortening. Influenced by a western basement high acting as a buttress, the block may have undergone counterclockwise subvertical-axis rotation along a fault and is linked to adjacent units via the anticline. This study highlights the high potential of LiDAR-based geologic analysis for resolving structural geometries in areas with limited outcrop exposure and provides new constraints on local structural variations in the fold-and-thrust belt of Taiwan.

Keywords: LiDAR-based geologic mapping, fold-and-thrust belt, basement-controlled structural pattern, fault-bounded block rotation

General Poster GP088

光達地質製圖應用在變形沉積岩區的測試：海岸山脈貓公溪剖面岩層位態的不確定性

LiDAR-Assisted Mapping of a Deformed Sedimentary Terrace: A Test of Attitude Uncertainties in the Maogung River Area, Coastal Range

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Abstract

Geological mapping is an essential component in the construction of geological models. However, achieving high-precision mapping with complete spatial coverage remains challenging, particularly when uncertainty quantification is also required. LiDAR-derived digital elevation models (DEMs) provide detailed representations of topographic variations without interference from vegetation cover. High-resolution DEMs are capable of identifying subtle terrace morphology at the scale of hundreds of meters.

To compare and quantify the consistency between LiDAR-assisted interpretations of bedding planes and field measurements, we collected more than 500 bedding attitude measurements along a 2-km profile in the Maogung River area. The dataset was then subdivided into 18 groups at 100-m intervals, and the mean value and 95% confidence interval were calculated for each group to represent the corresponding area. Bedding planes within the same areas were also interpreted from LiDAR data, thereby producing paired datasets for comparison.

The uncertainties of the two methods in both the strike and dip domains show similar magnitudes, with acceptable confidence intervals. Bland-Altman analysis indicates that, in the dip domain, there is almost no systematic error, with a limit of agreement (LoA) of 2.4°. In the strike domain, a systematic error of 4° is observed, with an LoA of 5.2°. These quantified results may serve as a criterion for evaluating whether the two methods are interchangeable.

General Poster GP089

以變質溫度探討大禹嶺脫序逆衝斷層系統之構造特性

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摘　要

台灣造山帶是由晚新生代以來菲律賓海板塊與歐亞板塊的聚合所形成，在中央山脈東翼中觀察到極高的抬升速率(約2.5-6mm/yr)，在Lee et al.,(2002)研究中央山脈快速抬升與造山帶核心區發育大禹嶺脫序逆衝斷層系統（Tayulin out-of-sequence fault system）有關，為了解此斷層系統特性，本研究利用碳物質的拉曼光譜方法，分析岩層最高變質溫度，藉由分析跨越此斷層系統的變質溫度，以分析斷層兩側變質溫度差異，變質溫度分析方法依據Beyssac et al., (2002) 及 Kouketsu et al.,(2014)，分別對應變質溫度高於330℃及低於330℃時的變質溫度。

本研究區域位於台灣中央山脈的大禹嶺地區，地層自西向東涵蓋廬山層、大禹嶺層、黑岩山層，大禹嶺斷層系統地表位置大致位於大禹嶺層與廬山層交界與大禹嶺層中。初步結果顯示，在大禹嶺斷層系統東側變質溫度約350℃，逐漸降至約300℃，到斷層西側廬山層變質溫度約250℃。

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General Poster GP090

中央山脈南段小鬼湖剖面的變質溫度初步分析

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摘　要

變質溫度是釐清造山總剝蝕量、構造特性的重要資訊，在南部中央山脈小鬼湖地區出露中生代、始新世畢祿山層及廬山層，此外過去Lee et al., (2002)認為以中央山脈東翼發育大禹嶺脫序斷層，此斷層西側亦為造山帶分水嶺。為釐清跨越構造變質溫度變化及變質溫度機制，本研究分析小鬼湖剖面的變質溫度。

變質溫度分析方法利用碳物質的拉曼光譜，分析方法依據Beyssac et al, (2002)及Kouketsu et al., (2014)，分別對應變質溫度高於330度及低於330度時的變質溫度。

初步分析結果顯示脫序斷層上盤的變質溫度無論在大南澳變質雜岩、始新世地層、甚至上盤東側的廬山層碳物質拉曼光譜變質溫度均約350度，而斷層下盤過去研究顯示廬山層變質溫度有極大的變異性，從約330-250度。未來將釐斷層下盤廬山層變質溫度並藉由密集採樣分析通過斷層變質溫度變化。

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General Poster GP091

Constraining Geological Cross-Sections in Southwestern Taiwan Using Proxies of Burial Depth and Gravity Anomalies

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Abstract

Southwestern Taiwan is an active fold-thrust belt that exhumed the widespread Gutingkeng mudstone Formation. The large formation thickness and the presence of overpressured strata and mud volcanoes suggest a possible contribution from shale tectonics in the fold-thrust belt deformation. Shale mobilization may influence fold geometry, structural style, and subsurface density structure. However, the lack of deep borehole and seismic reflection data limits our understanding of tectonic structures below ~2 km depth, and active deformation patterns sometimes contradict our current knowledge of geological structures (e.g. footwall uplift). To address these problems, this study aims to establish an integrated workflow combining multiple geological indicators to enhance our understanding of deep geological structure and tectonic evolution in the region.

This study integrates existing geological and geophysical data of the study area to construct a preliminary geological cross-section of southwestern Taiwan. Burial depth proxies provide additional constraints on subsurface structure. Porosity is used to constrain compaction degree and representative density of the layer, while vitrinite reflectance is used as an indirect indicator of burial and thermal history. Published Bouguer anomaly data are then used in gravity forward modeling to further constrain the cross-section. Porosity measurements under varying confining pressure will be conducted on Gutingkeng mudstone samples of different geological ages and burial histories. They will help refine the density depth-profile for gravity modeling and estimate maximum overburden pressure and burial depth.

General Poster GP092

利用磁性組構重建岩石應變增量之研發以及其應用於造山運動構造演化之揭示：以臺灣雪山山脈為例

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摘 要

造山帶位於板塊聚合邊界，其不同岩體受到擠壓、碰撞、側向剪切及剝蝕抬升等不同變形事件(Deformation Event)之影響，並反應於不同的地質構造。雖然現有研究仍缺乏有效量化這些大地構造之應變增量的方法，但磁性組構(Magnetic Fabric)已被證實是評估區域應變的良好工具，因此本研究利用磁感率異向性ㄐ(Anisotropy of Magnetic Susceptibility, AMS)，結合前人磁感率轉應變模型，計算應變增量(Incremental Strain)。此方法旨在量化不同變形事件間的應變增量，進而推估造山運動各階段的變形歷史。

臺灣造山帶處於歐亞板塊與菲律賓海板塊之斜向聚合帶，其大地構造演化極具代表性。雖然已有眾多研究與模型被提出，但雪山山脈與脊樑山脈地質區的應變演化細節仍有待釐清。由於前人已完成北橫公路沿線之磁感率數據並有明確的變形事件分期，因此本研究將運用其資料進行應變增量之推算與解析，從各階段的最終累積應變中計算各應變增量，量化不同變形事件的貢獻。預期研究結果將有助於理解臺灣雪山山脈與脊樑山脈西側各階段之應變，以更深入的探討北橫公路沿線的變形歷史，並可為全球造山帶之構造演化研究提供新的應變分析方法與理論依據。

關鍵字：造山帶、造山運動、磁性組構、磁感率異向性、應變增量

General Poster GP093

Polyphase deformation and late-stage extension in a transpressional regime: Evidence from fault-slip analysis in Taimali-Jinlun area, southeastern Taiwan

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The Taimali-Jinlun area in southeastern Taiwan is located within the transition zone between subduction and arc–continent collision, where deformation is dominated by transpressional tectonics. Although previous studies have documented complex fold-and-thrust structures and polyphase deformation, the relationships between fault-slip kinematics and paleo-stress evolution remain poorly constrained.

In this study, we conducted systematic field investigations, including measurements of fault planes, slickenside striations, joints, and bedding, complemented by microstructural observations, to reconstruct the deformation history of the Taimali–Jinlun coastal region. Our results reveal multiple fault systems, including a previously underrecognized set of N-S trending faults that are widely distributed from Taimali to the Jinlun River. Fault-slip analysis shows superimposed striations, indicating at least four distinct stress regimes. The deformation history is interpreted as follows: early E–W compression associated with folding and thrusting, followed by backthrusting and shear zone development, then a transpressional stage with strike-slip faulting, and finally a late-stage extensional regime characterized by N–S trending normal faults and associated joints.

This late-stage extension suggests localized stress reorganization during rapid uplift of the orogenic belt. Alternatively, these normal faults may represent reactivation of pre-existing thrust or shear structures that became steepened during uplift and structural rotation. These results provide new constraints on the polyphase stress evolution of southeastern Taiwan.

Keywords: Taimali - Jinlun area, fault-slip kinematic, paleo-stress, N–S trending normal fault

General Poster GP094

以岩象學探討雪山山脈帶的變質安山岩之初步研究

A Preliminary Study of Meta-Andesite Using Petrology in Hsuehshan Range Belt

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摘　要

變質安山岩，意味著該岩體保有安山岩原來的特徵，也就是說，從岩石的礦物組合與組構能夠解析殘留安山岩的資訊。中部雪山山脈帶有數處出露變質安山岩，這岩體有些已無法觀察出原岩安山岩特徵，但有些則仍保有安山岩原岩的組構與礦物相。因此，本研究先以岩象學作為探討變質安山岩特徵的方法以提供後續研究的基本資料。

本研究初步成果顯示，變質安山岩可分為有葉理及無葉理的2種，其中有葉理的劈理領域礦物組成以黑雲母及絹雲母為主，而夾質領域的組成礦物為石英、斜長石及方解石；無葉理的礦物有方解石、斜長石、石英、絹雲母。

關鍵字：斜長石、石英、方解石、變質安山岩、雪山山脈帶

Keywords: plagioclase, quartz, calcite, meta-andesite, Hsuehshan Range Belt

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General Poster GP095

透地雷達應用於南部廠址之地下管線調查案例研究

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摘　要

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。其中，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。此技術在先進國家已廣為使用，依照探測天線頻率之高低不同，分別可應用於鋼筋位置調查、混凝土裂縫空洞調查、管線調查、空洞調查、地層層位調查、水中沉積物調查與考古調查等。

本研究利用美國GSSI公司製造的SIR-3000透地雷達探測儀，搭配全罩式400 MHz的透地雷達天線，並以載具測距輪進行探勘工作。於南部廠址共5個試驗場址，分別施測34、15、23、12與30條測線，共探測114條測線，測線總長度為1,579.22公尺。雷達資料經過零點修正、背景移除、濾波和移位等處理，得出透地雷達剖面，並藉由反射訊號在剖面上的形態特徵來判識管線訊號。同時，藉由比對平行方向測線上的連續管線訊號，來確認地下管線的延伸方向與分布情況。

透地雷達經過判讀分析後，於試驗場址第1區探測出23條連續管線訊號；於試驗場址第2區探測出1組管群與21條連續管線訊號，並偵測到人造物、人孔與疑似樹根之位置；於試驗場址第3區探測出9條連續管線訊號，並偵測到鋼筋鋪面之位置；於試驗場址第4區探測出11條連續管線訊號，並偵測到鋼筋鋪面、人孔與人造物之位置；於試驗場址第5區探測出1組管群與13 條連續管線訊號，並偵測到鋼筋鋪面、鐵板與人造物之位置。結果顯示透地雷達結果能有效釐清試驗場址內地下管線之分布情況，以提升後續開挖工程之準確性與安全性。

中文關鍵字：透地雷達、地球物理探勘、非破壞性檢測、管線調查
英文關鍵字：Ground Penetrating Radar、Geophysical Survey、 Non-destructive Testing、Utility Locating

General Poster GP096

Utilizing Geomagnetic Depth Sounding to Analyze Electrical Conductivity of the Mid-mantle Beneath Subduction Zone

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Abstract

Most existing interpretations of mantle structure are based on seismic velocity analyses, whereas only a limited number of studies have used electromagnetic observations to constrain mantle electrical structure. Here we apply long period geomagnetic depth sounding (GDS) to investigate the mid-mantle electrical conductivity beneath Taiwan, where a complex subduction zone, setting at depths of 300–900 km for the first time. We analyze geomagnetic field data from six local observatories and three stations outside Taiwan. To improve the reliability of conductivity estimates, we correct for ocean induction distortions caused by the strong conductivity contrast between resistive continental crust and conductive seawater and marine sediments. Forward simulations are performed using a high resolution (0.1° × 0.1°) three dimensional conductivity model in spherical coordinates with locally refined horizontal meshing. The observed ocean induction effect is best reproduced with a land crustal resistivity of 100 Ω·m, substantially lower than values commonly assumed in previous global studies. After correction, we invert the GDS responses to obtain one dimensional conductivity–depth profiles for each local observatories. The average profile shows a monotonic conductivity increase from 0.06 $S \cdot m^{-1}$ at 300 km to 0.86 $S \cdot m^{-1}$ at 900 km. In the upper mantle, southeastern Taiwan is more conductive than northwestern Taiwan, whereas at greater depths conductivities converge toward global model values, indicating a more homogeneous lower mantle structure. This Taiwan case study demonstrates that high resolution ocean effect correction is essential for robust GDS responses estimation in ocean surrounded subduction zone regions.

General Poster GP097

使用點雲解釋建立泥貫入體三維模型之方法

Method for constructing a 3d model of mud diapir using point cloud interpretation

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摘 要

過往利用二維震測資料在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在震測剖面上圈繪其形貌，繪製泥貫入體頂部構造圖，在平面上推估分布範圍。目前已有商業軟體可以創建三維模型，但受限於台灣西南海域缺少三維震測資料，對於泥貫入體陡峭的翼部及泥貫入體間深部盆地之三維空間分布仍缺少客觀快速之方式進行描繪。

本公司過往已藉由結合不同的震波屬性，利用商業軟體的類神經網路分類，快速識別出泥貫入體在震測剖面上的位置。本次研究進一步依據二維震測影像及其類神經網路分類成果，分別進行泥貫入體之頂部層面解釋及內部構造的點雲解釋。結合三維空間建模技術，將點雲轉化為構造網格，並利用空間計算擴展其分布範圍，建立泥貫入體三維空間分布模型。本研究之成果相對於傳統構造建模方式對泥貫入體陡峭的翼部有更合理的描繪，亦能完整地描繪出兩個泥貫入體之間深部盆地的形貌，對後續於泥貫入體分布區進行地質建模之研究提供必要的資訊。

中文關鍵字：震測解釋、地質建模、泥貫入體

英文關鍵字：Seismic Interpretation, Geological modeling, Mud Diapir

General Poster GP098

微地動資料分析及其在斷層特性判釋中的應用：以台灣崁腳斷層為例

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台灣北部位於菲律賓海板塊與歐亞大陸板塊的聚合邊界，構造環境由碰撞造山作用逐漸過渡至弧後張裂構造，形成複雜的地體構造與多條活動或非活動斷層。位於台北盆地東北緣、鄰近大屯火山群的崁腳斷層呈東北—西南走向，被認為與區域應力場轉換及構造再活動密切相關。然而，目前對於崁腳斷層在淺部地下的構造特徵仍缺乏清楚的認識，包括是否存在低速破碎帶或速度不連續帶、是否伴隨基盤起伏或地層位移，以及該斷層是否仍持續影響盆地邊緣的地下地質構造。

本研究利用微地動（microtremor）量測資料探討崁腳斷層附近之淺層地下構造特徵。透過水平與垂直頻譜比（H/V spectral ratio）分析取得各測站之頻譜峰值頻率，以推估沉積層厚度及阻抗對比特性，同時進一步反演或建立淺層剪力波速度（Vs）構造，以分析地下介質力學性質的變化。藉由整合 H/V 頻譜峰值的空間分布與剪力波速度構造剖面，本研究評估崁腳斷層對淺層地下構造的影響與可能的構造表現。研究成果有助於釐清崁腳斷層的構造特性與潛在活動性，並進一步理解其在台灣北部碰撞—張裂過渡帶中的構造角色與地體演化意義。

General Poster GP099

透地雷達應用於地下管線與箱涵交錯關係調查

Investigating the Intersection of Underground Pipelines and Box Culverts by Ground Penetrating Radar

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Chun-Yu Chiang[1], Chien-Ping Lee[1]

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摘要

管線地下化具有優化土地使用、改善市容與提高管線安全性等優點，但於台灣都市地下空間有限的背景下常會出現不同單位管線重疊或交錯之情況，造成施工困難與安全風險提高，如 2014 高雄氣爆即為管線不當包覆於排水箱涵內，以致管壁由外向內腐蝕發生洩漏進而引起。本研究根據縣市政府之雨水箱涵圖資與本公司地下管線圖資挑選一潛在管線穿越箱涵之場址，以透地雷達探測地下管線與雨水箱涵之空間相對關係。探測作業使用美國 Geophysical Survey Systems, Inc. (GSSI) 之 SIR 4000 主機搭配 350MHz 單頻天線 (350 HS Antenna) 針對調查場址佈設網格狀分布之測線，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。根據透地雷達剖面所繪製出的地下管線與箱涵平面圖與既有圖資相符度高，於透地雷達剖面中共判釋出 6 條地下管線與 2 條箱涵，並發現 1 處疑似因過去開挖回填所造成之訊號異常區。由於各管線之埋設深度均小於箱涵深度，推測該管線與箱涵圖資交會點應無地下管線穿越箱涵之情形，唯開挖回填對部分關鍵區域的雷達訊號造成影響，判釋結果仍具有不確定性。

General Poster GP100

大地電磁響應中的季節性變化

Temporal Variability of MT Responses from Three-Year OBEM Records

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Abstract

Seafloor magnetotelluric (MT) responses are increasingly used to constrain lithospheric conductivity structure, yet the temporal stability of these responses remains poorly documented. Here we present three years of continuous seafloor electromagnetic records from multiple ocean bottom electromagnetic (OBEM) sites across the western Pacific. These instruments recorded electric and magnetic fields, enabling estimation of tippers, the classical 4-element MT impedance tensor based on two horizontal electric and two horizontal magnetic components, and 6-element impedance estimates based on two horizontal electric fields and all three magnetic field components. Transfer functions are estimated using moving window processing to examine their temporal variation. The results reveal temporal variability that differs among sites, years, and periods. At several stations, parts of record exhibit seasonal-like or quasi-periodic changes in tippers and impedance tensor, whereas other stations or period bands show no clear periodic pattern. Variability is generally larger in summer. When seasonal-like behavior is present, tipper maxima tend to occur in summer, and $\log_{10}$ apparent resistivity of xy component commonly increases by about 0.1. These features are most prominent over periods of several 10^3–10^5 seconds, although their strength and clarity vary among stations and from year to year. While the underlying causes remain unresolved, the observed temporal variability suggests contributions from multiple factors, potentially including slight mismatches between spherical Earth observations and planar MT formulations, as well as variability in the external source field.

General Poster GP101

Impact of Fluid Property Estimations on Velocity Models and Synthetic Seismic Responses for Geologic Carbon Storage

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Abstract

Correctly estimating fluid properties is essential for time-lapse seismic assessment at geologic carbon storage (GCS) sites. Incorrect fluid properties can lead to substantial misestimation of seismic velocities in CO_2-saturated zones. The commonly used Batzle-Wang formulation was developed for hydrocarbon fluids and may introduce significant error when applied directly to CO_2 under supercritical conditions. Differences in CO_2 density and bulk modulus can greatly influence rock physics predictions and seismic detectability assessment. In this study, we improve fluid property calculations by using the actual critical pressure and temperature of CO_2 instead of inferred values.

To understand the impacts, the estimated fluid properties are used in a rock physics workflow, incorporating reservoir simulations and subsequent seismic velocity models for a deep saline aquifer at a hypothetical site. Comparison of these methods shows that our modification method predicts a lower CO_2 bulk modulus than the original model, leading to stronger velocity contrast between the CO_2 plume and the background brine. The impact of different pressures and temperature ranges is also examined. Additionally, finite-difference synthetic seismic modeling shows stronger reflection responses and higher normalized root-mean-square differences. These results show that conventional fluid property calculations may underestimate seismic detectability assessment in GCS forward modeling studies. Our suggested modification methods greatly reduce the errors brought by the original Batzle-Wang formulation.

Keywords: Geologic Carbon Storage, Time-lapse Seismic, Rock Physics Modeling, Supercritical CO_2, Batzle-Wang Formulation

General Poster GP102

小油坑ERT剖面之電阻率日變化與多源環境參數的交互影響分析

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摘　要

陽明山國家公園作為臺灣唯一的火山自然景觀區，近年經多項地球物理與化學技術證實，其大屯火山群下方的岩漿庫與熱液系統仍具活躍性，屬具備噴發潛勢的活火山。其中，小油坑地區因強烈的水熱活動與地質蝕變，面臨顯著的「蒸氣噴發（Phreatic Eruption）」風險。根據演化模型，當深部熱能誘發流體相變為高壓蒸氣，若能量突破鬆散地層的載重與強度，即可能發生具高度破壞力的突發性噴發。鑒於近期觀察到小油坑噴氣孔有側向遷移跡象，對遊客往來頻繁的步道及遊憩場域構成直接環境威脅，建立高解析度的近地表監測系統已刻不容緩。

自1970年代以來，大屯火山群雖已累積豐富的深層構造與地殼變形資料，但針對「近地表」且具「高動態」的流體運移監測仍相對不足。本計畫提議利用地電阻影像法（Electrical Resistivity Tomography, ERT）作為核心技術，針對小油坑區域設置數條連續觀測線。ERT具備主動式、非破壞性且對地層導電性與含水量高度敏感的優點，能定期產出二維電阻率剖面圖，藉此勾勒地下熱液通道與噴氣孔隨時間的移棲規律。

為克服電性觀測的多解性並提升預警精準度，本研究多方地整合各項物理參數進行交叉比對。透過固體潮週期與微震分布的序列疊合，判讀地震前兆導致的電阻率異常變化。結合地溫觀測，確認電訊號位移是否伴隨深部熱流上湧。並且將地電阻率時序數據與區域降雨量進比對，可系統性地辨識並排除降雨滲透導致的淺部低電阻異常。這種對比能精準區分地層含水量變化是源於「外部大氣降水滲透」還是「深部熱液上湧」，有助於釐清淺層地電阻率變化的動力來源，從而大幅降低因極端降雨事件導致的預警誤報。

本研究針對「蒸氣噴發通道」的長時段高解析度電性特徵檔案，填補學術界對於淺部火山流體運移規律的理解空白。在防災實務層面，研究成果將轉化為科學化的風險評級指標，希望觀測到在熱液移棲趨勢顯著時，有可能的及時調整遊憩規劃並研擬對策。這不僅是技術上的跨域突破，更是落實科學監測、守護公眾安全與環境永續經營的重要里程碑。

關鍵字：近地表地球物理探勘，地電阻影像法，熱液，固體潮週期，地溫，降雨量

General Poster GP103

小油坑地區地下流體運移之時序地電阻監測與分析

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摘要

小油坑地區位於大屯火山群七星山西北麓，具備地表活躍之噴氣與地表泥漿滾動等後火山活動，亦伴隨多雨之氣候環境，塑造淺部地層中複雜的流體動態交互作用。為進一步釐清該區地下流體之時空運移特性，本研究於小油坑步道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）進行長期連續觀測，定期蒐集二維電阻率剖面。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，能有效追蹤流體運移所引發的電性構造變化。為探討降雨事件所產生的動態響應，本研究將觀測期間劃分為多個獨立雨場，透過計算電阻率之相對變化量，量化地下介質在不同降雨條件下所經歷的電性擾動，期以辨識地下高滲透性之優勢水流路徑與構造通道。

初步分析結果顯示，儘管各雨場之降雨強度與歷時存在差異，但在多次獨立雨場事件中，特定區域均反覆出現空間位置高度一致的電性顯著變化帶，且與現地觀測證據吻合。此現象證實其受控於地下既有之破碎帶，而非單一事件之偶然結果。此外，本研究進一步分析電阻率之相對變化量與累積降雨量之相關性，識別出層地層中孔隙率較高或滲透性較強之空間，暗示降雨入滲之優勢路徑，而低相關性之區域則可能代表著受降雨影響小，推測與低滲透性之黏土蓋層阻絕入滲有關。

關鍵字：地電阻影像法、小油坑

General Poster GP104

臺灣離岸風場海域洋流及廊道地質環境分析-竹苗及彰化外海海纜共同廊道地質環境分析

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摘　要

臺灣為因應全球碳淨零排放趨勢，行政院於 2022 年 3 月正式公布「 2050 淨零排放政策路徑藍圖」，促進離岸風電開發進程持續前進。隨著政策邁入第三階段「區塊開發」的大規模場址建設期，臺灣西部風場逐步邁入大規模區塊化階段，隨著西部風場逐步趨於飽和，工程施工（如海纜噴埋與基樁安裝）將愈發密集，特別是在竹南、苗栗與彰化等重點海域，共同廊道周圍是否存在地質災害風險至關重要。以往臺灣規劃建設主要借鑒歐洲北海及波羅地海等離岸風電先進國家經驗，然而臺灣海峽海床以厚層沉積物覆蓋為主，地質構造複雜且活躍，與前者岩盤為主的海床差異顯著，突顯建立符合臺灣海床地質特性之基礎資料與地質分析之必要性。

本研究將以蒐集竹苗及彰化外海海纜上岸廊道附近既有海域及陸域地質之研究文獻、公開環境影響評估書件，並利用 GIS 系統整合水深與海底地形及地質敏感區分佈，分析竹苗及彰化海域之海床地質特性與沿岸地質環境，作為海纜共同廊道工程規劃與風險評估之參考依據。初步地質分析顯示，竹南廊道區域及彰化外海均存在活動斷層分佈，彰化北側及彰化南側廊道沿岸位於沖積層覆蓋區域，具有中、高程度的土壤液化潛勢。海纜共同廊道於活動斷層附近應採用耐震設計，位於中、高土壤液化潛勢區廊道則需進行地質改良工程，以降低土壤液化產生影響。

關鍵字：離岸風電、海纜廊道、地質敏感區

以微地動探測於捷克山崩構造解析之應用

傳統的地表與地形調查方法在研究此類大規模深層山崩時，往往受限於技術困難且成本高昂，因此迫切需要更有效率的探測手段。本研究旨在利用寬頻地震儀對五處不同地質構造的山崩場址進行現地微地動量測，透過產製水平對垂直頻譜比（H/V）來辨識場址的共振特徵，並進一步對 H/V 比值資料應用逆推方法，以推導地下剪力波速度（Vs）構造模型。最終，本研究將分析結果與觀測到的場址效應及既有文獻紀錄之滑動面深度進行比對驗證，以確保結果的一致性與可靠性。分析結果顯示，於 Vaculov 地區成功解析出深度約 10 公尺與 40 公尺處之明顯地層分面，其結果與既有地質文獻高度相符。然而，Ondřejník 場址之觀測資料受限於儀器架設時間不足或地下構造過於複雜，導致資料無法有效擬合。本研究在未來將繼續透過既有的文獻資料結合研究微地動的成果，深入了解捷克五處山崩之地下構造，以建立山崩模型。

關鍵字: 微地動、捷克共和國

General Poster GP106

大地電磁資料穩健處理流程與時變性分析

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摘要

大地電磁法（Magnetotellurics, MT）是一種利用天然電磁場探測地下電性結構的被動式地球物理方法，具有探測深度大、頻帶範圍廣及非侵入式等優點，廣泛應用於深部構造研究、地熱資源探勘及地殼電性分析。然而，在臺灣等高人為雜訊環境下，MT 觀測資料常受電力設施、交通系統與通訊訊號等人為雜訊干擾，造成轉換函數估算不穩定，進而使視電阻率與相位曲線產生偏移、起伏或誤差擴大等問題。為提升高雜訊環境下 MT 資料處理之穩定性與可靠性，本研究以 SigMT 開源程式架構為基礎，針對既有流程進行測試、優化與模組擴充，建立一套較完整之穩健化資料處理流程。

本研究整合之處理流程包括自迴歸（AR）預白化、快速傅立葉轉換、Parzen 窗頻帶平均、頻譜標準差過濾、Mahalanobis 距離篩選、相干性判別，以及 Huber M-estimator 穩健阻抗張量估算。研究結果顯示，AR 預白化可有效降低頻譜外洩與主導頻率成分對估算結果之影響；Parzen 窗頻帶平均則有助於平滑頻譜、提升頻域估算穩定性；頻譜標準差過濾可剔除受高能量異常訊號影響之資料段；而 Mahalanobis 距離結合相干性篩選，則可進一步辨識並排除低品質樣本。經上述流程處理後，最終所得之視電阻率與相位曲線整體上更為平滑，誤差範圍亦明顯縮小，顯示本研究所建立之流程能有效提升高雜訊 MT 資料之處理品質。

此外，本研究亦將該流程延伸應用於長時間連續觀測資料之分析，以探討地下電性結構可能具有之時變特徵。以南橫地區 MT 長期監測資料為例，針對 2024 年 1 月 31 日至 2024 年 11 月 8 日之觀測資料進行連續處理，採用 14 天資料長度與 2 天移動步長進行滑動式計算，共獲得 129 組阻抗估算結果，並進一步繪製不同頻率下視電阻率與相位隨時間變化之熱圖。結果顯示，本研究所建立之流程除適用於高雜訊環境下之單次資料處理外，亦具備應用於長期監測資料連續計算與時變性分析之潛力。整體而言，本研究所提出之方法對於提升 MT 資料處理之穩健性、自動化與延伸應用價值具有實質意義，並可作為未來地熱潛能評估、深部構造探測及地球物理監測研究之參考。

General Poster GP106

Robust Processing Workflow and Time-Variation Analysis of Magnetotelluric Data

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Abstract

Magnetotellurics (MT) is a passive geophysical method that uses naturally occurring electromagnetic fields to investigate subsurface electrical structures. It is widely applied to deep structural studies, geothermal exploration, and crustal resistivity imaging. However, in high cultural-noise environments such as Taiwan, MT data are often contaminated by anthropogenic noise from power systems, transportation, and communication signals, resulting in unstable transfer function estimation and degraded apparent resistivity and phase responses.

To improve processing stability and reliability, this study develops a robust workflow based on the open-source SigMT framework through systematic testing and optimization. The workflow integrates autoregressive (AR) prewhitening, fast Fourier transform, Parzen-window band averaging, spectral standard deviation filtering, Mahalanobis distance selection, coherency screening, and robust impedance estimation using the Huber M-estimator. Results show that AR prewhitening suppresses spectral leakage, while spectral filtering and statistical selection effectively remove noisy segments. The processed responses are smoother and exhibit reduced uncertainties.

The workflow is further applied to long-term continuous data to investigate temporal variations. Using MT monitoring data from January 31 to November 8, 2024, a sliding-window scheme (14-day window, 2-day step) yields 129 impedance estimates. Temporal heat maps of apparent resistivity and phase reveal time-dependent behavior.

Overall, the proposed approach improves MT data quality in noisy environments and demonstrates potential for continuous processing and temporal variation analysis in long-term monitoring.

Nowcasting 模型對台灣區域的應用

林瑋棋、張景荃、陳宏嘉

台灣位於歐亞板塊與菲律賓海板塊的碰撞交界帶，地震活動極其頻繁且構造環境高度複雜，面對如此高頻率且具潛在破壞性的地震威脅，發展具備高時效性與科學依據的潛勢評估技術至關重要。因此，本研究旨在推廣並實作由加州大學研究團隊開發之隨機模擬模型 Earthquake Rescaled Aftershocks(ERAS)。此技術之核心價值在於相較傳統以斷層物理模型為基礎的預測方法，以地震目錄統計為核心的數據驅動方法的方式，將雜亂的地震目錄轉化為具備物理指標意義的地震潛勢指數(Earthquake Potential Score, EPS)。將此模型套用於台灣，能有效對應本島複雜的斷層系統，為區域減災提供一種新型態且直觀的地震即時潛勢監測。

在技術實現層面，本研究針對原始模型進行了系統性的優化與重構，成功克服了跨平台環境下的部署障礙與演算法相容性問題。透過建立自動化數據處理介面，本研究實現了與台灣中央氣象署地震目錄的完成與資料整合，大幅提升了模型在台灣構造環境下的運算穩定性與數據處理效率。此項優化工作不僅優化了地震潛勢分數的計算流程，更為建立標準化的區域地震監測系統奠定了堅實的技術基礎。

研究實踐上，本研究利用優化後的模型對台灣進行了細緻的空間解析。透過「反轉 Y 軸(Inverted Y-axis)」與「0.15 預警門檻」的視覺化設計，成功將抽象的統計指標轉化為直觀的風險管理語言。研究發現，在全台灣大尺度分析下，受限於構造複雜度，較難辨識出明確的地震循環特徵。然而，當縮小至特定區域時，模型展現出良好的區域解釋能力。以 2024 年 0403 花蓮地震區域為例，其 EPS 曲線多次接近預警門檻，反映了東台灣高度構造複雜與能量釋放極其頻繁的特徵，最新計算之 EPS 數值為 0.622。相較之下，西台灣區域則呈現明顯的地震循環態勢，最新 EPS 數值約為 0.445，曲線正處於明顯的向上攀升期。

本研究的成功實作，不僅驗證了 Nowcasting 技術在台灣地震監測的巨大潛力，更重要的是建立了一套標準化、自動化的數據處理流程。透過解決軟體環境的部署門檻與演算法的在地化對接，可以為後續導入生成式預訓練變換模型(QuakeGPT)，人工智慧輔助監測系統奠定了關鍵的數據基礎。未來於整合多維度地震學參數，將此自動化框架發展為全天候的地震潛勢監控平台，為台灣的精密地震防災與風險評估提供更具前瞻性的決策支持。

General Poster GP108

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 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. Before exploring the high-resolution attenuation mapping within the fault zone using DAS (4 m spatial resolution), we first analyzed six seismic events (roughly 20 km from the MiDAS site) using paired data from borehole seismometers and fiber nodes 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 raytracing to select events with incidence angles below 30°. 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 Qp and Qs, from Δtp^* and Δts^* by applying least-squares fitting. The results showed high consistency between the two sensing systems. Building on this initial validation, we scaled our analysis to over 1,000 local events with magnitudes ranging from 2.0 to 4.5. By applying a sliding window approach to this extensive DAS dataset, we aim to resolve the high-resolution attenuation (Q) profile across the entire depth of Hole A and characterize the depth-dependent attenuation variations along the borehole and within the fault zone. Preliminary results reveal low Q values (on the order of tens) across most depths in Hole A with a Qs/Qp ratio of about 1.5, with consistent estimates derived from both DAS and borehole seismometers. Currently, we are conducting synthetic waveform modeling via FK analysis with prescribed Q values. By comparing these synthetics with observed seismograms and subjecting them to the same analytical workflow, we aim to verify the reliability of our methodology and ensure the resolved Q values accurately reflect the physical properties of the fault zone.

General Poster GP109

Imaging Complex Tectonic Structures and Slab Interactions beneath Sulawesi Island, Indonesia, from Enhanced Three-Dimensional Vp, Vs, and Vp/Vs Tomographic Models

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Abstract

Sulawesi, located at the triple junction of the Philippine Sea Plate, Eurasian Plate, and Indo-Australian Plate, is one of the most tectonically complex regions in Southeast Asia, characterized by active subduction, arc volcanism, and frequent large earthquakes. The recent expansion of the seismic network by BMKG, which tripled the number of stations, has enabled the acquisition of higher-density seismic data and improved subsurface imaging. In this study, we construct a minimum 1-D velocity model using 1,788 well-located earthquakes, incorporating 17,365 P-wave and 6,787 S-wave arrival times to improve hypocenter locations and reduce travel-time residuals. This model is used as the initial model for a 3-D travel-time tomography inversion based on an expanded dataset of 15,060 earthquakes recorded by 144 stations, simultaneously resolving Vp, Vs, and Vp/Vs structures. The resulting tomographic model provides updated images of subsurface structure beneath Sulawesi. A high Vp/Vs anomaly beneath Gorontalo Bay may indicate a magmatic source associated with an isolated volcanic system and could be related to a southward subduction of Celebes Sea. In addition, the model improves the imaging of the northward subduction geometry, showing variation in depth and subduction angle. These results refine the tectonic interpretations of the Sulawesi region by providing new constraints on subduction geometry and its relationship to volcanic processes. The improved velocity model may also support regional earthquake monitoring and future seismic hazard assessments.

General Poster GP110

Aftershock Forecasting Performance of the ETAS Model for $M_L \geq 6.0$ Earthquakes in Taiwan

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Abstract

Operational earthquake forecasting provides time-dependent estimates of earthquake occurrence and plays an important role in seismic hazard mitigation. This study evaluates the performance of the Epidemic-Type Aftershock Sequence (ETAS) model for forecasting seismicity in Taiwan using both case studies and long-term regional analysis. An earthquake catalog from 1973 to 2024 is used, from which 76 events with ML ≥ 6.0 between 1999 and 2024 are selected. Model parameters are estimated using maximum likelihood methods, and forecasting performance is evaluated using Molchan diagrams.

The 1999 Chi-Chi earthquake sequence is analyzed within a simulated real-time framework to examine the temporal evolution of forecast skill. Results show that pre-mainshock forecasts are nearly random, whereas performance improves significantly after the mainshock and increases as aftershock data are incorporated. The spatial distribution of seismicity rapidly evolves into fault-aligned structures within one hour. Larger aftershocks also exhibit higher predictability than smaller events.

Extending the analysis to all ML ≥ 6.0 earthquakes in Taiwan shows that the ETAS model performs well for events associated with preceding seismic activity but has limited capability in forecasting isolated mainshocks without foreshock sequences.

These results demonstrate that the ETAS model provides reliable and rapidly adaptive forecasts of aftershock spatial distributions and may help identify potential mainshock locations in highly active regions. The findings highlight its potential for real-time seismic hazard assessment in tectonically complex regions.

Long-Term Earthquake Probabilistic Assessment and Rupture Scenarios in Southwestern Taiwan: Implications from Multi-Cycle RSQSim Simulations

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Abstract

This study investigates the long-term seismic cycle dynamics and rupture characteristics of the complex fault system in the Chianan Plain, a complex foreland basin geological setting in southwestern Taiwan. Applying the physics-based earthquake simulator RSQSim, we constructed a local networking fault geometry model integrated with rate-and-state friction formulations. Our simulation, taking over 200k years, generated a robust catalog of 2.96 million synthetic events (M_w 3–7). The results reveal significant spatiotemporal clustering and irregular recurrence intervals in each fault, challenging the conventional periodic earthquake model. High variability in inter-event times underscores the dominant role of Coulomb stress transfer and complex fault interactions in earthquake triggering within this region. These findings not only refine seismic hazard assessments for the onland region but also provide a mechanical framework for understanding heterogeneous subduction interfaces. Specifically, the observed clustering and stress-driven triggering mechanisms offer a direct correlate for interpreting microseismicity associated with seamount subduction in the Hyuga-nada region, Japan, where geometric asperities similarly modulate stress loading and fluid-mediated fault slip.

Keyword: RSQSim, Seismic cycle, Chianan Plain, Recurrence intervals, Seamount subduction.

General Poster GP112

Development of IESOBS Web Service Platform

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Abstract

Since 2000, the Institute of Earth Sciences, Academia Sinica, has initiated the planning of the broadband ocean-bottom seismometer program (IESOBS) to overcome the limitations of land-based observations and to advance the understanding of subsurface structures and geodynamic processes in the regions surrounding Taiwan. In 2005, the IES collaborated with the Woods Hole Oceanographic Institution (WHOI) in the deployment of ocean-bottom seismometers, while simultaneously establishing its first broadband ocean-bottom seismometer array. This was followed in 2006 by the Institute's inaugural ocean-bottom seismometer experiment, which successfully yielded observational data the following year.

To comprehensively showcase the experience and achievements accumulated over the past two decades in marine seismological observation, we have reconstructed the dedicated IESOBS laboratory website. Beyond presenting the background and development of the project and its instrumentation, the website highlights the practical expertise and scientific contributions gained through 20 years of sustained effort, including observational datasets and published research. Through this online platform, we aim to broaden public awareness of Taiwan's past and present endeavors in broadband ocean-bottom seismic observation and to foster engagement in future innovative research under IESOBS. The website is accessible at:
https://iesobs.earth.sinica.edu.tw

General Poster GP113

導入多智能體系統（Multi-Agent System）之智慧化地震測報架構：以 Earthworm 與 SeisComp 為基礎之應用與成效評估

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摘　要

地震測報業務對於國家防災減災與早期預警至關重要。目前，Earthworm 與 SeisComp 為全球廣泛使用之開源地震監測軟體。然而，面對高密度地震觀測網與極端震波事件（如主震後之密集餘震序列），傳統集中式、單執行緒且依賴靜態參數的處理架構，常因瞬間暴增的資料量引發系統運算瓶頸；並在面對複雜訊號時，遭遇震波交錯重疊而導致漏報與誤報的解析難題。此外，繁瑣的模組參數調校高度仰賴專家經驗，難以維持全天候的最佳即時測報效能。

為突破單點處理與靜態參數之限制，本研究提出一種基於多智能體系統（Multi-Agent System, MAS）的新型地震監測架構。在技術實作上，本研究全面導入 Ringserver 作為核心通訊樞紐，取代傳統依賴底層共享記憶體的緊密耦合設計。各式傳統測報模組與新建置的 AI 代理得以進行非同步、鬆散耦合的資料串流與訊息交換。

本架構將複雜的測報任務解耦為五大特化專家代理群進行分散式協同合作：首先由「資料品質代理」即時過濾觀測雜訊並賦予動態權重；接著「震相拾取代理」依據權重自動略過劣質測站，平行執行 AI 模型以精準萃取震波特徵；隨後「關聯定位代理」彙整全局資訊，透過分群演算法從重疊波形中分離出獨立地震事件。於此同時，背景運行的「參數最佳化代理」持續追蹤定位品質，並根據當下環境雜訊自適應（Adaptive）微調前端代理之觸發閾值，實現自動化的閉環控制；最終由「系統運維代理」進行全局資源監控與負載平衡，確保高可用性。

研究結果顯示，導入 MAS 架構的地震監測系統展現出顯著優勢。專業分工的代理機制成功解決了傳統系統在複雜地震序列中難以即時分離事件的難題，並大幅降低了人工調參的延遲與作業負擔。本研究證明，基於 Ringserver 的通訊設計不僅提升了系統的跨平台擴充能力，更賦予了傳統測報軟體自我演化與修復的能力，為次世代高強健性之智慧化地震測報基礎設施提供了具體的解決方案。

General Poster GP114

Nonlinear Structural Response of a High-Rise Building: Insights from Multi-Sensor SHM during the 2025 Dapu Earthquake Sequence

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Abstract

This study investigates the dynamic characteristics of a high-rise building at National Cheng Kung University (NCKU) using an integrated Structural Health Monitoring (SHM) system during the 2025 Dapu earthquake sequence. By analyzing seismic data from multi-floor accelerometer arrays, a 12th-floor horizontal array, and rotational measurements from a rotational seismometer (R-1) and array-derived rotation (ADR), this research evaluates the coupled translational-rotational behavior of the structure. Observations demonstrate significant floor amplification and spatially non-uniform responses. Spatial variations in seismic waveform amplitudes across floors and localized sensors provide evidence of non-rigid structural behavior, indicating limitations of rigid-floor assumptions. Comparative analysis between R-1 and ADR reveals localized deformations and non-uniform motions, confirming structural complexity. Spectral analysis shows dominant frequencies remain relatively stable across floors, while spectral amplitudes and directional properties vary significantly, with stronger heterogeneity along the building's short-axis. A coupling mechanism among translational motion, rotational response, and base tilting can be identified by incorporating tiltmeter data. These findings indicate the building's seismic responses cannot be fully described by linear elastic or rigid-body models. The integration of multi-sensor SHM data is essential for characterizing nonlinear and non-rigid dynamics of high-rise structures, with implications for improving seismic safety assessments and structural health diagnostics for future large-scale events.

Keywords: Structural Health Monitoring (SHM), Seismic Response, Rotational Motion, Translational–Rotational Coupling, Nonlinear Dynamics.

使用 ANSYS 軟體模擬爆破延遲時間對振動之影響

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摘　要

本研究以 ANSYS Mechanical 有限元素軟體建立單層鋼筋混凝土建築與周圍地質介質之三維模型，探討爆破延遲時間對結構振動反應之影響。爆破振動輸入係依現地量測之粒子振動速度歷時波譜產製人工爆破波形，並調整尖峰粒子速度（PPV）、振動頻率及延遲時間，施加於建物基礎底部進行瞬態動力分析，以模擬不同爆破設計條件下建築物之受振行為。研究聚焦於實務常用之毫秒級延遲設計，單排孔間延遲設定自 0 ms 至約 70 ms，並選取約 15 ms、30 ms、40 ms 與 67 ms 等代表性條件進行分析；排間延遲則設定約 30–110 ms，以評估震波於時間軸上之疊加與抵銷效應。結果顯示，當孔間延遲過短、接近同時起爆時，各孔振動波高度重疊，使監測點 PPV 與樑柱最大剪應力明顯放大，局部反應接近結構材料設計抗剪強度，安全性較為不利；相對地，當孔間延遲調整至約 25–30 ms 及 60–70 ms 區間時，振動波峰與波谷可於時間上錯開，振動能量較為分散，PPV 與剪應力反應均明顯下降，其中單排延遲約 29 ms 與 67 ms，以及雙排延遲組合中孔間約 29 ms 搭配排間約 52 ms，皆呈現較佳減振效果。此外，頻率響應分析顯示，約 33.9 Hz 時建築物剪應力與總位移均達最大值，顯示該頻率接近結構自然頻率，易產生共振放大效應。整體而言，爆破延遲時間不僅為施工設計參數，更是影響建築物受振安全之重要控制因子；透過數值模擬可提供具體延遲時間設計建議，作為現地爆破減振與結構保護之參考。

【學生壁報比賽】參與者於摘要尾端註記

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Enhanced Small Earthquake Detection with Deep-Learning Scheme for Structural Potential Characterization and Source Parameter Analysis in Northern Hualien, Taiwan

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ABSTRACT

Northern Hualien, Taiwan, lies at the collision boundary between the Eurasian and Philippine Sea plates and is characterized by complex tectonics and high seismicity (M1−M8; focal depths from near surface to ~150 km). To address limitations in seismic monitoring caused by Central Weather Administration (CWA) station coverage, this study was deployed an additional seismic observation system near Heping Village in 2020. The system comprising a 100-m-deep borehole seismometer, a surface strong-motion accelerograph, and a velocity seismometer. Integration of the borehole seismometer with CWA stations forms a seismic array that enhances detection of small earthquakes.

To cope with the increasing volume of seismic data and enable efficient event detection, this study uses manual analysis and a deep-learning-based approach. Between October 2022 and December 2023, 10,826 events were manually identified, including 496 events previously unlisted in the CWA catalog, which clustered north of the seismic array. Applied to 2024 continuous seismic data, the deep-learning-based RED-PAN detected 72,704 events, largely driven by the 3 April Hualien earthquake, improving phase picking and event identification. Further evaluation of the RED-PAN results, after removing false detections through manual inspection, yielded an updated precision of 83.4%. Overall, the RED-PAN model detected approximately 1.3 times more events than manual analysis. Source parameters were estimated using spectral fitting with the ω^{-2} source model, revealing no significant correlation between stress drop and seismic moment for events of M0−3, suggesting self-similar behavior.

Keywords:
Microearthquake, Borehole seismometer, Earthquake source parameters, RED-PAN model

General Poster GP117

The Influence of Foreshock “Swarm-Like” Activity on Aftershocks Behavior in Multi Region : A Comparative Analysis

群震型前震活動對餘震行為之影響:全球尺度比較分析

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Abstract

Foreshock sequences usually exhibit "swarm-like" behavior, characterized by small-magnitude earthquakes that occur close in space and time before the mainshock. Whether such swarm-like foreshock activity influences aftershock behavior remains unclear. In this study, we analyze 102 earthquake sequences with mainshock magnitudes larger than 5 from various tectonic settings in Taiwan, New Zealand, California, Japan and Greece to evaluate the relationship between foreshock and aftershock. Using the statistical ETAS (Ogata, 1988) and modified ETAS (Aso and Terai, 2023) models, we compare aftershock productivity and decay parameters from sequences with and without foreshocks.

Our results reveal that aftershock sequences preceded by foreshocks are characterized by shorter aftershock duration, higher aftershock productivity (*K-value*), and a larger *p-value*. These features are observed across various faulting types. Furthermore, we find that background seismicity and interseismic slip-rate also modulate the variations in both *K* and *p-values*. These findings suggest that foreshock activity may reflect underlying physical processes such as cascading triggering or aseismic slip that influence the evolution of the following aftershock behavior. We argued that integrating foreshock activity could improve the aftershock forecasts and enhance seismic hazard assessments following large earthquakes.

Keywords: *Foreshock, Aftershock Duration, K-value, Seismicity Patterns, ETAS.*

General Poster GP118

嘉南地區即時地震網整合與觀測

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摘　要

嘉南地區曾發生多次淺源地震，如1906年梅山地震、1941年中埔地震、1946年新化地震及1964年白河地震，均列入臺灣百年十大災害歷史地震。此外，還有1998年瑞里、1999年嘉義及2010年甲仙等中小規模災害地震。近年來，嘉南地區地震活動趨於頻繁，發生多起有感地震序列，包括新港-民雄、朴子-太保、布袋-義竹、中埔、麻豆-佳里及大埔-楠西等。顯示不僅西部麓山帶為地震活動熱區，西部平原也有增加趨勢。根據經濟部地礦中心2021年修正版活動斷層分布圖，現已不再區分第一類與第二類活動斷層。嘉南地區有複雜的地質構造，包含梅山、大尖山、觸口、六甲、新化、九芎坑、木屐寮、口宵里、後甲里及左鎮等活動斷層，涵蓋逆衝、橫移及潛伏於平原下的盲斷層。由於不同斷層類型的地表破裂與災害分布差異顯著，需進一步評估每條斷層的活動程度與關聯性，以防範更嚴重的災情發生。

為增進對嘉南地區即時地震活動的掌握，針對觀測網包覆不足的地方，設置10個短周期地震站，裝設即時傳輸設備並採用太陽能供電。為強化觀測量能，自2024年3月起陸續整合中研院地球科學所18個寬頻站，及中正大學地環系於西南部的10個寬頻站，在2025年7月更加入中央氣象署在嘉義縣、市與臺南市的116個TSMIP測站。運用SeisComP軟體，進行即時資料接收、交換與地震定位等分析工作。透過整合成更密集的地震觀測網，掌握地震時空分布，提供斷層參數以評估潛勢。2025年偵測超過2,500個地震事件，以1月21日大埔-楠西地震序列為主，主震位於序列中央且震源深度最深。另外在雲林古坑與嘉義番路，及臺南六甲、麻豆等地，也觀察到地震群集現象。依據古登堡-芮克特定律，分析嘉南地區的規模與頻率關係，嘉南地區a值為4.06、b值為0.65，反映活動頻繁，也暗示該區處於高應力狀態，需特別重視潛在的強震威脅。

2025 年 M_W 7.7 緬甸地震破裂過程的能量分配
Energy Partitioning During the 2025 M_W 7.7 Myanmar Earthquake

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摘要

本研究嘗試將地震資料推導的震源參數與實驗室岩石剪力摩擦試驗的參數連結起來，用以探討 2025 年 M_W 7.7 緬甸地震破裂過程能量分配。透過破裂方向性分析和震源時間函數，此地震為超剪力破裂，其地震矩(M_0)為 3.5×10^{20} Nm，地震輻射能量(E_S)為 3.5×10^{15} Nm，上揚時間為 17.66 秒，靜應力降為 0.73 MPa，動應力降為 0.772 MPa。透過實驗室摩擦試驗得到的動應力降與正向應力的關係及 Byerlee's law，最終得到動摩擦應力為 5.01 MPa，換算得到摩擦熱(H)與破裂能(E_g)總合為 6.35×10^{16} Nm，最後應變能($W = H + E_g + E_S$)為 6.7×10^{16} Nm，至此，可以大致了解緬甸地震的破裂過程的能量分配。由靜應力降與 E_S 估算輻射效益(radiation efficiency)為 0.756，此高於一般地殼地震的數值，但符合超剪力地震破裂的特徵。由 W 和 E_S 得到地震效益(seismic efficiency)為 0.052，亦符合先前研究指出的地震效益上限(0.06)。另外，動應力降與靜應力降數值相近，顯示其破裂過程相當穩定，可忽略應力過衝(overshoot)現象。

關鍵詞：2025 年緬甸地震、上揚時間、震源輻射能量、靜應力降、動應力降、應變能、輻射效益、地震效益

Keywords: 2025 Myanmar earthquake, rise time, radiated seismic energy, static stress drop, dynamic stress drop, strain energy, radiation efficiency, seismic efficiency

General Poster GP120

臺灣山脈的隆升與侵蝕：來自山椒魚的啟發

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摘　要

臺灣山區存在五種山椒魚，皆為保育類動物。筆者利用既有山椒魚分布與分化歷史的研究(朱有田，2022；雪霸國家公園管理處成果報告書)，來探討臺灣山脈隆升與侵蝕的過程。已知山椒魚對棲地環境的要求很高(水源清澈、濕度足夠、與能躲藏的環境)，必須在地形相對穩定的條件下才能生存。回顧文獻，共計12處山椒魚發現區擁有地表堆積物絕對年代，皆落於數千至數萬年前；轉換成剝蝕速率< ~2 mm/yr。山椒魚不會游泳，只能循河川上游稜脊地帶遷移；該地帶劇烈的侵蝕勢必阻隔山椒魚族群的交流，最終造成分化。的確，作為不同種類山椒魚界線的稜脊皆崎嶇，以瘦(窄)稜為主，常見高度急遽變化的陡稜；雪山山脈主稜由兩千爬升至三千公尺的轉折正是觀霧與臺灣山椒魚的分界；類似主稜高度的變化在中央山脈北段(見晴至南湖)分隔了觀霧與南湖山椒魚，中段(關門至丹大)區分了楚南氏與阿里山山椒魚(兩大山脈之間，臺灣、南湖、與楚南氏的分化及爾後的共域則仍需考慮溪流因素)。以上地形特徵臺灣山區屢見不鮮，其存在也都能用來解釋各山椒魚次類群的分布。一般視山椒魚為冰河孑遺物種。然而，山椒魚在數百萬年前進駐臺灣後，已經歷數十次冰期、間冰期氣候循環而不滅，顯然該氣候變遷並非其衰微的主因。本研究認為，百萬年來侵蝕的加劇、山崩活動的增加(移除植被、破壞水質與地下水系統)，才是山椒魚的首要威脅。推論山椒魚族群在臺灣造山之初、丘陵廣布時達到鼎盛，之後隨著山脈加速隆升，山崩規模/頻率增加，棲地被嚴重切割而走向衰微。按既有的熱定年資料，此一地殼運動、地形變遷的轉折當發生於距今一、兩百萬年前。即早在此之前，臺灣山脈由北至南已大致隆出水面；山脈南端北大武山阿里山次類群的分化證實了這個論點(該次類群為阿里山山椒魚中最早分化出來者)。

（關鍵詞：山椒魚、地形阻隔、山崩、臺灣山脈隆升與侵蝕）

General Poster GP121

Advancing AI-Based Infiltration Modeling in the Zhuoshui River Basin: Integrating Green-Ampt Simulations with Fine-tuned RealMLP Architectures

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The Zhuoshui River Alluvial Fan (ZRAF) is a critical hydrological resource in Taiwan, yet escalating groundwater extraction reaching 1.344 billion m^3 in 2020 threatens its long-term sustainability. Accurately modeling groundwater recharge is essential for resource management, but infiltration data remains scarce. This study presents a novel workflow that addresses data limitations by integrating physics-based simulations with artificial intelligence. Using historical soil and infiltration data, we employed a least-squares algorithm to optimize parameters for the Green-Ampt infiltration model. This physics-based model generated a synthetic pre-training dataset, which was subsequently used to train RealMLP, a specialized multilayer perceptron for tabular data. To bridge the gap between simulation and reality, a subset of the 1992 ZRAF historical records was utilized to fine-tune the model, allowing it to adapt to local site-specific hydrological conditions. The model demonstrated robust predictive performance when validated against the 1992 ZRAF records, outperforming traditional benchmarks such as Random Forest (RF), XGBoost, and a standard MLP in a comparison conducted without fine-tuning. The model achieved an R2 of 0.7292, an RMSE of 0.0918, and a Kling-Gupta Efficiency (KGE) of 0.8217. Finally, the trained model will be deployed to predict future infiltration trends using climate projections from the Taiwan Climate Change Projection Information and Adaptation Knowledge Platform (TCCiP). The results demonstrate that pre-training AI models with physics-based simulations is an effective strategy that deals with the "small data" problem in hydrology, providing a reliable tool for groundwater modeling under data scarcity.

Keywords: Zhoushui River Alluvial Fan, Infiltration, Physics-Informed Machine Learning, Transfer Learning

General Poster GP122

整合影像辨識與深度神經網路建立裂隙岩體透水係數推估模式—以沉積岩為例

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摘　要

準確且具連續性透水係數是掌握場址水文地質特性之關鍵，但現行多僅能於鑽孔中少數試驗區段取得離散資料，進而限制場址評估精度。即使可增加試驗區段克服，仍受成本與效率所限而難以施行。而透水係數受到岩體中的裂隙幾何、連通性、孔隙率等多重因素控制。因此，本研究從此方面進行突破，透過蒐集臺灣山區裂隙岩體岩芯影像，建立岩芯特徵辨識模型以萃取與透水特性之相關特徵參數，並結合深度神經網路建構透水係數推估模式，提升推估效率。期能快速產製隨深度之連續透水係數，提供水力特性判釋、工程評估之量化依據。

本研究分為兩階段進行，第一階段首先蒐集臺灣山區高解析度沉積岩性鑽孔岩芯影像，作為影像辨識模型之資料集，而模型採用 U-NET 架構，並以 300 張影像，依 7:3 比例劃分為訓練與驗證集；評估方式則自未參與訓練之影像中選取 30 張作為測試集，並以像素準確率(PA)與平均交併比(MIoU)作為評估指標；第二階段則以影像模型萃取之特徵參數作為輸入變數，透水係數作為輸出變數，採用深度神經網路(DNN)架構建構透水係數推估模型。透過系統性調整隱藏層層數、節點數與激發函數，以尋找模型之最佳配置。評估方式則係計算平均絕對誤差(MAE)、均方誤差(MSE)等指標，據以進行綜合比較與分析。

研究結果顯示，影像辨識模型測試集 MIoU 可達 0.7 以上，顯示其辨識效能良好，而透水係數推估成果的部分，設置節點數為 80、層數 2 與激發函數 tanh 之組合下為最佳的推估透水係數模式，其測試集之 MAE、MSE 為 0.59 及 0.63，顯示推估成果良好，具備實務應用潛力。

本研究結合 U-Net 影像辨識架構與深度神經網路，建立臺灣山區裂隙岩體透水係數推估模式。影像辨識模型可有效萃取裂隙寬度與裂隙頻率等關鍵參數，提升透水係數推估精度與效率，亦補足傳統方法解析度不足之限制，然而影像模型仍易受拍攝色調差異與光影遮蔽等因素影響，導致岩石品質指標誤差偏大與進而影響透水係數推估結果，建議後續強化影像蒐集之標準化流程，以提升資料品質一致性與整體推估穩定性。

關鍵字:裂隙岩體辨識、深度學習、透水係數、水文地質

General Poster GP123

河川流量影像監測系統之建置與應用－以金崙溪為例

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摘　要

本研究旨在建置一套基於大尺度粒子影像測速技術（Large-Scale Particle Image Velocimetry, LSPIV）之河川水流監測系統，以獲取河川表面流速並進一步推估流量變化，並於台東縣金崙溪進行實地安裝與應用。該系統由低成本影像擷取與控制模組組成，布設於目標河段監測區後，可每小時自動拍攝 10 秒連續水流影像，影格率為 30 fps，以記錄河道水體流動變化。所拍攝影像經幾何校正後，結合 LSPIV 分析，以水面紋理作為追蹤特徵，估算觀測河段之表面流速場。另結合人工量測之河道剖面與影像判釋所得之水深資訊，可進一步利用速度－面積法推估流量。本研究針對 2026 年 3 月至 5 月期間拍攝之河道影像進行分析，比較 LSPIV 所估算之表面流速與現地實測流速，並檢核影像判釋水深與現地量測結果之一致性，以評估其應用於流量推估之可行性；同時探討流量估算之潛在誤差來源，作為提升監測系統穩定性與流速估算可靠性之依據。綜合不同水位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），並於洪水等劇烈水位變化期間進行即時流量推估，以補足傳統水文觀測方法之限制。本研究建置一套可於目標河段快速架設、具低成本與高可靠性之河川監測系統，適用於危險河段及偏遠地區之監測工作，並有助於蒐集山區河川水文資訊，提升洪水災害之觀測與應變能力。

關鍵字：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

General Poster GP124

新豐紅樹林濕地根圈沉積物中微塑膠與塑膠降解微生物之研究

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摘　要

摘要內容微塑膠（Microplastics, MPs）為粒徑小於5 mm之塑膠顆粒，已成為全球關注之環境污染問題。紅樹林濕地因具有高沉積與攔截能力，可能成為微塑膠的重要累積區。本研究以新竹新豐紅樹林濕地為研究區域，針對根圈沉積物進行微塑膠污染調查，並探討其微生物群落結構及潛在塑膠降解能力。

研究中採集0－10 cm表層沉積物，經前處理後進行微塑膠分離與分類，並利用ATR-FTIR鑑定聚合物種類，同時透過Illumina MiSeq定序分析微生物群落。結果顯示，所有樣點均檢測到微塑膠，平均濃度約為7600 MPs/kg，且不同紅樹林物種間未呈現顯著差異。主要聚合物以聚乙烯（PE）、聚丙烯（PP）與聚苯乙烯（PS）為主。

微生物群落分析顯示，Proteobacteria為優勢菌群，另包括Bacteroidota、Desulfobacterota與Patescibacteria等菌門，其中部分菌群可能具備塑膠降解潛力。研究結果顯示紅樹林根系結構有助於微塑膠沉積與累積，而微生物在塑膠自然降解過程中可能扮演重要角色。本研究提供紅樹林生態系中微塑膠污染與微生物互動之基礎資料，並為未來發展生物降解與AI辨識技術提供參考。

↑每一段落請空兩中文字元

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General Poster GP125

利用疏水性碳酸鈣油汙吸附試驗

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摘　要

近年來海洋環境時常出現大型船舶擱淺且發生溢油事件頻繁，其中擱淺船舶所裝載的油品若外洩至周遭水域，這將對於海洋與環境生態造成非常大的破壞。開發對海洋或是任何水體去除油污的新 材料與技術是不可或缺的。因此，本研究發展出一套非常快速且簡單的程序，在單一程序、單一反應槽以及室溫下，將天然碳酸鈣礦物改質成超疏水碳酸鈣，其產量達100%。此程序中，僅利用酸鹼間的控制，就能使疏水和親水比率(activeratio)高達98%。透過XRD儀器檢測，結果顯示改質碳酸鈣產物為方解石。超疏水碳酸鈣其水接觸角高達143.8度。超疏水碳酸鈣與泡棉再製後，碳酸鈣每克 油污吸附能力高達 18.5 克油污，與原始泡棉相比，再製後吸油效果成長1017%，再使用至 10 次回收後，還保有吸附能力。本研究結果大幅降低生產超疏水碳酸鈣的能量消耗與原料成本，此簡便的 生產方式，更有利於疏水性碳酸鈣發展，並開拓其在各類型工業之研發與應用。

【學生壁報比賽】參與者於摘要尾端註記

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General Poster GP126

應用地電阻影像監測法解析含水層之側向補注動態與非飽和帶水文遲滯行為

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摘　　要

精確掌握含水層的補注機制對於地下水資源評估至關重要。水文觀測井僅能提供點狀的壓力水頭數據，難以完整捕捉非飽和含水層的動態補注行為。本研究針對樺加沙颱風事件，整合地電阻影像監測法與降雨量、河川水位、地下水井水位等數據，探討礫石含水層在颱風事件下的水文響應與補注機制。

首先，本研究進行降雨量、河川水位與 3 處地下水位之時空變化分析。結果顯示，儘管颱風期間累積降雨量達 489 mm，地下水位的抬升主要受控於卑南溪約 4 m 的水位上漲。沿河川至內陸方向，復興井、康樂井及與豐田井的地下水位上升時間點分別落後河川水位起漲點，地下水位上升之時間與幅度呈現隨河川距離遞增而延遲與衰減。電阻率時空變化顯示，電阻率下降訊號起始於地表下 6 公尺深處，並由深至淺逐漸向地表擴張，而淺層地表並未出現顯著的連續垂直入滲訊號。此結果表明本颱風事件中在電阻率監測場址的地下水急漲原因並非由該區域降雨垂直入滲造成，而是由河川高水頭邊界的壓力梯度引起之側向補注。

進一步針對電阻率變化重心深度與復興井水位的連動性進行定量評估，電阻率變化重心深度反映非飽和帶實際孔隙水份的填充情形，地下水位則代表含水層的壓力水頭，互相關分析結果顯示兩者具高度相關性，最大相關係數達 0.75，且電阻率變化普遍延遲於水位，互相關函數峰值對應之時間延遲為 5.1 小時。將兩者時序關係作圖，呈現出遲滯迴圈現象。本研究針對遲滯動態響應的物理詮釋為：在水位上升階段，壓力水頭的傳遞快於實質的孔隙水的填充速度，導致電阻率延遲於水位；而在水位下降階段，孔隙水受毛細現象滯留於非飽和帶，使電阻率重心的下降同樣落後於水位恢復。

本研究結果顯示，地電阻影像監測法作為面狀地球物理監測工具，能有效區分側向補注與垂直入滲，並捕捉非飽和帶孔隙水填充的時空動態，彌補單點壓力水位觀測在空間解析上的不足，上述觀測所揭示之遲滯特性與非飽和帶水分動態，可進一步用於約束含水層水力傳導係數與土壤保水能力等參數的定量推估。

General Poster GP127

屏東平原東南側第四系地層層序與水文地質架構

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摘　要

在屏東平原東南側東港溪與林邊溪下游流域的上部第四系中，目前劃分三套富水層與阻水層，大致對應上次冰盛期與全新世間冰期的海退與海進過程，與期間的重要海平面升降事件。海退/海平面下降時，上扇礫石堆積向下發散形成富水層；海進/海平面上升時，下扇與近海泥質堆積向上淹漫形成阻水層。然而，這些富水層與阻水層經常切過不同粒度的岩層，而且年代與指準層稀缺，因此水文地質分層與對比尚有疑義。本調查利用新鑽取的地礦中心與國科會岩心，進行岩相與層序地層分析，以獲得精確度更高的對比剖面，作為強化水文地質架構的基礎。

本區岩心的岩相特徵變異大，易辨識、統整為 5 礫石、3 砂層與 3 泥層相，並組成 6 沉積相：扇頂土石暴洪堆積部相泥礫夾砂層、扇央辮狀河平原相礫砂層夾泥層、扇尾河道氾濫湖沼平原砂泥相、三角洲平原半封閉海灣分枝河道相泥夾砂層、三角洲前部障蔽島入潮水道與瀉湖砂夾泥層、與三角洲前緣遠濱相泥夾砂層。各井岩心大多分出 2 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、沖積扇與三角洲平原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，堆積作用重新啟動。爾後出現的是沈積相更深、顆粒度更細的三角洲前部與前緣遠濱泥砂層，代表海平面大幅回升，海岸線入侵屏東平原東南側。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。

層序一底部與層序二上部行程幾乎連續的巨厚礫石層，分布幾乎遍及全區，是最佳富水層。層序一上部是砂礫夾泥層，也是廣布全區的次佳富水層。蹭序一中段高水位堆積層是分布最廣的厚泥層－阻水層；其下則有犬牙交錯的砂層與泥層，富水與阻水特性不顯著，分佈也相當受限。

中文關鍵字：屏東平原、上部第四系、岩相、層序地層、水文地質架構

General Poster GP128

以正矩陣因子分析解析桃園地區河川污染來源結構

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摘　要

桃園為臺灣重要工業發展之重鎮，隨著都市化與產業活動，河川水體承受來自生活污水、工業廢水等多重污染來源之影響。傳統水質評估多以單一指標或綜合水質指數進行判斷，雖可反映整體水質狀況，卻較難進一步解析不同污染來源之貢獻比例，亦不易釐清污染來源結構，而正矩陣因子分析(Positive Matrix Factorization ,PMF)為一種常用之受體模式，可透過多變量統計方法將監測數據分解為污染來源特徵與貢獻比例，進一步解析各污染來源對水質之影響。

為了解桃園地區河川水質污染來源結構，蒐集了 2020 至 2024 年桃園地區河川水質監測資料，並選取氨氮(NH_3-N)、銅及生化需氧量(BOD)等具代表性之水質指標進行分析，利用PMF進行污染來源解析。

研究結果顯示，桃園地區河川污染來源可分為四類主要因子，分別代表生活污染源、工業污染源、農業污染源及自然背景來源。不同污染來源對水質指標呈現不同程度之影響，其中氨氮與生化需氧量主要反映生活污水特徵，而銅濃度則與工業活動相關。PMF 模式可有效解析環境中不同來源之貢獻情形，提供桃園地區河川水質污染結構之資訊，並可作為未來水環境管理策略之參考依據。

關鍵字:正矩陣因子分析、桃園、河川水水質

General Poster GP129

資訊價值與轉移熵導向下多概念場址模式與貝氏方法整合之地下水污染監測井網最佳化

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摘　　要

地下水污染物於含水層中的傳輸受地層結構與地下水流場影響，具高度不確定性，傳統監測井網設計多依賴單一概念場址模式，難以同時反映地層異質性與模式不確定性。本研究以方法論發展為目的，建立一套整合多概念場址模式與貝氏推論之監測井網最佳化框架，並透過假設之真實模式進行驗證。

研究中建立三組地質概念場址模式，利用 FEFLOW 模擬污染物傳輸行為。各模式參數透過馬可夫鏈蒙地卡羅法 (Markov Chain Monte Carlo, MCMC) 抽樣，並以有效樣本數 (Effective Sample Size, ESS) 與 Geweke z-score 檢驗收斂性，確保後驗推論之可靠性。進一步依觀測資料計算概似函數，透過貝氏模式平均法 (Bayesian Model Averaging, BMA) 估算各概念模式之後驗權重，以辨識較接近真實模式之模式。

多模式整合後，將各位置濃度之後驗分布轉換為貝氏最大熵法 (Bayesian Maximum Entropy, BME) 所需之軟資料，並結合真實模式於既有觀測井之濃度資料（硬資料）進行空間推估，以獲得污染濃度之期望值與誤差變異。進一步以資訊價值 (Value of Information, VOI) 與轉移資訊熵 (Transinformation Entropy, TE) 量化候選井位之資訊貢獻，並納入建井成本建立多目標函數，透過非支配排序基因演算法 (Nondominated Sorting Genetic Algorithm II, NSGA-II) 搜尋解集合，並利用偏好排序組織法 (Preference Ranking Organization METHod for Enrichment Evaluation, PROMETHEE) 進行排序與決策分析。

此外，本研究設計不同決策篩選情境，分別強調成本、 VOI 與 TE 之權重，結果顯示不同情境下所選擇之監測井配置具有顯著差異，顯示本方法可提供決策者具彈性之配置策略。整體而言，本研究方法能有效整合模式與空間不確定性，並提升地下水污染監測井網設計之決策支援能力。

關鍵詞：貝氏模式平均法、貝氏最大熵法、地下水污染監測、監測井網最佳化、資訊價值

應用時序卷積網路（TCN）框架於地下水位之補遺：以濁水溪沖積扇為例

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摘　要

在地下水資源管理與地層下陷防治工作中，準確且連續的長期地下水位監測數據是不可或缺的科學基礎，然而，受限於感測器故障或傳輸問題等現實因素，原始地下水位數據常伴隨著數據缺失、異常監測數據等問題，原始地下水位數據在進行異常值清理過後，這些數據空缺若未經適當補遺，將會影響水文數值模型的預測精度，並增加地下水位預測模型的不確定性，進而影響地下水資源管理與地層下陷防治策略的制定。

為解決地下水位數據空缺以及不連續的問題，本研究應用時序卷積網路（Temporal Convolutional Network, TCN）架構進行地下水位的數據補遺，該模型核心採用的因果卷積（Causal convolutions）能確保時間序列的邏輯一致性，並透過擴張卷積（Dilated convolutions）大幅擴張感受野（Receptive field），從而精確地捕捉地下水位資料中長期且複雜的季節性變動特徵，此外，TCN 具備優異的並行運算能力，在處理大尺度區域站點的大量歷史數據訓練上極具效率。本研究透過TCN模型模擬地下水位的變動規律，進而對缺失時段進行高精度的時序重建，並提供一套自動化的地下水位補遺工具，協助研究人員取得高品質的連續觀測資料，進而提升區域水資源模擬及分析的科學可靠性。

關鍵字： 地下水位補遺、時序卷積網路（TCN）、濁水溪沖積扇。

General Poster GP131

利用二維時間序列地表變形資訊描繪濁水溪沖積扇的地層下陷機制

Characterizing Land Subsidence Mechanisms in the Chuoshui River Fluvial Plain from 2D Time-Series Surface Deformation Data

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摘　要

台灣中部的濁水溪沖積扇在過去50年來一直受到地層下陷之困擾，許多大地測量技術已經成功監測該地區的地表位移與特性，但在垂直方向的高時空解析度地表形變資訊仍顯不足 。有鑒於Sentinel-1衛星具備高觀測頻率和中尺度的空間解析度，本研究應用永久散射體差分干涉技術(PSI)，分析2016年至2021年Sentinel-1雷達衛星影像，獲得濁水溪沖積扇升、降軌道的視線方向(LOS)位移資訊。接著在時空上進行資料補遺和同步，建構出相同時間點和相同位置上都有升降軌道的LOS數值，並解算出二維(東西方向和垂直方向)的時間序列位移量。初步成果顯示濁水溪沖積扇的時間序列垂直地表位移，具有顯著的季節性週期變化，在彰化縣有20-30公分的下陷總量，而雲林縣的下陷總量則可達40公分。透過分群演算法（k-mean）分析垂直方向的時間序列位移資料，可將研究區域內地層下陷的行為分群為嚴重下陷、中度下陷、輕度下陷和穩定狀態四類。嚴重區域位在雲林縣的元長和土庫；中度區域分佈在雲林縣下陷中心的四周和彰化縣的溪州、溪湖和二林；輕度區域分佈在彰化縣的沿岸地區以及靠近西部麓山帶的平原區；穩定區域位在西部麓山帶。未來將針對地表垂直位移資訊進行訊號分解之工作，獲得各地下水井位置的長期和短期位移訊號，並與其地下水水位和地質材料進行比對與探討，推估地下水的水力參數與建構地層下陷之機制，協助地下水水資源管理和地層下陷災害防治。

關鍵詞：地層下陷、二維時間序列地表變形、永久散射體差分干涉技術、K-mean分群、訊號分解

Keyword：Land subsidence, 2D time-series surface deformation, Persistent Scatterer InSAR, K-mean clustering, Signal decomposition

General Poster GP132

Integrated Multi-Source Signal Detection and Classification for Submarine Fiber-Optic DAS

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Abstract

Distributed Acoustic Sensing (DAS) applied to submarine telecommunication fiber-optic cables enables dense spatial sampling and continuous monitoring of offshore dynamic signals. However, DAS data are complex and contain mixed sources, including earthquakes, volcanic activity, vessel movements, and environmental noise, making reliable identification challenging. This study proposes an integrated workflow for automated multi-source signal analysis. Candidate signals are first detected from DAS time-series using the Short-Term Average over Long-Term Average (STA/LTA) method to suppress background noise. Spatially coherent features are then identified in the time–channel domain, and Density-Based Spatial Clustering of Applications with Noise (DBSCAN) is applied to cluster propagating energy patterns in noisy, high-dimensional data. Cluster characteristics, including spatial extent, temporal persistence, and energy distribution, are used for preliminary classification. The clustered events are then converted into waterfall plot images and labeled by signal type. These labeled images are used to train a Convolutional Neural Network (CNN) for automated image-based classification, improving robustness and reducing manual effort. Fourier transform analysis provides additional spectral features as supplementary evidence. Applications to real submarine DAS data demonstrate that the workflow can robustly detect physically consistent events and achieve stable classification performance, offering an interpretable and extensible framework for multi-source DAS signal analysis. This workflow highlights the potential of DAS for monitoring offshore geophysical and environmental phenomena.

General Poster GP133

環境溫度波動對分散式聲波感測（DAS）觀測資料品質之影響：以 MiDAS 為例

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摘　要

分散式聲波感測（Distributed Acoustic Sensing, DAS）已廣泛應用於地震監測、工程監測等領域，並展現出許多令人振奮的成果。其高空間解析度的觀測特性使研究者得以捕捉傳統地震儀難以觀測的訊號。然而，儘管 DAS 具有多項優勢，相較於傳統地震儀，其主要量測量仍以光纖軸向應變為主，存在一定限制。除此之外，近期研究亦發現，環境溫度波動會對 DAS 的觀測資料品質造成顯著影響，尤其在低能量訊號與環境噪訊分析中更為明顯，可能導致訊雜比下降，進而影響訊號辨識與資料判讀。

本研究以花蓮 MiDAS 場址為例，探討 DAS 所在環境溫度波動對觀測資料品質的影響，並透過訊號振幅、能量強度與頻譜特徵等指標，評估溫度變化與資料品質之間的關聯。研究結果顯示，低頻振幅變動與環境溫度變化具有一致的週期性，且兩者呈現負相關；此外，當低頻波動發生時，整體頻段的背景雜訊亦會隨之改變，不同通道所受到的干擾程度並不相同，顯示溫度效應對 DAS 資料的影響具有空間差異性，增加後續資料解釋上的不確定性。整體而言，本研究結果指出，環境溫度會是 DAS 系統觀測品質需要考量的因素之一，在儀器佈設時應審慎考量觀測環境的溫度穩定性；深入理解溫度影響的效應，對於正確分析與詮釋 DAS資料至關重要。

General Poster GP134

利用MiDAS井下監測系統偵測極淺層地震

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摘　要

岩體於地底下受應力累積，透過瞬間破裂產生破裂面或使既有斷層面導致滑動以釋放地震能量，皆為常見天然地震之發震機制。而淺層岩體因受限於較低的正向應力，使得自然界中不易出現極淺層地震。根據目前已發表之研究顯示，極淺層地震相當罕見，且其震源深度通常為數百公尺。然而，本研究透過米崙斷層鑽井研究計畫（Milun Fault Drilling and All-inclusive Sensing project，簡稱 MiDAS 計畫）之地震監測系統，辨識出數十個震源深度小於 50 公尺的極淺層地震（ultra-shallow earthquakes）。該監測系統整合了傳統地震儀與分散式聲波感測技術（Distributed Acoustic Sensing，簡稱 DAS）之陣列，並部署在井中與地表。儘管這些地震之規模極小，但分析其震源特性及其與米崙斷層之關聯，有助於揭露傳統觀測中難以捕捉的淺層地震活動特徵，提供罕見且獨特的重要資料。本研究針對震源特性的進行分析，結果顯示共有 75 個地震事件發生於 0–50 公尺深度範圍內，震源距離 MDSB1 井下地震儀(85 公尺深)70–120 公尺。其主要頻率約為 160 Hz，規模（M）則透過振幅初步推估約為 M ~ -2（奈米級地震）。而根據定位結果，此群事件之震源主要分布於 MiDAS 井 B 附近之大排水溝下方，顯示其空間分佈與流體活動呈現一定相關性。另外，該排水系統之水流方向與米崙斷層走向平行。

本研究之結果揭示了具有非常規震源特性的極淺層地震之存在，並強調高解析度的近地表監測對於理解此類極淺層地震之發震過程的重要性，未來將持續探討此類非常淺之奈米級地震的震源特性，及可能對人類生活圈產生的影響。

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分散式聲學感測應用於被動式MASW探勘：都會區實例研究

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摘　要

分散式聲學感測(Distributed Acoustic Sensing, DAS)技術近年來在地球物理探勘領域受到廣泛關注，其透過普通光纖纜線即可實現高密度、長距離的連續震動監測，具備傳統地震儀陣列難以企及的部署彈性。本研究於柏油路旁人行道布設一條全長200公尺之光纖纜線，僅以膠帶全面貼附固定，連續記錄環境震動訊號達兩小時，並以高鐵行駛與道路車輛所產生之背景噪聲作為被動震源。

所獲取之噪聲資料採用被動式多頻道表面波分析法(Multichannel Analysis of Surface Waves, MASW)進行分析，頻散分析結果顯示可穩定獲取頻率3~20 Hz、相速度介於200~400 m/s之頻散曲線，並成功反演獲得沿測線之二維剪力波速度剖面，解算深度可達35公尺。結果顯示，速度構造與鄰近地區既有工程地質鑽孔紀錄吻合良好，可清楚辨識工程岩盤頂面位於深度約27公尺處，驗證本方法之可靠性。

本研究成果證實，以DAS結合被動式MASW進行淺層地下構造調查，在工程地質探勘上具有高度實用潛力。此方法毋須主動震源、部署迅速且對環境擾動極低，適合應用於道路、邊坡及重要基礎設施之地盤特性評估，為高密度開發環境下的工程地質探勘提供兼具效率、安全與經濟效益之新途徑。

岩石粉碎化調查：自然斷層與岩石三軸試驗

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摘　要

斷層帶中的岩石可作為重建斷層活動過程的重要依據，其中某些呈粉碎狀的斷層岩石，與一般由剪切滑移所形成的斷層泥或碎裂岩，在組織與成因上皆有所不同。此類岩石常被認為反映較劇烈的斷層作用，可能涉及地震事件中的動態載荷效應，以及破裂傳播過程所造成的高應變率變形。本研究利用 MiDAS 取得之斷層帶岩心，辨識出一段具明顯粉碎特徵的斷層岩石，並結合岩象觀察、X光繞射、同步輻射 X 光繞射與勞氏繞射等方法，探討其礦物組成與微觀變形特徵。同時，另以合成石英為材料，在單壓及 5 MPa 圍壓條件下進行三軸破壞實驗，並於試體破裂後觀察其微構造，以作為天然樣品之對照。研究結果顯示，該粉碎狀斷層岩石內部發育大量且廣泛分布的微米級裂隙。此類無內聚力的粉碎物質主要由石英組成，未見明顯剪切組構，也缺乏非晶質物質。勞氏繞射分析進一步指出，與斷層帶內其他岩石及鄰近圍岩相比，該粉碎狀石英具有顯著較高的殘餘應力。比對天然斷層岩石與實驗試體後可知，兩者微構造並不相同，顯示此類粉碎狀石英並非單純由靜態壓縮所造成。此外，本研究亦逐步檢驗其他可能成因，包括熱應力破裂與剪切磨細作用，結果皆不足以完整解釋其特徵。綜合觀察與分析結果，推論此一粉碎岩石應與近期強烈斷層活動有關。

中文關鍵詞：斷層岩石、粉碎、斷層作用

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

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Abstract

The method of potential large-scale landslide classification and grading were design by two kinds of forms, 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, 5 potential large-scale landslide sites in Hualien, eastern Taiwan. The Level 1 form evaluation results showed that the sites in the Wuhe and Chimei were classified as the highest activity level Grade B. The other 3 sites of Antong Village, Mt. Antong and Chuole were classified as lower activity Grade C.

The two Grade B cases with high activity were continues analyzed to Level 2 form scoring. The results showed that the sites in Wuhe were classified as high activity, the other sites in Chimei 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, Eastern Taiwan

0403 花蓮地震暨其後兩場豪雨誘發山崩特性分析

Analysis of Landslide Characteristics Triggered by the April 3 Hualien Earthquake and Two Subsequent Heavy Rainfall Events

李錫堤　張瓊文　許晉瑋　謝有忠

強震除了誘發大量的山崩之外，坡面上大範圍的崩塌裸露及崩積土石，則為後續土砂災害鍊提供了盛大的開場。裸露而脆弱的坡面受到降雨沖刷，將有持續刷深及崩塌範圍擴大的機會；不安定的崩積土砂受到降雨沖刷，漸次進入河道系統，則可能造成土石流或河道沖淤的情形。本研究藉由詳細解析 2024 年 4 月 3 日花蓮地震及其後同年內凱米及康芮兩次颱風豪雨事件之山崩目錄，希望能更清楚掌握強震事件後降雨誘發山崩的特性。

本研究以 0403 花蓮地震之強震區為研究區，約為最大地動加速度 250gal 以上地區，北起宜蘭土場，南至花蓮木瓜溪流域。為取得分析用之山崩目錄，並確保山崩判釋及數化品質，各事件山崩目錄以人工判釋高解析衛星影像，並進行數化及詳細檢核。一般研究常見以事件後所判釋的山崩目錄均當成該事件所影響，但是誘發一處新山崩跟沖刷既有山崩裸露的降雨條件差異不小，若要瞭解地震對後續降雨誘發山崩的影響，仍需解析出各處山崩的誘發因素。本研究對各事件後山崩目錄進行分類，分為新生山崩、前期山崩擴大及前期山崩未擴大三類。

分析用之地震強度採用愛氏震度(Arias Intensity)，其以類似能量的觀點來指出完整地震歷時期間地表受到地震晃動的強度，對崩壞比的解釋成功率最高；降雨強度採用最大 3 小時及最大 24 小時雨量，不過因為兩降雨事件之最大 3 小時及最大 24 小時雨量相依性很高，因此主要採用最大 24 小時雨量之分析成果。

由地震所誘發之新生及前期擴大山崩，最顯著的影響因子為地震強度、地形坡度及相對坡高。0403 花蓮地震誘發山崩之崩壞比與愛氏震度呈現良好的正相關，與集集地震相同之愛氏震度值域比較，兩地震事件之愛氏震度與崩壞比趨勢相近，崩壞比曲線均在愛氏震度 2 m/sec 處有明顯上升。誘發山崩之坡度分布主要位於 40 度至 60 度之間，集集地震誘發山崩則主要分布於 30 度至 50 度之間，主要因為 0403 花蓮地震震度最大地區正是坡度最陡峭的清水斷崖及立霧溪溪谷地區。震度最大區域之主要地層分布為九曲大理岩、得克利及開南崗片麻岩，因此研究區內這兩種岩性的崩壞比最高，達到 5%以上。許多研究指出地震誘發山崩多發生在坡頂或陡崖邊緣，此現象可由各山崩最高點之相對坡高加以分析。0403 花蓮地震誘發山崩有 72%的山崩個數其最高點位於相對坡高 0.5 以上之坡

面；而最高點位於坡頂，也就是相對坡高 0.9 以上者個數比例高達 23.15%，面積佔比更高達 54.27%。

由凱米颱風所誘發之山崩，包括新生山崩與前期山崩擴大兩項，崩壞比與最大 24 小時累積雨量整體略呈正相關，在雨量 300mm 至 500mm 地區之崩壞比偏高，且比康芮颱風在相同雨量區間及岩性條件下的崩壞比更高，經觀察發現，由於此雨量區間位於 0403 花蓮地震愛氏震度大於 4 m/sec 以上地區且坡度陡峭，震後所造成之坡面岩體強度降低或林間不穩定崩積物，受到凱米颱風降雨沖刷而崩出，以及一些地震誘發山崩受沖刷而範圍擴大，導致崩壞比上升。誘發山崩之坡度分布主要位於 40 度至 50 度之間，坡度分布較地震誘發山崩略低。各山崩之最高點在各相對坡高之分布頗為平均，沒有明顯偏向坡頂的狀況，不過位於坡頂區域的誘發山崩個數仍佔整體的 13.73%。經觀察，這些主要是位於愛氏震度大於 4 m/sec 強震區之擴大型山崩，這些山崩由地震所誘發，因此位置偏向坡頂。也可觀察到此區亦有一些新生山崩偏向坡頂位置，應是震後造成之坡面岩體強度降低或林間不穩定崩積物，受到凱米颱風降雨沖刷而崩出。

由康芮颱風所誘發之山崩，主要位於高雨量區，崩壞比與最大 24 小時累積雨量呈明顯正相關，在雨量最高的立霧溪溪谷有較多由地震所誘發之山崩發生範圍擴大的情形。另外宜蘭土場對岸蘭陽溪左側山區，因 24 小時累積降雨達 800 mm 以上，有較多新生山崩。0403 花蓮地震愛氏震度大於 4 m/sec 以上區域，在凱米颱風時受降雨沖刷有明顯山崩範圍擴大的情形，此區在康芮颱風時所遭遇的最大 24 小時累積雨量更大，但已幾乎沒有山崩擴大的狀況了，在 24 小時累積降雨 300 mm 至 500 mm 區間的崩壞比也比凱米颱風低，可能部分坡面上地震誘發山崩堆積已經在凱米颱風沖刷下崩出。康芮颱風誘發山崩之坡度分布主要位於 30 度至 50 度之間，坡度分布比凱米颱風誘發山崩更低一些，也更接近一般降雨誘發山崩之坡度分布。各山崩之最高點在各相對坡高之分布頗為平均，已沒有明顯偏向坡頂的狀況。

綜合分析顯示，震後豪雨對山崩分布的主要影響為(1)誘發高震度區既有地震山崩的擴大，(2)沖刷既有山崩裸露使崩積土砂進入河道系統，(3)豪雨新生山崩雖偏向河岸，但易與地震誘發山崩形成複合式土砂災害。因此，震後土砂災害鍊防治應特別注意高震度區的山崩擴大、運移與高崩壞比集水區的土石流潛勢。

關鍵詞：地震誘發山崩、愛氏震度、最大 24 小時累積雨量

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潛在大規模崩塌判釋與數值地形資料計量分析114年度工作成果

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摘 要

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。

114年度本計畫工作範圍為宜蘭縣、花蓮縣、臺東縣、南投縣、臺中市及高雄市之部分區域。數值資料分析於114年執行1,300幅1/5,000圖幅，潛在大規模崩塌判釋於114年執行444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1,906處。本計畫完成5處潛在大規模崩塌現場調查，其中省道台8線通過花蓮縣-秀林鄉-D317，趾部區域坡面道路於判釋範圍邊界均有受到破壞之現象，於崩塌趾部存在厚層之剪切帶，疑似局部滑動面出露，經調查後初步評估邊坡活動性中，邊坡局部區域仍處於持續緩慢活動之狀態。花蓮縣-卓溪鄉-D754，坡面範圍內全坡面道路多有擠壓、破裂及下陷之現象，各滑動體皆有特徵，且具有多處地表裸露之現生崩塌。故此推測潛在大規模崩塌活動性中，邊坡局部區域仍處於持續活動之狀態。

關鍵字：光達數值地形、潛在大規模崩塌、地形變異、品質分析、潛在活動塊體

General Poster GP140

Integrating landslide susceptibility modeling and climate change adaptation: A case study in Nantou, Taiwan

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Abstract

This study presents a machine learning model based on XGBoost for mapping landslide susceptibility in the Nantou demonstration area, Taiwan. It combines historical landslide records, the Taiwan Re-Analysis Downscaling rainfall data (TReAD) from the Taiwan Climate Change Projection Information and Adaptation Knowledge Platform (TCCIP), and various geological and topographic factors. The model effectively generates landslide susceptibility maps for heavy rainfall events and quantifies the relative importance of landslide conditioning factors.

Furthermore, by integrating AR5 HiRAM GWL climate projections from TCCIP, this study assesses potential future landslide impacts under the RCP8.5 scenario. Under the end-of-century warming scenario (GWL4°C), landslide risk increases substantially. An optimal forest species adaptation strategy, derived from landslide factor importance analysis, reduces the projected landslide rate by approximately 28% relative to the unadapted late-century scenario, effectively restoring the risk level to that projected under mid-century warming (GWL2°C).

動態降雨山崩潛勢模式更新-以北部地區為例

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摘　要

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。然而降雨誘發山崩之特性有地域性的差異，不同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，本研究不採用通用模式，改以通用分析流程於不同地區建置動態山崩潛勢模式，同時由不同地區之分析結果反饋，嘗試優化分析流程。目前，該分析流程於中、南部地區之預測成效良好，正確率皆可達到80%左右。然而本研究於北部地區採用此分析流程建置動態山崩潛勢模式，其預測正確率約為70%上下，經觀察、比對中、南、北部地區的訓練資料及分析結果，推測可能原因有二，1)北部地區的山崩樣本數量較少：北部地區多數為丘陵地形，山崩面積較小，且人為開發與自然崩塌於遙測影像判釋上易於混淆，故樣本數量較少，致使模式低估山崩數量；2)山崩分布不均：以蘭陽溪流域為例，芭瑪颱風之崩塌僅存在於冬山鄉，但其山崩目錄相對較多，其他事件崩塌之地形地質效應被稀釋，使得因子係數產生偏差造成誤判。本研究後續透過篩選山崩樣本，更新北部地區之動態山崩潛勢模式，預測正確率皆超過70%，解決山崩分布不均的問題，而山崩樣本數量問題，並無立竿見影的方法，僅能以逐步增加其他事件山崩目錄的方式解決。

關鍵字：山崩、山崩潛感、颱風
Keywords: landslide, landslide susceptibility, typhoon

General Poster GP142

地震災害應變系統之災情評估驗證：以2024年M_W 7.4花蓮地震為例

Rapid Seismic Impact Assessment and Validation: A Case Study of the 2024 M_W 7.4 Hualien Earthquake

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摘　要

臺灣地震頻繁，震後 15 分鐘內的災情評估是應變決策的關鍵。本研究旨在呈現國家災害防救科技中心（NCDR）開發之「地震災害應變系統」，並以 2024 年 M_W 7.4 花蓮地震為案例，驗證系統自動產製圖資之準確性。評估結果顯示：(1) 建物受損：震度分布圈繪之高風險區與實際災損吻合度高；(2) 受困人口：利用電信大數據估算之山區人口與官方統計相近；(3) 山崩潛勢：結合最大地表加速度與地文敏感值之評估則存在高估現象。研究證實該系統能於震後第一時間提供多面向評估，有效支援後續安全查報與救援資源調度。

General Poster GP143

2025年嘉義大埔地震致災因素探討

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摘　要

2025年1月21日凌晨，在臺灣西南部地區發生芮氏規模6.4之強震，最大震度達6強。根據地動分布圖，本次事件的強震區位在臺南市，且造成該地區有上千棟建物毀損，其中以楠西區與玉井區受災最為嚴重。為釐清本次事件之致災因素，本研究將分析地動觀測資料及受損建物之屬性，透過空間屬性連接技術，整合國家災害防救科技中心（災防中心）建物屬性資料庫與實際災損位置，探討地動、受損建物及建物屬性之關聯，並利用災防中心開發之多維度地震衝擊動力分析展示圖台（MDUES），以三維擬真方式呈現災損區域之空間分布特性，相關成果未來可提供地震防災與救災規劃參考。

General Poster GP144

Probabilistic Tsunami Hazard Assessment for Padang City, West Sumatra, Indonesia

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Abstract

Padang, a densely populated coastal city on the western coast of Sumatra, is one of the most tsunami-exposed urban areas in Indonesia due to its proximity to the Mentawai segment of the Sunda megathrust. Major historical earthquakes and tsunamis, including the 1797 and 1833 events, are documented in both historical accounts and coral microatoll records, indicating repeated coseismic deformation along this margin. This study presents a probabilistic tsunami hazard assessment (PTHA) for Padang by integrating scenario-based tsunami simulations with earthquake recurrence statistics. Tsunami sources were constrained using regional tectonic setting and earthquake catalog data, and simulations were performed for Mw 7.8–9.0 scenarios using nested bathymetry-topography grids derived from ETOPO, FABDEM, and BATNAS, with a finest resolution of 28 m. Maximum tsunami heights were extracted at five virtual tide-gauge sites, and hazard curves were constructed using a truncated Gutenberg-Richter model with annual parameters a = 7.363 and b = 1.16, together with lognormal aleatory variability (β = 1.00). At Padang Tide Gauge, simulated maximum tsunami heights range from 0.103 m for Mw 7.8 to 3.722 m for Mw 9.0, corresponding to return periods of approximately 157 years for 0.5 m, 277 years for 1.0 m, and 550 years for 2.0 m exceedance. The results provide a scientific basis for tsunami mitigation, evacuation planning, and coastal risk reduction in Padang.

General Poster GP145

INVESTIGATING THE ORIGIN OF ANOMALOUS TSUNAMI RUNUP FOLLOWING THE 1996 BIAK EARTHQUAKE

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Abstract

An anomalously high tsunami runup was observed along the southern coast of Biak Island, Indonesia, following the Mw 8.2 earthquake on 17 February 1996, located ~60 km off the northeastern coast. Notably, the highest runup occurred on the coast opposite the earthquake epicenter and the northern subduction zone. This unexpected energy distribution suggests source complexity not captured by conventional models that assume tsunami generation solely along the subduction interface. To investigate this anomaly, the Intensity Impact Analysis (IIA) method was applied to simulate tsunamis from multiple hypothetical sources. Synthetic scenarios were evaluated based on their coastal impact and compared with historical observations to eliminate less plausible candidates. Field survey data, including runup heights and arrival times, were incorporated to further constrain the analysis. The study focuses on identifying tsunami sources based on spatial energy distribution and characteristics of submarine landslide-generated tsunamis. To refine the most probable source locations, slope analysis was conducted on the remaining candidates. Given the strong association between submarine landslides and steep seabed gradients, bathymetric slope angles were analyzed to assess the plausibility of landslide initiation. Areas with high slope gradients were considered more likely sources of landslide-induced tsunamis. This integrated approach, combining numerical modeling, observational data, and slope analysis, provides a robust interpretation of the anomalous runup and highlights the importance of non-seismic sources in tsunami hazard assessment in complex tectonic regions.

Keywords : Runup height, Intensity Impact Analysis (IIA), Slope analysis.

General Poster GP146

利用機器學習建立火山異常活動之評估模式

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摘　要

大屯火山群鄰近臺灣人口最稠密的地區的臺北都會區，然而，臺灣在過去一萬年間並無確切火山噴發紀錄，但火山噴發時引致地質活動，對於都會區人口則是潛在的火山災害威脅，因此如何從各種不同的火山監測資料中辨識出真正反映火山活動的異常訊號，便成為一項高度挑戰性的研究議題。故本研究嘗試將國家災害防救科技中心目前應用於行動通訊人流資料之異常偵測方法，將具有連續性、即時性與地點特定性的人流資料轉化改為同樣具備這些特性的火山氣體監測資料，嘗試建立一套可協助火山異常活動的偵測方法。本研究使用經濟部地質調查與礦物管理中心所提供 2023至2024 年八煙地區二氧化碳每5分鐘記錄一次的即時濃度監測資料，並透過奇異譜分析（Singular Spectrum Analysis, SSA）處理具非線性特性時間序列，並依照資料之連續性與完整性，選取2024年 7 月與 10 月之資料紀錄作為測試，標定主要背景趨勢、觀測趨勢以及差異趨勢，作為火山異常活動判釋之指標。然而氣體濃度可能會受到環境背景之影響，須排除環境干擾因素後，才能更準確評估異常是否為火山活動。目前本研究雖已將人流異常偵測方法轉應用於火山氣體監測，並初步進行資料異常評估之測試；但仍待環境背景條件之影響更加釐清時，才能進入機械學習與自動化異常分析，進以提升偵測大屯火山異常活動之能力。

General Poster GP147

恆春半島西北部上中新統沉積環境—深海相底棲性有孔蟲之證據

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摘　要

恆春半島出露之中新統（牡丹層）屬深海相沖積扇沉積，但在半島西北部之上中新統（里龍山砂岩），其上段因其厚層砂岩含礫石層的岩性，局部可見牡蠣化石層及樹葉化石密集帶，偶見淺海相底棲性有孔蟲化石與生痕化石等特徵，而被認為沉積於淺海環境。

本研究於恆春半島西北部之里龍山砂岩標準剖面竹坑溪，自其上段含礫石之厚層砂岩間所夾泥岩層中洗選出深海相之底棲性有孔蟲化石如*Alveolophragmium indicum*、*Cyclammina compressa*、*Labrospira crassimargo*、*Recurvoidatus trochamminiformis*、*Trochammina globorotaliformis*等棲息於逾一千公尺水深之物種；另於里龍山北部牡丹層含樹葉化石的露頭採集之泥岩樣本中，發現*Haplophragmoides grandiformis*、*Textularia* cf. *T. agglutinans*等淺水物種與*Bathysiphon* sp.、*Cyclammina pussila*等深水物種並存之現象。

上述化石之發現，具有以下啟示：1. 里龍山砂岩上段之沉積環境可能仍屬於深海；2. 前人研究於里龍山砂岩所發現少許淺海相底棲性有孔蟲化石，應為濁流搬運與稀釋作用之結果；3. 樹葉化石可透過濁流作用搬運至深海堆積。依據近年與深水相濁流岩及深海沖積扇有關之沉積過程、沉積岩相、生痕化石、軟體動物生態調查等國際研究，亦可應用於恆春半島上中新統之沉積環境解釋。

General Poster GP148

高解析生物地層在西南麓山帶構造調查應用：以烏山頭斷層及口宵里斷層為例

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摘　要

臺灣西南部麓山帶上新統至更新統長期存在岩石與生物地層劃分爭議，使得區域地層對比與地質構造解釋有不同的看法。本研究針對臺南曾文溪剖面，烏山頭斷層與口宵里斷層間出露的地層進行鈣質超微化石生物地層分析，辨識出*Reticulofenestra pseudoumbilicus*、*Sphenolithus abies*、*Discoaster pentaradiatus*最高出現面，以及*Pseudoemiliania lacunosa*、*large Gephyrocapsa*最低出現面等關鍵生物事件，並將地層劃分出CNPL2至CNPL8等5個生物帶。藉由前述已建立的生物地層，顯見烏山頭斷層下盤的濁水溪層屬CNPL4-CNPL5生物帶，上盤隘寮腳層為較老的CNPL2-CNPL3生物帶。剖面東界的口宵里斷層，其上盤歸屬於較老的CNPL6-CNPL7生物帶，下盤出露之玉井頁岩被劃分為CNPL8生物帶上部，CNPL8生物帶下部受斷層截切致缺失。

綜上所述，本研究藉由比對斷層兩側生物帶落差與地層缺失關係，不僅確認烏山頭斷層與口宵里斷層位置，更具體證實高解析鈣質超微化石生物地層在複雜麓山帶構造解析中之關鍵應用潛力。

關鍵字： 鈣質超微化石、生物地層、口宵里斷層、烏山頭斷層

General Poster GP149

墨西哥灣Macuspana次盆地層序地層對比與油氣潛能

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摘　要

墨西哥灣盆地由數個張裂盆地所組成，為世界上知名的油氣富集盆地，台灣中油公司參與之礦區位於南墨西哥灣之東南盆地，相鄰於Cantarell油田，且在礦區內已由震測解釋圈繪出完整明確之封閉構造，但其所在之Macuspana次盆地與鄰近油田之地質架構存在明顯差異，有其必要分析Macuspana次盆地之地層特性與盆地演化過程。

根據次盆地內5口井之層序分析結果，皆未見東南盆地最主要之中生代生油岩與儲集岩，與鄰近之Cantarell油田之地層架構截然不同。Macuspana次盆地海域區域完整保留自晚漸新世Chattian 3層序以來至更新世之Calabrian 2 層序之新生代沉積物，本研究將劃定之層序界面作為各地質時期之對比等時面，進一步推論各時期沉積空間的時空演變，得知盆地的沉陷作用在Tortonian 2層序堆積時達到最高峰，觀察到9.26 Ma至6.98 Ma期間5口井之沉積速率有明顯增快之現象，屬於Macuspana次盆地之快速沉陷期，6.98 Ma之後轉變為局部沉陷期，沉陷作用以盆地西側為主。

綜合O-1井之油母質類型與成熟度分析結果，初步確認Macuspana次盆地海域地區之中部中新統以上地層無生成熱成熟氣潛能，但其漸新統沉積於半封閉且缺氧之水域，有利於有機質之保存，仍有機會作為潛在之生油岩。礦區南側井位可見早上新世、晚上新世與早更新世時堆積之三角洲沉積物，具備良好儲集岩。上新世期間於O-1井周邊區域形成之偽龜背構造可作為B礦區之主要封存構造。

General Poster GP150

義大利的第四紀新舊金釘子採樣及其與台灣第四紀地層的對比意義及探討

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摘　要

「全球年代地層單位界線層型剖面和點位」（GSSP，即金釘子）為國際地層委員會（ICS）確立之地質年代標準。其旨在提供全球一致的地層對比基準，以利不同區域之沉積序列進行高解析度年代校準，進而釐清跨區域之古氣候與地質時序。以地中海區域為例，其上新世至全新世的海相地層完整記錄了受米蘭科維奇循環驅動的沉積序列，因而被選定為更新世多個重要底界的 GSSP。本團隊前往義大利南部之GSSP剖面進行考察，以深入理解標準地層序列中的實際沉積特徵。

臺灣位處活躍的板塊交界帶，因複雜的造山帶地質背景，常導致地層序列不連續或定年困難，使精確劃分第四紀地層界線變得有挑戰性。然而臺灣部分具備高沉降與高沉積速率的海相地層，仍有受全球軌道週期所驅動的海水面與氣候變遷的沉積紀錄。本研究希望以義大利 GSSP 剖面考察所建立之標準概念為基礎，結合文獻回顧與區域沉積特徵之綜合比較，探討將GSSP對比應用於臺灣第四紀複雜地層之可行性。

General Poster GP151

Evaluating Dual-Energy CT for Material Discrimination in Heterogeneous Sediment Cores

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Abstract

X-ray computed tomography (CT) is an increasingly important non-destructive tool in sediment-core analysis, enabling high-resolution, quantitative characterization of three-dimensional internal features. In our previous work, sedimentary variability, including grain-size variation and compositional heterogeneity, was assessed using a multi-parameter framework derived from single-energy CT data. However, because CT intensity reflects the combined effects of material density and effective atomic number, distinct sedimentary components may yield overlapping grayscale values, reducing reliable discrimination of internal features. To address this limitation, this study investigates whether dual-energy CT (DECT) can extend this framework by providing parameters more directly related to material properties. A stoichiometrically calibrated DECT workflow was applied to a core from a seagrass-bed setting in Penghu, Taiwan, where mixtures of carbonate fragments, siliciclastic debris, and organic-rich materials provide a suitable test case for evaluating material discrimination in heterogeneous shallow-marine sediments. The core was scanned at low and high energies to derive effective atomic number (Zeff) and electron density (ρe), and these parameters were evaluated alongside conventional single-energy CT descriptors for their potential integration into the framework. Additional medical CT scans were used to examine how scanner type and spatial resolution influence DECT results and performance. Preliminary results suggest that DECT improves discrimination of materials that remain ambiguous in single-energy CT, particularly where siliciclastic debris and carbonate-bearing components exhibit overlapping attenuation values. It also aids in distinguishing organic-rich materials from boundary voxels affected by partial-volume effects. These findings demonstrate the potential of DECT as a practical extension of parameter-based CT analysis for discriminating heterogeneous sedimentary components. Improved feature identification may in turn support sedimentological interpretation and targeted subsampling for subsequent geochemical and potentially blue-carbon-related analyses in coastal cores.

Keywords: Dual-energy CT (DECT), Sediment-core analysis, Material discrimination, Effective atomic number (Zeff), Electron density (ρe)

General Poster GP152

Optimizing CT imaging conditions for large half-core samples

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Abstract

X-ray computed tomography (CT) is widely used for non-destructive characterization of geological cores. Large half-core samples (diameter > 100 mm); however, remain difficult to image because their non-cylindrical geometry increases beam hardening and scattering artifacts, leading to biased CT intensity distributions and degraded image quality. Previous studies suggest that such artifacts can be mitigated by using filtering media such as water or by positioning samples near the scanner center to improve image uniformity. Their effectiveness for large non-cylindrical half-core samples remains insufficiently evaluated. In this study, we evaluated three practical scanning configurations for large marine half-cores: (1) core placed against the pipe wall, (2) core against the wall with an overlying water bottle, and (3) core positioned near the center of the scanning field. CT intensity histograms and mean values from the core, pipe, and internal air regions were compared to assess image quality and intensity stability. Both the centered and water-assisted configurations improved image clarity relative to the wall-adjacent setup. In contrast, the water-bottle configuration produced a systematic leftward shift in core intensity distributions, suggesting beam hardening effects associated with pre-filtration. By comparison, centering the core reduced intensity variability without introducing additional bias. These results demonstrate that sample positioning is a key factor controlling CT artifacts in non-cylindrical samples. Among the tested configurations, centering provides the most reliable imaging condition, achieving improved image quality and stable intensity distributions without external spectral modification.

Key words: X-ray computed tomography (CT), Large half-core samples, Beam hardening artifacts, Non-cylindrical geometry, Sample positioning

利用 O-H 頻帶高斯分峰之微拉曼光譜於角閃石類石綿及相關纖維狀矽酸鹽礦物之鑑別研究

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摘 要

石綿與形態相似之纖維狀矽酸鹽礦物之鑑別，在實務應用中仍具挑戰性，尤其當其光學性質於偏光顯微鏡下高度相似時更易造成誤判。本研究利用微拉曼光譜分析六種受管制石綿，並以 O-H 伸縮振動區為主要探討重點。

透過高斯分峰處理（Gaussian deconvolution）分析 O-H 伸縮振動區之頻帶組成，以探討其與局部陽離子配置（Mg^{2+} Mg^{2+} Mg^{2+}）、（Mg^{2+} Mg^{2+} Fe^{2+}）、（Mg^{2+} Fe^{2+} Fe^{2+}）與（Fe^{2+} Fe^{2+} Fe^{2+}）之對應關係。分峰後之峰位與相對強度可作為區分透閃石與陽起石之實用判別依據，並可進一步與 Mg/(Mg+Fe) 比值建立關聯。

青石綿在可見光波段具有強吸收特性，於拉曼量測中易產生局部升溫與雷射損傷，因此本研究採用 458 nm 激發波長，以提升拉曼散射訊號並同時控制熱效應，取得穩定光譜。並輔以 SEM-EDX 分析確認元素組成。一市售誤判為海泡石之樣品經分析證實為溫石綿，顯示僅依形態判別之限制；相對地，海泡石與滑石呈現不同之拉曼特徵。滑石常與角閃石類石綿共生，與其變質作用相關之礦物演生過程有關，且於光學顯微鏡下易與透閃石與陽起石混淆。

研究結果顯示，結合拉曼光譜與元素分析可有效區分石綿與外觀相似之纖維狀矽酸鹽礦物，對實務鑑定具有重要應用價值。

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General Poster GP153

Micro-Raman spectroscopic discrimination of amphibole asbestos and related fibrous silicate minerals using OH-band Gaussian deconvolution

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Abstract

Accurate discrimination between asbestos and morphologically similar fibrous silicate minerals remains a critical challenge in practical identification, particularly when optical properties are highly similar. In this study, micro-Raman spectroscopy was applied to analyze six regulated asbestos types, with emphasis on the OH stretching region.

Gaussian deconvolution was applied to the OH stretching region to characterize band components related to local cation configurations (Mg^{2+} Mg^{2+} Mg^{2+}), (Mg^{2+} Mg^{2+} Fe^{2+}), (Mg^{2+} Fe^{2+} Fe^{2+}) and (Fe^{2+} Fe^{2+} Fe^{2+}). These spectral features enable correlation with Mg/(Mg+Fe) ratios and provide practical criteria for distinguishing tremolite from actinolite based on peak positions and relative intensities.

Crocidolite exhibits strong visible-light absorption and is prone to laser-induced heating and damage. Therefore, a 458 nm excitation wavelength was selected to enhance Raman scattering intensity while controlling thermal effects, enabling acquisition of stable spectra.

Complementary SEM-EDX analysis was conducted to verify elemental compositions. A commercially misidentified sepiolite sample was confirmed to be chrysotile, demonstrating the limitations of morphological identification. In contrast, authentic sepiolite and talc exhibited distinct Raman features. Talc commonly coexists with amphibole asbestos due to mineral paragenesis associated with metamorphic processes and can be easily misidentified as tremolite or actinolite under optical microscopy.

These results demonstrate that integrating Raman spectroscopy with compositional analysis provides a reliable approach for distinguishing asbestos from visually similar fibrous silicate minerals in practical applications.

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General Poster GP154

Crystal Structure and Luminescent Properties of Flux-synthesized Hashemite

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As the isostructural chromate analog of barite, hashemite crystallizes in the space group *Pnma*. The chemical composition of natural hashemite ranges from $Ba(Cr_{0.93}S_{0.07})O_4$ and $Ba(Cr_{0.64}S_{0.36})O_4$. Theoretical predictions suggest a band gap of ~2.7 eV for $BaCrO_4$, identifying hashemite as a semiconductor. Determining whether its band gap is direct or indirect is crucial for understanding its physical properties. This study investigates the structural and luminescent properties of synthetic $Ba(Cr,S)O_4$ crystals to elucidate their photoluminescence (PL) mechanisms and potential applications.

Utilizing WDS, XRD, and Raman spectroscopy, we successfully grew hashemite crystals across the entire $BaCrO_4$–$BaSO_4$ solid solution series via a flux method. The as-grown crystals exhibited a greenish tint, deviating from the yellow $BaCrO_4$. This coloration suggests the presence of Cr^{3+}, formed under oxygen-deficient conditions—a finding confirmed by XPS analysis. First-principles calculations indicate that $BaCrO_4$ possesses an indirect band gap. The optical band gap estimated from Tauc plots showed no significant increase as $BaSO_4$ content rose from 0% to 50%. After the addition of $BaSO_4$, PL intensity of the solid solution increases first and then decreases. UV-Vis absorption spectroscopy revealed intense absorption in the UV region, attributed to ligand-to-metal charge transfer (LMCT) from O *2p* to Cr *3d* orbitals. Correspondingly, the PL spectrum exhibited a broad emission band centered at ~500 nm. Due to strong electron-phonon coupling in the LMCT excited state, energy is largely dissipated through non-radiative pathways, resulting in weak emission intensity and photocatalytic performance.

蛇紋岩微量元素地球化學指標之地體構造意涵：以臺灣東部玉里帶與東臺灣蛇綠岩套為例

Trace Element Geochemistry of Serpentinites and Its Tectonic Implications: Evidence from the Yuli Belt and the Eastern Taiwan Ophiolite

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摘要

臺灣東部出露之蛇紋岩主要可歸屬於兩種不同構造背景來源，其一為玉里帶中經變質作用形成以葉蛇紋石為主要組成的蛇紋岩，代表隱沒帶環境下板塊脫水流體與岩石交代作用；其二為東臺灣蛇綠岩套中的蛇紋岩化橄欖岩，代表中洋脊形成之海洋地殼岩石圈殘餘。蛇紋岩在隱沒帶與海洋岩石圈演化過程中為重要的流體儲存與傳輸介質，其形成與演化常伴隨流體驅動之交代作用與元素再分配，因此它的元素地球化學特徵可反映不同構造環境下的流體作用與元素遷移過程。過去對臺灣蛇紋岩之研究多集中於原岩判別、變質條件與礦物化學，而對微量元素，特別是流體移動元素在蛇紋岩中的分布特徵與地球化學行為仍缺乏系統性探討。近年的研究指出，部分微量元素於隱沒帶流體活動與蛇紋岩化過程中可能產生顯著富集，其中砷常在弧前隱沒帶地函楔中呈現異常富集，並與隱沒帶流體作用及交代過程密切相關；此外稀土元素中鈰異常用於評估氧化還原環境。本研究以臺灣兩種不同構造背景來源之蛇紋岩為研究對象，整合 X 光粉末繞射 XRD 礦物鑑定、X 光螢光光譜 XRF 的主量元素與燒失量 LOI 分析，並以感應耦合電漿質譜法 ICP-MS 進行微量元素分析，比較不同構造環境蛇紋岩之地球化學特徵。結果顯示，玉里帶蛇紋岩之砷含量普遍高於東臺灣蛇綠岩套蛇紋岩，其中清水地區樣本多數高於 10 ppm，最高可達約 340 ppm；相較之下，東臺灣蛇綠岩套的蛇紋岩之砷含量普遍低於 2 ppm。砷－鈰關係圖顯示不同區域樣本雖具相似分布趨勢，但整體含量範圍差異顯著，反映兩類蛇紋岩在微量元素地球化學上具有系統性差別，且東臺灣蛇綠岩套蛇紋岩普遍缺乏砷等隱沒帶流體相關元素之富集特徵。本研究顯示，蛇紋岩中砷等流體移動元素之富集程度可作為判別隱沒帶與洋中脊構造環境之重要地球化學指標。

關鍵詞: 東台灣、蛇紋岩、隱沒、砷異常、鈰異常

General Poster GP156

Micro-XRF揭示菲律賓海鐵錳結殼中元素遷移行為與生長間斷特徵

Micro-XRF Reveals Elemental Migration Behavior and Growth Hiatus Features in Ferromanganese Crusts from the Philippine Sea

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摘　要

鐵錳結殼中微量元素之富集與再分配，受其所含鐵氧化物與錳氧化物礦物相比例與相轉變影響，並同時受成岩作用所控制。本研究以菲律賓海（水深約5,700公尺；站位42：16°56′N, 129°48′E）之鐵錳結殼為研究對象，利用微區X光螢光光譜分析技術（Micro X-ray fluorescence analysis；Micro-XRF）探討其礦物相變化與元素遷移機制。元素分布結果顯示，Mn與Ni於成長層中呈現高度正相關，指示低結晶度之錳氧化物之表面或結構具有強烈的Ni吸收能力。相較於Ni的變化，Co的分配機制在結殼不同深度位置有明顯轉變：在靠近表層的新生層中，Co主要富集於錳氧化物相。而在底部較老層位中，Co主要富集於鐵氧化物相。此一轉變顯示隨成岩作用進行，錳氧化物相隨時間的結晶度變化或相轉變可能顯著影響了其對Co的富集能力，進而導致元素遷移與再分配。另外，在同一沉積層內，Ti與錳氧化物相的相關性高於鐵氧化物相，顯示Ti傾向於富集於富錳礦物中。而在沉積中斷的交界處，Ti顯著富集形成高濃度帶。顯示富Ti層可作為辨識結殼成長中斷之關鍵指標，推測其成因可能與底層水動力增強或外源碎屑輸入事件相關，進而抑制自生氧化物之沉澱作用。綜上所述，Micro-XRF有助於解析礦物相變化、元素遷移與沉積環境變遷間的複雜交互作用，為深海鐵錳結殼成長歷史及其地球化學過程提供關鍵資訊。

中文關鍵字
鐵錳結殼、微區X光螢光光譜分析、生長間斷、元素遷移

Keywords in English
Ferromanganese crust, Micro-X-ray fluorescence analysis, Growth hiatus, Elemental migration

丹唇未啟笑先聞：黃石地幔柱噴發前的動態地形抬升

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摘　要

傳統碰撞造山運動多產生與板塊邊界平行的構造抬升；相較之下，地幔對流（如地幔柱上湧）則會誘發尺度達上千公里的區域性地表隆起，即動態地形（Dynamic Topography）。由於地幔具高黏滯之流體特性，理論與數值模擬均顯示地幔柱在抵達地表（岩漿噴發）前，即會引發預先抬升。然而，這種未見其人，先聞其聲的地質證據至今仍相當稀缺。

本研究以黃石地幔柱的升起作為實證對象。在中新世約 20 Ma，該區正經歷科迪勒拉山系（Cordillera）從造山帶崩解轉向北洛磯山脈盆地與山嶺（Basin and Range）伸張構造的過渡期。透過分析蒙大拿州西南部八個漸新世至中新世沉積剖面的岩石磁性，我們發現在早中新世 20 Ma的不整合面之後，磁性礦物含量急遽增加，並伴隨碎屑鋯石年齡譜系的顯著變化，證實物源區發生了重大偏移。

研究結果確認，哥倫比亞河玄武岩群（Columbia River Basalt Group）噴發之前的火成活動為漸新世至早中新世主要的沉積物來源。這顯示早中新世的大陸分水嶺當時位於現今位置以西約 400 公里處。此一由地幔柱隆起驅動的地形重組過程至少持續至 10 Ma。本研究不僅為過去僅能仰賴模型估算的動態地形提供了堅實的地質、時間與空間限制條件，更強調了地幔柱動力對區域性抬升、沉積物分散路徑及水系格局的關鍵影響。

General Poster GP158

Thermal evolution of the Martian basal molten silicate layer and the core: Insights from mantle convection simulations

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Abstract

A basal molten silicate layer (MSL) has been suggested to exist below the Martian mantle, above the core (Samuel et al., 2023; Khan et al., 2023). Such a MSL largely affects interior thermal evolution in multiple ways, through the redistribution of heat producing elements (HPE) between the MSL and the mantle, and the likely suppression of both mantle and core convection. An additional layer of uncertainty lies in the mode of heat transport from and across the MSL itself, and is crucial to the thermal evolution of the whole Martian interior. This is, however, dependent on the convective state of the MSL, which is yet to be determined and confirmed. While the large amount of heat generated within the HPE-enriched MSL can be conducted to the mantle above and the core below, possible vigorous convection of the liquid-state MSL (compared to the timescale of solid-state mantle convection) allows additional heat loss from this layer.

Here, we focus on mechanisms that affects the MSL heat transfer, especially when this molten silicate layer is convective. By checking with mixing length theory, we examine the effect of boundary layers, as well as the maximum amount of heat that can be carried across the MSL. Incorporating this knowledge in mantle convection simulations using the thermochemical code StagYY, we study how they affect the dynamic behavior of the upperlying mantle and the thermal evolution of the underlying core. A 1D core model is recently implemented (Tackley2026) and takes account for downward heat fluxes at the core-mantle boundary, suitable for our scenario where the HPE-enriched MSL lies directly above the core. We further investigate the role of compositional (namely, Fe-) gradient in the stability of the MSL. In particular, we are interested in the influence of these various mechanisms on MSL temperature, average and lateral variations in CMB heat fluxes, as well as core temperatures through time.

龜山島鄰近區域之地震分布與火山活動之關聯

Seismicity and Volcanic Activity in the Vicinity of Turtle Island, Northeastern Taiwan

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摘 要

龜山島位於台灣東北部宜蘭外海約 11 公里處，地處沖繩海槽（Okinawa Trough）向西延伸的最南端，是一座由岩漿活動所形成的火山島，也是台灣地區兩座活火山之一。構造上，該區域受菲律賓海板塊向北隱沒至歐亞板塊之下所驅動的弧後擴張作用影響，沖繩海槽持續向西南方向張裂，在龜山島周邊形成了一系列正斷層系統與淺部地塹構造。島嶼周圍海底可觀察到活躍的熱液噴發與硫磺噴氣活動，指示其下方仍存在具溫度異常的岩漿與熱液系統。然而，由於龜山島鄰近人口密集的宜蘭平原，潛在的火山與地震災害對區域安全構成顯著威脅，精確掌握該區微震活動的時空分佈特徵及其與地下構造的關聯，便成為災害評估上不可迴避的核心課題。

大屯火山觀測站（Taiwan Volcano Observatory at Tatun, TVO）長期於龜山島與宜蘭平原地區部署寬頻地震觀測網，持續監測當地的地震活動。本研究利用該觀測網於 2025 年所記錄之連續地震波形資料，透過 SEISAN 地震分析系統依序完成事件偵測、P 波與 S 波震相之人工挑選，以及基於一維速度模型的初步震源定位，共識別出約 5,000 個微震事件，建構出涵蓋 2025 年觀測期間的地震目錄。

儘管上述初步定位已能勾勒出地震活動的大致輪廓，但由於一維速度模型難以適切描述火山環境中劇烈的橫向速度變化，加上測站分佈嚴重不均勻，未能充分涵蓋研究區域，初步定位結果不可避免地含有顯著的系統性誤差。為進一步提升震源位置的精度，本研究導入雙差分重定位技術（double-difference (DD) algorithm）。此方法針對空間上相鄰的事件對，利用其在共同測站上所觀測之到時差異與理論到時差異間的殘差進行聯立求解，藉此有效消除速度模型不確定性所帶來的偏差。在實際操作上，本研究首先以目錄中的地震震相到時建構事件對的差分到時資料，再針對波形相似度較高的事件對，以波形互相關技術（waveform cross-correlation）計算高精度的差分到時。兩類資料以階段式策略依序帶入迭代求解，先以目錄資料約束大尺度的相對位置架構，再以互相關資料精修細部空間分佈，確保結果兼具穩定性與高解析度。

初步結果顯示，重定位後的地震空間分佈由原先模糊分散的群聚型態轉變為清晰的線性與面狀排列，揭示了區域內隱伏構造的幾何特徵及其與火山活動間可能存在的空間關聯。

General Poster GP160

大屯火山次聲波訊號之時頻分析與自動辨識

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摘　要

大屯火山群位於台北都會區北方，研究顯示下方存在活躍的熱液或深部岩漿活動，因此火山活動的監測對台北都會區安全至關重要。本研究針對大油坑與小油坑兩處主要噴氣孔場域建置了高密度次聲波即時監測系統，每處各設置六個觀測站形成環形監測網，利用次聲波的低頻特性(頻率低於 20Hz)全天候記錄噴氣活動產生的聲波變化。為因應長期監測所產生的大數據挑戰，引入機器學習，期透過系統化的數據處理與自動化分析流程，有效縮短資料處理時程並降低人為誤判。資料結果顯示，紀錄次聲波訊號在時頻域具有顯著的特徵變化，這些特徵反映了噴氣活動的動態變化。基於該時頻特性，並導入影像辨識技術，進行訊號分類與判別。本研究採用 YOLOv9 深度學習模型實現自動訊號識別，已建立達千張高解析度時頻圖像與訊號標籤的標準化數據集。結果顯示，藉由 YOLOv9 的高度特徵提取能力，系統能識別不同類型的噴氣模式。此次密集聲波監測系統的建立與火山監測系統相輔相成，並透過 AI 視覺辨識模型的監測架構，強化了小油坑與大油坑噴氣活動的即時掌握能力，也為火山監測提供了不同的解析能力。

大屯火山地質製圖原則：層序年代學初探

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摘 要

大屯火山產物複雜多變，對比困難，實務上並無全區尺度的分層標準。火山地區容易辨識的不連續面對於野外地層層序調查或岩體地層單位劃分具直觀而實用的特性。然而，火山產物的不整合面多缺乏良好延續性，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，現代火山地層學加入火山作用地形演育概念（宋聖榮等，2009、2010、2021；陳文山等，2003、2007），以各種火山噴發產物之獨特地形紋理特徵、岩相與成分異質性，搭配不整合面界限，定義新的火山岩體地層單位－岩組（synthem）（Martí et al., 2018），並劃分層序先後關係。火山岩組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），是火山地層學家與地質製圖工作者的共同課題。

本報告以大屯火山群七星山系與磺嘴山系為例，配合最新(鈾-釷)/氦、氬/氬岩石定年得到之岩漿噴發年代（Pi et al., 2025; Lee et al. in preparation）修正火山岩組層序，並由年代修正之火山岩體層序保守估計晚更新世以來火山噴發再現週期之上限，七星山系不高於 20 千年，末次噴發期約 16~5.5 千年；磺嘴山系不高於 236 千年，末次噴發期為 144~72 千年。本文強調建立火山噴發層序之絕對年代是未來火山噴發時間概率、規模計算與長期災害風險評估不可或缺的鑰匙。

關鍵字：大屯火山、地質製圖、地質年代學、岩組、(鈾-釷)/氦定年、氬/氬定年

General Poster GP162

Boron and Lithium Isotope Constraints on Subduction Components in the New Georgia Group, Solomon Island Arc

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Abstract

The New Georgia Group of the Solomon Islands represents part of a tectonically complex subduction system characterized by ridge subduction and polarity reversal, offering an excellent chance to investigate material cycling in hot subduction zones involving multiple slab inputs from both the Pacific and Indian–Australian domains. We analyzed B and Li isotope systematics in a set of well-characterized high-Mg andesites from the subducting Indian–Australian plate and picrites and basalts collected from volcanic front and forearc regions of the New Georgia Group to constrain slab-derived contributions in magma genesis. Large variations are observed in fluid-sensitive geochemical tracers, including Li/Y, B/Nb, and $\delta^{11}B$. The high-Mg andesites record metasomatized mantle influenced by Pacific subduction, and their B/Nb and $\delta^{11}B$ systematics indicate slab-fluids contributions mainly derived from altered oceanic crust (AOC). Similar signatures are observed in forearc and volcanic front basalts distal from the area of inferred ridge subduction (on islands of Ranongga, Ghizo, Rendova, Vangunu; group 1) and also for volcanic front basalts proximal to that area (on islands of New Georgia and Kolombangara; group 2). Group 1 samples display mantle-like Li/Y ratio, consistent with input of slab-derived fluids released at relatively low temperatures and shallow depths. In contrast, group 2 samples show elevated Li/Y and low $\delta^{11}B$ values, suggesting contributions from slab melts derived from AOC and/or sediments. The picrites define mixing trends between a depleted mantle source and an enriched component characterized by relatively high Ni, elevated $\delta^{11}B$, and high B/Nb and Li/Y, likely reflecting serpentinite breakdown at greater slab depths. These results highlight spatial variations in slab inputs linked to thermal structure of the subduction system. Further Li isotope analyses are needed to better constrain the proposed petrogenetic model.

花蓮石梯坪中酸凝灰岩疑似脫氣構造之分析

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摘　要

花蓮石梯坪地區位於臺灣東部海岸山脈中段，地層屬於都巒山層頂部之石梯坪凝灰岩層，岩性以中酸凝灰岩為主，具有平行與交錯層理，露頭可見到由火山活動造成的撞擊與塑性變形構造。在石梯坪海階外緣有一因構造抬升與海水差異侵蝕形成的單面山，山體向西傾，呈現地形上東側陡峭、西側平緩的樣貌，露頭中可觀察到部分白色的幼新火山碎屑（juvenile clasts）顆粒呈現直立狀，形態上類似於火山脫氣構造（volcanic degassing structures）。火山脫氣構造是指岩漿在上升和冷卻過程中，因揮發性氣體（如 H_2O、CO_2、SO_2 等）自岩漿中析出，並向外逸散，於尚未完全固結的介質內形成孔洞、管狀通道或具方向性的排列構造。目前對於石梯坪露頭觀察到的構造是否由脫氣作用形成，仍缺乏相關的研究分析，因此需要進一步進行詳細調查和判斷。

本研究以石梯坪海岸露頭中疑似的火山脫氣構造為研究對象，研究目的主要在於確定該構造是否屬於火山活動形成的脫氣構造，並嘗試分析幾何特徵和空間分布，以提供判斷此構造形成機制的資料。研究方法先透過實地的野外地質調查，於石梯坪露頭進行系統性的觀察和拍攝影像紀錄，包含岩性特徵、顆粒形態、大小、分布情形，以及與周圍岩體的關係，並使用單眼相機進行多角度的影像拍攝，掃描整個露頭，建立完整的露頭影像，以作為後續分析的資料。

在影像資料處理部分，本研究嘗試利用三維模型建模的方式，透過多張重疊影像建立露頭的三維模型，分析疑似火山脫氣構造在露頭中的空間分布和幾何形態，相較於傳統二維影像，三維模型能提供更完整的空間資訊，有助於提升分析露頭構造的精確度。

透過實地露頭觀察和三維模型分析，本研究期望能釐清石梯坪露頭中疑似火山脫氣構造的形態特徵，並嘗試判別出是否真為火山脫氣作用形成。研究成果可為石梯坪地區提供更完整的地質研究資料，由於在臺灣對於火山脫氣相關的研究較為缺乏，本研究可作為推進火山脫氣研究在臺灣發展的重要里程碑。

關鍵字：石梯坪、中酸凝灰岩、火山脫氣構造、三維模型

General Poster GP164

U-Th disequilibrium dating of young igneous zircon from Guishan Island, Taiwan using femtosecond laser ablation ICP mass spectrometry

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Guishan Island is a young, volcanically active island situated at the westernmost margin of the Okinawa Trough in northeastern Taiwan, its magmatic activity is associated with subduction of the Philippine Sea Plate and represents the southwestern extension of the Ryukyu volcanic island arc. The most recent eruption occurred during the Holocene, as constrained by thermoluminescence and U-Th-He dating. To further resolve magma chamber processes occurring below the temporal resolution of conventional U–Pb zircon geochronology, ^{238}U–^{230}Th disequilibrium dating was applied to igneous zircons. Two drill-core samples from Guishan Island were analyzed by ^{238}U–^{230}Th dating using femtosecond laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) U–Th dating at the Geochemical Research Center, The University of Tokyo. To capture the latest stages of zircon crystallization, each analytical spot was ablated sequentially in two successive layers, each approximately 5 μm deep. Throughout the analytical session, reference zircons 91500 and Plešovice yielded $^{230}Th/^{238}U$ activity ratios of 1.02 ± 0.02 (MSWD = 0.89, n = 182), demonstrating robust analytical precision and accuracy.

U–Th isotopic evolution of zircons from both the two samples indicates that the final stage of zircon crystallization occurred at around 20-30 ka, suggesting late-stage magma crystallization shortly prior to the most recent volcanic activity. This youngest crystallization signal is preserved only within the outermost few micrometers of zircon rims. In contrast, ages derived from the second ablation layer are systematically older, reflecting crystallization of interior zircon domains. These results suggest that conventional zircon preparation involving polishing may remove critical rim material and thus obscure the youngest crystallization record.

General Poster GP165

Linking Zircon Geochronology and Crystal Records to Pre-eruptive Magmatic Conditions at Mt. Shamao, Tatun Volcano Group, Taiwan

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Multiple lines of evidence show that the Tatun Volcano Group (TVG), northern Taiwan, hosts an active magmatic system, highlighting the need to better constrain its eruption history. Its proximity to the Taipei metropolitan area makes defining eruption timing and pre-eruptive conditions critical for hazard assessment. Mt. Shamao is a key target as one of the youngest centers, yet its eruption age and pre-eruptive conditions remain debated. Zircon double dating indicates a late Pleistocene eruption at ~16 ka, while crystallization ages record prolonged magma growth over ~200 kyr with episodic fluxes.

Mt. Shamao lavas are porphyritic hornblende andesites dominated by plagioclase (35–37%), amphibole (12–15%), and minor pyroxene (~5%). Plagioclase shows widespread disequilibrium textures, including sieve structures, resorption, complex zoning, anorthite spikes (>10 mol%), and melt inclusion rich zones, occurring as single crystals, synneusis clusters, and glomerocrysts. Amphiboles form two populations, with magnesiohornblende and pargasitic domains, while pyroxenes are mainly orthopyroxene with clinopyroxene rims. These features indicate repeated mafic recharge, reheating, and partial re equilibration.

Thermobarometry indicates a vertically extensive, transcrustal reservoir spanning ~15–20 km depth. Shallow crystallization (~5 km), recorded by large magnesiohornblende, suggests a transient or small, water rich upper crustal reservoir that contributed to dome forming eruptions.

General Poster GP166

初來地區高溫地熱井下採樣與深層流體地球化學特性分析

Downhole Sampling and Geochemical Characterization of Deep Fluids in the Chulai High-Temperature Geothermal System

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摘要

經濟部地質調查及礦業管理中心已全面啟動地熱潛能區探勘調查工作，近年針對臺東縣海端鄉初來地區完成地下地球物理探勘等地質調查工作，對於該區地表與地下地熱潛能範圍的空間分布已有瞭解及掌握，規劃本計畫「東部變質岩區地質鑽井及資源測試」進行核心潛能區探勘井鑿設CL01號井-1500公尺及產能測試，以驗證初來地區地熱探勘成果，並提供該區後續電廠規劃之參考。工業技術研究院於本案執行井下溫壓量測、噴流試驗及深層流體取樣與分析等工作。

本案採用高溫高壓井下採樣設備(PDS)，於不同深度成功取得五組流體樣本，最大壓力約130barG、最高溫度160˚C。水化學分析顯示，CL01 地熱流體隨深度呈高鹽度與高溫特徵，屬NaCl型成熟水體，反映深部強烈的水岩相互作用。碳氫氧同位素分析證實流體未受鑽井泥漿污染，僅淺部樣本具微量地下水混入跡象；氣體成分以大氣來源為主，但靜態條件下可辨識深部地殼訊號。地質溫度計推估結果顯示，深層儲集層溫度可達173~183˚C，高於產能測試溫測結果(~164˚C)，顯示井底深處可能存在更高溫的流體供給。開發風險方面，LRI指數顯示流體具強烈腐蝕潛勢，為管材選用之首要挑戰；結垢風險則相對低。

PDS 採樣技術確保了樣本在保壓狀態下不發生相變，精準還原儲層資訊。工研院具備豐富實績，該設備已成功應用到高溫高壓條件，最高140 barG、溫度207˚C。其應用範疇除地熱開發外，更可擴及至石油與天然氣探勘、碳封存及深部地下水環境調查等領域。本研究成功掌握初來地區深部流體之化學特性，不僅驗證其地熱潛能，相關分析數據更可作為東部變質岩區資源開發的重要科學佐證，並為後續跨領域的深層流體研究提供技術參考。

關鍵字：地熱、井下採樣、地球化學、同位素

Keyword：Geothermal、Downhole Sampling、Geochemistry、Isotopes

General Poster GP167

台灣東北部 Y 井伊利石化學特徵及其對古溫壓之指示意義

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摘要

Y 井位於蘭陽平原西緣，地處琉球隱沒系統中，沖繩海槽向西擴張並進入台灣東北部的位置。在弧-陸碰撞階段，深埋的變質砂岩與板岩受擠壓抬升並剝蝕出露，構成雪山山脈北段受低度變質作用影響的構造單元。自更新世以來，隨著沖繩海槽持續向西擴張，台灣東北部轉入伸張構造環境，地殼張裂引發的潛在岩漿活動，被視為造成本區高熱流環境的主要機制。本研究針對 Y 井不同深度的變質岩屑進行伊利石 EDS 分析，透過在剖面上的化學特徵與結晶溫度估算，解析該區域的溫度演化。

本研究分析結果顯示，伊利石中的 Al 與 Si、(Fe+Mg)呈現高度負相關，反映其化學組成因溫度影響發生離子替代作用。各元素特徵在約 4,000 公尺的深度跨度內表現出極高的一致性，表示 Y 井剖面曾經歷相似的變質事件，可以排除後期局部熱液干擾的可能性。從結晶溫度指標來看，全剖面的古變質溫度介於 260 – 270°C 之間，且缺乏隨深度遞增的熱梯度；而從樣本呈現 3.2 – 3.4 apfu 的高 Si 含量特徵，推測當時的高壓環境估計達 6 – 7 kbar。此現象暗示該區地層曾作為整塊岩體處於極深埋位置，隨後整體被推擠抬升至現今深度。

General Poster GP168

臺灣海域台西盆地南部深部地層之有機物特性與沉積環境

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摘要內容

本研究針對台西盆地南部地區中新統及其下深部各地層之有機質特性進行評估，以及釐清該區域在漫長地質年代中的沉積環境演變。為掌握地層中有機質的組成，本研究運用氣相層析質譜儀（GC-MS）以及氣相層析串聯質譜儀（GC-MS/MS）從複雜的碳氫化合物中獲取脂肪烴與多種生物指標的完整地球化學資訊，為後續探討有機物特性與沉積環境提供了科學化的基礎。

在探討有機質來源與沉積時的水體性質時，類異戊二烯烷烴與正烷烴(Pr/n-C_{17} 及 Ph/n-C_{18})的關聯圖分析扮演了關鍵角色。分析結果顯示，研究區內地層的有機質並非單一來源，而是展現出顯著的海、陸混合來源特徵，這說明當時的沉積區域可能深受海岸線變動與陸源碎屑輸入的雙重影響。從整體環境來看，這些有機質主要沉積於一種氧化與還原作用交替的過渡地帶。然而，在木山層與五指山層沉積時期，分析數據顯示陸源物質的輸入量顯著攀升，且環境整體的氧化程度也隨之提高。

進一步細化沉積環境，利用了 C_{27}-C_{28}-C_{29} 類固烷(Steranes)的三元分佈圖解析，清楚觀察到從始新統至中新統，其沉積特徵高度符合淺海環境。綜合上述各項地球化學指標的演變趨勢，評估台西盆地南部自始新統演進至中新統的沉積過程中，水體逐漸變淺以及環境中含氧量程度增加。雖然陸源有機質的供應看似豐富，但這種偏氧化的環境，本質上會加速有機質的氧化，進而導致有機質的保存條件嚴苛。因此，從始新統至中新統這種「淺海化與氧化增強」的趨勢，可能會限制了生油岩在地層中的發育與保存潛力。

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General Poster GP169

Landslide-Induced Reorganization of Carbon Pathways and CO_2 Evasion in Eastern Taiwan

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Abstract

Chemical weathering regulates the global carbon cycle through its sensitivity to erosion. In active orogens, the exposure, transport, and retention of freshly eroded materials reorganize weathering pathways, shifting the balance between silicate CO_2 consumption and carbonate-derived CO_2 release. Large landslides, by perturbing sediment supply and hydrological stability, can alter carbon budgets across transient to geological timescales; however, the underlying mechanisms remain poorly constrained.

In July 2025, a massive landslide in Taiwan's Central Range mobilized 320 million m^3 of material, forming a dam at the Mata'an River confluence between the mainstem and a tributary. A subsequent September typhoon breached this dam and released ~52 million m^3 of sediment, providing a natural laboratory to investigate weathering dynamics. Leveraging high-frequency hydrochemical data, we resolve landslide-driven shifts in weathering end-members. Compared with a decade earlier pre-event baseline, landslide-triggered sulfide oxidation significantly stimulated carbonate weathering, outpacing carbonic acid-driven silicate weathering. This dominance later shifted toward carbonic acid-driven carbonate weathering as dam-breaching effects waned.

The CO_2 yield during this event was comparable to 2013 levels, but an order of magnitude higher than 2014 and a neighboring catchment with similar geology. These patterns are driven by dynamic changes in landslide intensity, hydrological drainage, and the mobilization of hillslope and fluvial materials. Overall, landslide-associated bank sediments serve as a persistent, critical source of CO_2 evasion in rapidly eroding mountain systems.

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General Poster GP170

濁水溪河階台地土壤主要元素分布與遷移行為之研究

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摘　要

土壤風化作為地球表層系統中關鍵的地球化學過程之一，不僅影響元素循環、土壤肥力、地貌演化，並且與碳循環及氣候調節密切相關。以濁水溪流域形成的河階台地是臺灣重要地形，其土壤發育及風化過程具有重要的研究價值。過去研究已針對濁水溪河階台地土壤風化進行討論，但對於土壤剖面中主要元素的累積、流失等情形仍有待釐清。因此，本研究分析濁水溪河階台地土壤剖面中主要元素濃度的變化，並探討風化作用與元素遷移之行為。本研究以濁水溪河階台地八卦、竹山與斗南的六個土壤剖面作為研究標的，進行化學組成分析。樣品先透過前處理去除土壤中的有機質與碳酸鹽礦物後，分別使用酸溶法(HF-HNO3)及鹼溶法（NaOH與Na_2CO_3混合）融樣，再利用感應耦合電漿放射光譜儀(ICP-OES)進行測定化學組成；此外，使用X光繞射儀(XRD)及TOPAZ分析與量化土壤剖面中礦物相轉變。本研究將結合礦物成分和化學風化指標，評估元素分佈及遷移。

General Poster GP171

Biogeochemical and mineralogical approaches for turbidity mitigation and Pb/Cd removal using Natural Reservoir Clay

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Abstract

Lead (Pb), cadmium (Cd), and arsenic (As) are persistent inorganic contaminants that can be mobilized by natural weathering and anthropogenic disturbance, thereby generating coupled challenges for water-quality protection and sediment management. This study evaluates an environmentally focused remediation concept that integrates mineral-surface adsorption for metal

sequestration with biogeochemically enabled turbidity control. Natural-reservoir-clay (NRC) collected from Shimen Reservoir (Taiwan), characterized by XRD and XRF, indicating a clay mineralogy dominated by kaolinite/montmorillonite, which is enriched in SiO_2-Al_2O_3-Fe_2O_3 phases, provide reactive surfaces for sorption. Batch experiments conducted at near-neutral pH7 and 27°C demonstrate that low NRC dosages (0.03-0.05g) rapidly and effectively remove Pb, achieve moderate Cd removal, show comparatively limited performance for As, consistent with differential metal-mineral affinities. At 0.03g NRC, Pb attenuation is essentially instantaneous (>99%, 10s), whereas Cd approaches high removal within ~60s. Equilibrium data are more accurately described by Langmuir-isotherm than by Freundlich model, supporting predominantly monolayer uptake, and kinetic behavior follows a pseudo-second-order rate law, indicating surface-controlled adsorption. Because clay amendment elevates turbidity to several hundred NTU, urease derived from *Sporosarcina pasteurii* applied as a bio-clarification step, reducing turbidity to low-tens. Under optimized coupled treatment (NRC + urease), simultaneous removal of Pb (>99%) and Cd (>94%) was achieved while markedly lowering turbidity relative to clay-only conditions.

Keywords

Biogeochemical turbidity control, Natural reservoir clay, Heavy metal adsorption, Lead and cadmium removal, Urease-mediated clarification.

General Poster GP172

以天然及合成磁性礦物移除砷污染物

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摘　要

本研究旨在比較天然與合成磁性微粒對水中砷 (As) 的移除效能。研究中使用取自台灣陽明山國家公園之天然磁石，經分析含有菱鐵礦、赤鐵礦或磁鐵礦等礦物成分。合成磁性微粒則是利用巴氏芽孢桿菌 (Bacillus pasteurii) 與腐植酸 (HA) 進行生物引發共沉澱法製得，產生 γ-Fe2O3 變體。本研究透過 SQUID振動樣品磁強計 (VSM) 評估磁力，並使用雷射粒徑分析儀 (LS Particle Size Analyzer) 分析粒徑大小。批次吸附實驗於 25°C 下進行，設定砷濃度為 2 ppm，並測試不同吸附劑劑量 (10 mg 至 100 mg) 及 pH 值 (3-9) 之影響。吸附容量係根據磁力與比表面積進行測定。實驗結果顯示，合成與天然材料均展現出良好的砷移除能力，並具有永續回收之潛力。

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General Poster GP173

Petrogenesis of the Korba Granites: implications for Mesoproterozoic tectonomagmatic evolution of the Central Indian Tectonic Zone(CITZ)

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Abstract

The 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). There are a number of batholiths within the CITZ that record different stages of crustal evolution that culminated during the terminal stages of collision at 1000-850 Ma. The '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 first geochemical and geochronological results from the Korba granitic rocks. Granites, pegmatites, and meta-sedimentary rocks were collected from Korba District, Northern Chhattisgarh. The *in situ* zircon U-Pb geochronology results indicate an Early Mesoproterozoic (1565.9 ± 6.8 Ma) emplacement age. The granites (SiO_2 = 60-76 wt%) are peraluminous, alkali-calcic to calc-alkalic, ferroan in composition. The $\varepsilon_{Hf}(t)$ values of Korba granites range between -6.6 and +4.6. The sillimanite-bearing pegmatites zones are found throughout the upper parts of the Korba granites suggesting that there was period of late stage Al-rich fluid fluxing. Moreover, blocks (1−10 m wide) of meta-sedimentary rocks are found within the granites and may represent a roof pendant. The Korba granites are mineralogically and compositionally similar to granitoids derived by partial melting of sedimentary rocks during crustal thickening associated with collision. The results of this study suggest that there was a regional collisional event ~500 million years before the Neoproterozoic terminal collision, which is also likely recorded by the Sauser group at southwest side of CITZ. We suggest that it was rifted continental crust from the Southern India Craton that collided with the Northern Indian Craton during the Early Mesoproterozoic.

Key words：Central Indian Tectonic Zone, peraluminous granite, sillimanite-bearing pegmatite, geochemistry, zircon U-Pb geochronology

General Poster GP174

澎湖群島中新世沉積物碎屑鋯石鈾鉛定年與鉿同位素特徵

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摘　要

澎湖群島位於華南大陸（South China Block, SCB）邊緣，主要由中新世（15~8 Ma）板內張裂玄武岩所構成。被動大陸邊緣的玄武岩熔岩流與沉積物互層的近岸環境，形成了一個良好的源—匯（source-to-sink）系統地體控制點。本研究針對澎湖群島沉積物中的碎屑鋯石進行鈾鉛定年與鉿同位素分析，並透過與鄰近地體資料比對以探討其物源來源。結果顯示，澎湖群島前寒武紀鋯石比例高達約 60 %，其年齡分佈特徵與東海盆地基盤（East China Sea Basin, ECSB）相似，而不同於華南大陸本身。

依據玄武岩之定年結果，本研究將澎湖群島沉積層分為三階段，其鋯石年齡群百分比、鋯石顆粒大小、形狀、淘選度在三個沉積階段中呈現漸進式變化。第一階段（15~12 Ma）以小型、顆粒圓滑、淘選度良好的前寒武紀鋯石為主，占總族群約 70 %。第二階段（12~10 Ma），前寒武紀鋯石比例下降至 61 %，第三階段（10~8 Ma）則進一步降低至 47 %。值得注意的是，第三階段出現大量大型、具稜角且淘選度差的鋯石型態，顯示物源距離顯著縮短，具有近源供應特徵，且相較前兩期樣本富含白堊紀（~120 Ma）鋯石。然而，華南大陸內普遍缺乏 ~120 Ma 之白堊紀鋯石族群。由第一階段至第三階段，鋯石鈾鉛年齡譜呈現~120 Ma 鋯石增加，且顆粒尺寸、稜角度增加與淘選度變差的趨勢，支持 10 Ma 之後的沉積物有近供應源加入之解釋。

綜合台灣西部麓山帶碎屑鋯石研究成果，本研究支持澎湖地區於晚中新世期間（~10 Ma）接受來自北港高區（Peikang High）之沉積物供應，此與菲律賓海板塊（Philippine Sea Plate, PSP）之隱沒作用造成北港高區的抬升、剝蝕有關。本研究不僅修正了東亞大陸邊緣中新世之源—匯系統架構，同時也透過澎湖群島碎屑鋯石年齡譜與鋯石顆粒變化特徵，揭示台灣造山運動前期的時間。

關鍵字：碎屑鋯石、鈾鉛定年、鉿同位素、澎湖群島、北港高區

General Poster GP175

由三地門-知本剖面變質度定量約制探討台灣脊梁山脈碰撞造山初期構造演化

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菲律賓海板塊火山島弧持續斜向地撞上歐亞大陸邊緣，造就台灣島至今活躍的蓬萊造山運動。台灣島之主脊—脊梁山脈橫跨被動大陸邊緣沉積物蓋層變質而來的西板岩帶、東板岩帶，以及核心區域曾為先第三紀變質基盤的太魯閣帶、南海海洋岩石圈與中新世深海沉積物混合變質的玉里帶，其由北至南傳遞的造山演化為蓬萊造山運動的弧-陸斜向碰撞提供重要證據。惟造山帶變質基盤與沉積蓋層之關係、構造掘升歷史等問題仍有所爭議。

藉由變質度之定量測定配合前人研究進行地質構造約制，對於釐清造山帶之演化歷程至關重要。透過碳物質拉曼光譜（Raman spectroscopy of carbonaceous material，RSCM）地質溫度計，可測量脊梁山脈所含大量板岩與石英雲母片岩中碳物質受構造深埋再掘升回地表前曾於地殼中所獲之峰值變質溫度。本研究選定脊梁山脈南段位處初始弧-陸碰撞至成熟階段過渡區域之三地門-知本剖面，透過高空間解析度的逐公里岩石採樣，共獲 33 筆 RSCM 數據，填補前人數據除了位處成熟碰撞造山區域之中橫、南橫公路以外僅集中於山脈兩翼邊緣之不足，延續前人之構造演化歷史探討。

綜合初步 RSCM 定量變質度約制、野外調查與薄片觀察結果，脊梁山脈三地門-知本剖面至北側相距 40 公里之南橫區域構造、岩性延伸性佳，而峰值變質溫度卻有顯著差異。相較於南橫至中橫公路沿剖面連續漸變且高達約 500°C 之趨勢，本剖面核心最高溫度驟降約 150°C。然而，除板岩外仍有高度變形的石英雲母片岩出露，顯示於此溫度區間，板岩、片岩之發育並未受單一溫度邊界控制，而可能受局部應變不均影響。此外，峰值變質溫度沿剖面變化甚小，僅於西部板岩帶有約 60 度之連續遞減，顯示退變質掘升過程中部分區域並未有劇烈構造變形，大致呈現碰撞初期底部加積（Basal accretion）作用下的構造深埋疊加變質。綜上所述，本研究將搭配前人變質度、熱年代學等資料，藉由定量變質度約制提出台灣脊梁山脈蓬萊造山初期可能之地質構造演化模型。

Geochemical characteristics of antigorite serpentinites from the Yuli belt, eastern Taiwan: implications for protolith affinities and subduction-related metasomatism

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Antigorite serpentinites occur within exhumed high-pressure metamélange units of the Yuli belt in eastern Taiwan. These antigorite serpentinites were subjected to multiple stages of serpentinization and metamorphism. However, the geochemistry of these antigorite serpentinites has not yet been systematically investigated. This study provides the first geochemical characterization of antigorite serpentinites from all metamélange units in the Yuli belt aiming to interpret their protolith affinities and fluid-related serpentinization and metamorphism. Bulk-rock major- and trace-element compositions indicate that the antigorite serpentinites were derived from depleted mantle peridotite protoliths, predominantly of harzburgite–dunite composition. These antigorite serpentinites exhibit geochemical features typical of subducted-type serpentinites, as indicated by trace-element and rare earth element patterns similar to those of compiled harzburgite-derived subducted serpentinites. Enrichment in fluid-mobile elements (Cs, Ba, U, Sr, and Pb) and light rare earth elements indicates the involvement of externally derived fluids from the dehydration of subducted materials. Although some serpentinites may have been influenced by ocean-floor serpentinization, no distinct seawater-related signature was observed, likely owing to overprinting by subduction-related processes. This study demonstrates that antigorite serpentinites preserve records of fluid–rock interaction driven by fluids released from the dehydration of subducted materials along the slab–mantle interface.

Keywords: serpentinization, fluid-rock interaction, slab-mantle interface, subduction zone

General Poster GP177

Structural Anatomy of the Southern Central Range, Taiwan: Implications for Mountain Building Processes

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Abstract

Tectonic deformation, surface erosion, and their interaction contribute to mountain growth and crustal exhumation in orogenic belts, with crustal thickening or thinning accommodated by diverse structural features. In the Taiwan orogen, however, the structural processes dominating tectonic deformation remain debated. Here we integrate LiDAR-based geomorphic analysis, UAV imagery, field observations, and microstructural studies to investigate deformation structures and the controls on the structural framework of the southern Taiwan metamorphic hinterland (Central Range). Our results show that the western Central Range is dominated by top-to-foreland reverse shear (forethrusting), whereas the eastern segment records sinistral-dominated transpression. These structures formed near peak metamorphism and were locally overprinted during cooling by top-to-arc reverse shear (backthrusting) and extensional deformation. By integrating our observations with geological and geophysical constraints, we propose a tectonic model for mountain building and exhumation in southern Taiwan. Eastward underthrusting of the Eurasian margin produced forethrusting and east-dipping nappe stacking, while oblique convergence generated sinistral-dominated transpression in the eastern Central Range, together leading to significant crustal thickening. This thickening promoted shallow-crustal gravitational collapse and enhanced erosion that facilitated uplift and exhumation, while forearc lithosphere subsidence likely drove backthrusting and rotation, collectively shaping the structural architecture of the southern Taiwan metamorphic hinterland.

General Poster GP178

弧前盆地關閉的構造與運動學：海岸山脈奇美–太巴塱地區水璉盆地的見解

Structure and Kinematics of Forearc Basin Closure: Insights from the Suilian Basin in the Tafalong–Chimei Region, Coastal Range

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Abstract

The kinematics of basin closure play a fundamental role in the crustal-scale development of fold-and-thrust belts. Quantifying shortening along associated structures is therefore critical for understanding the tectonic framework and mountain-building processes of the Coastal Range. However, reconstructing this process remains challenging because of the limited availability of onshore data.

In this study, we constructed a series of balanced cross-sections based on closely spaced profiles integrated with high-resolution LiDAR-assisted geological interpretation. The LiDAR-derived digital elevation model (DEM) reveals subtle topographic variations without interference from vegetation cover, thereby enabling systematic regional-scale mapping of sedimentary sequences and fold geometry. The dense and evenly distributed geological data provide robust constraints, making it possible to construct cross-sections at intervals of only a few kilometers.

Combined with stratigraphic relationships and constraints from paleomagnetic and biostratigraphic evidence within the Paliwan Formation and the Chimei fault block, the newly constructed NW–SE-oriented balanced profiles across the Tafalong–Chimei region indicate a progressive increase in shortening toward the north. Geological constraints derived from LiDAR-assisted bedding interpretation suggest that shortening reaches at least 12 km in the Chimei area and exceeds 20 km in the Tafalong area. This spatial pattern implies a possible anticlockwise rotation during the late stage of basin closure.

中國龍門山與紐西蘭南阿爾卑斯山的熱－力耦合造山楔形體模型

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摘　要

本團隊研究建立熱–力耦合造山楔形體（orogenic wedge）模型，結合深度相關脆性-韌性轉換與地質構造幾何，可再現台灣造山帶主要構造單元、變質溫度分布、熱定年特徵及抬升–冷卻歷史。在此基礎上，將相同架構延伸於中國龍門山與紐西蘭南阿爾卑斯山，以檢驗楔形體模型於不同邊界條件與地殼流變性質下的適用性。

龍門山位於四川盆地與青藏高原交界，具有顯著地形梯度。該區於中生代經歷造山，新生代受印度–亞洲板塊碰撞遠場效應影響再次活躍。低溫熱定年學顯示，龍門山南段斷層上盤 ZFT 年代約 10~14Ma，向西北增加至 25~31Ma，高原區呈現 partial reset 至 unreset age (100~200Ma)；造山前緣 AFT 年代約 3~5Ma，向高原增加至 8~26Ma，顯示剝蝕集中於逆衝帶。為模擬新生代造山，本研究於盆地與龍門山交界設置斷坡，使變形集中於逆衝帶，邊界速度為 0.15 cm/yr，並加入中生代既有的地形。儘管龍門山形成機制有多種解釋（如 crustal flow），模型顯示以上部地殼縮短即可再現熱定年特徵與地形變化。

南阿爾卑斯山位於澳洲-太平洋板塊交界，板塊斜向聚合作用集中於 Alpine Fault，其中中段為擠壓變形與抬升最集中的區域，本研究聚焦於中段造山作用。低溫熱定年學顯示抬升始於約 7–5Ma，Alpine Fault 附近 AFT 與 ZFT 年代極為年輕（0–2 Ma），年代向東南向逐漸增加，顯示剝蝕集中於斷層上盤。本研究於 Alpine Fault 設置約 30°傾角斷坡，模型邊界速度為 0.5 cm/yr，並考慮東西兩側降雨差異造成之剝蝕速率差異。模型結果顯示抬升集中於主要斷層上盤，且與熱定年學特徵相符，並呈現西側迎風面較高之抬升速率。

綜合三個造山帶結果，顯示造山帶構造受邊界條件、地殼流變性質與侵蝕作用控制，並可於統一楔形體架構下描述，顯示模型具有良好延伸性與適用性。

關鍵字： 造山楔形體 、熱–力耦合模擬、低溫熱定年學、剝蝕抬升、龍門山、南阿爾卑斯山

Keywords: orogenic wedge, thermo-mechanical modeling, low-temperature thermochronology, exhumation, Longmen Shan, Southern Alps

Arsenic Cycling and Environmental Risk in Hydrothermal Systems of Taiwan

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Abstract:
Hydrothermal systems play a critical role in controlling groundwater chemistry through intense water–rock interactions that mobilize trace elements, including arsenic (As). This study presents the first comprehensive hydrogeochemical reconnaissance of arsenic cycling in hydrothermal springs across Taiwan, aiming to evaluate its environmental behavior, speciation, and potential risk to surface and groundwater resources. Water samples from sixteen geothermal springs representing igneous, metamorphic, and sedimentary geological terrains were analyzed for physicochemical parameters, major ions, trace elements, and arsenic species [As(III) and As(V)]. Results revealed three dominant hydrochemical facies: acidic sulfate-rich waters (H–SO_4 type), circum-neutral Na–HCO_3 waters, and alkaline Na–Cl–HCO_3 waters. Arsenic concentrations ranged from 0.036 to 1.456 mg/L, exceeding the World Health Organization guideline value (10 µg/L) in all sampled springs. The highest arsenic levels were observed in springs hosted in igneous terrains, followed by sedimentary and metamorphic settings. Arsenic speciation showed a dominance of the more toxic and mobile As(III) form in most waters, indicating reducing hydrothermal conditions favorable for arsenic mobilization. Positive correlations between arsenic and iron, manganese, phosphorus, and boron suggest strong geochemical coupling between arsenic release and mineral dissolution processes. The discharge of arsenic-rich geothermal waters into surface streams and shallow aquifers represents a significant environmental and public health concern, particularly for drinking and irrigation water resources near geothermal zones. This study highlights the importance of geological setting and hydrothermal processes in arsenic cycling and provides critical baseline data for environmental risk assessment and groundwater management in tectonically active regions such as Taiwan.

Keywords:
Arsenic contamination, Hydrothermal springs, Groundwater geochemistry, Arsenic speciation, Environmental risk, Taiwan

Student Poster SP002

Furfural Removal from Industrial Wastewater Using Indigenous *Pseudomonas putida* and *Pseudomonas aeruginosa* with Low-Cost Suphala Fertilizer: Process Optimization for Field Application

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Abstract

Furfural is a toxic organic compound commonly released in effluents from petrochemical and oil-refining industries, causing serious environmental and health concerns. Eco-friendly and cost-effective remediation strategies are therefore essential. This study investigates the potential of indigenous bacterial strains for the biodegradation of furfural under aerobic conditions using a low-cost nitrogen–phosphorus fertilizer (Suphala) as a nutrient source. Two bacterial isolates, OSBH3 and OSBH4, obtained from furfural-contaminated oily sludge, were identified through 16S rRNA gene sequencing as *Pseudomonas putida* and *Pseudomonas aeruginosa*, respectively. Batch degradation experiments revealed that *P. putida* showed superior furfural removal efficiency compared to *P. aeruginosa* under all tested conditions. Complete degradation of 500 mg/L furfural was achieved within 12 h in the presence of Suphala-amended media. The effects of nutrient concentration, glucose supplementation, and pH on furfural degradation were systematically evaluated. Optimal conditions were determined as 1 mg/L Suphala, 2 mg/L glucose, and pH 7.2. A Taguchi L9 orthogonal array design confirmed Suphala concentration as the most influential parameter, followed by pH and glucose. The results also indicated that *P. putida* utilized furfural as the sole carbon source, converting it primarily into acetic acid. Overall, the findings demonstrate that indigenous *P. putida* combined with inexpensive fertilizer-based media offers a promising, sustainable, and field-applicable approach for the bioremediation of furfural-contaminated industrial wastewater.

Keywords:

Furfural biodegradation; *Pseudomonas putida*; Industrial wastewater; Bioremediation; Suphala fertilizer; Taguchi optimization

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Tidal controls on mangrove carbon sequestration and burial: Implications for climate change mitigation

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Abstract

Mangrove ecosystems are important blue carbon landscapes, yet carbon stocks, burial rates, and source contributions vary substantially along tidal gradients in subtropical estuaries. This study quantified ecosystem carbon stocks, recent sediment carbon burial, and organic carbon sources across active tidal sediment (ATS), partially active tidal sediment (PATS), and an adjacent mudflat (MF) in the Puzi Estuary Wetlands, southwestern Taiwan. Carbon stocks were estimated by integrating aboveground biomass, belowground biomass, litter, and sediment organic carbon to a depth of 1 m. Sediment accumulation and carbon burial rates were reconstructed using excess ^{210}Pb dating, while organic carbon sources were resolved using δ^{13}C and C/N ratios within a Bayesian mixing model. Total ecosystem carbon stocks differed significantly among tidal settings, with the highest values in ATS (238.14 ± 9.99 Mg C ha^{-1}), followed by PATS (139.06 ± 11.62 Mg C ha^{-1}) and MF (69.56 ± 0.32 Mg C ha^{-1}). Sediments accounted for more than 50% of total ecosystem carbon across all zones. Linear sedimentation rates were higher in ATS (2.94 mm yr^{-1}) than in PATS (1.82 mm yr^{-1}), resulting in significantly greater mean carbon accumulation rates in ATS (0.449 ± 0.030 Mg C ha^{-1} yr^{-1}) compared with PATS (0.107 ± 0.006 Mg C ha^{-1} yr^{-1}). Mudflat sediments showed disturbed radionuclide profiles, preventing reliable burial estimates. Stable isotope signatures (δ^{13}C −28.1‰ to −23.9‰) and mixing model results indicated that sediment organic carbon was dominated by allochthonous inputs (≈88%), with smaller contributions from mangrove-derived and aquatic sources. These findings demonstrate that tidal inundation intensity and vegetation structure strongly regulate sediment carbon storage and burial efficiency, highlighting the importance of conserving hydrological connectivity and minimizing sediment disturbance to sustain blue carbon sequestration.

Keywords: Blue carbon, Mangrove ecosystems, Sediment carbon burial, Tidal gradients, Stable carbon isotopes

Sustainable removal of lead, cadmium, arsenic, and turbidity from contaminated water using natural reservoir clay and *Sporosarcina pasteurii* derived urease

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Abstract

Heavy metals (HMs), including lead (Pb), cadmium (Cd), and arsenic (As), are persistent inorganic pollutants that pose serious environmental and health risks. The present study investigates an eco-friendly approach for the simultaneous removal of HMs and turbidity from contaminated water using natural reservoir clay (NRC) and urease derived from *Sporosarcina pasteurii*. Removal efficiencies were optimized by varying initial HM concentrations (20–1000 mg L^{-1}), adsorbent dosage (0.01–0.7 g), and contact time (0–24 h) at neutral pH (7.0). Mineralogical analysis using X-ray fluorescence and X-ray powder diffraction revealed kaolinite and montmorillonite as the major components of NRC. The HM removal efficiency followed the order Pb > Cd > As. Notably, Pb removal reached 99% within 10 s at an initial concentration of 100 mg L^{-1}, while 99% Cd removal was achieved within 60 s from 80 mg L^{-1} at an adsorbent dose of 0.03 g. Urease derived from *S. pasteurii* significantly reduced water turbidity, as reflected by decreased NTU values. Combined treatment using NRC (0.3 g) and urease resulted in the simultaneous removal of >99% Pb, >94% Cd, and turbidity from contaminated water. Adsorption isotherm analysis (Langmuir and Freundlich models)

indicated favorable monolayer adsorption, supported by empirical constants ($n < 1$). Kinetic studies showed that HM uptake followed a pseudo-second-order model, suggesting chemisorption as the dominant mechanism. Overall, this green and sustainable approach demonstrates the effective removal of heavy metals and turbidity from water using NRC and *S. pasteurii*-derived urease, highlighting its potential for environmentally friendly water treatment applications.

Keywords: Heavy metal (Pb, Cd, and Ni) removal, Natural reservoir clay-material, Turbidity

Mechanistic Insights into Fluoride Adsorption on NaOH-Activated Lotus Seed Pericarp Biochar

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Abstract:

Fluoride contamination in groundwater poses a significant risk to human health and environmental sustainability, making the development of efficient and low-cost defluoridation technologies a critical challenge in water treatment. In this study, NaOH-activated biochar was synthesized from lotus seed pericarp (LSPB) by optimizing key pyrolysis parameters, including temperature, heating rate, and residence time (750 °C, 2 °C min^{-1}, 1 h, under N_2 atmosphere). The optimized biochar (LSPB-7) exhibited an amorphous carbon structure, as confirmed by XRD and SAED analyses, and a high specific surface area of 350 m^2 g^{-1}, comparable to previously reported biochars. LSPB-7 showed a maximum fluoride adsorption capacity of 8.6 mg g^{-1}. Equilibrium data were best described by the Freundlich (R^2 = 0.937) and BET (R^2 = 0.935) isotherm models, indicating multilayer adsorption on a heterogeneous surface, while kinetic behavior followed a pseudo-second-order model (R^2 = 0.99), suggesting chemisorption-controlled adsorption. The presence of competing anions (NO_3^-, Cl^-, SO_4^{2-}, and CO_3^{2-}) had minimal impact on fluoride uptake. Regeneration studies demonstrated that LSPB retained approximately 50% of its adsorption capacity after five adsorption-desorption cycles, highlighting good reusability. Spectroscopic analyses revealed that hydrogen bonding, electrostatic attraction, and surface complexation govern the adsorption mechanism. Density functional theory (DFT) calculations further confirmed enhanced fluoride adsorption energy on NaOH-activated carbon. Overall, the synthesized LSPB shows strong potential as a sustainable and cost-effective adsorbent for field-scale defluoridation.

Key words: Biochar; Fluoride; Regeneration; Adsorption Mechanism; DFT

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Student Poster SP006

Linking Sea Temperature to Oyster Shell Chambering

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Abstract

Chambering structures in oyster shells represent interruptions in biomineralization between successive aragonite and calcite layers, and was historically attributed to tributyltin (TBT) contamination. Although TBT had been banned for two decades, chambering in oyster is still common, indicating that environmental factors beyond heavy metal pollution, such as seawater temperature or pH may significantly influence biomineralization in shell. To investigate the environmental controls on oyster shell chambering, this study integrates multiple analytical techniques, including micro-computed tomography (Micro-CT), micro-X-ray fluorescence (Micro-XRF) elemental analysis, micro-Raman spectroscopy, and cathodoluminescence (CL) imaging. Cultured and wild oyster shells collected from the western coast of Taiwan were systematically examined. Non-destructive Micro-CT analysis used to evaluate the relationship between the shell thickness index (STI) and internal chambering characteristics. In wild oysters, a significant negative correlation was observed between STI and both chamber number and chamber volume ($P < 0.01$, $n = 21$), whereas no statistically significant relationship was found in cultured specimens, indicating that STI is not a universally applicable proxy for shell chambering. Micro-XRF and CL analyses further demonstrate that the formation of chambering structures is not directly linked to organotin or heavy metal contamination, but is instead associated with temperature-influenced biomineralization processes. Elemental mapping reveals enrichment of Mn and Fe within chamber regions, suggesting secondary incorporation during or after chamber formation. In addition, adjacent aragonitic layers exhibit elevated Sr/Ca ratios (~0.3), indicative of calcification under relatively high seawater temperatures. Consistently, these regions display strong red cathodoluminescence, attributed to Mn activation, reflecting temperature-dependent trace element incorporation and crystal growth kinetics. The spatial co-occurrence of elevated Sr/Ca ratios, Mn enrichment, and intense CL signals defines a coupled temperature–trace element–luminescence system, suggesting that chambering structures record growth under elevated temperature conditions rather than simple pollutant exposure. By integrating non-destructive imaging with shell geochemical analyses, the study establishes link between oyster shell chambering and seawater temperature, identifying temperature as environmental factor control on oyster shell biomineralization.

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(2) Degree/Grade：**Master**

Student Poster SP007

Priming effect on petrogenic organic carbon degradation in the aquatic system

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Abstract

In rapidly eroding mountain belts such as Taiwan, rivers transport significant quantities of petrogenic organic carbon (OC_{petro}), which can be oxidized, thereby releasing previously underestimated CO_2. One potential mechanism is the priming effect (PE), in which the addition of labile organic matter (LOM) accelerates the mineralization of recalcitrant organic matter (ROM). Although well studied in soils, PE in aquatic systems remains unclear. We hypothesize that: (1) LOM addition stimulates OC_{petro} degradation via PE, and (2) PE intensity varies according to the type of LOM added and the source of the microbial community. To test these hypotheses, incubation experiments used estuarine sediments from the Beinan River as the ROM and OC_{petro} source, river water or seawater as microbial inoculants, and ^{13}C-labeled glucose, algae, or plant-derived LOM as PE trigger and tracer. PE intensity was quantified based on the ^{13}C content of dissolved inorganic carbon (DIC) relative to treatments without ^{13}C-labeled LOM. Results from river water incubations showed an initial increase in DIC concentration, followed by a decline during later stages, suggesting additional DIC-consuming processes. Meanwhile, PE intensity in bulk sediments varied strongly during the early stage, with higher intensity in the algae-added treatment and lower in the plant-added treatment. The following analyses of rhenium concentrations will be used to quantify OC_{petro} degradation. This study highlights the potential role of priming effects in enhancing sediment organic carbon oxidation in rapidly eroding landscapes.

Keywords: carbon cycling, priming effect, petrogenic organic carbon, isotope labeling

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Efficacy of *Bacillus subtilis* for Heavy Metal Immobility in Industrial Soil in Chunghua County, Taiwan

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Abstract

Indigenous microorganisms in soil can form minerals or stabilize inorganic pollutants including heavy metals by restricting their mobility in soil. Therefore, this study focused on the immobility of chromium (Cr), copper (Cu) and zinc (Zn) by *Bacillus subtilis* through the changes of metal fractions in soil. The bacterium was isolated from an industrial soil sample in Chunghua, Taiwan and used for treating the soil sample polluted by Cr, Cu and Zn as a bioremediation way. The changes of these metals including bioavailable, carbonate-bound, iron and manganese oxide-bound, organic-bound and residual fractions were analyzed to determine the heavy metal immobility capacity of the bacterium in soil. Furthermore, the activity of urease and dehydrogenase in soil were measured to determine the transformation from bioavailable fraction with high mobility to residual fraction with low mobility. The result showed that *Bacillus subtilis* was efficacy for the immobility of Cr, Cu and Zn with residual fraction of 57, 97 and 98 %, respectively. Furthermore, the activity of urease and dehydrogenase in treated soil with *Bacillus subtilis* increased by 40.7% and 4.84%, respectively, compared to control without treatment. This study investigated that *Bacillus subtilis* can survive in the environment with high heavy metals and restricts the mobility of heavy metals in soil, thus it can play important role in bioremediation for soil polluted by heavy metals.

Student Poster SP009

應用雙段式風場與沿岸阻力係數校正提升暴潮模擬精度：以2025年丹娜絲颱風為例

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摘　要

2025年7月，中度颱風丹娜絲以罕見路徑登陸臺灣西南部，在臺南七股等沿岸地區引發嚴重海水倒灌，凸顯了當地暴露於暴潮災害下的脆弱性，以及暴潮預報準確度提升可為當地帶來顯著的貢獻。

潮位觀測資料顯示此次事件呈現與以往暴潮事件不同的特徵，特別是東石潮位站在颱風登陸時出現明顯的「先降後昇」現象，顯示颱風登陸臺灣西南部前後對該站點產生顯著的風剪力效應。現有暴潮預報技術在本次作業預報中暴露出重要瓶頸，未能準確捕捉東石站的異常潮位變化特徵，顯示現行模式在處理複雜地形條件下的風場與潮位交互作用仍有改進空間。

本研究所使用之暴潮系集預報模式，是基於COMCOT模式透過颱風氣象力（氣壓梯度力及風剪力）之加入，具備以非線性之淺水波方程式計算並分析風暴潮生成、傳播以及近岸溯上之完整歷程。COMCOT風暴潮模式在統御方程式中加入了颱風氣象力之影響，可由氣壓梯度項（Pressure Gradient Term）和風剪力項（Wind Shear Stress Term）等來描述風暴潮之傳遞行為。

本研究透過以下方法對預報系統進行改進。首先，將計算邊界之地形解析度從 1 km 提升至 200 m，以更精確地描述近岸地形效應 ；其次，開發雙段式理想風場模型（Two-Segment Model），將風場結構分為內外兩段描述，針對丹娜絲颱風窄小且集中的強風特徵進行描述，克服了傳統模型分布過廣的問題 ；最後，針對阻力係數（Cd）在淺海環境不遵循深海「高風速飽和或下降」的假說，本研究引入 Charnock 參數並結合雙曲正切平滑因子，建構出隨風速陡增後趨於穩定之淺海專用阻力係數曲線 。模擬結果顯示，在考量瞬間最大陣風達 56-62 m/s 的情境下，結合優化後阻力係數的與高解析度地形，模式能高度吻合東石與將軍站之觀測水位 。本研究證實整合高解析地形、發展風場結構與淺海阻力係數修正，能顯著提升暴潮預報之精確度，為未來預報系統提供關鍵的科學校準依據 。

【學生壁報比賽】參與者於摘要尾端註記

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運用機器學習以建立現生珊瑚辨識系統

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摘　要

珊瑚礁生態調查必須長期依賴專業人工判視，然而在面對大尺度與長時間序列監測需求時，會受到觀測者差異與作業效率限制的影響。為能提升資料一致性與強化處理效率，近年來深度學習技術已逐漸成為珊瑚礁生態分析的重要工具。本研究提出一套基於深度學習之珊瑚語義分割框架，並以跨模型架構之系統性比較為核心，評估其於實際水下環境中的辨識效能與應用潛力。我們以台灣四大代表性海域（野柳、龍洞、墾丁及小琉球）為場域，建構高解析度標註資料庫，涵蓋六大珊瑚形態（分枝狀、表覆形、葉狀、團塊狀、桌狀及軟珊瑚），共計 2,166 顆珊瑚個體與超過 4.7 億像素影像。透過統一訓練流程，對 DeepLabV3+、U-Net 與 YOLOv11-seg 三種代表性架構進行基準測試，系統性比較其收斂特性、邊界辨識能力與運算效率，並分析其於異構硬體環境下之適應性。結果顯示，不同模型架構於應用上具有明顯功能分化。YOLOv11-seg 在即時推論與整體辨識效率上表現突出，其中 Large 模型於桌狀與表覆形珊瑚之 Mask mAP 分別達 0.811 與 0.771，顯示其對複雜形態邊界具優異擷取能力，適用於即時影像監測。相較之下，DeepLabV3+ 透過空洞卷積機制，在靜態影像中提供較高之空間解析度與覆蓋率量化精度，適合作為高精度生態指標分析工具；U-Net 則於資料規模受限情境下展現穩定但相對保守之表現。為能實現大面積範圍的分析，語義分割模型進一步整合至 25 m^2 正射影像與實際水下影片資料中，實現由局部影像辨識至大尺度空間製圖之跨尺度應用。儘管 SfM 拼接過程所產生之邊界偽影與幾何扭曲對分割精度造成一定影響，YOLOv11-seg 仍可於動態水下環境中穩定辨識珊瑚形態並即時生成遮罩，有效提升資料處理效率與監測連續性。此框架有效銜接精細生態量化與大尺度監測需求，為海洋生態調查提供具標準化、可擴展性與實務導向之自動化解決方案。

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP011

Spatial Patterns of Holocene Coral in Baishawan, Kenting, Southern Taiwan

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Abstract

Corals are ecologically significant organisms capable of preserving and reflecting long-term environmental changes in marine ecosystems. This study conducted a spatial analysis of coral distribution on the uplifted reef platform at Baishawan, Kenting, southern Taiwan, employing photogrammetry to document a survey area exceeding 400 m², from which a three-dimensional model was reconstructed and a two-dimensional orthomosaic image was generated for manual annotation. A total of 687 coral colonies were recorded and identified across five genera: *Acropora* (n = 317), *Platygyra* (n = 176), *Montipora* (n = 166), *Favites* (n = 25), and *Goniastrea* (n = 3), through manual annotation of the photogrammetric model. Within *Montipora*, 2 colonies were further identified to the species level as *Montipora foliosa*.

Hotspot analysis revealed a non-random, aggregated distribution pattern concentrated predominantly on spur structures, while grooves (14.19% of total area) exhibited little to no coral presence. Overall coral cover was estimated at 4.63%. The Simpson's Diversity Index (1 − D) of 0.66 indicates moderate dominance, with community structure largely governed by *Acropora*, *Montipora*, and *Platygyra*, were characterized primarily by encrusting and massive forms, reflecting that these morphotypes conferring greater structural resilience against wave action and disturbance. Two exceptionally large colonies were identified: a Favites colony (0.79 m², r ≈ 0.50 m) and a Platygyra colony (0.38 m², r ≈ 0.35 m), estimated at approximately 100–120 years old based on established linear extension rates (0.5–1.2 cm/yr). The age of these colonies, combined with geological records of local raised reefs dating to the early Holocene (~5,000 years B.P.; Peng et al., 1977). These findings contribute to a broader understanding of coral reef growth and preservation dynamics within the Holocene uplifted reef context at Baishawan.

Key words: Holocene uplifted reef, photogrammetry, spatial analysis, coral morphotypes

Student Poster SP011

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Student Poster SP012

Ocean Heat Transport Variability in the Western Pacific Warm Pool During the Last Deglaciation: Insights from TraCE-21ka

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Abstract

The Western Pacific Warm Pool (WPWP) serves as a pivotal nexus in the global climate system, undergoing profound thermal restructuring during major climatic transitions. Utilizing TraCE-21ka simulations, this study elucidates the evolution of the regional heat budget and identifies horizontal Ocean Heat Transport (OHT) as its primary determinant. While the overall intensification of OHT throughout the deglaciation (22–9 ka) is fundamentally anchored in rising ocean temperatures, millennial-scale fluctuations are predominantly modulated by ITCZ-induced perturbations in current velocity. Specifically, the latitudinal migration of the ITCZ reconfigures the tropical wind field, thereby shifting the equatorial current bifurcation point and redistributing the volume of warm water into its northward branches.

This kinematic regime, however, collapses during Heinrich Stadial 1. During this interval, a southward-shifting ITCZ theoretically favored the intensification of the Gulf of Papua Current; yet, this effect was precisely offset by a concurrent weakening of the South Equatorial Current, leaving the regional circulation virtually quiescent (+0.1%). Despite the absence of a kinetic surge, OHT nonetheless increased by 9.5%. This enhancement was underpinned by a thermodynamic warming signal—propagated from high latitudes via Antarctic Intermediate Water—rather than by velocity-driven flux. Such a decoupling underscores the functional independence of thermal and kinetic signals on millennial timescales, necessitating the use of independent velocity proxies to fully resolve the warm pool's heat budget.

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Student Poster SP013

「科學展覽作品的規律性議題分析」從時序與社群網絡探索學術趨勢

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摘要

地球科學中許多自然現象具有明顯的時間循環特徵，例如恆星演化週期、米蘭科維奇氣候循環、地震活動週期以及颱風生成與移動規律等。本研究以「時間序列規律」的觀點出發，探討科學研究主題是否同樣呈現類似的演化與循環特徵。研究蒐集全國科學展覽地球科學類(涵蓋天文、大氣、海洋與地質)歷年投稿與得獎作品資料，建立跨年度的研究主題資料庫，並透過多種資料分析方法，探索地球科學研究主題在教育場域中的發展趨勢與知識網絡結構。

在研究方法上，整合社群網絡分析(SNA)、PageRank 節點權重分析、時間序列模型(GRU)、樞紐分析(Pivot analysis)與關聯規則學習(Apriori)等方法，建構多模型整合分析架構。首先透過熱力圖與關聯規則進行整體趨勢掃描，再以社群網絡結構辨識研究主題之間的連結關係與核心節點角色，進一步結合時間序列模型分析研究主題在不同年代的演化變遷。研究結果顯示，部分專家與應用類別組合在長時間尺度上呈現穩定的研究動能，其中自然災害與風險評估類別在近年有明顯升溫的趨勢。透過整合2014~2025年時間切片、學籍別、關鍵字與研究類別等多維資料，建立了多維綜合指標 ω，用以評估研究主題與教師節點在知識網絡中的影響力與結構位置。

進一步分析師生合作網絡亦發現，部分教師在不同研究類別之間扮演跨領域橋樑角色，促成研究主題的交流與學生探究能力的培養。同時，將研究主題變化與重大自然事件(如地震、聖嬰-南方振盪與颱風)進行時間對照分析，結果顯示科展研究主題的產出與自然環境事件之間存在一定程度的回應關係，呈現「事件強迫vs. 知識回應」的刺激對應反應模式。整體而言，建構出一套結合社群網絡與時間序列分析的地球科學知識演化分析架構，不僅能解釋科展研究主題的長期發展脈絡，也可作為預測未來熱門研究方向與規劃科學教育發展的重要參考依據。

關鍵字 ： 規律週期,社群網絡, 時序分析, 綜合指標, 外部指標

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Student Poster SP014

山區公路擋土牆裂縫分布特徵與邊坡活動塊體判識之研究

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近年來，台灣山區道路、邊坡與擋土牆等基礎設施，因長期受降雨、風化與地形地質條件影響，易產生各類裂縫與破壞現象，進而提高邊坡失穩與道路災害之風險。傳統以人工巡檢為主之裂縫調查方式，於山區環境中受限於人力與時間成本，且高度依賴調查者經驗，難以進行大尺度且一致性之評估。因此，建立一套自動化裂縫辨識與量化分析方法，並探討其與邊坡災害風險之關聯，為目前工程監測與防災管理的重要課題。

本研究以台灣山區公路與擋土牆為研究對象，建立一套基於深度學習之影像辨識流程。首先透過 YOLO 模型進行裂縫之目標偵測與語意分割（detect 與 segment），自環景影像中自動擷取裂縫區域，並進一步裁切為獨立裂縫樣本。接著針對裂縫影像進行幾何特徵量化分析，包含裂縫長度、寬度、面積、密度、數量及展開程度等指標，建立可反映裂縫發展狀態之多維度參數。

在裂縫分類方面，本研究依據其空間分布與形態特徵，將裂縫區分為橫向裂縫、縱向裂縫、網狀裂縫及坑洞等類型，以對應不同受力機制與劣化行為。進一步結合裂縫分布特徵與量化參數，作為邊坡與擋土牆潛在不穩定性之判釋依據，並用於辨識可能之活動塊體與破壞區域。

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針式貫入儀於評估臺灣軟弱岩石力學行為之初探

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摘　要

臺灣地質年代較為年輕，西部麓山帶遍佈許多膠結不完全的軟弱岩體。這類岩體之力學行為多透過鑽取岩心並進行壓縮試驗求取之。然而，鑽探工作規畫不易，若想要在現地調查階段求取力學參數並進行初步規劃，這類軟弱岩體抗壓強度極低且易受風化影響，在不同的含水量下力學行為有明顯落差。在野外環境限制下，試體之獲取、搬運與裁切相對困難，往往不易製備符合單軸壓縮試驗所需之試體。因此，研究人員發展出一些簡單且經濟的現地試驗方法，能用以估算岩石的力學行為。然而，大地工程界常用的施密特錘試驗，對於軟弱岩體的適用性較差，在許多含水量高的軟弱岩體中，常因岩體強度過低而無法求取回彈數值，導致無法推估岩石單壓強度。

為解決此問題，本團隊引入了一種便攜式且輕量化的測試設備—針式貫入儀（Needle Penetrometer, NP）。該設備透過測量針尖貫入阻力（Needle Penetration Resistance, NPR）評估軟弱至極軟弱岩石的單軸抗壓強度。針貫入儀試驗屬於一種幾乎非破壞性的檢測方法，可在現場或實驗室環境中進行測試。其對試樣的準備需求極低，且適用於西部麓山帶之軟弱岩體。

本研究以台中石岡壩附近之錦水頁岩為研究對象，利用針貫入試驗進行測試。，透過比較針尖貫入阻力值與岩石材料之單軸抗壓強度，進一步建構兩者於錦水頁岩之關聯。除此之外，也同時比較將試驗結果與施密特錘試驗數據，進一步探討針貫入試驗與施密特錘於軟弱岩體強度估算之適用性與可靠性。

Student Poster SP015

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP016

環境因素對消費級光達長期監測之性能探討

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摘要

臺灣位於菲律賓海板塊與歐亞板塊的交界處，構造活動頻繁，加上地形陡峭與降雨量豐沛，使崩塌與土石流等地質災害相當常見。近年來在強降雨與颱風事件影響下，多起重大邊坡崩塌事件相繼發生，例如2009年莫拉克颱風造成高雄小林村崩塌事件、2010年國道三號基隆七堵段3.1公里邊坡崩塌事件，以及蘇花公路沿線多次邊坡崩塌災害等案例，皆顯示臺灣山區邊坡具有不穩定性。因此，建立有效且可長期運作之邊坡監測技術，對於崩塌潛勢評估與災害預防具有重要意義。

近年來，光達（LiDAR）技術因能快速取得高密度三維點雲資料，已廣泛應用於地形測繪與邊坡變形監測。透過多時期點雲資料比對，可有效掌握地表形變情形。然而，傳統地面型雷射掃描儀（Terrestrial Laser Scanner, TLS）設備價格昂貴，使得長期監測或大範圍多點部署在實務應用上受到限制。為降低監測成本，使用消費級光達（Consumer-grade LiDAR）進行地形掃描與變形監測。此類設備價格相對低廉，但其量測精度與穩定性相較於傳統高階光達仍存在一定差異，因此仍需透過實驗與監測資料進行驗證。

本研究以降低外部環境干擾並建立基礎量測特性先於地下室環境進行固定站位之長時間監測實驗。透過定時掃描取得多時序點雲資料，並同步量測環境溫度變化，以建立環境條件與點雲量測結果之時間序列資料庫。後續將利用點雲比對方法分析不同時間點之地表位移情形，以評估消費級光達在長期監測應用中的穩定性與可靠度。

目前初步分析結果顯示，環境溫度變化與點雲位移量之間存在一定程度的相關性，當溫度升高時，計算得到的位移量呈現往負值方向變化的趨勢。然而，該位移變化是否為實際地表位移，或為環境因素與人為干擾所造成之量測誤差，仍需進一步觀察與分析。後續研究將持續監測時間序列資料，以釐清溫度變化與點雲位移之間的關係。

【學生壁報比賽】參與者於摘要尾端註記

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應用環境噪訊互相關與 HVSR 分析中心崙邊坡穩定性變化

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2024 年 0403 花蓮地震及多起颱風事件對嘉義縣竹崎鄉中心崙 T003 大規模崩塌潛勢區造成不同程度影響。凱米颱風期間，中心崙地區單日降雨量達 871mm，並於強降雨過程中發生邊坡崩塌；由於 128-1 縣道穿越該區，邊坡變形可能影響重要聯外交通。為監測並量化中心崙邊坡穩定性與自然事件之關聯，本研究利用現地地震站記錄，並採用環境噪訊互相關分析（ANCA）與水平垂直頻譜比法（HVSR）兩種被動式地球物理方法，以推估邊坡波速變化（dv/v）、反演一維層狀 Vs 模型，並分析 HVSR 頻譜變化。

ANCA 結果顯示，凱米與康芮颱風期間 dv/v 均出現下降，其中以凱米颱風期間最為明顯，降幅約 1–2%；全年觀測結果亦顯示，dv/v 下降與多起降雨事件具有明顯相關性，顯示其可作為邊坡穩定性變化之監測指標。 HVSR 分析顯示，反演所得之一維 S 波速度剖面與鑽井資料具有良好對應；全年頻譜結果則顯示主峰頻率具時間變化特徵，其中約 10 Hz 之主峰於雨季較為明顯，且崩塌後頻譜能量分布出現顯著改變。 綜合 dv/v 與 HVSR 頻譜結果，推測兩者均與中心崙邊坡穩定行為具有關聯，顯示環境噪訊分析具有作為邊坡長期監測與防災決策量化依據之潛力。

Student Poster SP018

霧社地區板岩深層重力邊坡變形之多尺度構造控制

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摘　要

深層重力邊坡變形(Deep-Seated Gravitational Slope Deformation, DSGSD)為具時間相依性的長期坡體變形過程，反映區域地質構造控制與局部邊坡破壞間的密切關聯。雖然DSGSD發育緩慢，但其空間幾何型態與分布常受區域構造強烈束限，進而影響邊坡不穩定的發生位置與型式。因此，釐清地質構造、DSGSD型態與局部邊坡破壞三者之關係，對大尺度邊坡穩定性評估具關鍵意義。

本研究以臺灣南投縣仁愛鄉廬山層板岩為主的區域為對象，探討其DSGSD坡面的發育特徵及破壞機制。研究區主要構造為霧社、萬大複向斜與眉溪斷層，地質構造使岩體劈理呈中至高角度傾斜。區域尺度上，褶皺與斷層提供控制DSGSD空間分布與型態的力學異向性與運動學條件；中尺度上，DSGSD主要表現為受坡向與劈理位態關係控制的岩體變形，多數邊坡可歸類為逆向坡拖曳褶皺型；局部尺度上，邊坡破壞與蝕溝侵蝕多集中於DSGSD較破碎區域。

本研究利用高解析度光達坡度圖判釋地形特徵與線型構造，並進行系統性空間分析。結果顯示，判釋之線型與引致構造發育之大地應力方向呈現力學相符；坡頂與坡面之崩崖和張裂縫可視為深層破壞累積與漸進式剪裂帶發育至地表之崩塌地形特徵。依文獻提出之DSGSD演化階段分類，約60%邊坡處於部分崩塌階段，近70%邊坡仍可觀察到持續發育中的崩崖，顯示研究區仍處於活躍的漸進式變形狀態。局部邊坡破壞分析指出，崩塌範圍較大且歷史紀錄發生超過十次者，多屬順向坡，顯示坡向與劈理傾向接近一致的順向坡拱彎褶皺型較易發生局部破壞。崩崖比(Scarp ratio)介於3%至32%；就已發生崩塌之邊坡而言，當崩崖比約達6%時，可能可視為連續深層滑動面形成與大規模不穩定開始之臨界值。綜上，DSGSD為區域地質構造與局部邊坡破壞之間的關鍵中介，多尺度構造解析整合地貌指標可作為評估坡體漸進變形與潛在失穩區位之實用方法。【學生壁報比賽】

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基於崩塌地形特徵與活動度架構於潛在大規模崩塌之評估

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摘　要

臺灣山區地質構造複雜，受極端降雨與地形條件影響，崩塌災害頻繁發生，草嶺與馬太鞍等大型崩塌事件即顯示山區具高度潛在風險。面對大量潛在大規模崩塌場址，在有限防災資源下，如何建立有效的分級與分類方法，以優先篩選高風險區域，為災害管理的重要課題。本研究應用崩塌地形特徵分級表（L1），針對崩塌體不同地形部位進行系統性評分與分級，並結合活動度評分表（L2），依破壞機制、關鍵不利地形特徵及活動指標（歷史崩塌、裸露面積與位移比d/L）評估活動度等級。另利用數值高程模型進行水系分級分析，區分蝕溝、支流與主流，並改良L1中河道侵蝕之評分方式，使原本較具主觀性的判別轉為客觀指標。本研究已完成1,865處場址之L1評分，結果呈常態分布，其中A級6處、B級119處、C級1,163處、D級577處。各項目以滑動體、兩側邊界與崩崖平均值最高，為反映地形起伏與滑動程度之主要指標。區域分析顯示，中南部地區平均值較高，新北基桃地區最低；攻擊岸地形可顯著提高L1總分，且於A、B級場址中占比較高，顯示河岸侵蝕為重要控制因子。岩性分析指出，砂岩類地層平均值最高，而上新世至更新世沉積岩最低，顯示岩層年代與膠結程度對地形特徵具關鍵影響。針對A級6處、現調場址2處及地礦中心潛在大規模崩塌區33處，共41處案例進行L2分析，依統計結果以Q1（34）與Q3（64）作為低、中、高活動度分級門檻。結果顯示主要破壞機制以重力邊坡變形為主（37.2%），其次為巨厚崩積層、平面滑動與弧形滑動。不利特徵以蝕溝侵蝕、滑動體破壞及新鮮趾部崩塌最常見。整合L1與L2結果呈正相關，相關係數為0.706，顯示地形特徵分級可有效篩選高活動度崩塌場址。綜上，本研究證實大規模崩塌地形特徵演育程度與其穩定性具有高度關聯；所建立之L1與L2兩階段評估流程，可作為後續防救災資源配置、監測優先順序及山區風險管理之科學依據。

關鍵字：潛在大規模崩塌、分類分級、活動度、地形特徵、水系分析、攻擊岸

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Student Poster SP020

Constraining shear-wave velocity structure using Rayleigh-wave ellipticity: The Eastern Taiwan metamorphic belt and MaTaiAn landslide dam

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Abstract

The East Longitudinal Valley, eastern Taiwan is seismically active with complex subsurface structures. As drilling is costly and difficult in remote areas, cost-effective geophysical methods are essential. Recently, the degree of polarization–ellipticity method for Rayleigh waves (DOP-E) has been applied to estimate ice-sheet thickness variations and delineate shear-zone depths in landslide areas. This study selected Wulu and Yanping, Taitung, as sites. Four seismic stations were installed at deep boreholes (WL6G, GW2G, GW3G, YP1G). Each station was equipped with a three-component low-frequency geophone (HG-6-A-Coil) and connected to a DiGOS DataCUBE3 recorder (200 Hz, gain 16). Solar-powered systems ensured continuous operation at remote sites. Signal windows excluded drilling and rainfall; 30 days of data were used, with high-quality ellipticity selected by thresholds. The Neighborhood Algorithm inverted velocity structure and detected discontinuities. Furthermore, relationships among borehole cores, well logs, and shear-wave velocity structures were examined. In addition, the 23 September 2025 landslide dam failure in the upstream MaTaiAn Stream caused severe damage, highlighting internal stratification. Therefore, a seismic array consisting of 40 SmartSolo nodes (IGU-16HR 3C 5Hz) was deployed at the landslide dam site, with a sampling rate of 500 Hz and a gain of 16. Two orthogonal lines (E–W and N–S) were surveyed over two days. DOP-E-derived shear-wave velocity profiles from Wulu and Yanping link velocity structures to lithology, providing fundamental information on dam stratification. Overall, this study demonstrates that microtremor observations combined with the DOP-E method can provide reliable shear-wave velocity information. The results effectively complement traditional borehole investigations and offer practical value for subsurface structural assessment at both drilling sites and landslide dams.

Keywords: Degree of polarization-ellipticity (DOP-E), Wulu and Yanping sites, Shear-wave velocity structure, MaTaiAn landslide dam

(1) National Yang Ming Chiao Tung University / Wei-An Chao
(2) Master's /2nd year

Student Poster SP021

Natural Hydrogen Potential in Eastern Taiwan Revealed by Soil and Vent Gas Geochemistry

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Abstract

As Taiwan advances toward its 2050 net-zero carbon emissions goal, hydrogen energy has been identified as one of the nation's twelve key strategic technologies. Natural hydrogen, characterized by low production cost, zero carbon emissions, and the potential for continuous natural replenishment, has gained increasing global attention in recent years. However, in tectonically active regions, its occurrence and geological controls remain poorly constrained.

This study aims to investigate the potential occurrence and characteristics of natural hydrogen in eastern Taiwan, focusing on the Qingshui geothermal area in Yilan and the Luoshan mud volcano area in Hualien. An integrated approach was adopted, combining in situ soil gas measurements with laboratory-based gas composition analyses. A total of 108 field sampling sites were established, and 35 gas samples were analyzed using gas chromatography. The results reveal the presence of two distinct gas emission systems in the study area. The Qingshui geothermal area represents a fault-controlled hydrothermal system, where hydrogen concentrations reach up to 996 ppm; however, the gas composition is dominated by carbon dioxide (>95%), indicating strong degassing processes and dilution of hydrogen. In contrast, the Luoshan mud volcano area is characterized by a sediment-dominated system with methane as the primary gas component, and hydrogen concentrations falling within the known anomalous range.

Overall, this study provides the first in situ evidence for native natural hydrogen resources in eastern Taiwan and offers preliminary insights into their geological controls.

(1) University/Advisor: National Central University/ Dr. Pei-Chuan Chuang
(2) Degree/Grade: Second-year Ph.D. Candidate

Student Poster SP022

Integrated Geophysical Insights into the Structural Controls on Geothermal Systems in the Tatun Volcano Group, Northern Taiwan

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Abstract

Geothermal systems suitable for power generation require sufficient temperatures, favorable structural conditions, and reservoir permeability at depths shallower than ~3–5 km. This study investigates geothermal resources and prospective development sites in the Tatun Volcano Group (TVG), northern Taiwan, using a new magnetotelluric/audio-magnetotelluric (MT/AMT) dataset integrated with gravity, magnetic, microseismic, borehole, and geological information. A 3D resistivity model was constructed from MT inversion, and seven geological cross-sections were developed using the kink method and refined with multiple geophysical constraints to relate resistivity structures to subsurface geology. Two geothermal systems are identified—the Mt. Qixing–Matsao–Mt. Shamao and Mt. Huangzui–Dayoukeng–Mt. Dajianhou systems—each characterized by a low-resistivity clay cap (<10 Ω·m) overlying a moderately resistive reservoir

(10–60 Ω·m). A deep high-resistivity batholith and steep intrusive bodies spatially align with the Jin-shan and Shan-chiao faults. Both geothermal systems occur within hanging-wall domains, which also host dense microseismic clusters, whereas adjacent footwalls consist of either high-resistivity volcanic units or thick conductive altered zones, both indicative of low-permeability conditions that inhibit fluid flow. These relationships demonstrate that fault architecture governs the localization of fractured reservoirs and hydrothermal upflow pathways. We interpret the batholith as the principal magmatic heat source and the fault-controlled structural framework as the primary regulator of reservoir distribution. Together, these findings highlight the hanging-wall regions of the Jin-shan and Shan-chiao faults as priority targets for future geothermal exploration and development in the TVG.

Keywords:

Tatun Volcano Group (TVG), geothermal exploration, Magnetotelluric (MT), fault-controlled geothermal system

應用地電阻影像剖面法探討紅柴林地區地下構造與地熱潛勢

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摘　要

台灣宜蘭平原位於沖繩海槽張裂構造影響區域，受張裂構造與斷層活動控制，具有深部地熱發展潛能。其中紅柴林地區被認為是潛在地熱區之一。前人研究透過整合多種方法對地熱潛能區進行基礎探勘，常見的方法包括地質調查、鑽井資料分析、岩心與岩屑研究、大地電磁探測等，掌握研究區域內地熱儲集體的空間分布與潛在發展條件。本研究在宜蘭縣紅柴林地區採用地電阻影像剖面探測法（Electrical Resistivity Tomography, ERT）以詳細了解淺層地下構造及可能的地下熱液通道。

本次調查於紅柴林地區設置三條 ERT 測線，使用美國 AGI 公司製造的 SuperSting R8 電探儀進行施測，採用雙極排列法（Pole-pole array），測線長度均超過 1.5 km，最大探測深度約可達 1000 公尺。本研究使用 Rücker 等人所開發之開源地球物理反演框架 PyGIMLi 進行電阻率反演計算，使用 Gauss－Newton 迭代反演架構，並利用 L-curve 方法選取最佳正則化參數（λ），以權衡資料擬合度與模型平滑度，取得最佳反演剖面。研究結果顯示部分區域存在低電阻異常區，推測可能與地下熱水流體及裂隙系統相關。此外，紅柴林一號井（HCL-1）岩心資料顯示淺層約 0－400 公尺主要為變質砂岩與礫石沖積層，其在電阻率剖面上呈現為相對高電阻率區。

綜合三條測線反演結果並建立三維空間柵狀圖分布，可辨識低電阻帶之邊界與側向延伸範圍，提升淺層構造上的解析度。研究結果顯示紅柴林地區地下可能存在受構造控制之地熱流體通道系統，部分低電阻區域可能代表潛在地熱儲集層或流體上升區。

【學生壁報比賽】
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Student Poster SP024

觀音山地區磁力資料正演分析與地下火成岩體構造推估

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摘　要

新北市觀音山坐落於台灣北部西側，淡水河出海口南方，與大屯火山群間隔淡水河相望，緊鄰台北都會區，由大屯火山及觀音火山噴發之火山熔岩以及火山灰堆積形成，蘊含高磁感率火成岩體，也被認為是具有地熱潛力的地區之一。

在火山區進行地熱調查與研判地下地熱地質構造時，磁力資料具有重要的地球物理意義，磁力強度可反映地下岩體磁感率的變化，可用於解析火山地區的地下岩體分布與構造框架，可作為熱液變質帶、火山岩體分布及地下構造推測的依據，對於建立地熱系統之地質模型具有重要參考價值。董倫道（2014）對台灣北部地區進行了磁力勘測，將磁力資料經過歸極換算處理後，觀音山地區有磁力高區，推測與觀音山地區地下有高磁岩體的分布有關。本研究使用地礦中心的磁力勘測資料，對觀音山地區進行資料處理，在該地區切出數條由西北到東南的剖面線，分別進行磁力正演化計算，結合正演化結果及地表地質，研判地下構造，推論在觀音山頭下方應具有火山通道，而觀音坑下方可能具有岩蓋，此結果為觀音火山區的構造框架，提供重要的依據及新穎的解釋。

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觀音山地區火成岩岩相分析與演化歷史推斷

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摘　要

觀音山地區位於大屯火山群的西南方，火成岩主要分布於其北側及東側區域。觀音坑緊鄰於觀音山南側，地形呈一近圓形窪地，觀音坑山佇立於窪地中心，可見一岩牆出露於觀音坑山北側山坡。依據既有定年資料與礦物組成特徵，目前可將觀音山地區火成岩依年代劃分為三期不同的熔岩流，分別是0.53 Ma、0.43 Ma及0.34 Ma，而位於觀音坑山的岩牆則是更早於前三時期的火山活動(0.63 Ma)。儘管過去已有許多研究針對本區域中的火成岩之化學組成與噴發時期進行探討，但對觀音山整體地質演化過程仍存在若干不同解釋。

本研究蒐集觀音山地區三期火成岩及岩牆樣本，以及鄰近觀音坑岩牆的鑽井(KYK-1)取得之岩心樣本，首先觀察其岩石產狀，包含質地(texture)、顏色與巨觀特徵，再製作岩石薄片並利用偏光顯微鏡鑑定其礦物組成。透過比對熔岩流火成岩、岩牆與岩心樣本之岩相與礦物特徵，本研究進一步探討觀音山各區之間的關聯性，以及其可能的火山活動演化過程。

目前已完成初步樣本分析結果如下：一期熔岩流以粒徑小於 1 mm 之黑色與白色礦物組成基質，無肉眼可辨識之晶體。二期熔岩流以黑灰色基質為主，內含淺綠色斑晶，粒徑最大可達約 5 mm，呈現明顯斑狀構造。三期熔岩流則由淺色與灰色礦物組成基質，整體細緻且同樣缺乏肉眼可辨識之晶體。岩心與岩牆樣本皆以灰白色基質為主，並密集分布粒徑約 1–2 mm 之黑色斑晶，顯示兩者在岩相特徵上具有高度相似性。由於目前推測岩牆下方可能為連通的岩漿系統，而鑽井於大約 57~300m 主要由火成岩組成，推測兩者屬於同一期或相近時期之岩漿作用產物。

關鍵字:觀音坑、觀音火山、岩相分析、岩蓋、岩石薄片、偏光顯微鏡

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Student Poster SP026

觀音坑安山岩裂隙特徵分析：節理與構造裂隙之判識及古應力重建

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摘　要

臺灣北部觀音山火山區經歷多次火山活動，具有複雜的構造演化背景。本研究聚焦於火山區南側的觀音坑窪地，窪地中心的觀音坑山北坡存在一道岩脈，其年代約為0.63 Ma。以岩脈北方100公尺處鑽井岩心(KYK-1)與高解析度超聲波井壁影像為主要資料，共測量281組裂隙位態（走向、傾角）資料，研究結合觀察岩心的岩石品質指標（RQD），並製作岩石薄片於顯微鏡下分析礦物組成。綜合以上資訊進行安山岩裂隙特徵的定性與定量分析。裂隙位態統計採用投影圓與玫瑰圖進行群集劃分，並基於共軛裂隙幾何關係反演主應力軸，以重建古構造應力場。

觀察鑽井岩心樣本，由地表至井深約57公尺為沉積岩，其後至300公尺皆為安山岩，採120公尺處安山岩心樣本，具隱晶質基質，並含有細粒的黑白斑晶與黑色長條狀礦物，其岩石產狀與地表出露的觀音坑中心岩脈相似。在裂隙分布判識上，RQD 隨深度呈現顯著變化，可推測有三個主要破碎帶的發育：(1)淺部66.36公尺出現厚1.63公尺的角礫狀（Rubble）破裂帶；(2) 中段140–160公尺為高密度裂隙切割區，RQD 整體低於0.4；(3) 深部220.16公尺存在厚度2.16公尺、伴隨顯著岩心流失（Core Loss）與斷層泥特徵的主斷層帶。此220.16公尺的主斷層帶為裂隙位態與區域應力場的重要構造分界。淺部（<220.16公尺）裂隙呈現多期構造疊加特徵，節理包含N50°W/60°S 與N80°W/60°S兩組主要方向，兩者夾銳角約25.9°；深部（>220.16公尺）則表現為單一優勢方向，主要為走向N28°W、傾角64°W的高角度構造裂隙。古應力反演結果指出，淺部最大主應力方向約為N65°W至N70°W（近水平至向西北傾12°）。此最大主應力方向與地表觀音坑安山岩岩脈的長軸延伸方向（N70°W）具高度一致的幾何關係，此發現對於探討觀音坑岩漿侵入期的應力狀態及後續斷層活動的區域應力演化，具有重要的地質意涵。

關鍵字：觀音坑岩脈、裂隙特徵、構造裂隙、超聲波孔內影像、古應力重建。

【學生壁報比賽】

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Student Poster SP027

Characterizing Injection-Induced Pore Structure Changes in Penghu Basalt via Computed Tomography

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Abstract

Carbon Capture and Storage (CCS) is a promising strategy for reducing atmospheric CO_2 by storing it in subsurface formations. Basalt is particularly attractive due to its abundance of divalent cations that promote mineral trapping through fluid–rock reactions. When CO_2 is injected into basalt, dissolution and precipitation can dynamically modify pore structures and alter flow pathways, affecting CO_2 migration and injection efficiency. To investigate how mineral reactions changes pore structures, two Penghu basalt cores were subjected to a one-month injection experiment. The samples were monitored using non-destructive 3D Computed Tomography (CT) before and after injection. By comparing CT scans, voxel-level intensity variations were analyzed to identify regions of structural alteration. Porosity profiles along the core depth were then calculated to quantify the associated bulk volumetric changes. To further characterize the pore network structure, Pore Network Modeling (PNM) was applied to analyze pore–throat numbers. These results show that mineral reactions and fracture formation can induce structural modifications in the pore network within the experimental timescale. Despite minimal changes in bulk porosity, variations were observed in pore–throat structure, with throat showing greater changes than pore. These findings indicate that porosity alone is insufficient to capture pore structure change and highlight the importance of pore–throat characterization in understanding flow-relevant structural changes in basalt.

Keywords: X-ray Computed Tomography (CT), Porosity, Pore Structure, CO_2 Injection, CCS

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CT-Based Evaluation of Permeability in Sandstone Samples: Stability across Sample Scale and Resolution

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Abstract

To achieve the 2050 net-zero goals, understanding subsurface fluid flow is essential for underground resource management and the safe implementation of Carbon Capture and Storage (CCS). Permeability is a key parameter controlling fluid flow, but it is commonly measured using discrete samples, which may not adequately capture the heterogeneity of geological materials. Computed tomography (CT) offers a non-destructive way to characterize internal structures continuously at the core scale. However, high-resolution scanning of large samples is often impractical because of the trade-off between field of view and image resolution. Recent studies suggest that CT-derived metrics (Lower Partial Standard Deviation index, LPSD, Liu, 2025) can provide a promising approach for permeability estimation, but their stability at larger sample scales and their limits under low-resolution conditions remain untested. This study addresses these two challenges independently. First, larger sandstone samples with diameters up to 55 mm are used to test whether the method remains stable when sample size increases toward engineering-scale applications. Second, 1 cm diameter samples with high-resolution CT data are used to investigate resolution effects through both multi-resolution scans and digital downsampling. These results are compared with triaxial permeability measurements and pore network model (PNM) parameters. This work aims to evaluate the stability and applicable limits of CT-based permeability estimation across sample scales and resolution conditions. If validated, the method could provide an efficient way to estimate continuous permeability trends while better preserving core-scale heterogeneity, offering a practical bridge between pore-scale observations and engineering-scale applications for CCS.

Keywords: X-ray computed tomography(CT) , Permeability, Pore Structure, Carbon Capture and Storage (CCS)

Student Poster SP029

Risk Assessment and Injection Optimization for Geological CO2 Storage Considering Hydro-Mechanical Coupling Processes

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Geological storage of carbon dioxide (CO_2) plays a crucial role in achieving net zero emission by 2050. Indeed, underground accumulation of CO_2 is a widespread geological phenomenon. However, injection of supercritical CO_2 triggers complex hydromechanical (HM) processes, where the fluid overpressure and stress perturbations possibly lead to the reactivation of pre-existing faults. This issue is particularly critical in the tectonically active region, such as Taiwan, sitting on the convergent boundary between the Eurasian plate and the Philippine Sea plate. Given the accelerating deployment of carbon storage projects, there is an urgent need for robust numerical framework to ensure the long-term stability of the sequestration site.

In this research, we aim to simulate coupled hydromechanical processes and capture the reactivation of faults in complex geometry using TOUGH-FLAC simulator. The numerical framework first deploys TOUGH2 with module ECO2N to simulate CO_2 plume migrations and fluid pressure buildup. This pressure data will transfer at each time step and be used to calculate the stress and deformation distribution in FLAC. Finally, the changes in porosity, permeability, capillary pressure from FLAC update to TOUGH, the data transfer at each.

A conceptual model is designed comprising three distinct formations intersected by a curved fault geometry. To evaluate the mechanical stability of this system, the sensitivity study is conducted, focusing on injection rate, injection schedule, and well-to-fault proximity. The primary objective is to define a safe operating condition that can maximize the injection amount and optimize injection site. Ultimately, these models will serve as a benchmark for scaling to high-fidelity, 3D field-scale coupled simulations.

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Student Poster SP030

二維礦化封存模擬與反應－以TOUGHREACT模擬為例

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摘　要

隨著全球氣候變遷加劇，二氧化碳碳捕獲與封存（CCS）被視為減緩大氣CO_2濃度的重要技術。在四大碳封存機制中，礦化封存能將CO_2與岩石礦物反應生成穩定的碳酸鹽礦物，是最具長期穩定性的封存形式。因此本研究建立二維反應傳輸模型，並利用TOUGHREACT進行非等溫反應傳輸模擬，以探討不同地質條件對CO_2礦化封存效率的影響，此模型包含了39種水相反應式及17種礦物反應式。研究主要透過觀察孔隙率、礦物沉澱濃度與CO_2飽和度與等指標，針對不同地質與人為條件進行敏感度分析。

模擬結果顯示，較高的滲透率會增加CO_2在地層中的遷移距離並使其分布更均勻，進而擴大水－岩反應的空間範圍。當滲透率提高至1000豪達西（md）以上時，礦物沉澱的範圍會顯著擴大，但滲透率的改變對局部礦物生成的沉澱速率影響相對有限。在較低的孔隙率環境下，因地層可供儲存的空間有限，CO_2必須遷移至更大的範圍才能達到平衡：然而，隨著孔隙率增加，礦物的沉澱量卻呈現下降趨勢，可能原因為較高孔隙率導致單位體積岩石中可參與反應的礦物含量降低，進而限制可提供反應離子的來源。此外，較高的注入速率造成大量CO_2在短時間內進入地層，使其被推擠至更遠的位置，略為增加礦物沉澱的範圍，但同時也會造成地層壓力發生較大幅度的提升，反而提高地層穩定性的潛在風險。模擬結果顯示，在相同總注入量下，較低注入速率可降低地層壓力上升幅度，有助於減少地層穩定性風險。未來，本研究將以此次建立的二維模型為基礎，導入彰濱電廠場址的實際地層參數進行比較，透過現地實驗數據來進一步驗證模擬的真實性，以更準確地評估真實地層環境對CO_2礦化封存效率的影響。

關鍵字

二氧化碳地質封存、TOUGHREACT、礦化封存、敏感度分析

【學生壁報比賽】

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三軸壓縮條件下花崗片麻岩裂隙演化之音射訊號分析

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摘　要

岩石材料在受力過程中，微裂隙會萌生、擴展與連結，最終導致巨觀破壞。了解岩石材料破裂過程中的裂隙演化機制，對於地下工程、隧道開挖、礦山與地熱開發等工程之穩定性評估具有重要意義。音射技術（Acoustic Emission, AE）能夠即時監測材料在受力過程中因微裂隙形成與滑移所釋放之彈性波訊號，因此廣泛應用於岩石破壞機制及裂隙演化行為之研究。本研究以花崗片麻岩為研究對象，透過三軸壓縮試驗結合音射技術，探討花崗片麻岩在不同受力階段之裂隙演化特性及其音射訊號變化規律。

本研究針對花崗片麻岩試體進行三軸壓縮試驗，於不同圍壓條件下施加軸差應力，並同步量測應力－應變關係及音射訊號。音射參數包含事件數（AE count）、累積事件數（cumulative AE count）以及音射能量（AE energy）等指標，並將其與應力－應變曲線進行對比分析，以辨識岩石破裂過程中的重要應力階段，包括裂隙起始應力（Crack Initiation, CI）及裂隙損傷應力（Crack Damage, CD）。此外，透過分析音射活動與體積應變變化之關係，進一步探討花崗片麻岩在壓縮過程中由微裂隙萌生至裂隙快速擴展的演化過程。

研究結果顯示，花崗片麻岩在三軸壓縮過程中的音射活動具有明顯的階段性特徵。在初期彈性階段，音射事件數與能量皆較低，顯示岩石內部結構仍處於相對穩定狀態。當應力逐漸增加並接近裂隙起始應力時，音射事件數開始逐漸增加，代表岩石內部微裂隙開始萌生。隨著應力持續增加並達到裂隙損傷應力後，音射事件數與能量釋放量呈現顯著上升，顯示大量微裂隙開始快速擴展並逐漸連結形成巨觀破壞面。研究亦發現圍壓條件對岩石破壞模式與音射活動具有顯著影響，在較高圍壓條件下，岩石內部裂隙擴展受到抑制，使破壞模式由脆性破壞逐漸轉為較具延性之變形行為。

【學生壁報比賽】參與者於摘要尾端註記

(1) 國立臺北科技大學/邱家吉
(2) 碩士/二年級

Student Poster SP032

SWIFT: A Multi-Station Deep Learning Framework for Probabilistic Ground-Motion Prediction in Earthquake Early Warning Systems for Indonesia

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Abstract

The tectonic arc from Sumatra, Java, and Bali is one of the most earthquake-prone regions in Indonesia, placing communities in this region at risk of large, potentially devastating earthquakes. Speed and accuracy in predicting ground shaking are crucial for an Earthquake Early Warning (EEW) system in these densely populated regions. This study introduces SWIFT (Seismic Warning Inference via Fast Transformers), a multi-station deep learning architecture designed to predict the probabilistic distribution of peak ground acceleration (PGA). This model employs a Convolutional Neural Network (CNN) for temporal feature extraction from seismic waveforms, followed by a Transformer encoder to capture spatial correlations between stations. To accommodate the complexity of local geology in Indonesia, SWIFT integrates site-specific velocity (VS30) and waveform-derived physical features to enhance its ability to capture strong ground-motion characteristics. Furthermore, the model utilizes a Mixture Density Network (MDN) to generate PGA predictions along with associated uncertainty. Application of SWIFT demonstrates that it effectively suppresses false alarms for weak earthquakes and provides reliable warnings in strong earthquakes, making it a robust and adaptive EEW framework in mitigating seismic risks in the Sumatra, Java, and Bali regions.

“Students’ Poster Competition”.

(1) University/Advisor : National Central University / Chung-Han Chan
(2) Degree/Grade : Master / 1

風暴潮為沿海地區的重要氣象災害，其預測準確度對防災應變與減災策略至關重要。然而，傳統颱風風場參數化模型（如 Holland 模型）未能充分考量地形對颱風結構之影響。於台灣西部沿海地區，受中央山脈阻擋效應影響，常導致風速與氣壓場產生顯著偏差，進而降低風暴潮水位預測之準確性。

本研究發展基於物理導向神經網路（Physics-Informed Neural Networks, PINNs）之人工智慧模型，以提升颱風風場模擬能力，並改善風暴潮預測精度。相較於傳統參數化模型，PINNs 透過整合歷史颱風風場資料、再分析資料及控制方程（如動量方程與質量守恆），於訓練過程中同時滿足物理約束與資料驅動特性，使風速與氣壓分布能更真實反映地形對颱風結構之影響。

當熱帶氣旋之路徑與強度已知時，PINNs 模型可自然呈現地形阻擋效應。考量颱風移動速度遠低於風速，流場可迅速由過渡階段轉為準穩態，因此本研究初步假設可忽略由路徑變化引致之瞬態效應。

模型訓練整合近二十年歷史颱風之 10 公尺風速場與海平面氣壓場資料，以及中央氣象署最佳路徑（Best Track）資料，並透過物理約束損失函數強化對動力過程之描述能力，進而隱含納入地形阻擋效應。經 PINNs 修正後之風場資料，作為風暴潮數值模擬之輸入。

本研究採用 COMCOT-SS 模式進行風暴潮模擬，並整合天文潮汐資料，以計算潮汐與風暴潮之非線性交互作用，並以中央氣象署潮位站實測資料進行驗證，同時與傳統參數化風場模型進行比較。

結果顯示，PINNs 模型重建之風場於不同颱風移動速度條件下，均可有效降低風速與氣壓之誤差，並提升風暴潮水位預測精度。特別是在移動速度較慢之颱風情境中，由於地形阻擋與累積效應更為顯著，PINNs 模型之修正效益尤為突出。

此外，本研究亦指出，雖多數情境下流場可迅速達到準穩態，但在極端快速移動颱風條件下，局部瞬態效應仍可能影響模擬結果，顯示穩態假設於特定條件下仍需審慎評估。

整體而言，本研究所提出之 PINNs 模型可有效提升不同移動速度颱風條件下之風暴潮模擬能力，並對流場穩態性假設之適用性提供初步驗證，為未來防災應用與預警系統建置提供具體技術依據。

Student Poster SP034

利用卷積神經網絡從地質剖面辨識馬爾可夫隨機場之空間相關性因子

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摘　要

傳統地質剖面通常由地質學家基於鑽井資訊、野外調查及自身經驗繪製而成。然而，由於地質分佈固有的空間變異性，剖面中的地層交界處仍存在不確定性。因此，部分學者提出馬爾可夫隨機場（Markov Random Field, MRF），以機率方法生成地層空間分布，可量化地質不確定性。空間相關性因子（Spatial Correlation Factor, 以下稱 a）是 MRF 的關鍵參數之一，a 與地層的延續性有關，當 a 愈大表示地層延續性愈佳，反之亦然。本研究利用卷積神經網絡(Convolutional Neural Network, CNN）從地質剖面辨識 MRF 之空間相關性因子，首先設定輸入 a 值為 1, 2, 3, …, 10，以 MRF 模擬各 100 張地質剖面，輸入到 CNN 中進行訓練，一旦 CNN 學習到不同輸入 a 值所對應到的剖面紋理特徵後，即可建立 a 與地質剖面的相關性；而後，再將另外 100 張剖面輸入到訓練後的 CNN 模型進行測試，結果顯示 CNN 模型預測的 a 值與測試剖面的輸入 a 值高度吻合。值得注意的是，儘管使用相同的輸入 a 值進行 MRF 模擬，但由鄰近 a 值模擬的地層紋理特徵可能呈現相似的幾何形狀；因此，訓練後的 CNN 模型可能預測多個 a 值，但它們通常與輸入 a 值相當接近。本文顯示，訓練後的 CNN 模型能夠基於 MRF 模擬剖面的紋理特徵有效預測最可能的 a 值，此方法成功地捕捉並學習到地質剖面的特徵，有助於決定空間相關性因子 a ，為 MRF 模擬提供可靠的基礎。

【學生壁報比賽】

(1) 國立中央大學/董家鈞
(2) 碩士/二年級

利用PSInSAR 觀測南海海槽之慢滑移事件

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摘　要

南海海槽隱沒帶是地震災害的高風險區域，而慢滑移事件(Slow Slip Event)是理解板塊介面應力演化的重要線索。即使日本擁有高密集度的 GNSS 觀測網，能夠例行性偵測慢滑移事件，但南海區域周圍的測站仍各相距數十公里，對地表形變的描繪仍可能受限。為了能夠更仔細得監測慢滑移事件，本研究引入永久散射體 InSAR（PSInSAR）作為輔助的高空間解析度之觀測方法。我們使用 2019–2023 年的 Sentinel-1 SAR 資料，透過 SNAP 與 StaMPS 處理，從永久散射體（具穩定相干性的目標）反演地表變形時間序列。接著將 PSInSAR 的地表變形訊號與 GNSS 測站資料及地震活動進行對照分析，以評估 PSInSAR 在辨識慢滑移事件之能力，以及提升南海海槽沿線構造形變之觀測與理解。

Student Poster SP036

Investigating the interseismic surface deformation pattern in northern Taiwan by multi-temporal InSAR analysis

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Abstract

Understanding surface deformation in active orogenic belts is crucial for unraveling tectonic evolution and assessing natural hazards. With a rapid convergence between the Eurasian and Philippine Sea plates, the island of Taiwan provides an opportunity to observe how surface is deformed in response to tectonic architectures. The Taoyuan area is situated within the tectonic transition zone, bridging the mature collision to the south and the post-collision orogenic collapse to the north. However, the surface deformation and structural kinematics during this critical tectonic transition remain poorly understood. To address this observational gap, we estimate high-resolution surface movements based on the integration of varied geodetic observations in order to examine the spatiotemporal patterns of surface deformation and possible implications to neotectonics. We utilize Sentinel-1 imagery processed with the Small Baseline Subset (SBAS) InSAR algorithm. Since the natural environment often causes decorrelation, SBAS-InSAR leverages distributed scatterers to enhance spatial coherence and derive reliable time-series surface displacements. To further validate and constrain InSAR results, we integrate them with GNSS and precise leveling data. Our preliminary results reveal subtle deformation patterns in the Taoyuan region that do not align with currently known structures. These findings underscore the complexity of this tectonic transition zone and the necessity of integrating GNSS and leveling data for further constraint. Ultimately, this research not only fills a critical monitoring gap in the Taoyuan region but offers new insights into the kinematics of tectonic transitions.

Keywords: Multi-temporal InSAR, Tectonic Transition Zone, Sentinel-1, Small Baseline Subset (SBAS)

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Student Poster SP037

Tectonic Activity and Surface Deformation at the Incipient Orogenic Front: Insights from Geodetic Observations of Liuchiu Island, SW Taiwan

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Abstract

Investigating surface deformation at the incipient orogenic front is essential for understanding tectonic evolution and seismic hazards. Along the frontal accretionary wedge in southwestern Taiwan, the interplay between mobile shale and active structures and its effect on rapid uplift and fault kinematics is one of major research topics. While terrestrial research highlights significant mud diapirism, the offshore area remains poorly constrained due to the lack of geodetic data. Liuchiu Island is the only offshore island offshore southwestern Taiwan, and it has distinct tectonic geomorphology features. Therefore, in this study, we utilize Liuchiu Island as a key window to characterize offshore frontal deformation. We performed InSAR time-series analysis using 11 L-band ALOS-2 images (2015–2022). L-band's penetration mitigated vegetation decorrelation, while GNSS data integration corrected orbital errors to reconstruct high-resolution velocity field. In addition, we conducted a high-resolution DEM derived from unmanned aerial vehicles for geomorphic interpretation. Our preliminary results reveal that the central valley of Liuchiu Island forms a prominent velocity boundary coinciding with its eastern margin. Also, we executed a simple inversion for fault motion, which implies active left-lateral creep, with LOS rates reaching 6–8 mm/yr in the north and decreasing southward, implying a deepening creeping depth. We suggest that the central valley evolved from initial crestal stretching or erosion into a graben system driven by shale diapirism. InSAR observation shows that these pre-existing weaknesses have been reactivated as left-lateral faults under current regional compression. This study fills an offshore observational gap and provides a new perspective on the coupling between shale tectonics and regional stress.

Keywords: Orogenic front, Mobile shale, InSAR time series, Liuchiu island

(1) University: National Taiwan University/Advisor: Ray Y. Chuang
(2) Degree: B.S./Grade: 4

雲林-嘉義地區地表形變之探討

陳映璇[1]、郭昱廷[1,2]、盧志恒[3]、陳嘉俞[1,2]、顏君毅[4]、張中白[5]、徐乙君[5]
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摘　要

雲林-嘉義地區位於臺灣西南部，處於西部前陸盆地與褶皺逆衝帶之過渡帶，長期受地下水過度抽取影響而產生顯著的區域性地層下陷，因此成為探討人為活動、含水層壓密與構造活動交互作用影響地表形變的重要區域。本研究利用2018-2020 與 2023-2024 年期間取得的高解析度合成孔徑雷達衛星TerraSAR-X影像，透過GMTSAR及StaMPS軟體進行永久散射體差分干涉(PSI)分析，以量測地表形變並探討其與地下水變化及地質構造之關聯。

研究結果顯示，沿海平原仍持續發生大規模地層下陷。2018-2020年速度場顯示下陷區主要集中於雲林沿海，在視衛星方向(LOS)上最大遠離速率超過20 mm/yr；至2023-2024 年，下陷範圍進一步向東南擴展至雲林平原及鄰近嘉義北部地區，且變形速率明顯增加，LOS方向最大遠離速率達45 mm/yr。時間序列位移結果顯示，在主要降雨事件(如 2023 年初)之後，局部區域曾出現短期的變化，這些訊號可能反映對流層延遲效應，亦可能與地表對水文條件的敏感反應有關，仍需透過獨立的大氣校正與敏感度測試進一步驗證。

綜合地下水位觀測資料、GNSS資料與含水層特徵分析，推測研究區的地表形變除了受到人為抽水影響，亦與含水層系統的壓密作用有關。此外，在梅山斷層兩側可觀察到明顯的變形速度梯度，顯示構造邊界對地層壓密空間分布具有調控作用，進而影響地表形變型態。

本研究結果呈現研究區地表形變的時空演化特徵，顯示PSI方法可有效應用於區域尺度的地表形變監測，並有助於評估地層下陷與活動構造之間的相互作用，為地質災害防治、基礎設施管理與地下水資源永續規劃提供重要參考。

關鍵字：雲林-嘉義地區、地表形變、地層下陷、梅山斷層、永久散射體差分干涉技術

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Student Poster SP039

2024年日本能登半島地震前後之地表變形特性分析

Surface Deformation Characteristics during Pre- and Post-seismic Periods of the 2024 Noto Peninsula Earthquake

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摘　要

2024年1月1日，日本能登半島發生規模7.5的強震，造成顯著的地表位移與破裂。透過震源機制與過去研究顯示向東南傾斜的逆衝斷層帶活動是引發此次地震的原因，其中包含門前沖斷層、猿山沖斷層、輪島沖斷層、珠洲沖斷層。然而，在地震事件的前後，地表是否存在不同的變形行為並未被詳細的描述清楚，因此，本次研究旨在透過雷達衛星影像，比較該地震發生前後的地表變形特性。本研究利用 Sentinel-1雷達衛星影像，針對震前一年與震後一年進行時間序列分析。我們使用兩個降軌道影像（T17_F468、T119_F466），T17_F468在震前有31張影像、在震後有28張影像；T119_F466在在震前有29張影像、在震後有31張影像，並採用了 StaMPS (Stanford Method for Persistent Scatterers) 軟體進行分析。此軟體能夠挑選出地表上的永久散射體，並透過時間和空間上的相位分析，獲得地表潛移的活動特徵與位移量值，此外，也結合日本國土地理院所提供的 GNSS 連續觀測站資料驗證InSAR結果的可信程度。初步研究結果顯示，在震前階段，能登半島的地表活動速率呈現東半部高於西半部的現象；而在震後階段，InSAR與GNSS 觀測資料均顯示該區域出現了廣泛且顯著的地表沉降現象，這與Suito等人針對2024前半年利用GNSS與黏彈性模型模擬後得到的結果相同。本研究透過衛星遙測與地面觀測資料的整合，完整描述能登半島在地震前後的完整變形過程，對於該地區構造演化具有重要的參考價值，未來將利用地表變形數據，反演地下的斷層滑移模型，並從構造機制上解釋地表變形行為。

關鍵詞：2024能登半島地震、Sentinel-1、PSInSAR、StaMPS、地表變形、地震週期

Keyword：2024 Noto Peninsula Earthquake, Sentinel-1, PSInSAR, StaMPS, Surface Deformation, Seismic Cycle

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Student Poster SP040

利用干涉合成孔徑雷達(InSAR)與現地資料分析乾旱事件對濁水溪沖積扇地表變形之影響

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摘要

濁水溪沖積扇是台灣重要的平原地帶，在過去幾十年因過度抽取地下水造成地層下陷，其中以雲林縣元長鄉與土庫鎮最為嚴重，1992年至2024年間累積下陷量達到約2公尺。在2020年至2021年台灣先是經歷了降雨量歷史新低的梅雨季與颱風季，造成年度降雨量僅為1078.1毫米，遠低於平均值的1954.6毫米，導致各大水庫蓄水量不足並實施大規模的限水措施；過少的降雨量在當時也影響了諸多地區的地下水補注。 本研究旨在探討乾旱事件是否加劇濁水溪沖積扇地區之地表沉降。研究採用2020年至2024年的Sentinel-1衛星影像，使用小基線子集法(Small Baseline Subset,SBAS)計算InSAR速度場並得到時間序列分析，並以乾、濕季分期。從初步速度場分析顯示，乾旱確實加劇了沉降的速度，4年間的最大平均沉降速率集中於雲林的土庫與元長一帶，大約每年8公分，其中在2021年上半年期間的沉降速率接近15公分，2021年下半年則是約5公分小幅度地表抬升，推測可能與後續降雨及地下水補注恢復有關，為此則需要進一步的利用其他現地資料來對比與佐證。 現地資料包含了鑽井、地下水位歷線和GNSS等。研究區域依據沖積扇性質劃分溪畔、扇頂、扇央與扇底，並且從各個區域挑選代表性的井位，這些井位分別位在斗六市鎮南國小、土庫鎮秀潭國小、四湖鄉建陽國小和溪州鄉溪州國小，探討不同區域的地表變形。並且分析地層岩性與地下水位變化對地表變形的關係，以評估乾旱事件對地層下陷之可能影響。

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Student Poster SP041

2006 - 2021 年嘉義地區地表變形之時空演變：GNSS、精密水準測量與 PSInSAR 觀測成果

向品叡[1]、郭昱廷[1,2]、陳嘉俞[1,2]、陳宏宇[3]、童忻[3]、顏一勤[4]、呂靜渝[1,2]、盧志恒[5]、顏君毅[6]、鄭凱謙[1]、莊昀叡[7]

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摘　要

嘉義沿海平原之地層下陷長期受到關注，其形成與活動構造及人為地下水抽取密切相關。本研究整合 2014 - 2021 的 PSInSAR、2006 - 2021 的 GNSS 與精密水準測量結果，分析其地表變形特徵，並建立多組相互重疊時段之速度場以解析其時序演化。從水準資料得知，嘉義西部沿海平原之沉降於 2015 年後有加劇趨勢，並於 2018 - 2021 年最為顯著，主要沉降集中於距海岸線約 8 - 17 km 之區段(120.2° - 120.3°E、23.6°N)，沉降速率由 2015 - 2019 年的 -10 至 -5 mm/yr 至 2018 - 2021 年增強為 -16 至 -10 mm/yr；另一方面，從 2015 - 2021 年 GNSS 資料得知距海岸線約 10 km 內之區段沉降速率逐漸增大，至 10 – 15 km 區段垂直速度明顯回升，顯示其沉降幅度相較前者有所減弱，但受限於 GNSS 測站分布較為稀疏，僅依據離散測站資料仍難以精細判定研究區變形之空間相關性，因此利用 PSInSAR 分析 Sentinel-1 升降軌之雷達衛星影像，以補充並驗證區域尺度之地表變形分布。其視衛星方向速率場顯示，嘉義沿海平原沉降主要集中於西部低地，東側山麓及內陸區域則相對穩定至輕微抬升，且沉降範圍與強度隨時間逐漸增加，升、降軌結果整體分布一致，並於平原與山麓交界處呈現明顯變形梯度，顯示地表變形可能受構造控制。另外，山麓附近之內陸區域也呈現不同之變形型態：嘉義前緣構造以東地區整體表現為相對穩定至輕微抬升，使該地質邊界兩側形成明顯之垂直變形梯度，顯示嘉義前緣構造可能為沿海沉降平原與內陸抬升區之過渡帶。再往東之構造包括嘉義斷層及其相關褶皺，則表現約為 10 mm/yr 的輕微抬升或極小的垂直變化，與持續中的地殼縮短作用一致；梅山斷層帶兩側未觀測到顯著震間垂直位移，顯示該右移型斷層目前可能處於鎖定狀態，且未見明顯潛移；然而 GNSS 水平速度仍顯示其兩側存在約 10 - 15 mm/yr 之微弱剪切變形，與其走向滑移性質相符。整體而言，嘉義地區地表變形反映構造作用與水文過程之複雜交互影響。本研究透過整合多源測地觀測與區域地質架構，更全面地闡明盲逆衝構造與人為活動如何共同控制地層下陷之分布，並可作為區域災害減緩與永續土地利用規劃之重要依據。

Student Poster SP041

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP042

SWOT衛星資料於臺灣地表水監測之應用：以曾文水庫為例

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摘　要

Surface Water and Ocean Topography (SWOT)衛星是由美國NASA及法國CNES共同合作發射的測高衛星，搭載著Ka波段干涉式雷達測高儀KaRIn (Ka-band Radar Interferometer) ，能夠對地表大範圍的水體水面高程以及空間分布資訊進行準確的觀測。傳統的天底衛星測高儀(nadir satellite altimetry)只能沿底點方向進行水體觀測，能測到的範圍受到衛星軌道的限制。SWOT可以以刈幅(swath)的方式進行水體觀測，打破傳統測高儀的限制，能大幅觀測地表水體，提供高空間解析的地表水面高觀測，在海洋、內陸水體、河川等水體監測、水位分析、水文與海洋研究皆具有重要的發展潛力。

本研究使用SWOT衛星提供的LakeSP (Lake Single Pass)資料產品，針對臺灣南部曾文水庫進行空間擷取，並且與地面水位站所量測的水位資料進行比對與校正，藉此評估SWOT衛星用於臺灣水體監測的可行性與進行精度分析。初步比較發現SWOT衛星LakeSP的水位資料大致與水庫水位一致，相關係數達。由於發現臺灣的地表水體真實位置與LakeSP資料的位置不一致，同時有部份空間篩選錯誤的情況，未來將進一步使用 更精細的SWOT衛星Pixel Cloud 資料產品進行細部的水面高程重新計算與校正，以建構出一套適用於臺灣SWOT衛星地表水位監測的處理流程。本研究建立的作業流程將進一步使用於天然水體的分析，包括堰塞湖、高山湖泊等水體辨識。未來可以用於花蓮馬太鞍溪堰塞湖溢流案例研究，預期可以對於水資源、堰塞湖監測與防災預警等方面提供實質的貢獻。

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP043

應用 sentinel-2 影像判分析馬太鞍溪堰塞湖變遷

莊竣閔、吳善薇

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摘要

2025 年 9 月，颱風樺加莎外圍環流為花蓮帶來強降雨，觸發馬太鞍溪上游先前因地震與豪雨形成的堰塞湖溢流。9 月 23 日午後，大量泥水、碎石與洪水迅速沖向下游光復鄉，造成道路與橋梁毀損，並導致聚落淹水，造成 19 人死亡、5 人失聯以及 157 人受傷。堰塞湖通常由地震、崩塌或土石流形成，在強降雨作用下容易發生溢流或潰決，進而對下游地區造成嚴重災害。由於本研究區的堰塞湖位於山區，多為樹林覆蓋，因此本研究利用多期 Sentinel-2 衛星影像進行時序分析，並結合 NDVI 監測地表植生覆蓋變化。綠色植物會吸收可見光中的藍光與紅光，並強烈反射近紅外光，因此可利用近紅外光（NIR）與紅光（Red）的反射值計算 NDVI。NDVI 的數值範圍介於 −1 至 1 之間，其中接近 1 表示植被茂密且，接近 0 表示植被稀疏或裸露地表，而接近 −1 則多代表水體。透過 NDVI 的時序變化，可判釋崩塌範圍、堰塞湖形成前後坡面植被消失及裸露地擴展情況，並分析堰塞湖的形成時間、空間分布、面積變化與堆積體位置；同時追蹤潰決後水位下降與地貌演變，以建立堰塞湖從形成到消退的完整變化過程，作為未來災害監測與風險評估的重要參考。

關鍵字:馬太鞍溪堰塞湖、sentinel-2、NDVI

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CARBONSAR: 透過合成孔徑雷達進行樹高推測

謝秉皓[1]、郭昱廷[1、2]、林玉儂[3]、衛強[4]、陳嘉俞[1、2]

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摘　要

森林冠層高度為描述森林垂直結構的重要參數，也是估算地上生物量與森林碳儲量的重要基礎資訊。在全球氣候變遷與淨零排放政策推動下，如何精確且大範圍地監測森林結構，對碳循環研究與森林資源管理具有關鍵意義。傳統上，光達可提供高精度的三維森林結構資料，並已廣泛應用於森林高度與生物量估算。然而，光達資料取得成本較高，在大尺度區域監測上仍受限於空間覆蓋率與資料更新頻率。相較之下，合成孔徑雷達具有全天候、全天時觀測能力，且可提供大範圍且連續的觀測資料，因此逐漸成為森林結構反演的重要工具。其中，利用干涉式合成孔徑雷達結合高解析度光達資料與物理散射模型估算森林冠層高度的方法，近年來受到廣泛關注。

在多種干涉式合成孔徑雷達森林高度反演方法中，Random Volume over Ground（RVoG）模型被視為描述森林雷達散射機制的重要理論模型。此模型假設森林由隨機分布的體積散射層與地表散射組成，並藉由選用HV極化（Horizontal-Vertical Polarization）雷達影像以降低地表散射的影響，再透過干涉相關性結合局部光達資訊進行模型參數反演。此外，模型假設由植被含水量變化所造成的介電常數波動參數，以及由風引起之樹木隨機運動參數，在雷達影像範圍內為均勻分布，據以推估衛星影像範圍內的森林冠層高度。

本研究預期利用日本ALOS-2 衛星影像，結合我國內政部高解析度空載光達資料，在特定的試驗林區，先建立地面到低空（光達）的森林樹高驗證，再透過低空到高空（SAR）的結合，建立大範圍森林冠層高度地圖，並進一步分析地形高程、局部入射角及不同森林類型對反演誤差之影響，期望提升森林結構監測方法之穩健性，並為未來大規模森林地上生物量估算提供科學依據。

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP045

氣候變遷對澎湖及所羅門島海岸環境的影響:結合多源多光譜影像與機器學習的應用

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摘　要

近年氣候變遷與極端事件對島嶼海岸穩定性造成顯著影響，為提升海岸線長期監測效率，本研究著重於提升海岸線自動化萃取方法與區域比較。研究區域包含臺灣澎湖群島與南太平洋所羅門群島（Simbo與Ranongga），兩者皆屬火山島嶼，澎湖群島之海岸變遷主要受氣候與潮汐作用影響，而所羅門群島則同時受氣候、環礁地形及構造活動控制。藉由兩區之對比分析，以探討不同控制因子下之海岸線變遷機制。本研究於採用2016–2026年Sentinel-2影像進行分析，並於澎湖地區額外採用高解析度SPOT衛星影像，以提升海岸線辨識精度。在澎湖地區，透過計算水體指標（NDWI），並以NDWI = 0作為水陸分界閾值進行分類，將影像區分為水體與陸地；進一步結合 Sobel 邊緣偵測法強化水陸交界之梯度變化，以提升海岸線定位與辨識精度。本研究於澎湖與所羅門群島兩地皆採用CoastSat自動海岸線辨識模型，透過影像分類方法將地表區分為水體、沙灘與陸地，並據此快速提取海岸線位置。該模型具備自動化處理長時間序列影像之能力，且能維持分類一致性，特別適用於高雲覆蓋區域之海岸線變遷分析。考量研究區域雲量較高，本研究將雲覆蓋閾值設定為0.2，減少人工判釋以提升辨識效率。此外，研究區域曾在2007年發生Solomon Islands earthquake、Mw為8.1，於上盤的Ranongga島於地震中產生約1-2m地殼抬升，下盤的Simbo島則未觀察到明顯構造變化，形成構造控制與自然海岸演變之對照條件。海岸線變遷分析顯示，澎湖吉貝嶼南部海岸線位置隨時間呈現明顯擺動與後退現象，侵蝕速率為28.36m/yr，主要受季節性波浪與沿岸流影響。Ranongga島南半部近十年以侵蝕為主，最大侵蝕速率約0.81m/year，部分時段受雨季沉積物供應增加影響，可能出現短暫海退現象。Simbo島整體變化較小，西南側輕微堆積，速率約0.41m/yr，其餘區域多為侵蝕。Ranongga可能仍受地震抬升後影響，Simbo島主要受波浪作用與環礁地形控制。本研究比較不同方法與參數，建立適用各島嶼的海岸線萃取流程，並顯示構造事件能短期改變基準面，影響長期海岸演變，對監測與氣候調適具參考價值。

【學生壁報比賽】

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Student Poster SP046

Revealing Heterogeneity Ground Recovery After Long-term Subsidence in Jakarta Metropolitan Region (JMR), Indonesia

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Abstract

Chronic groundwater overextraction drives land subsidence in rapidly urbanizing megacities, yet the response of subsurface deformation to groundwater management remains poorly constrained. Here we investigate the coupling between surface and subsurface processes to characterize ground recovery in the Jakarta Metropolitan Region (JMR). We applied SBAS-InSAR to quantify long-term spatiotemporal subsidence using ALOS-1 PALSAR-1 (2007–2010) and Sentinel-1 (2014–2025) observations. Results reveal pronounced spatial heterogeneity in subsidence recovery across the Jakarta Metropolitan Region (JMR). Over 18 years, vertical deformation rates declined, varying from −180 to −70 mm yr^{-1}, indicating partial recovery. Two deceleration phases around 2018 and 2023 occur mainly in inland areas and are locally followed by uplift, consistent with elastic rebound of previously compacted aquifers. In contrast, coastal zones exhibit persistent or accelerating subsidence driven by irreversible consolidation of shallow sediments. These contrasting behaviors agree with extensometer and groundwater-level observations, highlighting groundwater replenishment as the primary control on inland recovery, while shallow-layer consolidation sustains coastal subsidence. Our results demonstrate that subsidence responses to groundwater management are strongly site-dependent and governed by distinct subsurface processes.

Keywords: Subsidence recovery; InSAR; Groundwater rebound; Soil consolidation; Tilt rate; Infrastructure risk

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(1) University/Advisor : National Cheng Kung University/ Ruey-Juin Rau
(2) Degree/Grade : Doctoral degree/3rd years

Student Poster SP047

背散射訊號分析於沉積物粒徑推估之適用評估

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摘　要

隨著多音束聲納之發展與應用，透過其背散射訊號特性推估海床沉積物粒徑，已是海床底質測繪中逐漸推廣的方法。但不同的分析方法應用於不同調查環境往往有不同的適用性，如何進一步驗證其可靠度，仍是需持續探討之議題。本研究以新海研 1 號於臺灣西南海域所蒐集之多音束聲納資料為例，探討背散射訊號分析技術，並評估其於臺灣周遭海域海床沉積物粒徑推估之適用性。

本研究利用 CARIS 軟體處理水深與背散射資料，再透過角距分析（Angular Range Analysis，ARA）推估海床表層沉積物粒徑。進一步與岩心樣本交互驗證，結果顯示高屏峽谷外地形平緩區域之推估粒徑與岩心中值粒徑呈中度相關（R^2 = 0.68）；但針對複雜地形，如峽谷內之區域，其沉積物粒徑推估準確度則較低（R^2 = 0.06），而單點背散射強度亦無法有效反映沉積物粒徑大小。此外，不同沉積物組成對推估結果影響亦明顯，其中泥含量與粒徑推估最具相關性（R^2 = 0.73），而淘選度影響有限。

本研究結果顯示，在地形平緩且沉積環境均勻的區域，多音束背散射資料可有效反映沉積物粒徑之相對變化趨勢，具提供連續空間資訊的潛力，惟其定量推估準確性仍受系統誤差、沉積物空間分布不均勻及資料庫適用性等因素限制。未來可透過建立基礎的沉積物岩心特性資料庫作為校正依據，或引入人工智慧分析方法以優化定性結果，進一步提升推估結果之可靠性。

【學生壁報比賽】

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Student Poster SP048

Acoustic Characterization of Fluid Seepage Controlled by Tectonic Structures Offshore Southwestern Taiwan

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Abstract

This study quantifies spatial variations in acoustic seepage intensity offshore southwestern Taiwan and investigates the dominant controls on cross-system variability. A total of 21 gas plumes from 13 seep sites were identified using single-beam echosounder data from 11 cruises, and seepage intensity was characterized using volume backscattering strength (Sv) and plume geometry. After transmission-loss correction, seep sites located along the passive margin exhibit higher Sv and greater plume heights than those on the active margin. Tidal sensitivity analysis shows that tidal forcing does not significantly alter the relative differences in Sv among seep systems, and the weak relationship between Sv, gas flux, and methane origin further suggests that these factors are not the primary controls on seepage intensity. Instead, high Sv seepage observed at passive margin ridges is closely associated with overpressured free-gas reservoirs and hydrofracturing, indicating efficient and persistent fluid pathways. In contrast, relatively weak Sv at the mixed-origin G96 site suggests partial conduit infilling.

Based on these observations, we propose that while tectonic setting defines the first-order structural framework, the continuity and evolutionary state of fluid conduits exert the dominant control on seepage intensity. An evolutionary framework is therefore proposed, linking variations in Sv to conduit development stages, from accumulation (Stage 2), active seepage (Stage 3), to sealing and decline (Stage 4).

Keywords: acoustic seepage intensity, conduit continuity, volume backscattering strength (Sv), gas plumes, fluid conduits, offshore southwestern Taiwan, evolutionary framework

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Student Poster SP049

竹苗海域活動斷層之特性與分布

Structural Architectures and Distribution of Active Faults in the Offshore Hsinchu-Miaoli

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Abstract

The Offshore Hsinchu–Miaoli lies at the deformation front of the orogenic belt and forms the seaward extension of the onshore fold-and-thrust belt. Previous studies have proposed possible faults and preliminarily assessed potential seismogenic structures. However, the detailed characteristics of these faults, including length, dip, strike, vertical displacement, and activity, remain insufficiently understood. This study aims to quantify fault parameters from multichannel seismic and sub-bottom profiler data offshore.

Multichannel seismic reflection data were used to identify major fault planes and unconformities and to examine the type of fault-related folds. Fault planes were correlated across profiles to estimate length and angle in the depth domain. The sub-bottom profiler data further provide evidence of long-term vertical displacement for the Holocene strata, helping delineate potential hazard zones affected by active faults.

Seismic interpretation identifies eight major NE–SW trending thrust faults in the study area, with mostly 1–7 km long and one up to 15 km long. The fault tips terminate below the seafloor, and the overlying strata form asymmetric anticlines interpreted as fault-propagation folds. A laterally continuous shallow unconformity on top of the truncated folds is interpreted as the Last Glacial Maximum unconformity (LGMU). Sub-bottom profiles further reveal uplifted strata above LGMU, suggesting recent fold deformation and fault activity. These results clarify the distribution, geometry, and activity of thrust faults in the Offshore Hsinchu–Miaoli.

Keywords: Offshore Hsinchu–Miaoli Area, active faults, fault-propagation fold, multichannel seismic reflection

(1) National Taiwan University / Sung-Ping Chang and Ho-Han Hsu
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海陸聯合震測揭示苗栗離岸－近岸沉積層與地殼 P 波速度構造

Onshore–Offshore Seismic Study of P-Wave Velocity Structure of Sediment and Crust near Miaoli

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摘要

歐亞板塊與菲律賓海板塊的碰撞形成臺灣造山帶，並在其西側發育褶皺逆衝斷層帶與前陸盆地系統。苗栗地區位於臺灣褶皺逆衝斷層帶的西北部，並鄰近臺灣海峽東側發育的前陸盆地—臺西盆地。我們分析 2022 年 9 月苗栗 21 部陸上測站接收「新海研一號」空氣槍震源(約 65 公里長)的海陸聯合震測資料。海陸震測資料顯示可接收來自沉積層界面（速度層第 2~5 層）下方的首波訊號以及來自地殼（第 6~8 層）的折射波訊號。走時反演建構苗栗離岸至近岸沉積層與地殼之二維 P 波速度–界面模型顯示，海域淺層 P 波速度(1-2 公里/秒)較前人研究低，而在靠近海陸交界帶深度 7 公里處的 P 波速度達到約 6~7 公里/秒，以及在苗栗海域觀測到速度可達約 8 公里/秒的 P 波訊號。透過海陸震測資料的整合分析，本研究可改善海上或陸上震測在近岸區域解析度不足的問題。研究成果除有助於釐清苗栗地區地下構造與地層分布外，亦可作為區域地質研究、地震構造分析及二氧化碳地質封存評估的重要基礎資料。

關鍵詞: 海陸震測、P 波、臺西盆地、走時反演

Keywords: Onshore–Offshore Seismic Survey, P-Wave, Taishi Basin, Travel-Time Inversion

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Student Poster SP051

桃園沿岸海陸聯合震測之沉積層 P 波速度構造分析

Analysis of Sedimentary P-wave Velocity Structure Based on an Onshore–Offshore-Seismic Survey along the Coastal Taoyuan

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摘要

2023年5月在桃園至新竹沿岸佈設60部陸上地震測站，同步接收勵進研究船於桃園外海空氣槍震測激發之震波訊號。本研究選取其中15部陸上測站記錄之東北—西南向測線震測資料，透過折射波與反射波走時反演橫跨海陸之沉積層P波速度模型，解析桃園沿岸3-4公里深之沉積層P波速度構造。反演結果顯示，桃園沿岸上部地層主要由中新世至上新世沉積地層組成，其 P 波速度從1.8–2.5公里/秒遞增至3.5公里/秒以上，並在1–1.5公里深處辨識南莊層頂部的前陸基底不整合面。在桃園海岸附近南莊層下方的地層深度1–2.8公里辨識一組低速帶 (2.3–3.4 公里/秒)。其中，上部低速體位於南莊層內，P波速度約為2.3–2.5公里/秒；其下方另可辨識一呈錐形分布之低速體，P波速度約為3.1–3.4公里/秒。該低速帶位置接近中油KY-1鑽井揭露之舊氣田區域，其速度顯著低於周圍地層，可能與較高孔隙度沉積物或流體富集現象有關。因此，本研究推測上述低速帶在具備適當蓋層條件與構造封閉條件下，具有作為未來二氧化碳地質封存場址之潛力。未來研究將整合多條海陸震測測線及更多陸上測站資料，發展三維海陸聯合震測速度成像與構造解析，以建立低速體之三維空間分布與周圍地層關係，並進一步評估其作為二氧化碳地質封存場址之可行性與安全性。

關鍵詞：低速帶、海陸聯合震測、P 波速度模型、走時反演

Keywords: Low-velocity zone, Onshore–offshore seismic survey, P-wave velocity model, Travel-time inversion

Student Poster SP051

【學生壁報比賽】

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學位/年級：碩士一年級

Student Poster SP052

臺灣西南海域高屏峽谷之地震活動觀測
Observation of Earthquake Activity in Kaoping Canyon, Offshore Southwestern Taiwan

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摘要

本研究分析2025 年 6 月 18-21 日 NOR3-0271 航次取得之海底底質剖面（Sub-bottom Profile, SBP）與海底地震儀（OBS）資料，探討高屏峽谷淺層地震活動。海底底質剖面經濾波與振幅增益處理後，可辨識多組淺層正斷層與逆斷層構造。8部海底地震儀於航次期間同步記錄區域地震事件，並進行 P 波、S 波與表面波到時拾取與震相分析。比對多測站到時差異與波形特徵，可推估震源距離及區域速度構造變化。結果顯示，各測站到時差異一致，反映震源位置與地下構造控制效應。綜合海底底質剖面之淺層斷層與海底地震儀資料震相分析，已完成速度模型建構。區域速度構造變化，顯示不同測站間地下構造及速度分布之側向差異(0.3–0.6 公里/秒)。本研究尚需震源定位驗證，以釐清高屏峽谷孕震構造之機制，並提供該區地下構造之初步地球物理觀測依據。

關鍵詞：高屏峽谷、海底地震儀、地震活動、震相分析

Keywords：Kaoping Canyon, Ocean-bottom seismometer (OBS), Earthquake activity, Seismic phase analysis

【學生壁報比賽】

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Student Poster SP053

Cluster-based Chemostratigraphy for Event Stratigraphic Correlation in Central/Northern Japan Trench

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Subduction zone megathrust earthquakes, such as the AD 2011 Tohoku-Oki earthquake, represent one of the most powerful geological hazards. With the long recurrence intervals hold the challenges for understanding long-term records. The International Ocean Discovery Program Expedition 386 (IODP EXP 386) aims to fill the knowledge gap by exploring submarine paleoseismology of the Japan Trench. While physical properties have been previously correlated, between the central Japan Trench and the central/northern part remains inconclusive. Therefore, by applying X-ray Fluorescence Core Scanning (XRF-CS) combined with multivariate statistics, Principal Component Analysis (PCA) and Cluster Analysis (CA), differentiate the chemical characteristics of the events.

This study focuses on sediment cores M0083D from the central Japan Trench and M0093B from the central/northern Japan Trench. Events in M0083D are well-defined, challenge poses on M0093B with limited chronological tie points. To address the limits, XRF-CS gives the chemical fingerprints, then classified into five groups with different colors via PCA and CA. Green cluster shows high value in Mn. The blue cluster reflects events with high Ca and Sr. The red cluster highlights events with high Si, K and Rb. The orange and purple shows high Cl and Br with relatively low Mn. In M0093B, 8 event deposits were defined. The top 4 events were correlated to the top 4 events of M0083D, from the AD 1454 Kyotoku, AD 869 Jogan earthquake, the 2.3ka event and a thin, red-clustered event. Although depositional process remains discussion, cluster-based chemostratigraphy provides the ability to establish stratigraphy in complex cores.

Keywords: XRF-CS, Japan Trench, Event-stratigraphic correlation, submarine paleoseismology

中文標題：利用 XRF-CS 化學地層對比：應用於日本海溝中部與北部之事件地層

研究

中文關鍵字：XRF 岩心掃描、日本海溝、事件地層對比、海底古地震學

【學生壁報比賽】

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Student Poster SP054

Sequence Stratigraphy and Compound Clinoform in the Choshui Subaqueous Delta

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Abstract

The coastal region of central Taiwan, primarily part of the Choshui Delta, functions as a highly dynamic source-to-sink system. Driven by an exceptionally high sediment yield from a small mountainous catchment, this area provides a critical record of tectonic and climate variability in Late Holocene. However, the evolution of the subaqueous delta remains unexplored. In this study, we utilized high-resolution single-channel sparker seismic profiles to reconstruct the sequence stratigraphy of the subaqueous delta since the Late Holocene.

The high-resolution seismic profiles extending from the river mouth to the offshore area reveal a compound subaqueous delta system, distinguished by subaqueous platform where sediments were subsequently reworked by wave and alongshore processes. Based on key bounding surfaces, this subaqueous delta succession is subdivided into five distinct seismic units. The subaqueous clinoforms reveal a significant north-south migration of the depocenter, suggesting a Late Holocene river avulsion. The estimated progradation directions align with modern fluvial input, indicating a river-dominated system.

Furthermore, the Wheeler diagrams show two scales of depositional variability within the subaqueous clinoform, suggesting shifting sediment fluxes. Calibrated against independent onshore age data, these stratigraphic hierarchies were estimated millennial and centennial periodicities. Consequently, this study establishes a robust stratigraphic framework to constrain future high-resolution dating and paleoclimate reconstructions, offering a unique archive that links upstream environmental forcing to offshore deposition.

keywords

Millennial- to Centennial-Scale sequence stratigraphy; subaqueous delta; high-resolution seismic reflection; offshore central Taiwan

“The Students’ Poster Competition”

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(2) Master's Degree/ Second year

南沖繩海槽棉花海底火山之地質構造分析

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摘　要

棉花海底火山（Mienhua Submarine Volcano, MSV）位於南部沖繩海槽的北部邊緣，其形成可能於台灣造山運動碰撞後的時期。棉花海底火山周圍伴隨著活躍的熱液活動，為了瞭解花海底火山相關的構造斷層、火山侵入體和熱液活動，本研究在火山周圍收集了多條電火花高解析震測剖面。結果顯示，棉花海底火山的東西兩側呈現不同的地質特徵。在東側觀察到不整合面、強振幅反射面和聲學空白帶。這些聲學空白帶可以表示熱液流體已經滲透地層並向上和往兩側移棲，在水層中也發現大量熱液柱。換言之，東部區域熱液活動活躍。相較之下，棉花火山西側則較少發現不整合面或熱液活動，還觀察到可能是海底滑坡造成的塊體搬運沉積物。火山西北側觀察到往火山傾斜的地層，合震測屬性分析和底質剖面影像進一步確認，推測可能是因為斷層和熱液存在造成。研究結果顯示，棉花海底火山周圍構造具明顯不對稱性。其火山構造與斷層的交互作用引發了地層傾斜與塊體搬運，有助於理解沖繩海槽北緣的構造演化與熱液循環機制。

【學生壁報比賽】

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Student Poster SP056

加瓜海脊地殼速度構造及其與不同類型海脊之差異

Crustal velocity structure of the Gagua Ridge and its differences from different types of ridges

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摘要

加瓜海脊位於臺東外海約 200 公里處，是一條南北向的線形海脊，其將西側的花東海盆與東側的西菲律賓海盆分隔開來。加瓜海脊的形成與周邊海盆的演化密切相關，因此，釐清加瓜海脊的形成機制對於理解菲律賓海板塊之地體構造演化具有重要意義。然而，加瓜海脊的形成機制仍有歧見，目前可能的解釋包括：(1)始新世時走滑擠壓作用發生於西菲律賓海盆內的破裂帶，形成擠壓抬升的海脊構造；(2)古太平洋板塊在中生代時隱沒至花東海盆之下，初期所形成的島弧；(3)華夏地塊邊緣在白堊紀時發生張裂，隨著邊緣海新生代的生長與閉合，移動至現今位置的大陸碎塊。我們認為這三種形成機制將使地殼在速度與厚度上有所差異，因此藉由 P 波速度與地殼厚度可用以區分不同的地殼性質，進而探討加瓜海脊的可能形成機制。本研究使用 2009 年 TAIGER 計畫所收集的多頻道反射震測與海底地震儀走時資料，運用能夠聯合逆推折射波與反射波走時資訊的 TOMO2D 層析成像法，並採用蒙地卡羅與自適應重要性採樣策略，建立地殼速度構造剖面。蒙地卡羅與自適應重要性採樣法讓我們廣泛的探索不同參數對於模型結果的影響，並且有效率地獲得大量的成功模型，使最終速度模型更具可信度。結果顯示，加瓜海脊平均下地殼速度為 7.15 km/s，較前人研究之 7.06 km/s 略高；而地殼厚度為 14 km，則明顯高於前人研究之 9 km。西側的花東海盆平均下地殼速度為 7.25 km/s，地殼厚度 7.4 km。東側的西菲律賓海盆平均下地殼速度為 7.36 km/s，地殼厚度 8.3 km。此外，我們繪製沿測線的地殼厚度－平均下地殼速度圖（H-V_p plot），將加瓜海脊與島弧海脊（大東海脊、九州－帛琉海脊、伊豆－小笠原－馬里亞納）比較，得到相同的速度（7.0 – 7.2 km/s）與厚度（10 – 15 km）範圍。後續我們會將加瓜海脊與海洋地殼海脊、大陸碎塊海脊比較，並分析海脊與周圍海盆的速度關係，以釐清其地殼性質，討論加瓜海脊的形成機制。

關鍵字：加瓜海脊、海底地震儀、地殼構造、TOMO2D、H-V_p

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Student Poster SP057

Assessment of fault activity at offshore carbon storage prospects off Taoyuan

Abstract

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The offshore Taoyuan area is considered a prospective site for carbon capture and storage (CCS), but the possibility that faults may compromise the reservoir–seal system remains a key concern. In this study, fault activity history and fault displacement were analyzed to evaluate seal integrity. The Nanchuang Formation and Kueichulin Formation are the main reservoir units, whereas the Chinshui Shale serves as the regional seal. The geological evolution of the area since 20 Ma records a transition from post-rift to foreland basin development.This study integrates 42 multichannel seismic profiles and one exploration well. Fault geometries were identified through cross-interpretation of isopach maps and seismic reflection profiles, and T-z plots were used to constrain fault activity history. A total of 8 normal faults were identified and classified into three groups: post-rift faults, foreland basin faults, and composite faults. The foreland basin faults mainly cut the Kueichulin Formation to the Toukoshan Formation, with peak displacement during deposition of the Chinshui Shale. The post-rift faults mainly cut the Mushan Formation to the Nanchuang Formation, with peak activity during deposition of the Shihiti Formation. Composite faults extend from the Mushan Formation to the Toukoshan Formation and show two displacement peaks, suggesting linked fault development across two tectonic stages.Quantitative results show that the maximum vertical separations across the Chinshui Shale, Kueichulin Formation, and Nanchuang Formation are about 0.025 s TWT (~40 m), 0.022 s TWT (~35 m), and 0.020 s TWT (~30 m), respectively. Because the maximum displacement within the regional seal is smaller than the shale thickness at the well location (~81 m),

the seal is unlikely to have been fully breached. These results suggest that offshore Taoyuan remains a viable candidate for geological carbon storage.

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Student Poster SP058

Seismic Sequence and Seismic Facies Analysis of the Depositional System Offshore Central Taiwan

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Abstract

This study aims to establish the stratigraphic framework of the offshore central Taiwan foreland basin, reconstruct its sedimentary infill history, and examine how orogenic development influenced its depositional environment. Seismic sequence and seismic facies analyses were integrated with well data. Three sequence boundaries (SB-A to SB-C) and four seismic sequences (SQ1 to SQ4) were identified. SB-A and SB-B are onlap contacts, indicating two phases of accommodation increase that record basin initiation and deepening during orogenic loading. SB-C is a downlap contact, indicating basinward progradation. SQ1 is characterized by parallel reflections, low amplitude and moderate continuity. The bottom of SQ2 onlaps onto SB-A and shows wedge-shaped geometry with parallel to sub-parallel reflections; its lithology is mainly shale. The bottom of SQ3 onlaps onto SB-B and also shows wedge-shaped geometry, with parallel reflections occasionally interbedded with chaotic and erosional reflections; well data indicate coarser lithology than the previous stage. SQ2 and SQ3 likely represent the establishment and deepening stages of the foreland basin, when flexural subsidence controlled by orogenic loading formed an underfilled depositional environment. SQ4 exhibits shingled and localized chaotic geometries with N-S-oriented channel erosional reflections. Well data indicate lithology coarser than SQ3, suggesting that as orogenic development weakened and sediment supply exceeded flexural subsidence, the basin was gradually filled and evolved into an overfilled stage. Isopach maps show southward migration of depocenters from SQ2 to SQ4, possibly reflecting southward progression of the Taiwan collision orogeny and migration of the basin's flexural subsidence center. Overall, the reconstructed framework shows a transition from underfilled to overfilled, providing a regional stratigraphic basis for understanding foreland basin development offshore central Taiwan.

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Student Poster SP059

Fault Structures and Morphotectonic Evolution Offshore Hualien: Insights from seismic stratigraphic and geomorphologic features

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Abstract

The eastern offshore region of Taiwan is situated within an active plate convergence zone characterized by frequent seismic activity. Despite this, offshore faults are relatively underrepresented in seismic hazard assessments, potentially limiting the accuracy of hazard models. This study aims to identify offshore faults and their geometric characteristics from multichannel seismic and bathymetric data. The fault systems identified offshore Hualien mainly trend north-south, with eastward-thrusting thrust faults. Notably, a southwest-verging thrust fault extends along the southwestern margin of the Hsincheng Ridge and may represent the westernmost segment of the West Yaeyama Fault Zone. In addition, the near-surface trace of the Milun Fault extends offshore along the western flank of the Hualien Ridge and terminates at the ridge. Further south, multiple eastward-thrusting faults can be identified and classified into three or more distinct fault structures based on variations in fault dip and hanging-wall deformation, indicating a compressional environment associated with ongoing plate collision, characterized by active crustal deformation and progressive crustal thickening. Overall, this study reconstructs the structural framework of the eastern Taiwan offshore region through integrated geophysical observations. The results reveal spatial variations in fault distribution and associated deformation, indicating that fault-controlled deformation governs present-day seafloor morphology. Incorporating offshore fault systems into regional structural models provides a more comprehensive basis for understanding tectonic processes and morpho-tectonic development in eastern Taiwan.

Keyword: fault structures, seismic, geomorphology, offshore Hualien

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Student Poster SP060

晚更新世濁水溪扇洲與彰雲沙脊之沉積地層對比：利用海域高解析震測與陸域井測資料

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濁水溪為臺灣沉積物輸出量最高的河川之一，攜帶大量沉積物輸入臺灣海峽，於陸域形成濁水溪扇洲，在外海則相鄰彰雲沙脊。過去研究多將兩者分別視為陸域沖積扇與海域潮流沙脊，本研究嘗試透過沈積地層的對比，探討濁水溪扇洲與彰雲沙脊之時空分佈，藉以探討晚更新世以來台灣中部源匯系統的發展。本研究整合近年離岸風電調查所取得之海域資料，包括水深、多頻道反射震測、火花式放電震測與底質剖面資料，並結合 13 條火花式放電震測剖面、1 條多頻道震測剖面以及濁水溪扇洲上 40 口井測資料，分析濁水溪扇洲至彰雲沙脊之間的沉積環境變化。在海域部分，透過震測特徵辨識出彰雲沙脊下方四條不整合面（MD1、MD2、MD3、MD4）與五個震測層序（MS0、MS1、MS2、MS3、MS4），其中 MD3、MD4 各別分佈於西、東彰雲沙脊之下，且 MD4 向西進覆於 MD3 之上、即 MS4 堆覆於 MS3 之上，顯示了沉積中心由外海向近岸遷移。在陸域的部分則彙整前人岩芯資料、井測資料及定年結果，區分出三個地層邊界(TD1、TD2、TD3)與三個地層單元(TS1、TS2、TS3)，觀察 TS1 到 TS2 時期的厚度可以發現沉積物主要集中於沿海地區，最大厚度或有向北遷移之趨勢，反映沉積物在不同時期的空間變化。本研究分析濁水溪扇洲至彰雲沙脊之沉積分布與發展，藉由不同時期之沉積環境及其可能沉積作用，希望能建立濁水溪扇洲與彰雲沙脊沉積演化之關聯性，作為更新世以來扇洲、高沈積物通量之源匯系統發展的案例。

【學生壁報比賽】

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中文關鍵字：濁水溪扇洲、彰雲沙脊、臺灣海峽、火花式放電震測

Student Poster SP061

超長週期地震傾斜探討2009年莫拉克颱風期間高屏峽谷海底濁流載重效應

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在傾斜海底地形上，海水的運動會受多種環境與動力因素影響，由峽谷上游被沖刷或崩落進入海洋的高密度流體常可誘發深海濁流。然而，除濁流彼此之間以及濁流與地形之交互作用外，尚有諸多控制因子共同影響其生成與能量傳播過程，使得海底濁流之全面觀測與量測極具挑戰性。本研究利用中央研究院地球科學研究所之陸上寬頻地震陣列（Broadband Array in Taiwan for Seismology , BATS） 所記錄之超長週期（0.04-0.3mHz）地震訊號，過去研究(Yang等人)指出距離對此頻率之傾斜值影響最敏感，我們選用距離高屏峽谷最近的4個測站(TWKB、MASB、TPUB、PHUB)做比對，並結合高屏峽谷地形特徵，以及2009年間莫拉克颱風侵臺期間所發生之海底電纜斷裂紀錄進行比較分析，比對高屏峽谷中海底濁流之流速與位移。針對兩次與電纜斷裂事件對應之濁流活動進行分析，比較其時間演化與空間方向特徵，結果顯示，高屏峽谷周邊測站傾斜訊號之起始時間與方位角演化趨勢，與電纜斷裂位置沿峽谷軸線之空間分布具有高度正相關性。此外，前人文獻中指出莫拉克颱風過境後於該海域曾採集到陸源沉積物，可推測當時曾有流體由峽谷上游將沉積物搬運至海底之事件發生。因此，為證明電纜斷裂期間所觀測之超低頻地震訊號，不僅受到颱風期間河水水體影響，亦可能與水體中的沉積物或岩石及附近海底濁流運動相關，我們會利用young’s modulus進一步以理論地震傾斜值進行探討。本研究將陸上寬頻地震陣列訊號與海底電纜斷裂之時間及經緯度紀錄結合，顯示此方法有助於反演與解析深海濁流之運動歷程，並為未來相關研究提供新的觀測與分析途徑。

【學生壁報比賽】

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Student Poster SP062

利用高解析度多頻道震測探討能登半島東北外海之斷層再活化與構造反轉

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摘　要

2024年1月1日，日本能登半島發生規模M7.6強震，為近年來日本海側最具代表性的地震事件之一。根據震源分析，其致震斷層長度約達150公里，呈東北—西南之走向，顯示該區域存在大尺度且連續之活動構造系統。為釐清此次地震相關之地殼變形特徵與斷層構造，本研究利用2024年3月於研究船白鳳丸執行之緊急調查航次，取得高解析度多頻道反射震測資料，測線涵蓋能登半島北岸斷層帶珠洲沖段及富山海槽西緣斷層帶。根據震測相與反射訊號接觸關係的分析，研究區地層可劃分為三個震測地層層序：P0、P1與P2。P0主要呈現不連續且混亂之反射特徵。向上之P1主要呈現大致平行但受斷層與褶皺變形影響之反射訊號，具有振幅較弱及頻率較低之特徵。P1頂部之層序邊界可觀察到發育良好的侵蝕面，該侵蝕界面向西北方向延伸並與七島—嫁礁隆起帶東南側相連，顯示區域性抬升與侵蝕作用之存在。其上覆之P2則以進覆於P1上界面為主要接觸關係，並呈現高振幅、高頻率且連續性良好之反射特徵，相較於P1，其受構造變形程度明顯較低。依據上述震測相特徵與區域地層邊界深度對比，P0、P1與P2分別可對應於音響基盤、南志見沖層群以及輪島沖層群。進一步透過等厚圖分析顯示，P1最厚處位於能登半島北岸斷層帶之東南側，而P2最厚處為斷層帶之西北側，或顯示沉積中心有西北向之遷移。而根據震測剖面解釋，部分斷層在深部為正斷層構造，但在淺部表現為高角度的逆斷層構造，加上P1形成時應為正斷層發育，而P2形成時P1已被抬升並侵蝕，說明該區斷層系統可能由早期張裂環境下之正斷層系統，在後期受擠壓應力影響而再活化為逆斷層系統，反映研究區經歷構造反轉作用。綜合而言，本研究透過高解析度震測資料，揭示能登半島東北外海斷層系統之構造演化歷程與再活化機制，有助於深化對2024年能登地震震源構造之理解，亦對區域地震及海嘯災害潛勢評估提供重要之地球物理依據。

【學生壁報比賽】

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Student Poster SP063

Active tectonic characteristics and seismic hazard potential of the Abra River fault system, northwestern Luzon, Philippines

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Abstract

The Philippine fault system is a primary seismogenic structure traversing the entire Philippine archipelago. On Luzon Island, the destructive 1990 M_W 7.7 Luzon and 2022 M_W 7.0 Abra earthquakes underscored this fault system's substantial seismic hazard potential. However, the precise location and characteristics of fault traces along some segments of this fault system remain poorly understood, particularly the Abra River fault system (ARFS) near the 2022 Abra earthquake epicenter. Therefore, this study aims to identify and characterize active traces of the ARFS based on tectonic geomorphic features using a 5-m resolution DEM, augmented by field investigations.

Based on geomorphic manifestations and results from our field investigations, we identified at least three major sinistral fault traces of the ARFS along the Abra River valley. Although our mapping results are generally consistent with the published map by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), the new mapping provides better constraints and information for previously uncertain segments. Geomorphic features and field investigations confirm recent activity and predominant sinistral motion of the ARFS, the latter is not consistent with the reverse-motion focal mechanism of the 2022 Abra earthquake. This suggests the ARFS was not the seismogenic source of the earthquake, and its accumulated strain remains unreleased. We estimated that the ARFS can generate $M_W > 7.0$ events, posing great seismic hazards for the area. Preliminary slip rates and recurrence intervals were also calculated, providing tentative fault parameters that can be further refined by future paleoseismic studies.

Please note the information in the bottom of abstract if you choose to attend to "the Students' Poster Competition".

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Student Poster SP064

朝鮮半島蔚山斷層中段的構造地形特徵及活動特性分析

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摘 要

蔚山斷層(Ulsan Fault)是朝鮮半島東南部的一條活動斷層，該斷層自梁山斷層(Yangsan Fault)中段起，往南南東方向延伸約50公里，為該區主要的東傾逆斷層系統。雖然朝鮮半島位於相對穩定的歐亞板塊內部，斷層平均活動速率較低，但歷史地震研究及近代儀器觀測皆表明，在朝鮮半島東南部曾多次發生災害性地震，其中包含公元779年的慶州地震，及2016年和2017年的慶州與浦項地震等。這些地震事件顯示該區域的活動構造系統具有孕震潛能，因此瞭解這些斷層系統的活動特性與確切位置對於區域地震災害評估時相當重要。

為了瞭解蔚山斷層自晚第四紀以降的活動特性，本研究透過高精度數值地形模型及野外地質與地形調查，尋找並分析蔚山斷層中段沿線可能保留的活動構造地形。本研究在中生代深成岩體和第四紀沖積層的邊界以西，吐含山(Tohamsan)西側河谷的沖積扇上發現一系列近南北向、東高西低且平行發育的構造崖，可能與蔚山斷層的前緣構造有關。這些構造崖的延伸處也常見現生河道之坡度變化，顯示該區沖積扇地形與河流地形的發育皆受構造活動影響。透過野外露頭觀察，本研究亦發現地形崖附近區域的沉積物有受構造活動擾動之跡象，指示蔚山斷層在沖積扇形成之後仍有持續之活動。綜合該區域前人研究的成果，本研究結果暗示蔚山斷層中段可能已向西發展成一個較寬的活動斷層破裂帶，且斷層平均活動速率可能較區域的侵蝕與沉積速率為高。此一結論與韓國東南部的第四紀海階研究成果相若，顯示蔚山斷層上盤區域於晚第四紀期間具有明顯的垂直抬升，為該區重要的潛在孕震構造之一。

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP065

結合構造地形及接收函數法探索嘉義斷層

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摘　要

台灣位處板塊邊界，除了東部之碰撞帶，西部則以一系列之覆瓦狀褶皺—逆衝斷層帶吸收其板塊縮短量，並發育許多未知之盲斷層。鑑於台灣西南部近期陸續發生多起規模5以上之地震（如新港、中埔及大埔地震），且歷史上該區亦曾發生多次災害性地震（如1906年梅山地震），顯示此區域存在許多未知的發震構造。針對歷史上造成許多死傷的梅山地震，近期研究指出其成因為梅山斷層與嘉義斷層錯動相互誘發所致。然而，目前對於此二斷層（特別是嘉義斷層）之地表變形特徵、地下幾何結構，以及兩者間的構造交互關係，仍缺乏深入了解。

因此，本研究聚焦於嘉義地區麓山帶前緣，透過測繪沖積扇與河階等地形指標分布，並透過其坡度變化辨識是否具有斷層活動特徵。此外，本研究亦透過分析河流陡峭度指標與河流蜿蜒度指標，探討跨越不同地質構造區之差異。為更瞭解嘉義斷層之三維幾何結構，本研究運用接收函數法（Receiver Function）結合Common Conversion Point（CCP）方法，建構該區之地下地層幾何結構。影像結果清晰顯示地層受嘉義斷層活動影響而形成斷層擴展褶皺（Fault-propagation fold），且其向地表延伸之軌跡與地表變形特徵之位置高度吻合。隨後，本研究利用高精度即時動態定位技術（RTK-GNSS），針對斷層沿線進行野外測量，以量化細微之地表變形特徵。

研究結果顯示，在梅山斷層以北區域，受限於現有地震測站分布密度及數值高程模型（DEM）之解析度，尚難以清晰觀測嘉義斷層造成之變形；但在梅山斷層以南區域，則可清晰辨識受嘉義斷層控制之地表變形特徵與地下幾何構造。資料進一步顯示，嘉義市區內至少存在三處顯著之地表撓曲現象。且CCP剖面觀察到此區域正處於九芎坑斷層與六甲斷層之構造轉換帶，因而呈現出複雜之地層擾動特徵。

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP066

台灣西北部石門斷層與大平地斷層之構造關係探討

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摘要

石門斷層與大平地斷層位於台灣西北部麓山帶前緣，石門水庫西側，為研究區內兩條相鄰之逆衝斷層。前人繪製地質圖中雖已有石門斷層與大平地斷層地表斷層跡線，然而受限於斷層沿線缺乏明確且可連續追蹤之斷層露頭，使得斷層的精確位置、傾角、活動性及兩者地下連接關係仍然存在不確定性，斷層構造關係亦難以直接由地表判定。因此，本研究依據野外地質調查所得之岩性分布與位態資料，並結合高解析度 DEM 所產製之日照陰影圖，利用地形明暗與差異侵蝕特徵判釋與構造大致平行之地形線形，重新繪製研究區域內地表岩性分布，作為剖面建構之地表依據；並整理鄰近石門斷層之鑽井岩心資料，辨識岩心中破碎帶、斷層角礫岩以及剪切構造較為集中的區段以判定斷層帶於岩心中的位置，作為斷層地下淺部構造的限制條件。綜合地表地質分布、鑽井、前人研究與地層厚度資料及區域構造背景的約束下，所建構之 A-A’與 B-B’地質剖面推測，石門斷層與大平地斷層可能屬於同一逆衝斷層系統，並於深部連接至低角度滑脫面。此外，鑽井中中新世地層覆蓋於鬆軟的礫石沉積物之上，由於該鑽井位置位於大漢溪襲奪前古流域範圍內，因此可解釋為大漢溪所搬運之沉積物，但該礫石沉積物與古大漢溪之關聯性，以及其對石門斷層活動時間之推估，仍有待後續沉積來源分析與年代資料做進一步驗證。

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Student Poster SP067

Thermomechanical Modeling of Subduction Initiation at the Gagua Ridge: Implications for the Age of the Huatung Basin

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Abstract

How and why subduction initiates are fundamental for understanding the evolution of plate tectonic systems. The Gagua Ridge is a bathymetric high dividing the Huatung Basin and the West Philippine Basin. A previous study using bathymetry and seismic tomography revealed deformed oceanic crust and asymmetric crustal thickening along the ridge, suggesting that it may represent the surface expression of a failed subduction system. As plate thermal ages strongly influence the forces for subduction initiation, upper-plate deformation, and subduction polarity, constraining plate ages is critical for understanding the geodynamics of this region. While the age of the West Philippine Basin is relatively well constrained at ~56–35 Ma, the age of the Huatung Basin remains debated due to magnetic anomalies obscured by thick sedimentary cover, with estimates ranging widely from 140 Ma to 15 Ma.

We use 2-D numerical thermomechanical modeling to investigate the physical processes and temporal evolution of subduction initiation at the Gagua Ridge. The models systematically vary the thermal age of the Huatung Basin and convergence velocity to examine their effects on initiation forces, upper-plate deformation, and subduction polarity. Results indicate that a younger Huatung Basin preferentially subducts beneath the West Philippine Basin, whereas an older basin tends toward obduction. The force required to initiate subduction scales positively with basin age, while convergence velocity for equivalent shortening minimally impacts slab geometry and initiation force. These findings provide new insights into the possible age range of the Huatung Basin and geodynamic evolution of the Gagua Ridge.

highlight:
Subduction Initiation, Gagua Ridge, Huatung Basin, West Philippine Basin, Numerical method

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Student Poster SP068

車瓜林斷層之剪切行為

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摘　要

車瓜林斷層位於高雄，呈東北-西南走向，北起內門，向西南延伸經大廓庭山，於燕巢區崎溜山以南進入平原區，全長約25公里，為第一類活動斷層，造成地表工程建築的持續變位問題。

多項研究利用大地資料與遙測資料監測車瓜林斷層之變位情況，並分析斷層兩側之地表相對位移。結果顯示，雖然在中寮隧道附近存在分歧，但整體而言，車瓜林斷層的剪切行為可概括為:以中寮山為分界，東北段呈現相對左移運動，西南段則為相對右移運動，而中寮隧道附近為轉換帶。本研究將對車瓜林斷層的剪切行為進行探討，目的在釐清同一斷層沿線出現不同剪切行為之成因，但前人研究多以遙測資料所得，因此本研究擬透過地質調查與岩石薄片分析，以了解車瓜林斷層的剪切行為。

車瓜林斷層帶沿線可觀察到多條深色剪切帶，這些剪切帶由多條位態相近、呈髮辮狀交織的深黑色斷層泥脈所組成，被視為剪應變集中之產物，其間常夾有透鏡狀的斷層角礫。本研究透過觀察斷層泥脈所構成之剪切構造，或斷層角礫相對於斷層帶邊界所形成之不對稱性，以判識斷層帶的剪切行為，然而，當斷層泥脈過於密集或稀疏時，難以作為判識依據，因此藉由採集具斷層泥脈的泥岩樣本，並製作岩石薄片，觀察內部礦物受到剪切並形成帶有剪切行為指示的構造。

野外調查結果顯示，在車瓜林斷層東北段，中寮隧道北側之數個露頭中，所觀察到的剪切構造皆指示為左移；而在西南段崎溜山的數個露頭中，則一致呈現右移剪切，現階段結果與前人遙測結果所認定一致。

本研究驗證車瓜林斷層沿線確實存在剪切行為之分段差異，而這可能透露此區域的構造可能更加複雜，若能了解此區域的構造，將為區域工程設計與地質災害評估提供幫助。

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Student Poster SP069

Late Cretaceous to Eocene Sedimentary Source Change and Tectonic Evolution of Nanao Event in Taiwan: Implications from Detrital Zircon U-Pb Geochronology

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Abstract

The tectonic evolution of the Taiwan orogenic belt from the Mesozoic to the Cenozoic remains unclear because of a lack of deterministic geochronological data for unraveling stratal sequences. The precise timing of the Nanao event is crucial for uncovering this evolution and is the focus of this study. We conducted fieldwork and collected 20 rock samples for U-Pb dating along two river transects that expose representative stratigraphic sections of the upper parts of the Mesozoic Tailuko belt and its overlying Cenozoic Nansuao Formation in northern Taiwan. Our results suggest that the Nanao event occurred between 97 and 60 Ma and comprised two phases. The first phase (97–78 Ma) is characterized predominantly by subduction-related granitic intrusions, which likely persisted until 60 Ma. The second phase (78–60 Ma) is primarily characterized by regional metamorphism produced by a proposed collision with a seamount. The Nanao event was followed by crustal rifting along the southeastern margin of the Eurasian continent, which persisted until at least 34 Ma in the Taiwan region. Relative probability distributions and population ternary diagrams of detrital zircon ages reveal similarities among the Nansuao Formation, the basal meta-conglomerate of the Nansuao Formation, and the underlying Tailuko belt. These data and field observations of clast compositions and fabrics suggest that the Nansuao Formation and its basal meta-conglomerate were locally derived. This is in contrast to previously published studies that argued for a source in southeastern China.

Student Poster SP069

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Student Poster SP070

運用熱運動學模擬解析台灣山脈北段地下構造

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摘　要

在有關山脈形成的研究中，增積楔的形成與演化決定了山脈的主要造山機制，而變質溫壓歷史則是在演化過程中所留下的獨特足跡，與其母岩來源、地下構造和其他環境因素息息相關。在經典的造山模型中，經常採用前緣加積(frontal accretion)作為解釋增積楔模型的主要機制。但如今，隨著熱定年工具、地質溫度計等研究方法問世，有更多的岩石熱歷史數據顯示出山脈構造的複雜性，並提出底部加積(basal accretion)可能在造山機制中佔有重要的地位。為了探討並確立山脈增積楔的主要形成機制，本研究使用了以碳質物拉曼光譜(RSCM)方法取得之保存在含碳岩石中的「最高變質溫度」紀錄。藉由「熱運動學模型」模擬剖面在不同構造假設下的造山過程與其對應的岩石熱歷史紀錄，再與實際的岩石樣本數據比對，作為驗證構造剖面可能性之約束條件，期望能藉此檢驗現今已提出模型的可能性或是提出修正意見。本研究將目標聚焦在台灣北部的山脈剖面，利用其已發表的眾多剖面假設與岩石熱歷史等相關研究資料，重建台灣山脈造山過程並探討地下增積楔之形成機制。

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP071

Paleo-subduction in the Taiwan orogen: insights from Lu–Hf garnet geochronology and petrological modelling

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Abstract

Exhumed high-pressure (*HP*) metamorphic rocks are direct petrological records of paleo-subduction. In the Yuli belt of the Taiwan orogen, evidence of *HP* metamorphism has been reported within several serpentinite-bearing subunits, yet the timing remains poorly constrained. This study presents the first Lu–Hf garnet ages for metabasaltic and metapelitic lithotypes within the subunits, integrated with thermobarometric constraints from phase equilibrium modelling. The estimated peak pressure–temperature (*P–T*) conditions of 1.3–1.5 GPa, 575–585 °C for the metabasites and 1.4–1.7 GPa, 500–575 °C for the metapelites indicate subduction-zone *HP* metamorphism. Lu–Hf dating yields bulk garnet crystallization ages of 13.5–12.6 Ma (four metabasites; ±0.4–0.8 Ma; ±2σ) and 12.0–10.2 Ma (three metapelites; ±0.2–0.3 Ma; ±2σ), interpreted as the timing of (near-)peak metamorphism. These Lu–Hf garnet ages (*c.* 13.5–10 Ma) predate or partially overlap with previously published $^{40}Ar/^{39}Ar$ white mica dates (*c.* 11–9 Ma) from the so-called glaucophane schists. We find no geochronological support for previously proposed Late Cretaceous or Early Pliocene (*c.* 5 Ma) timing of *HP* metamorphism in the belt. The small but resolvable Lu–Hf age offset between the two investigated lithotypes, together with apparent differences in peak conditions and prograde *P–T* paths, suggests juxtaposition along the paleo-subduction interface. We conclude that *HP* metamorphism in the Yuli belt reflects short-lived intra-oceanic subduction during the Miocene prior to the transition to arc–continent collision.

Keywords: intra-oceanic subduction, subduction interface, high-pressure metamorphism, pseudosection modelling, Yuli belt

Student Poster SP071

【學生壁報比賽】

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Student Poster SP072

Discovery of garnet amphibolite in the northern Tailuko belt, NE Taiwan

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Abstract

The Tailuko metamorphic belt represents the exposed basement of the Taiwan orogen. Peak metamorphic conditions of this belt are generally been inferred from limited occurrences of amphibolites in its northern part, whereas the belt had been subjected to polymetamorphism but the majority of rocks show mineral assemblages of relatively low-temperature greenschist-facies metamorphism. Here we report the first finding of garnet amphibolite in the northern Tailuko belt. The newly discovered garnet amphibolites occur as meter-scale blocky foliated melanosomes riddled with tonalitic leucosomes, as well as showing discontinuous to anastomosing leucosomes, developed within migmatitic gneiss domains in enclave-bearing metagranitoids. Garnet occurs as porphyroblasts in a matrix of amphibole (magnesio-hornblende to tschermakite) and plagioclase (An_{40-45}). Garnet compositions are almandine-rich (Alm_{40-47} Prp_{6-15} Sps_{16-25} Grs_{24-40}) and show decreasing in Fe, Mg and Ca and slightly increasing in Mn from core to rim. Ilmenite is rimmed by titanite. The inferred peak assemblage is garnet + magnesio-hornblende + plagioclase + ilmenite. Mineral paragenesis and compositions of the studied garnet amphibolites suggest higher metamorphic temperatures and pressures than the garnet-free amphibolites previously documented in the region. Our findings establish a new upper metamorphic pressure-temperature boundary for the Tailuko belt.

Keywords: peak metamorphism, migmatite, garnet zoning, amphibole, plagioclase.

Student Poster SP072

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Student Poster SP073

以DAC地形演育模型模擬台灣中部濁水溪與烏溪流域百萬年尺度地形演育

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摘　要

頭嵙山層乃台灣西部更新世重要之地層，其保留了台灣造山運動時期大量從中央山脈快速剝蝕後的產物，紀錄了沉積物被剝蝕後經河流搬運向西輸送至台灣前陸盆地的過程，反映出當時構造運動如何劇烈改變當時的地形特徵與河流動力。過去研究多著重於分析岩芯、古生物化石層面還原古環境，較缺乏針對構造的活動速率及其誘發之河流演育動態進行定量探討。若要重建這段演化歷程，關鍵在於了解古河流系統如何隨著構造抬升驅動分水嶺的遷移與流域重組。

本研究應用Divide and Capture（DAC）模型，模擬台灣中部地區濁水溪與烏溪流域的地形演育過程。DAC與傳統模型的差異之處在於其採用數值解—解析解耦合模式去模擬分水嶺遷移，在大尺度（公里級）地形上使用數值解計算，但在分水嶺變遷（公尺級）上改採解析解。此法突破了傳統模型中由於網格離散化導致網格邊界的限制，能以連續性的模式追蹤分水嶺遷移以及遷移後造成流域襲奪導致流域面積動態重組的歷程，從而更真實地還原自然環境下的河流行為與地形演變。

為了強化數值模擬結果之可信度並連結實際野外所呈現的地形，我們進一步將宇宙源核種^{10}Be濃度納入模型演化計算中。透過對比模擬之核種濃度變化與實際野外採集樣本測定之^{10}Be濃度結果，藉以修正模型參數，為台灣造山運動時期中部流域在百萬年尺度下分水嶺變遷與地形演育，提供具系統性且定量的詮釋。

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP074

顯微紅外光譜重建低溫地質熱歷史之研究：以馬達吉達溪蕃薯寮層與恆春半島竹坑溪里龍山層為例

有機質之顯微紅外光譜特徵作為低溫古地溫計與物源指標：以台灣造山帶蕃薯寮層與里龍山層為例

Micro-FTIR Characteristics of Sedimentary Organic Matter as a Low-Temperature Paleogeothermometer and Provenance Indicator: A Case Study of the Fanshuliao and Lilongshan Formations, Taiwan Orogenic Belt

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摘　要

台灣造山帶各構造單元經歷高度相異之熱演化歷程，然而於低溫區間（<300 °C）之古地溫精確重建仍極具挑戰。傳統地質溫度計（如:鏡煤反射率）在特定成熟度區間的解析度受限，且常規之全岩分析往往難以解開複雜的碎屑來源訊號。本研究利用連續監測之顯微傅立葉轉換紅外光譜（Micro-FTIR）技術，針對沉積岩中去礦物化之有機質，進行單一有機碎屑之顯微原位光譜解析。藉由量化有機分子結構中特定官能基（如:脂肪族與芳香族）之演化特徵，評估作為低溫古地溫計與沉積物源指標之可行性。研究樣品取自台灣造山帶兩種截然不同構造背景之沉積地層：恆春半島竹坑溪之里龍山層以及海岸山脈馬達吉達溪之蕃薯寮層。顯微紅外光譜分析結果顯示，有機質分子結構的演化與岩層經歷之最高古地溫具高度相關，且與同層位之鏡煤反射率數據呈現極佳之系統性對應。於物源相對單純之里龍山層中，光譜參數所推導之熱成熟度與核飛跡熱歷史模擬所限制之古地溫條件高度吻合；反之，在沉積物源複雜之蕃薯寮層中，個別有機碎屑之顯微光譜分析成功解析出多組離散之熱成熟度族群。此現象表示沉積岩中之碎屑有機質能有效封存其母岩區之繼承性熱訊號。本研究不僅證實顯微紅外光譜參數可作為高靈敏度的低溫地質溫度計，更突顯其在分析多源區混合沉積物時，具有解開不同構造單元剝蝕與沉積歷史之應用價值，為造山帶盆地分析提供了一項創新的有機地球化學工具。

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關鍵詞：顯微傅立葉轉換紅外光譜、熱成熟度、古地溫計、物源分析

Micro-FTIR, Thermal maturity, Paleogeothermometer, Provenance analysis

Geochemical characteristics of antigorite serpentinites from the Yuli belt, eastern Taiwan: implications for protolith affinities and subduction-related metasomatism

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Antigorite serpentinites occur within exhumed high-pressure metamélange units of the Yuli belt in eastern Taiwan. These antigorite serpentinites were subjected to multiple stages of serpentinization and metamorphism. However, the geochemistry of these antigorite serpentinites has not yet been systematically investigated. This study provides the first geochemical characterization of antigorite serpentinites from all metamélange units in the Yuli belt aiming to interpret their protolith affinities and fluid-related serpentinization and metamorphism. Bulk-rock major- and trace-element compositions indicate that the antigorite serpentinites were derived from depleted mantle peridotite protoliths, predominantly of harzburgite–dunite composition. These antigorite serpentinites exhibit geochemical features typical of subducted-type serpentinites, as indicated by trace-element and rare earth element patterns similar to those of compiled harzburgite-derived subducted serpentinites. Enrichment in fluid-mobile elements (Cs, Ba, U, Sr, and Pb) and light rare earth elements indicates the involvement of externally derived fluids from the dehydration of subducted materials. Although some serpentinites may have been influenced by ocean-floor serpentinization, no distinct seawater-related signature was observed, likely owing to overprinting by subduction-related processes. This study demonstrates that antigorite serpentinites preserve records of fluid–rock interaction driven by fluids released from the dehydration of subducted materials along the slab–mantle interface.

Keywords: serpentinization, fluid-rock interaction, slab-mantle interface, subduction zone

Student Poster SP076

應用機器學習自動波相拾取與地震-重力序列反演於花蓮地區四維速度與密度構造建構

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(1)國立中央大學地球科學學系

摘　要

花蓮地區位於歐亞板塊與菲律賓海板塊的碰撞邊界，是台灣地震活動最頻繁的區域。儘管已有眾多研究，但由於板塊間複雜的構造交互作用，該區詳細的地下幾何型態與斷層分布仍未被完全解析。本研究旨在利用 2012 年至 2024 年間由中央氣象署地震測報中心（CWASN）及台灣強震網（TSMIP）所收集的地震資料，精進 3D 速度構造模型。

為了處理龐大的資料集並提升地震目錄的完整性，我們採用了機器學習演算法—利用 EQTransformer（Mousavi et al., 2020）進行震相挑選，並使用 GaMMA（Zhu et al., 2022）進行震相關聯。隨後，我們應用雙差分層析成像法（TomoDD; Zhang and Thurber, 2003），並納入重力限制以更好地解析淺層速度。我們進行了順序反演，以獲得水平網格間距為 5 公里的高解析度 P 波與 S 波速度構造。

我們的初步反演結果在陸域顯示出高解析度，並揭示了碰撞帶內的關鍵構造特徵。這些構造幾何特徵大體上與先前的層析成像模型（例如 Huang et al., 2014）一致，確保了我們基礎速度模型的可靠性。

基於此可靠的基礎模型（由 2012–2020 年資料建立），我們藉由整合 2021–2024 年的後續資料，進一步探討速度的時間變化（4D 層析成像）。透過整合精進的速度模型與重定位地震，我們想要在此活躍碰撞帶內複雜的地下構造及其時空變化，發現更詳細的構造特徵。

【學生壁報比賽】

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Student Poster SP077

應用機器學習自動波相拾取與地震—重力聯合反演探討 2025 年大埔地震之孕震構造及速度時變特徵

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摘　要

2025年1月20日發生於台灣西南部的 ML 6.4 大埔地震，位處於褶皺與逆斷層發達的西部麓山帶。此地震序列呈現出複雜的斷層交互作用，近期的觀測指出其可能為包含東傾滑脫斷層與西傾基盤構造的共軛破裂型態。然而，由於該區域缺乏高解析度的三維速度模型，詳細的地下構造仍缺乏良好的約束。

為釐清其孕震構造，本研究結合機器學習技術進行自動波相拾取，並進行地震走時與重力資料的聯合反演。我們整合了詳盡的資料集，包含：(1) 中央氣象署 (CWA) 於 2012 至 2020 年間記錄的長期背景地震活動；(2) 2025 年大埔主震及其餘震序列；以及 (3) 研究區域內密集的重力觀測資料。藉由加入重力資料，我們的模型不僅提升了淺層地殼構造的解析度，更提供了密度約束，以輔助傳統地震層析成像。

本研究著重於高解析度三維速度與密度構造的成像，以辨識控制此次斷層破裂的特定岩性或構造邊界。此外，我們也探討主震前後地震波速構造的時變特徵，以偵測潛在的應力釋放過程。本報告將展示所求得的構造非均質性與餘震空間分佈之間的關聯，為大埔地震序列的地震構造特性提供新的物理約束。

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP078

Integration of Seismic Data Processing Techniques for Evaluating Geological Suitability and Structural Integrity in Carbon Storage Projects: A Case Study from the Offshore Kuanyin Area, Northwestern Taiwan

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Abstract

To mitigate the impacts of climate change and achieve the goal of net-zero carbon emissions by 2050, Carbon Capture, Utilization, and Storage (CCUS) has been widely recognized as one of the important technologies. The offshore Kuanyin area in northwestern Taiwan, located on the western side of the deformation front of the arc–continent collision orogenic belt, represents a relatively stable tectonic setting and therefore has potential for geological carbon storage. Due to limited data, additional high-resolution seismic data are required to further evaluate the geological suitability and storage safety of the region. In this study, we integrated the existing onshore and offshore seismic profiles as well as with newly acquired high-resolution marine seismic reflection data to investigate the potential reservoir-seal system for carbon storage. Because shallow marine seismic data are commonly affected by multiples, predictive deconvolution and surface-related multiple elimination (SRME) were applied to suppress multiples during seismic data processing. The processed seismic profiles clearly reveal the regional stratigraphy, which can be divided into eight major units deposited both the passive continental margin and the foreland basin stages. The stratigraphic tops become progressively shallower from east to west, indicating a consistent regional tectonic trend. Potential reservoir-seal horizons generally dip toward the northwest and are offset by several normal faults, reflecting an extensional tectonic regime that influences the structural continuity of the reservoir-seal system. These results provide important geological constraints for evaluating the feasibility and safety of carbon storage in the offshore Kuanyin area.

Keywords: Marine seismic data processing, Multiple attenuation, Carbon storage

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(2) Degree/Grade: Master/ 2nd year
(3)

Student Poster SP079

台灣西南部龍崎地區泥貫入體之反射震測研究

Research on reflection seismic measurements of mud-diapir in Longci area of southwestern Taiwan

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台灣西南部前陸盆地受歐亞板塊與菲律賓海板塊的碰撞影響，形成了活動褶皺的逆衝斷層帶，而台南與高雄交界的龍崎地區，則位於此造山運動的前緣。該區發育了極厚層的古亭坑層泥岩，這類上新世至更新世的深海沉積物，由於其高含水率、低密度及強塑性的物理特質，在受到強大的構造擠壓應力時，極易產生類似流體的流動行為。本研究的核心議題在於探討於龍崎地區下的龍船斷層逆衝構造，與地下深層泥岩間的交互作用。在強烈的構造應力下，泥岩往往沿著斷層面或地層弱面向上侵入，形成獨特的泥貫入體構造，這些構造不僅改變了地層的原始排列方式，更是引發地表惡地地貌與潛移變形的主因。而本研究採用反射震測法作為主要探測手段，資料採集涵蓋了穿透龍船斷層關鍵變形帶的剖面。

震測成像結果顯示，龍崎地區地下構造具有高度複雜性。龍船斷層在剖面上呈現逆衝特徵，在斷層的上盤，地層受到劇烈擠壓而產生顯著的背斜褶皺，而本研究也發現到和先前觀測研究所得到的地表變形位置接近的區域。另一方面在古亭坑層泥岩的部分，本研究所繪製的泥貫入體位置與先前地電阻研究所框定的範圍相符 ，而它在震測影像中其展現出了典型特徵：內部反射訊號紊亂（Chaotic reflection)， 此現象反映了泥岩侵入過程中的高度變形與碎裂化， 同時受限於泥岩的高衰減特性。本研究建立的地下模型對於當地的公路維護、 土地開發以及地震災害評估具有高度的實務價值，為理解軟弱地層如何反應強 大構造應力提供了一個經典的研究案例。

關鍵字：龍崎地區，泥貫入體，龍船構造，反射震測。

Student Poster SP080

高解析度泥岩地區地表變形分析：以台灣西南部半天寮為例之微地動與地表變形監測

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摘要

高雄旗山的半天寮地區位於台灣西南部的構造活動帶中，該區泥火山分布密集，地質條件極為複雜。此區域長期受高孔隙流體壓力、高塑性泥岩層以及持續地殼變形等因素交互影響。根據 Tsukahara 與 Takada（2018）利用 L-band InSAR 及 GNSS 資料進行的大尺度觀測研究，於台南至旗山之間偵測到一個明顯的非地震性隆起帶，南北向延伸約 25 公里，東西向約 5 公里，且北段最高隆起速率達 37 毫米/年。該研究推測，該地區的變形主要與深部泥貫體活動及淺層潛移逆衝斷層有關，顯示當地具有顯著的構造不穩定性。然而，該研究的觀測尺度較大，較難直接說明特定場址內部的細部變形特徵，或與實際建物損壞現象之間的聯繫。

有鑑於此，本研究選擇該隆起帶內的一個更具區域代表性且變形跡象明顯的區域——半天寮泥岩場址——作為詳細調查對象。此地已有多棟建物出現明顯的結構損壞，例如牆面裂縫與地基錯動，顯示該場址可能正位於一個局部劇烈變形帶之上。自 2024 年 4 月起，我們在該地展開一項持續性的監測計畫，主要採用四種觀測方法：

(1) 使用 SmartSolo 儀器進行長期微地動觀測，分析強降雨與地震事件對泥岩地層共振頻率的影響；
(2) 透過 CUBE 系統布設兩組地震陣列以反演淺層剪力波速構造，並使用單站 H/V 頻譜比分析萃取場址的主頻（f_0），進而推估地層深度與共振方向；
(3) 應用高精度 RTK（即時動態定位）技術，在短時間內進行場址內高密度測量，提升變形觀測的空間解析度；
(4) 使用 Trimble 5700 GPS 進行長時段靜態觀測（超過四小時），以獲取穩定且準確的三維地表位移數據。

透過本次場址尺度的調查，我們期望能進一步釐清泥貫入體在地表微動與變形上的實際表現，辨識出更多細微但可能具關鍵性的地層變化特徵，並評估泥貫體活動對場址內人造設施所帶來的潛在結構風險。研究成果將有助於未來類似地質環境中的監測作業與建築安全規劃。

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(3)

Student Poster SP081

透地雷達應用於考古調查：初探蔦松遺址

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摘　要

透地雷達是探測近地表二維及三維地下構造的有力工具，廣泛應用於實際開挖前之各種工程、考古及環境調查領域。本研究旨在應用透地雷達探測及分析技術，調查位於台南永康車站周遭之蔦松遺址相關文化層可能的空間分布。文化層意指該堆積層中存在人類活動遺留之痕跡，前人調查結果顯示，蔦松遺址為金屬器時代之遺址，層內可見陶質容器遺留，該遺址之文化層距地表約 0.3 公尺、堆積厚度為 1.6公尺，即使僅進行淺層開挖亦可能破壞該遺址，近年更因私人住宅土地開發與鐵路地下化需求，針對蔦松遺址的考古調查更顯急迫。

為進一步釐清研究區域文化層之延伸範圍，本研究使用 450 MHz 及 750 MHz 之透地雷達天線進行調查，以期掌握地下淺部 1 至 3 公尺內之地層反射特徵，並利用不同頻率訊號之穿透深度及解析度特性，進行研究區域地下構造解釋、層面追蹤及屬性分析。調查結果顯示地表下深度約 0.5 公尺內之地層整體而言具備強反射及低頻的訊號反射特徵，地表下 0.5 公尺開始反射特徵較為雜亂，推測可能為經歷人為擾動之地層。竹圍二街東側存在疑似古河道之V型強振幅反射，其底部深度約為 0.8 公尺、視寬約 80 公尺。龍中街北端起點 200 公尺處亦存在疑似古河道之強振福反射，底部深度約為 2 公尺、視寬約 20 公尺。

相較於傳統的透地雷達剖面判釋工作，本研究成果顯示透過分析瞬時振幅及相位等屬性，可有效幫助掌握蔦松文化層之透地雷達反射特徵，進而追蹤此古河道及區域地層界面之空間延伸，並可作為未來擴大調查範圍及進一步更完整描繪該時期地理空間分佈的重要依據，此外，本研究成果亦可提供其他區域之文化層及古河道調查之借鏡。

關鍵字：透地雷達、屬性分析、文化層、蔦松文化
Keywords：GPR、Attribute Analysis、Cultural Layer、Niaosong Culture

【學生壁報比賽】

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Student Poster SP082

Scaling and Source Characteristics of Non-Volcanic Tremors in Taiwan

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Abstract

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.

(1) National Taiwan Normal University/Kate Huihsuan Chen

(2) Master/3

Student Poster SP083

臺灣海峽中新世玄武岩之火山學特徵：電火花反射震測

Volcanological Features of Miocene Basalts in the Taiwan Strait: Sparker Seismic Reflection Data

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近年臺灣海峽海域探勘研究中，多頻道反射震測發現澎湖周圍海域地層內存在大面積的玄武岩層，且至少可區分為兩期以上火成活動事件。雖然前期研究已大致了解玄武岩之空間分布與截切關係，惟前期多頻道反射震測使用聲源相對低頻的 GI 空氣槍，對於單層玄武岩層間的接觸關係難以精確辨識。欲釐清臺灣海峽中新世的玄武岩細部幾何形貌，本研究利用電火花反射震測具高頻的聲源，其垂直解析度約 50 公分。玄武岩之辨識主要依據為沉積岩與玄武岩間之聲阻抗差異所產生的強振幅反射，以及侵入作用所致的強制褶皺構造等，並配合鑽井資料比對岩性與年代。分析玄武岩層上、下界面之反射特徵、厚度變化及側向振幅強度差異，以探討其與周圍地層之接觸特徵。並整合低頻多頻道反射震測資料，比對相同位置下不同頻段之震測剖面。

解釋結果顯示，高頻震測剖面除顯示上覆沉積岩層的進覆關係外，亦更清楚辨識侵蝕面與岩體尖滅方向等幾何特徵。研究發現，深部玄武岩之側向厚度變化相對一致；然而，位於侵蝕面上方之玄武岩，其表面形貌崎嶇且厚度高度不連續，推測為玄武岩噴發後受到顯著侵蝕作用所致。除此之外，原先於低頻資料中歸納之 5 層玄武岩層，於高頻資料中可細分為 6 層，顯示其可更精確解析玄武岩的侵入特徵與層間接觸關係。本研究結合低頻多頻道反射震測與高頻電火花反射震測，有效提升玄武岩層對比與幾何判釋能力，為區域火成活動與盆地演化關係提供更完整的解釋。

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(2) 碩士班 / 一年級

Student Poster SP084

Instrument Response of the Differential Pressure Gauge of NOT array and A Seafloor Compliance Study for the Northern Okinawa Trough

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Abstract

The Northern Okinawa Trough (NOT) provides an ideal natural setting to investigate the early-stage processes through which continental rifting evolves into an oceanic back-arc basin. Despite its tectonic importance, the shallow shear-wave velocity (Vs) structure beneath the NOT remains insufficiently constrained. In this study, we apply the seafloor compliance method to investigate the shallow Vs structure in this region. The analysis utilizes broadband ocean-bottom seismometer (OBS) data collected by the Institute of Earth Sciences, Academia Sinica, during the 2018–2019 deployment.

Because the differential pressure gauges (DPGs) installed on the OBS instruments lack documented response functions, we first estimate the instrument response by searching for an appropriate pole value that minimizes the phase shift between the negative vertical displacement and the DPG recordings. This pole value is determined through a nonlinear inversion using the Nelder–Mead optimization algorithm. The conversion factor from digital counts to pressure (Pa) is subsequently obtained by calibrating the Rayleigh-wave amplitudes.

After correcting the DPG data for the instrument response, we compute the seafloor compliance and perform inversions for the shallow Vs structure. The inversion employs a Bayesian framework using a Markov Chain Monte Carlo (MCMC) sampling approach combined with B-spline parameterization to model the Vs distribution within

sediments and the upper crust. To stabilize the inversion process, prior constraints are imposed on the B-spline functions to enforce a generally increasing Vs trend with depth. Preliminary station-based Vs models will be presented.

就讀學校/指導教授：國立臺灣大學 / 郭本垣老師、柯彥廷老師
學位/年級：碩士生二年級

Student Poster SP085

縱谷斷層北段8個中尺度地震之強地動特性分析

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摘　要

縱谷斷層為臺灣島活躍斷層之一，並且為臺灣發生地震頻率最高的孕震構造(Yu *et al*., 1992;Yu and Kuo, 2001)。Wen (2018)針對縱谷北段的中尺度地震進行強地動特性分析， Lin et al. (2022)針對縱谷的秀林區段之 2000 年與 2019 年兩起 M>6 的地震事件進行分析。綜合前人研究可知，縱谷斷層不同區段在破裂特性與強地動控制機制上具有顯著差異。然而，位於縱谷斷層北段的壽豐地區，過去較少發生中尺度地震，相關研究亦相對有限，使得該區域地震之破裂方向性與震源特性仍缺乏系統性的探討。

在過去，壽豐區域的地震活動相對不活躍，數年才會有一次$M > 5$ 的地震。然而，自 2020 年以來，該區域陸續發生地震系列，也提供了研究區域地震行為的良好機會。雖然中尺度地震所造成的傷亡與經濟損失通常不如大型地震顯著，但此類密集發生的地震序列仍可能隱含未來地震活動的重要訊息。因此本研究選取 2020 年至 2022 年之間，發生在壽豐區域 8 起$M > 5$的中尺度地震事件作為研究對象，利用經驗格林函數法(empirical Green's function method)分析壽豐區域的強地動特性，探討此 8 起中尺度地震之強地動產生區、破裂方向性以及應力降等震源參數。

【學生壁報比賽】

(1) 就讀學校/指導教授：國立中正大學/温怡瑛
(2) 學位/年級：碩士/一年級

Student Poster SP086

花蓮近岸海嘯危害度評估：整合 1920 與 0403 事件情境之潛勢分析與模擬評估

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摘要

2024 年 4 月 3 日，花蓮發生規模芮氏規模 7.2 的地震，震源深度為 22.5 公里。本次地震引發海嘯。海嘯高度在烏石潮位站達 89 公分。並於壽豐鄉鹽寮村沿海一帶產生達約 2.5 公尺之海嘯溯上高。所幸海嘯發生之時為低潮位時期，因此沒有造成傷亡。然而本次事件卻也證明，台灣東部花至少在花蓮至宜蘭一帶，其地形有助於海嘯波高放大。因此若遇到更大之海嘯源，將對花蓮至宜蘭一帶造成破壞。而本次地震所在位置，位於菲律賓海板塊與歐亞大陸板塊接攘處，斷層與海溝分布複雜。本次地震主因目前學界尚在討論，然普遍認為是由海岸山脈或中央山脈斷層系統破裂所導致。然而也因為本次地震鄰近琉球海溝，因此 1920 年規模 8 之琉球隱沒帶地震也因此備受關注。

本研究將由 2024 年之 0403 花蓮地震海嘯為起點，透過豐富的沿海潮位站資料以及首度揭露之地震中心海底電纜資料，以 COMCOT 海嘯模式進行模擬與分析，以推求 0403 花蓮地震之海嘯源，並進而分析與還原 1920 琉球隱沒帶之地震海嘯。由於隱沒帶之地震有更高機會達到規模 8 以上，因此本研究亦將進行情境分析，以了解潛在大規模海溝型海嘯對於花蓮至宜蘭，甚至全島之威脅。

本次地震相當特殊，與一般海嘯不同的是，0403 花蓮地震之震央位於陸地，仍然於東海岸引發海嘯，為研究此種鄰近海岸型態之海嘯，本研究將進行定性分析，探討近岸地震之震央與海岸之距離關係，並歸納此類地震須發布海嘯警戒之門檻值，評估海嘯波高及其影響。

指導教授：吳祚任

就讀學校：國立中央大學

學位/年級：水海所碩一

Student Poster SP087

深度學習地震預警系統的技術演進：從物理驅動的 TT-SAM 至 SAVANT 雙目標預測框架

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摘要

發展精準的地震預警對社會防災至關重要。傳統模型多著重預測地表最大加速度（PGA），然而，大量研究表明，地表最大速度（PGV）與實際的結構破壞關聯性更高。本研究提出一個從單一目標演進至雙目標預測的深度學習架構。研究初期，我們開發了「TT-SAM (Taiwan Transformer Shaking Alert Model)」模型，結合 CNN 與 Transformer 擷取波形及空間特徵，並整合 Pd、CVAV 與 TP 等物理參數。為解決高震度樣本稀缺的問題，採用了「規模重採樣」與「偏好近測站」策略。在 2016 年美濃地震的測試中，該模型在 ±1 震度誤差內達到了 97.8% 的準確率。基於此核心架構，我們進一步開發新一代的 SAVANT (Seismic Acceleration and Velocity Alerting Neuralnet Transformer model) 框架。其獨特的雙分支結構能分別從加速度與速度波形中擷取特徵，實現 PGA 與 PGV 同時預測。為克服數據不平衡，SAVANT 引入全新的損失函數，有效優化強震的預測結果。此外，該框架結合了「滾動式更新」策略，不僅能在地震初期發布初步預警以縮小盲區，還能隨連續波形輸入進行迭代修正，持續提升精度。獨立測試顯示，SAVANT 在 PGA 與 PGV 預測上，於 ±1 震度誤差內皆達到了超過 99% 的準確率，展現 State-of-the-Art 的表現。本次技術演進證明，整合物理特徵、優化數據不平衡與實施滾動式預測，能顯著提升預警的即時性、覆蓋率與可靠性，為地震防災提供穩健的支持

(1) 就讀學校/指導教授 ：國立中央大學/詹忠翰

(2) 學位/年級：碩士班/二年級

Student Poster SP088

Observed coseismic stress rotations during the 2019 Cotabato earthquake sequence in Mindanao, Philippines

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We determined the b-value time series and coseismic stress directions in Cotabato, Philippines to determine the crustal state and stress conditions. From Oct. 16 to Dec. 15, 2019, the Cotabato region in Mindanao, Philippines experienced four large strike-slip earthquakes with $M_w > 6.4$. Since the crustal state and differential stress can be inferred from b-value time series and degree of coseismic stress rotations, we calculated these parameters for the earthquake sequence.

We used 6102 events from January 2017 to June 2025 to plot the b-value time series with N_m = 100. Using maximum likelihood curvature for the frequency-magnitude distribution, we calculated an Mc of 2.2 for the catalog (binning = 0.1) and a b-value of 0.70. Then, using 70 focal mechanism solutions from the Global CMT from January 1976 to March 2025, we determined the stress directions before the 2019 earthquake sequence to determine the baseline orientation of the stress directions. Subsequently, we determined the stress directions during the first large earthquake (Oct. 1-20), during the second and third earthquakes (Oct. 21-Nov. 11), during the fourth earthquake (Dec. 5-25), and the period after (2020-2025) using iterative joint stress inversion.

A drop in b-value (0.534) was noted after the occurrence of the first earthquake, then it continued dropping to 0.489 during the second and third earthquakes. Then the b-value rose again to 0.953, only to drop to 0.475 during the fourth earthquake.

Meanwhile, the baseline direction for the regional σ_1 was 279.68°. During the first earthquake, it rotated counterclockwise and became 270.06°, and up to 253.79° during the second and third earthquake. It bounced back to 273.96° during the fourth earthquake, then it rotated counterclockwise to 260.74° afterwards.

The drop in b-values reflected the stress drops that occurred during the earthquakes. On the other hand, the large angular (~20°) difference of the σ_1 orientation with respect to the pre-earthquake direction implies a large differential stress in the area, which might point out to a ‘weak’ crustal state in the region. This might have been brought about by the presence of preexisting structures in the Cotabato Fault System, as the region has experienced a complex geodynamic evolution.

Student Poster SP089

Modeling Earthquake Triggering in Eastern Taiwan: A Comparison between Spatial 2D and 3D ETAS Approaches

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Abstract

Operational Earthquake Forecasting (OEF) is an essential objective in modern seismology for supporting seismic hazard assessment and risk-informed decision making. Within this field, the Epidemic-Type Aftershock Sequence (ETAS) model serves as a widely utilized statistical framework for describing the spatiotemporal occurrence of earthquakes and estimating seismicity rates. Previous studies have commonly implemented space–time ETAS models in a spatial 2D framework, which considers only the horizontal distribution of earthquakes alongside the temporal dimension.

However, in tectonically active regions such as eastern Taiwan, seismicity is driven by active subduction processes and complex conjugate fault systems that exhibit pronounced depth-dependent structures. In such environments, spatial 2D ETAS models may be insufficient to represent the spatial cascading processes of earthquake triggering because hypocentral depth is not explicitly incorporated.

To address this limitation, this study uses the seismicity of eastern Taiwan as a case study to compare how well spatial 2D and spatial 3D ETAS models explain earthquake activity. By evaluating the model formulations and examining differences in the calculated conditional intensities, we demonstrate the limitations of the spatial 2D approach in the study area. Our results highlight the potential advantages of incorporating hypocentral depth into ETAS-based seismicity analysis and earthquake forecasting.

Please note the information in the bottom of abstract if you choose to attend to "the Students' Poster Competition".

(1) University/Advisor: National Central University/ Ming-Che Hsieh
(2) Degree/Grade: Master's Degree/ 1st Year

Student Poster SP090

Integration and Event Matching Analysis of Cross-Regional Earthquake Catalogs between Taiwan and Ryukyu: Case Studies of GDMS, BATS, JMA, and NIED

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Abstract

Taiwan and Ryukyu share similar tectonic settings and frequent seismic activity within the Ryukyu Subduction Zone. Integrating seismic observation data from both regions not only deepens the understanding of cross-regional seismicity but also provides a scientifically robust database for applications in statistical and engineering seismology.

To construct a cross-regional earthquake dataset,this study integrates earthquake catalogs from Taiwan (CWASN and, BATS) and Japan (JMA and, NIED). To address data heterogeneity, preprocessing included unifying field specifications, synchronizing event times to UTC, and standardizing geographic coordinates. Furthermore, preliminary corrections and conversions(e.g., M_L andM_J) were applied to address inconsistencies in magnitude definitions across catalogs, thereby ensuring a reliable foundation for subsequent analyses.

Following data processing, an automated algorithm was used to match events across catalogs by filtering for consistent origin, epicenters, and magnitudes. The algorithm also incorporates statistical deviations from magnitude conversion formulas to dynamically adjust filtering criteria. Through this multi-dimensional cross-verification, the study effectively reduces misidentification while preserving common events, thereby providing high-quality data samples for analyzing seismic characteristics in the Ryukyu subduction Zone.

【學生壁報比賽】

(1) 就讀學校/指導教授 : National Central University/ Chung-Han Chan

(2) 學位/年級 : Master/ First year

Student Poster SP091

利用反餘弦相似比對法與新事證重建1867年基隆海嘯之潛在海嘯源

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摘 要

1867年基隆海嘯為近代儀器觀測建立之前，臺灣官方紀錄中最具代表性的海嘯事件之一。若類似事件於現今重現，可能對人口密集之臺灣北海岸城市，如基隆與金山，造成重大衝擊。過去研究對該海嘯事件之成因提出多種假設，包括地震、海底山崩及海底火山活動等可能機制。然而，近年於宜蘭頭城地區陸續發現新的歷史證據，例如宗族族譜與廟宇遷建紀錄，顯示1867年海嘯影響範圍可能由基隆與金山延伸至宜蘭頭城，使得既有海嘯源假設需重新檢視。

本研究結合歷史文獻資料與數值模擬方法，重新分析1867年基隆海嘯之可能震源位置。研究採用中央氣象署之 COMCOT 海嘯速算系統進行海嘯模擬，並提出反餘弦相似比對法（Inverse Cosine Similarity, ICS）以評估模擬結果與歷史波高比例之相容性。相較於傳統僅比較絕對波高之方法，ICS 著重於不同觀測地點間之波高比例結構，可有效辨識符合歷史記載空間分布特徵之潛在海嘯源位置。透過 ICS 分析，可先行篩選出比例結構不相符之震源區域，縮小後續數值模擬之搜尋範圍。

在 ICS 篩選結果基礎上，本研究進一步針對臺灣東北海域之火山島、海底火山與海底峽谷等潛在地形區域建立多種海嘯情境進行模擬。結果顯示，若於基隆陸棚或棉花峽谷斜坡發生海底山崩，將對金山地區產生顯著波高影響。此外，地震單一機制所產生之海嘯難以完全解釋歷史文獻所記錄之波高特徵，顯示1867年海嘯可能並非單一海嘯源所致。

綜合 ICS 比例分析與數值模擬結果，本研究推測1867年基隆海嘯可能為多重海嘯源共同作用之事件，其中較為合理之情境為規模約7.0之山腳斷層地震，結合棉花峽谷斜坡之海底山崩所共同引發。研究結果顯示，ICS 方法能有效提升歷史海嘯事件震源辨識之效率，並可作為未來歷史海嘯源反演研究之重要分析工具。

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Student Poster SP092

基於機器學習波相挑選與三維速度模型重新定位之台灣西南部發震構造解析

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摘　要

台灣位處於弧陸碰撞帶，強烈的造山活動形成了條件複雜的地質環境，活躍的構造活動也造就頻繁的地震事件。台灣西南部為重要的構造活動顯著區域，地下的斷層與複雜的基盤構造，極大影響了該地區的地表地形特徵，歷史上也曾發生過多次嚴重的地震災害事件，例如 1946 年新化大地震、1964 年白河大地震。若能透過台灣西南部地區的地震資料，來深入解析地區的地質與孕震架構，對於區域的構造演化過程、地震災害的理解將會有相當程度的提升。本研究主要利用機器學習方法，經由演算法自動化辨識地震波相，並在三維速度模型中進行地震的重新定位。本研究將針對台灣西南部的發震構造單元，進行地震資料分析提升地震定位精度與配合地震震源機制解解析發震構造。相較於傳統人工拾取，機器學習預計可提供更精確且一致性較高的 P 和 S 波波相挑選。有助於理解發震構造的幾何形態與建構斷層模型，在後續可再進一步應用於震災風險評估與地表變形模擬等相關領域。

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Student Poster SP093

使用 FNO 為基礎的機器學習模型自動化井下地震陣列微震相位判定:以 MiDAS 資料為例

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摘　要

花蓮地區位於臺灣弧陸碰撞轉換為隱沒系統的區域，地質構造複雜，地震活動頻繁。 2018 年 2 月 6 日花蓮地震造成米崙斷層發生錯動。為觀測近斷層帶之地震活動，震後於斷層架設穿越斷層帶的井下地震觀測站，提供近斷層帶內微小地震活動的高品質資料。由於井下觀測資料具有 S–P 到時差短、頻率成分偏高等特性，加上資料量龐大，現行以人工判識為主的地震波相挑選流程在效率上面臨顯著挑戰。

本研究應用傅立葉神經算子（Fourier Neural Operator, FNO）建立自動化地震波相挑選流程。FNO 能透過頻率域中的全域運算結合時間域卷積特徵學習，使模型同時擷取波形在頻率與時間域中與地震波相相關的重要資訊，具備處理高頻特性井下地震資料的潛力。本研究以既有人工標註資料進行模型訓練與測試，結果顯示 P 波與 S 波之 F1 score 分別達 0.94 與 0.95。進一步將模型應用於連續地震資料，其與人工建立之地震目錄（ground truth）的對應比例為 0.868，且可額外偵測出部分未被人工目錄收錄之潛在地震事件，顯示該方法具備作為地震波相判識輔助工具的可行性。

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Student Poster SP094

臺灣地震事件芮氏規模之探討

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摘　要

規模為描述地震的重要參數，代表事件釋放的能量大小。目前中央氣象署採用之規模為芮氏規模(Local Magnitude, M_L)，其具快速且直接定義的特色。芮氏規模的計算是比較規模零理論最大振幅及觀測最大振幅，然振幅與地區的衰減特性有關，因此前人研究多將M_L與更具震源物理意義的地震矩規模(Moment Magnitude, M_W)比較。南加州觀測資料顯示M_L<6.5時M_L與M_w呈1比1，代表該區logA_0值符合區域衰減特性，故本研究嘗試建立符合臺灣衰減特性之logA_0模型。前人研究多將淺源及深源地震的logA_0模型分開建立，然為實務使用便利，有一適用不同深度之模型可減少計算時間及誤差。本研究以1990~2020年經重新定位M_L大於3.5之事件進行探討，最後總計5553起事件，使用了225個測站共375,077筆最大振幅紀錄建立符合臺灣衰減特性且適用不同深度事件之logA_0模型，經迴歸分析所得模型如下：

$$logA_0 = -0.605 - 1.522logR - 0.0014R + 0.632\log(D + 45.1) \pm 0.285$$

所得結果在相同震源距下，logA_0值會隨深度變化，顯示此模型可表示出不同深度衰減特性之差異。重新計算之M_L與M_W關係呈1比1，平均差值降低至-0.017，標準差為0.182。本研究提出的logA_0模型適用不同深度，降低震源深度對模型選擇的影響，提升實務使用之便利。

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Student Poster SP095

Developing a Machine Learning Framework for Automated Earthquake Cataloging in Taiwan: Evaluation and Benchmark

建立台灣自動化地震目錄之機器學習架構：評估與基準比較

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摘　要

臺灣位於弧陸碰撞造山帶上，地震活動頻繁，而地震目錄的完整性有助於分析孕震構造和評估地震潛勢及災害。目前中央氣象署在地震目錄建置上仍高度仰賴人工判定與震相挑選，易有受主觀判讀影響導致的誤差以及漏判情形。

近年來隨機器學習技術快速發展，自動化波相判識和定位方法在效能與穩定度上皆有提升，有助建立更完整且標準一致的地震目錄。本研究整合深度學習波相挑選、反投影網格搜索法及三維速度模型進行定位，建立自動化地震定位流程。

為檢驗機器學習方法於實際地震監測中的可行性，本研究以2019年1月及2025年1月之人工辨識地震目錄作為基準進行比較分析。結果顯示此方法在已知事件的P, S波的召回率約為76%，其中訊噪比(signal to noise ratio; SNR)大於1和2的召回率分別可達80%和95%。對氣象署目錄之基準地震事件之辨識度達約80%；針對資料品質較佳、至少具備4測站且其波相SNR大於2的事件，偵測率可提升至94%。此外，該方法亦能額外偵測出人工目錄中未收錄之地震事件，並排除基準目錄中可性度較低之地震事件。結果顯示此方法在地震事件自動化判斷上具備明顯優勢，能夠有效提升建構長期地震目錄之效率，與提升地震目錄完整性。

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Student Poster SP096

擠壓造山帶內之伸張構造：以中央山脈南段淺層高角度正斷層為例

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摘　要

台灣位於菲律賓海板塊與歐亞大陸板塊之弧陸碰撞帶，主要受到西北-東南向的板塊擠壓作用，形成一系列造山帶。然而，在中央山脈南段，除典型擠壓構造外，也發現發育一系列淺層且高角度的正斷層。此類伸張構造與整體擠壓環境形成顯著對比，在造山過程中如何出現局部伸張現象，長期以來一直是構造地質與地震學界關注的重要議題。在前人的文獻中，已觀察到此區域存在明顯的正斷層露頭，斷層面傾角陡峭，常伴隨清晰的斷層擦痕與碎裂帶，顯示其具有近期活動跡象，但其成因與在整體造山系統中所扮演的構造角色，尚未有明確的解答。

本研究針對中央山脈南段之地震事件，整合中央氣象署地震觀測中心測站資料，進行初步定位分析。後續進一步結合機器學習模型（RED-PAN）挑選 P 波與 S 波到時，並採用三維速度模型進行重新定位。定位結果顯示，事件分布較原先結果更為集中，且震源深度呈現相比原本呈現較深的結果，顯示三維模型與高品質相位挑選能有效改善定位精度。

本研究旨在透過高解析度地震定位與構造分析，釐清中央山脈南段正斷層之三維幾何型態與空間分布，並進一步探討其在造山活動中可能的形成機制。此結果不僅有助於理解擠壓為主的造山帶中，為何會出現局部伸張構造，亦可為台灣中南部地震危害評估提供更可靠的構造背景，對於未來地震風險評估與造山帶變形模式的研究，具有重要的參考價值。

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Student Poster SP097

以二維 ETAS 模型探討臺灣東部地震活動特性及孕震構造意涵

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摘　要

臺灣東部地處菲律賓海板塊與歐亞板塊聚合帶，北段受板塊隱沒影響，南段為縱谷縫合帶，並沿此發育出縱谷斷層系統與中央山脈斷層系統。上述斷層系統造就近年多次重大地震事件，如2018年2月6日M_L6.2花蓮地震、2022年9月17日M_L6.6及18日M_L6.8關山－池上地震序列。前述事件及其餘震，對理解該區域斷層構造活動特性具重要意涵。本研究利用中央氣象署GDMS地震目錄探討東部地震活動特性及其與孕震構造之關聯，研究區域分為兩類：第一類依地震序列主餘震分布選取，涵蓋2013瑞穗至2022關山池上等六次重大地震；第二類依孕震構造劃分，包含米崙斷層、縱谷斷層各段及中央山脈斷層。本研究採用傳染型餘震序列(ETAS)模型，透過最大概似估計法進行參數估計。然而2019年11月後之氣象署目錄尚未完備，因此採用雙尺度經驗機率積分轉換(BEPIT)進行資料補全，並對照補全前後之目錄差異及空間分布，以解析地震活動特性。研究結果顯示，ETAS參數與目錄完備度及規模篩選條件密切相關，部分觀測空白區因完備度較低，需提高閾值方能獲得穩定參數估計。在大森－宇津公式分析中，經BEPIT補全後各序列之K值均有所上升，反映補入事件後地震生產力相應提高；c值普遍下降，主因補全事件填補早期餘震缺失，降低了時間修正項之需求；p值變化較為複雜，其中2018花蓮與2022關山池上序列因具顯著前震活動，補全後序列起始段事件密度增加，整體衰減曲線趨於平緩，致使p值下降。ETAS參數分析中，三類斷層之餘震時空衰減特性呈現系統性差異，其中米崙斷層餘震隨時間衰減較慢，且空間參數反映其地震活動較為集中；中央山脈斷層餘震隨距離衰減較慢，可能受限於該區餘震數量較少及目錄尚未完備所致之統計不穩定；縱谷斷層則介於兩者之間。上述結果顯示，ETAS模型參數不僅能有效區辨各斷層系統之餘震時空衰減差異，亦可作為東部地震活動性評估與孕震構造分析之量化指標。

【學生壁報比賽】

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Student Poster SP098

台灣木屐寮六甲斷層帶密集網地下三維衰減構造研究
3D Attenuation Structure beneath Muchiliao-Lioujia Fault Zone Revealed by Dense Seismic Network Data, Taiwan

賴宣蓉、温士忠
國立中正大學地球與環境科學系

摘要

臺灣西南部地區位於造山帶前緣之西部麓山帶，屬於典型褶皺－逆衝斷層帶(Fold-and-thrust belt)，其地質構造複雜且地震活動頻繁。歷史上曾發生 1906 年梅山地震、1941 年中埔地震及 1964 年白河地震等重大事件，近年亦觀測到多起淺層地震序列，顯示該區地下構造仍持續活躍。過去研究多透過地震波速度構造探討地下地質特性，然而速度異常具有非唯一性，對於岩石物性與構造環境之解釋仍具限制。相較之下，衰減因子 Q 對溫度、孔隙率、裂隙密度等物性參數通常較速度敏感，可彌強速度構造於岩石物理參數判釋上的限制。本研究採用由 100 個測站組成之密集且均勻分布之地震網，於 2023 年 2 月 8 日至 7 月 20 日在木屐寮-六甲斷層帶所蒐集之地震資料。在假設 Q 的頻率介於 1-20Hz 中為常數之條件下，透過頻譜分析與非線性擬合計算震波路徑衰減因子 t*。本研究採用群組地震法，並引用既有三維速度模型，利用區域性地震層析成像法反演臺灣西南部三維衰減構造，以降低震源效應與拐角頻率與路徑衰減因子 t*之間折衷關係對結果的影響，並且提升 Q 值反演穩定度與精確度。過去多數研究以臺灣整體或較大區域為研究範圍，其衰減模型解析度相對有限，難以有效解析局部斷層尺度之衰減結構特徵。本研究藉由高密度測站資料，探討臺灣木屐寮六甲斷層帶之 Q 值異常與速度構造、斷層破碎帶及地下流體活動之關聯，進而提升對臺灣西南部孕震構造與地殼構造特性的理解。

關鍵詞:台灣西南部、衰減模型、路徑衰減因子 t*
Key words: Southwestern Taiwan, attenuation model, attenuation operator (t*)

【學生壁報比賽】
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Student Poster SP099

Diagonizing MiDAS DAS events through Machine Learning

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The 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 a 10-meter gauge length, 4-meter spatial resolution, and a 1000 Hz sampling rate, enabling high spatial and temporal resolution for detecting subsurface motions. To address the challenges posed by the ultra-dense spatial sampling and continuous recordings of DAS, we firstly utilized PhaseNet-DAS (Zhu et al., 2023) for seismic events identification. Built upon a U-Net-like fully convolutional network, this deep learning model is specifically designed to extract features from 2D spatio-temporal DAS data, demonstrating robust performance in seismic phase picking across various fiber arrays.While the pre-trained model generalizes well, its application to the MiDAS dataset shows lower accuracy due to distinct site effects, vertical borehole geometries, and complex fault-zone ambient noise. To address this, we propose "PhaseNet-MiDAS" by fine-tuning the base model utilizing an existing earthquake catalog (Zhan, 2024). From this catalog of 2,857 events (comprising 2,771 P-wave and 2,210 S-wave records), we applied the pre-trained PhaseNet-DAS to the continuous data and extracted only the picks located within a ±1-second window of the cataloged origin times. This process successfully yielded 2,950 precise P- and S-wave labels across Boreholes A and B, which were subsequently used as ground truth to retrain the model. This localized adaptation enhances picking accuracy for low signal-to-noise microseismicity, providing a high-resolution catalog for future Milun fault analyses.

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(1) 國立中央大學/馬國鳳
(2) 碩士班一年級

透過P波極化特性研究木屐寮六甲斷層帶淺層結構

Study on shallow structure of the Mujiliao Liucia fault zone using P-wave polarization characteristics

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摘要

在近地表的數百公尺內，無論透過體波成像、噪訊成像等方式皆難以取得較高解析度的淺層速度模型。本次研究中，目標以P波極化特性探討木屐寮六甲斷層帶的淺層結構。由於過去此區觀測資料不足，缺乏完整淺層構造證據，導致地震風險評估不確定，但近年於此地區已佈設密集地震網，提供豐富的地震P波資料，地震波的極化特性能有效反映地下介質的動力學參數。研究顯示，P 波的極化角度主要受測站下方剪切波速度所控制，而不受壓縮波速度影響。此外，其對深度的敏感度則取決於地震波頻率與地層剪切波速度的組合效應。本研究測試不同的頻率範圍及可解析深度，以得到最佳的收斂效果，並且結合中央氣象署地震目錄及定位資料，以提高波線參數(ray parameter)精確度。透過密集地震網觀測資料，可反演各測站下方之一維淺層速度模型，並進一步整合建立三維淺層速度模型，以描繪研究區域下方之三維淺層速度構造。由於研究區涵蓋嘉南平原及西部麓山帶，預期成果除可反映由東向西沉積層厚度逐漸加深、麓山帶下方堅硬岩盤分布等地質特徵外，亦希望能揭示斷層是否為盲斷層或具地表破裂潛能，幫助預測未來可能的地震規模與破裂型態。本研究建立之高解析淺層速度模型，結合監測數據可提升地震預警系統的準確度，將有助於後續更精確之波傳模擬、場址效應分析及地震災害評估。

關鍵字: P波極化特性、淺層速度模型、木屐寮六甲斷層帶活動潛勢

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Student Poster SP101

Crustal Velocity Structure and Seismotectonic Segmentation of Western Nepal from Local-Earthquake Tomography.

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Abstract

Western Nepal lies within the Central Himalayan Seismic Gap, a region with potential for large earthquakes due to the absence of recent great events. Unlike the relatively narrow seismicity zone in adjacent Himalayan segments, seismicity here is distributed across a broader belt, reflecting crustal heterogeneity and fault segmentation. Yet the three-dimensional crustal architecture remains poorly constrained. We apply seismic tomography using travel-time data from the temporary HiK-NET array and permanent RSC/DMG networks to image crustal velocity beneath western Nepal. Broad station coverage enables resolution of lateral and vertical variations and their relation to earthquake distribution and geological models. Results reveal pronounced crustal heterogeneity, providing new constraints on Himalayan wedge architecture and rheological segmentation. Vp models indicate generally lower velocities than in eastern Nepal, suggesting along-strike variations in crustal properties and lithology. Laterally, continuous low Vp/Vs domains trend parallel to the Himalayan strike in both northern and southern parts of the study area and merge westward, a pattern consistent with imbricated tectonic slivers or duplex-style crustal architecture within crystalline-metasedimentary crust of the Lesser Himalaya. In contrast, high Vp/Vs values in the southwest, extending to shallow depths, may indicate fractured rocks with elevated fluid content, while moderately high values in the east-central region may reflect a mid-crustal low-velocity zone. These findings refine the seismotectonic framework and improve seismic hazard assessment along the Himalayan arc.

Keywords: Western Nepal, 3D velocity, Seismic Tomography, Lateral variation

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Student Poster SP102

From Rays to Waves: Unraveling Taiwan's Orogenic Architecture with Adjoint Full-Waveform Tomography

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Abstract

We apply adjoint full-waveform tomography to resolve the complex orogenic structure beneath Taiwan. The inversion uses seismic waveforms from 60 local earthquakes and incorporates empirical Green's functions (EGFs) from 91 stations to jointly constrain crustal velocities. By exploiting spectral-element simulations and frequency-dependent sensitivity kernels, our approach accounts for complex 3-D finite frequency sensitivity kernels beyond the ray-theory approximation. Through a multi-stage strategy, we progressively introduce shorter periods of data down to 2 s to mitigate cycle skipping and iteratively refine the model via L-BFGS optimization over 26 iterations. The inversion substantially improves waveform fitting, including independent validation dataset of ambient noise EGFs, with the mean phase delay reduced from −1.44 s to 0.22 s. The new V_s model reveals strong heterogeneities with velocity perturbations up to 30% relative to the initial model. A high-velocity core with V_s exceeding 3.5 km/s revealed in the upper crust beneath the Central Range may represent exhumed metamorphic material associated with the subduction of the Eurasian Plate. Beneath Lyudao, a vertically continuous low-velocity conduit from ~50 km depth to the surface suggests subduction-related magmatism. The model also refines the geometry of Eurasian Plate subduction beneath eastern Taiwan and reveals a prominent low-velocity Pingtung Basin. These results demonstrate the power of full-waveform tomography in resolving complex subsurface structures and constraining lithological and rheological properties.

Information

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Student Poster SP103

Reconstructing the 2018 Palu Liquefaction and Predicting Future Liquefaction Scenarios Using Fused Vs and N-SPT Analysis

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The catastrophic liquefaction triggered by the 2018 Palu earthquake exposed the extreme vulnerability of densely populated areas in the Palu Bay area and highlighted the urgent need for reliable methods to reconstruct past failure mechanisms and anticipate future liquefaction hazards. In response to this need, this study aims to reconstruct the liquefaction induced by the 2018 event and to evaluate potential future liquefaction scenarios in three severely affected areas of Central Sulawesi, Indonesia, namely Balaroa, Jono Oge, and Petobo. The analysis adopts a fused subsurface characterization framework that integrates shear-wave velocity (Vs) data and corrected standard penetration resistance (N-SPT) data to improve the assessment of site-specific liquefaction behavior. MASW-derived Vs profiles and borehole-based geotechnical information were used to characterize layered soil conditions, while liquefaction potential was evaluated using cyclic stress ratio (CSR), cyclic resistance ratio (CRR), factor of safety (FS), and probability of liquefaction (PL). The reconstruction phase was performed using the actual 2018 earthquake loading condition, represented by Mw 7.4 and a peak ground acceleration (PGA) of 238.8 gal. The predictive phase considered scenario earthquakes of Mw 7.7 for 500-year, 1000-year, and 2500-year return periods, corresponding to PGA values of 1294.48 gal, 1618.10 gal, and 2157.46 gal, respectively. The results indicate that liquefaction susceptibility is strongly influenced by local stratigraphic conditions, shallow stiffness contrasts, and the persistence of low-to-moderate Vs layers. Several subsurface profiles exhibit critical to highly susceptible liquefaction conditions even under the 2018 real-case event. Under the future scenario earthquakes, CSR increases substantially, whereas FS decreases and PL increases over a wider depth range and across more locations, indicating a pronounced escalation in liquefaction hazard relative to the 2018 event. Overall, the findings demonstrate that the integrated Vs and N-SPT approach provides a robust basis for both reconstructing past liquefaction and predicting future site-specific liquefaction severity.

Keywords: liquefaction, Vs, N-SPT, MASW, Palu earthquake, Central Sulawesi

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多事件地震情境下的穩健相位判定

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摘要

在自動化地震監測中，準確且穩健的地震相位判定仍然是一項基礎且具挑戰性的問題，特別是在波形條件複雜的情況下。近年來的深度學習模型，如 PhaseNet 與 EQTransformer，在常用的基準資料集上已展現出良好的表現。然而，這些模型在架構設計上的選擇，也帶來了在時間解析度、序列建模能力，以及對更真實地震情境的泛化能力上的限制。

PhaseNet 採用卷積式 U-Net 架構，對於波形分割任務相當有效，但其能力受到 receptive field以及有限的動態時間建模能力所限制。相較之下，EQTransformer 使用 encoder–attention–decoder 架構，能夠捕捉長距離依賴關係；然而，為了緩解自注意力機制平方級計算成本，它依賴激進的temporal downsampling。這種高度壓縮的策略可能會丟失細緻的時間資訊，並降低相位起始點判定的精確度。

在本研究中，我們提出 EQMamba，一個用於地震相位判定的序列建模框架，其設計重點在於維持時間資訊的高細緻度以及有效建模長距離依賴關係。所提出的架構結合了結構化狀態空間模型與高效率的線性注意力機制，使得長時間序列的地震波形可以在極少降採樣的情況下進行處理。透過在維持計算可行性的同時保留高解析度的時間資訊，EQMamba 更能反映地震訊號所具有的連續時間與動態系統特性。

除了在受控的單一事件情境下進行評估，本研究特別關注模型在更貼近真實波形條件下的行為，包括事件疊加、振幅不平衡以及不同相位之間的時間干擾等情況。我們提出一種新的資料建構與評估策略，用以系統性地檢驗模型在多事件情境以及主震–餘震場景中的穩健性，而這些情境在標準基準資料集中往往較少被涵蓋。模型表現的分析不僅依賴傳統的 phase picking 指標，亦包含誤差分布、相位混淆模式，以及隨波形複雜度增加所出現的失敗模式等面向。

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結合解迴旋與時頻分析之結構主頻演化研究：東華大學校園建物之觀測結果

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摘　要

地震動對結構物動態特性之影響，為工程地震學與結構健康監測（SHM）之核心議題。強震作用下結構自然頻率之變化，可作為判斷結構非線性行為與潛在損傷之重要指標，然而場址效應與土壤非線性常使觀測結果難以直接解釋，限制震後評估之可靠性。本研究以東華大學校園內多層建築為研究對象，結合自由場與建築內三分量加速度觀測資料，探討地震歷程中結構主頻之時間演化特性。

本研究建立一套整合解迴旋（deconvolution）與時間-頻率分析之方法。透過以自由場記錄作為輸入訊號，推估結構系統之脈衝響應函數（Impulse Response Function, IRF），以分離場址效應與結構反應；並利用連續小波轉換（Continuous Wavelet Transform, CWT）之ridge追蹤技術，萃取主頻隨時間之演化軌跡，定義初始頻率、最低頻率與震後回復頻率等關鍵參數，以量化地震作用下之動態變化行為。

初步結果顯示，多數地震事件中結構主頻皆呈現明顯下降（f_init > f_lowest），顯示地震作用下結構剛性之暫時性降低，反應非線性行為之發生。此頻率下降現象於三分量中均可一致觀測，顯示其主要反應結構整體動態特性之變化，而非單一方向之局部效應。於2024年花蓮地震序列期間，頻率下降幅度與分布範圍顯著增加，顯示強震對結構反應之影響更為明顯。此外，多數事件之震後頻率未完全回復至初始值（f_final < f_init），可能表示微損傷累積或材料非線性殘留效應。

本研究結果顯示，結合自由場與結構反應之分析方法，可有效提升結構動態特性判釋之可靠性，並具備應用於震後快速評估與長期監測之潛力，對工程地震學與結構安全評估具有重要參考價值。

關鍵字：花蓮地震序列、結構健康監測、結構主頻演化、解迴旋分析

【學生壁報比賽】

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Structural Frequency Evolution Using Deconvolution and Time–Frequency Analysis: Observations from Campus Buildings at NDHU

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Abstract

The dynamic characteristics of structures under seismic loading are a key concern in engineering seismology and structural health monitoring (SHM). Variations in natural frequency during earthquake excitation can serve as important indicators of structural nonlinearity and potential damage. However, the interpretation of structural responses is often complicated by site effects and soil nonlinearity, which may obscure the intrinsic behavior of the structure. This study examines the temporal evolution of the structural fundamental frequency using seismic observations from campus buildings at National Dong Hwa University (NDHU) in eastern Taiwan.

An integrated analysis framework combining deconvolution and time–frequency analysis is developed. By treating the free-field record as input, the impulse response function (IRF) of the structural system is estimated to separate site effects from structural response. Continuous wavelet transform (CWT) ridge tracking is then applied to extract the temporal evolution of the fundamental frequency, from which key parameters, including the initial frequency, minimum frequency, and post-event recovered frequency, are defined to quantify the dynamic response during seismic events.

The results show that, for most events, the fundamental frequency exhibits a clear transient reduction ($f_{init} > f_{lowest}$), indicating a temporary decrease in structural stiffness associated with nonlinear behavior. This frequency reduction is consistently observed across all three components, suggesting that it reflects the overall structural response rather than direction-dependent local effects. During the 2024 Hualien earthquake sequence, both the magnitude and variability of frequency reduction are significantly enhanced, highlighting the impact of strong ground motion. In addition, the post-event frequency often does not fully recover to its initial value ($f_{final} < f_{init}$), implying possible accumulation of minor damage or residual nonlinear effects.

These findings demonstrate that integrating free-field and structural observations can effectively improve the reliability of interpreting structural dynamic characteristics. The proposed approach demonstrates strong potential for rapid post-earthquake assessment and long-term monitoring, providing valuable insights for engineering seismology and structural safety evaluation.

Keywords: Hualien Earthquake Sequence, Structural Health Monitoring, Fundamental Frequency Evolution, Seismic Deconvolution

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(1) University: National Dong Hwa University/ Advisor: Wen-Yen, Chang
(2) Degree: PhD Program/ Grade: 2nd-year

結合反應譜與地質資料克利金內插之台北盆地地震微分區

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摘　要

台北盆地在地震時受盆地幾何與場址條件共同影響，地震動分布改變且長週期成分增強，對高樓與關鍵設施構成威脅。在結構耐震設計中，反應譜中的轉角週期可整合震源、路徑與場址效應，簡潔描述地震運動的頻率內涵。憑藉台北盆地內高密度實測資料，轉角週期可直接推求並用於地震微分區與耐震設計評估。然而，現行規範以「里」作為微分區單元，強震測站卻未能完全涵蓋各里範圍，僅依賴傳統空間內插進行空間推估仍有其限制。

本研究蒐集 1992 至 2024 年間台灣地區中大型地震事件紀錄(地震矩規模大於五，或盆地內任一測站觀測到 PGA 大於 10gal 的地震事件)，在統一流程下完成基線校正與濾波，建立 5%臨界阻尼比之反應譜資料庫，並計算各測站之反應譜與轉角週期。研究首先依震源特性將地震分為地殼、隱沒帶介面型與隱沒帶內部型三類，並取各類之反應譜平均值作為搜尋轉角週期時的目標反應譜。結果顯示，轉角週期在地殼地震與隱沒帶介面型地震均呈現明顯的區域差異，盆地西北側至北北東一帶的轉角週期最長，可達 1.9 秒以上，東南側邊緣則最短；然隱沒帶內部型之空間差異不顯著。相關性分析進一步顯示，轉角週期空間分佈與剪力波速、軟弱土層深度分布等地質條件相關係數達 0.4 以上，表示擁有越深厚沉積層之地區轉角週期越長，顯示地質條件可用以解釋反應譜形狀的區域變化。為此，本研究進一步將上述地質參數納入克利金空間內插運算，以提升地震微分區結果的解析度與物理解釋力，期能為台北盆地耐震設計提供更精細且有據的參考資料。

關鍵字：台北盆地、地震微分區、反應譜分析、轉角週期、克利金內插

【學生壁報比賽】
(1) 就讀學校/指導教授：國立中央大學 / 董家鈞
(2) 學位/年級：碩士班 / 二年級
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Student Poster SP107

利用 MiDAS 井下地震儀陣列探討米崙斷層周邊場址特性與 2024 年花蓮地震之非線性效應分析

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摘要

2018 和 2024 兩次花蓮地震造成花蓮地區嚴重災害，其中米崙斷層錯動所引發的強地動效應為成災主因。本研究利用「花蓮米崙斷層科學鑽探：地震活動及前兆井下監測計畫(Milun Fault Drilling and All-inclusive Sensing project，簡稱 MiDAS 計畫)」之兩口科學鑽井(MDSA、MDSB) 觀測紀錄進行分析；其中上盤井 MDSA 深度為 700 公尺，下盤井 MDSB 深度為 500 公尺，兩井均於不同深度配置光學加速度儀或短週期地震儀，形成垂直觀測陣列；本研究旨在透過此高解析度之垂直陣列優勢，探討該區域地層之波速特性、場址效應以及強震引發之非線性效應。

研究首先利用反捲積（Deconvolution）方法提取層間走時差，初步建立 MDSA 與 MDSB 站之縱波（Vp）與剪力波（Vs）波速剖面，用以探討近斷層地層之物理特性。過往研究顯示，強震期間可能存在因剪力模數弱化導致之波速暫態下降現象。本研究針對 2024 年花蓮地震，進一步對比強震前後之地震紀錄，預期透過分析強震過程的地層非線性變化與震後恢復過程，作為特定場址地震危害度分析之參考依據。

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- 指導教授：郭俊翔教授
- 學位/年級：碩士二年級

Student Poster SP108

速度構造對近斷層速度脈衝影響的模擬研究

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摘　要

近斷層速度脈衝為近斷層區域常見之長週期、大振幅且能量集中的脈衝型震動，可能對中高樓層建物的耐震需求造成較明顯影響。為探討地層速度構造對速度脈衝生成與特性的影響，本研究以數值模擬方式，比較台灣、加州區域以及岩盤、沖積層等，不同特性之速度構造對近斷層速度脈衝之影響差異。本研究採用 F-K 波數積分法（Frequency-wavenumber method），在點震源的假設下使用一維水平分層模型進行模擬，並進行速度脈衝提取與反應譜比較。目前結果顯示，含淺部鬆軟沖積層之速度構造可明顯放大 PGV 與較長週期（約 1 至 2 秒）之 PSV 頻譜值，其放大幅度約為岩盤模型的 2.5 至 4 倍；相較之下，岩盤模型的主能量頻段雖相近，但放大效應有限。整體而言，本研究已初步釐清速度構造對近斷層速度脈衝及中長週期地動特性的影響，並為後續研究速度脈衝特性建立了基礎。

就讀學校：國立中央大學
指導教授：郭俊翔
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利用反射震測約束之Vs反演探討淺層速度特性

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(1)國立中央大學地球科學學系（Earth Science, National Central University, Taiwan）

摘　要

了解地下介質之速度特性，對於評估其對建築物與基礎設施的潛在影響至關重要。速度剖面可提供地震災害評估所需的重要資訊，包括平均剪力波速（V_{S30}）的估算、場址非線性效應的評估，以及數值波傳模擬等。此類速度剖面可透過多種方法取得，例如懸盪式速度井測（Suspension P-S Logging）、多波道表面波頻譜分析法（MASW）以及微地動陣列量測（MAM）等。然而，不同方法在解析度與探測深度上的差異，往往使其在地球物理與工程應用上的跨域整合變得具有挑戰性。

本研究結合淺層反射震測與微地動陣列量測之成果，建立分層速度模型。反射震測資料經處理後獲得各層區間速度（V_p），並以其界面深度作為約束條件，於參數空間中隨機取樣（Monte Carlo sampling）產生剪力波速度（V_s）模型，透過比較正演雷利波相速度頻散曲線與觀測曲線，藉由迭代修正來降低殘差，進一步整合多次反演所得模型之集合進行統計分析，以尋找殘差最小的最佳模型。

最終建立之分層V_p與V_s模型，有助於提高淺層速度構造之解析度，並可提升場址條件評估與數值波傳模擬之準確性，特別是反射震測所提供之層界深度資訊，可作為表面波反演之額外結構約束條件，有助於限制速度模型之可能解空間。本研究旨在提供一套有效之方法流程，能整合不同地球物理探測技術所得之P波與S波速度剖面，以刻畫淺層地震場址特性。

【學生壁報比賽】
就讀學校：國立中央大學
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Student Poster SP110

Ambient Noise Tomography of Luzon Island using Land-based and sea-based seismic stations

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Abstract

Luzon Island is a tectonically active region located between two opposing subduction zones: the Sunda Plate to the west and the Philippine Sea Plate to the east. This tectonic setting has formed sedimentary basins, ophiolite complexes, and volcanic arcs, and generates frequent earthquakes and volcanism that pose significant hazards to densely populated areas. In this study, we apply ambient noise tomography (ANT) to assess subsurface lateral structural heterogeneity relevant to seismic and volcanic hazard mitigation. Continuous vertical-component recordings from 46 land-based stations of the Philippine Seismic Network, supplemented by nine ocean-bottom seismometers along the Manila Trench, were cross-correlated and stacked to extract Rayleigh-wave Green's functions. Group- and phase-velocity dispersion curves were measured using the EGFAnalysisTimeFreq software over period ranges of 3–33 s and 3–29 s, respectively. We then employed the Fast Marching Surface Tomography (FMST) package to determine two-dimensional (2D) group- and phase-velocity maps as functions of period. Preliminary results show strong correlations with known geological and tectonic features. Additionally, long-period group-velocity maps reveal signatures consistent with slab tearing along the Manila Trench and structures associated with the East Luzon Trough slab.

Keyword: Ambient Noise Tomography; ocean-bottom seismometers; Luzon Island

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Student Poster SP111

Long-Period Rayleigh-Wave Eikonal Tomography of the Chiayi–Tainan Plain Using Teleseismic Events

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The subsurface structure of the Chiayi–Tainan Plain reflects the influence of Cenozoic South China Sea rifting, which produced extensional tectonics and normal fault systems. Some of these inherited normal faults may have been reactivated as reverse or strike-slip faults during the later arc–continent collision between the Eurasian Plate and the Philippine Sea Plate. Over the past 50 years, 16 earthquakes with magnitudes greater than 5 have occurred in the Chiayi–Tainan Plain, with focal depths mostly ranging from 10 to 20 km. However, whether these earthquakes are associated with inherited normal faults or with fault structures reactivated under later compressional tectonics remains unclear.

To better understand the tectonic structure beneath this region, this study analyzes teleseismic Rayleigh waves generated by earthquakes with magnitudes greater than 5 and epicentral distances larger than 2000 km. These data provide high-quality Rayleigh-wave observations for tomographic analysis. Eikonal tomography is then applied to construct a phase-velocity model of the Chiayi–Tainan Plain. Because the lateral resolution of Eikonal tomography is primarily controlled by station spacing, the recent expansion of the Central Weather Administration seismic network, including TSMIP stations, provides an important improvement. The average station spacing in the Chiayi–Tainan Plain has been reduced to approximately 5 km, allowing higher-resolution imaging of lateral velocity variations. The resulting velocity model is expected to improve earthquake relocation accuracy and provide new constraints on fault structures and tectonic interpretation beneath the Chiayi–Tainan Plain.

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Student Poster Competition

Applicant: Chaninthon Rattanavetchasit[1] PhD student 4th year
Advisors: Hsin-Hua Huang[2,1] and Yih-Min Wu[1]

1 Department of Geosciences, National Taiwan University
2 Institute of Earth Sciences, Academia Sinica

Session: S3 Seismology: Evironmental and ambient noise seismology
Type: Poster + Student poster competition

Integrating Seismic Velocity Changes with GNSS and Groundwater Observations to Constrain Coupled Hydrological and Deformation Processes in Western Taiwan

結合震波速度變化、大地測量與地下水觀測探討台灣西部平原的水力與地殼變形耦合機制

Chaninthon Rattanavetchasit[1]
Hsin-Hua Huang[2,1]
Ya-Ju Hsu[2]
Yih-Min Wu[1]

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2 Institute of Earth Sciences, Academia Sinica

Abstract

The western plain of Taiwan experiences significant land subsidence associated with groundwater extraction. Understanding its dynamic processes linking rainfall, groundwater variations, and ground deformation is therefore essential. However, this relationship is complex due to the combined influences of tectonic activity, seasonal weather variability, and large earthquakes. In this study, we apply passive seismic monitoring using ambient noise to estimate temporal changes in seismic velocity (dv/v). By incorporating dv/v measurements with independent datasets, including meteorological observations, Global Navigation Satellite System (GNSS) data, groundwater level records, and multi-level compaction well measurements, we aim to improve the understanding of hydrological processes and their impact on subsurface mechanical properties in a tectonically active and environmentally complex setting. Our results demonstrate that dv/v provides additional constraints on subsurface changes, offering new insights into the coupling between groundwater dynamics and land deformation.

Keywords: Ambient noise monitoring, Seismic velocity change, Groundwater, Land subsidence

Keywords (Chinese): 周遭噪訊監測、震波速度變化、地下水、地層下陷

Student Poster SP113

High-Resolution 3D Crustal Shear-Wave Velocity Structure of Sulawesi, Indonesia, from Joint Inversion of Group and Phase Velocities of Ambient Noise Surface Waves

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Abstract

Sulawesi is located in eastern Indonesia between Borneo and the Moluccas, lies within a tectonically complex region where three major tectonic plates—the Eurasian, Australian, and Pacific plates—interact. This setting leads to significant seismic and volcanic hazards across the region. Understanding the crustal structure is crucial for constraining regional tectonic evolution and assessing geohazards in this region. This study presents a new high-resolution three-dimensional (3D) crustal shear-wave velocity (Vs) model beneath Sulawesi, Indonesia, derived from ambient noise tomography. One year of continuous vertical-component broadband seismic data from 67 stations were cross-correlated to retrieve Rayleigh-wave empirical Green's functions. Group and phase velocity dispersion curves were measured using frequency–time analysis and jointly inverted in a one-step inversion method to construct a 3D Vs structure. The resulting model reveals pronounced lateral velocity contrast correlated with major tectonic structures, including the left-lateral strike-slip Palu–Koro Fault. Low velocity anomalies coincide with sedimentary basins and active extensional regions, as well as magmatic and volcanic activity along the Sangihe–North Sulawesi arc. Additionally, a shallow low-velocity anomaly beneath Palu City reflects thick unconsolidated Quaternary sediments, consistent with previous geological observations. In contrast, high-velocity anomalies correspond to exposed metamorphic basement complexes, including Malino, Palu, and Mekongga metamorphic complexes. Overall, the crustal Vs model provides enhanced imaging of crustal heterogeneity and fault-controlled structures, providing important insights into regional deformation and seismic hazard assessment.

Keywords: *Ambient Noise Tomography, Shear wave velocity structure, Sulawesi, Palu-Koro Fault.*

Student Poster SP114

利用噪訊地震學方法探討花東縱谷北段之淺層速度構造

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摘　要

花東縱谷位於歐亞板塊與菲律賓海板塊之碰撞帶，地震活動頻繁。

2021年7月花蓮縱谷北段發生顯著震群，國立東華大學團隊於秀林至鳳林佈設47部SmartSolo密集陣列，結合中央氣象署測站資料進行餘震重新定位、三維速度構造反演及震源機制解分析。結果顯示縱谷兩側皆存在斷層構造，且Vp/Vs呈現東高西低之分布特徵，反映東西兩側岩性與構造差異。震源機制解指出，中央山脈東側多為帶滑移分量之正斷層，而縱谷東側則以帶滑移分量之逆斷層為主，顯示兩側斷層系統具有不同變形機制。

然而，上述研究主要依賴體波資料，其結果受限於震源分布與射線路徑覆蓋，對淺層構造解析能力有限。為補強此限制，本研究整合SmartSolo密集陣列、中央氣象署及BATS測站資料，採用環境噪訊地震學方法，計算測站對交相關函數（CCFs），提取Rayleigh waves訊號並分析淺層剪力波速度結構。考量SmartSolo於0.2–0.8 Hz頻段具較佳穩定性，本研究聚焦此頻段進行群速度估算與空間分布分析。

相較於體波方法，環境噪訊表面波具較均勻之路徑覆蓋，可提升淺層剪力波速度構造之解析度。本研究建立之群速度分布與二維速度模型，有助於約束縱谷北段淺部構造特徵，並補強體波反演之不足。

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(2) 碩士班/一年級

Constraining Basal Conditions of the Greenland Ice Sheet Using Rayleigh-Wave Ellipticity From Ambient Seismic Noise Records

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Abstract

The physical conditions at the base of the Greenland Ice Sheet (GrIS) significantly influence ice dynamics and its response to climate change. Due to limited radar and borehole data, and the reliance of thermo-mechanical ice-flow models on prescribed parameters, the shallow internal structure and basal environment are not well-constrained by seismological observations. This study investigates Southwest Greenland, where basal conditions are poorly understood despite models predicting thawed beds. We analyze ambient seismic noise from about 80 temporary seismic stations(each with a geophone HG-6-A-Coil and DiGOS DataCUBE3).Rayleigh-wave ellipticity is extracted using the Degree of Polarization–Ellipticity (DOP-E) method and inverted for the shear-wave velocity(Vs) structures using the Neighborhood Algorithm (NA). Prior to performing the inversion for all available stations, a subset of stations was used to test and tune the inversion parameters, including reference and initial velocity models and the number of iterations. Station-specific 1D inversions yield local estimates of Vs structure. These discrete, data-constrained points are interpolated to create a 3Dmodel of ice thickness, with approximately 100 m spacing consistent with station density, and inter-station values constrained by interpolation. The resulting model is then compared with seismic reflection analysis and the BedMachine model. Finally,a 3D model of the ice and underlying bedrock in the study area is constructed. This study offers new seismological constraints on the GrIS's internal and basal conditions, supplementing existing observations and models. This passive seismic method provides a flexible and efficient way to constrain ice thickness in remote areas.

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Student Poster SP116

微地動監測技術應用於崩塌偵測、潰壩過程及潰決洪水預警研究：以燕子口堰塞湖為例

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摘　要

臺灣山區陡峭地形與多雨、颱風氣候易導致山崩發生。若形成堰塞湖，潰壩的二次傷害嚴重威脅到周遭及下游區域安全。2025 年 10 月 17 日約五點在太魯閣國家公園內，中研院寬頻地震站 NACB(寧安橋)與 GFZ GEOFON 測站 TQ02(布洛灣)觀測到山崩地動訊號，約 0.8 公頃崩落土石堵塞立霧溪河道，形成燕子口堰塞湖。本研究著重於壩體發生侵蝕破壞時，利用近堰塞湖微地動站(站碼 YZK1)之微地動時序訊號計算功率頻譜密度(Power Spectral Density, PSD Estimate)及 CCTV 觀測潰壩土石崩落行為與微地動訊號之關聯性，並將侵蝕破壞過程分為數階段，以驗證自然形成堰塞湖與大型野潰壩試驗中未夯實壩之侵蝕崩塌行為相似度。

壩體侵蝕第一階段前，觀察到不自然地動訊號脈衝，推測為現場降挖引流機具撤離造成。侵蝕第一階段，PSD 訊號先是變強烈後，短暫減弱，並在觀察到第二階段特徵之垂直下切後恢復。推測上游潰口崩塌，土砂材料短暫阻擋潰口使訊號減弱。隨水流持續侵蝕，潰口再次形成，正式進入可觀察到噴流及潰口加深的第二階段。後續右翼山壁崩塌符合第三階段之側向拓寬特徵，同時 CCTV 與微地動訊號皆觀測到洪峰特徵。第三階段後的穩定期分為兩段：潰口暫時穩定的第一穩定期；堰塞湖蓄水穩定排出，回歸常時水流的第二穩定期。同時觀察到強烈 PSD 低頻脈衝皆出現在大規模崩塌後，推測壩體受侵蝕後提高河川供砂條件，其中大粒徑顆粒主導的泥砂運移作用所導致。

自然形成堰塞湖受地理位置及持續性觀測時間影響，觀測分析難以進行，故此次燕子口堰塞湖是難得的事件，雖然僅靠微地動感測器與 CCTV 不能完整觀測過程，需配合水位計、空拍機等儀器進行更全面研究。但連續微地動訊號觀測仍有助於了解天然堰塞湖生命週期，後續可與下游微地動觀測站(YZKG、YZK2、NACB、YZK3)訊號比對，了解潰壩後水流是否符合預期，並幫助提升潰決洪水預警準確性。

關鍵詞: 燕子口堰塞湖、微地動、潰壩、潰決洪水預警

Student Poster SP116

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Student Poster SP117

Depth-Dependent Recurrence and Slip-Rate Behavior of Repeating Earthquakes in Northern Chile

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[2]Department of Geophysics, Freie Universität Berlin, Berlin, Germany

Repeating earthquakes provide constraints on fault slip and loading processes along subduction zones. We analyze a comprehensive repeating earthquake catalog from northern Chile spanning more than two decades (Folesky et al., 2025), consisting of 3153 repeating earthquake sequences with magnitudes ranging from −0.3 to 4.7. These sequences cluster at two depth intervals: a shallow group (<70 km) and an intermediate-depth group (70–210 km), spanning from the plate interface to within the subducting slab.

We compare the recurrence behavior and slip-rate response of shallow and intermediate-depth repeating earthquakes. Shallow repeaters show strong sensitivity to large megathrust earthquakes. Following the 2014 Mw 8.1 Iquique earthquake, inferred slip rates accelerated to peak values of up to 51.96 cm/yr, then decayed over approximately five years to a quasi-steady level of 3.3449 cm/yr, and eventually returned toward a background rate of 0.549 cm/yr. In contrast, intermediate-depth repeating earthquakes exhibit little systematic response to large megathrust events.

Despite these contrasting responses, both shallow and intermediate-depth repeaters record comparable background slip rates of ~0.5–1.0 cm/yr. Along-strike and space–time analyses further indicate that north–south variability at intermediate depth is expressed primarily in recurrence patterns rather than in slip-rate amplitude. These results demonstrate pronounced depth-dependent differences in repeating earthquake behavior and provide new observational constraints on fault slip processes from the shallow megathrust to intermediate depths.

Student Poster SP118

利用海底電纜光纖感測技術探究臺灣東北部海陸域孕震構造
Characterizing Inland and Offshore Seismogenic Structures in Northeastern Taiwan with Marine Fiber-Optic Distributed Sensing Data

李威廷[1,2]、馬國鳳[2]、王昱[1]、黃信樺[2]、林欽仁[2]、古進上[2]
(1)國立臺灣大學地質科學系、(2)中央研究院地球科學研究所

摘　要

分散式光纖感測 (Distributed Acoustic Sensing，DAS) 可將既有通訊光纖轉化為高密度地震感測陣列，具備靈敏度高、經濟效益佳與長期穩定監測等特性，使其成為近年地震學的研究趨勢。DAS相關技術在國際上已有許多相關應用，而臺灣亦於花蓮 MiDAS 計畫及頭城、枋寮海纜等區域展開初步嘗試。本研究旨在評估海底光纖電纜 (Submarine Optical Fiber Cable) 結合DAS技術於海域地震觀測之應用潛力。相較於傳統陸域寬頻地震儀、強地動觀測網或海底地震儀 (Ocean-Bottom Seismometer，OBS)，DAS 技術具備高靈敏度、高採樣率及極高空間解析度之優勢，能有效彌補海域觀測站點稀疏之限制，獲取更密集的地震觀測資料，作為研究海陸域孕震構造的資料來源。

本研究利用中央研究院地球科學研究所自中華電信位於宜蘭頭城的近東西走向海纜 SMW3，並將其轉換成數公尺級的觀測節點，取得海纜觀測資料，針對如臺灣地震模型 (Taiwan Earthquake Model，TEM) 中的南北宜蘭構造、龜山島火山活動及沖繩海槽之地震序列進行解析。研究方法首先進行海纜位置之定位、檢測光纖海纜沿線訊號品質，隨後導入機器學習模型 PhaseNetDAS 進行地震波相自動偵測與挑選，以捕捉未被傳統測網記錄之微震事件，並進一步執行震源定位與解算震源機制。預期成果能利用DAS之高空間解析度，彌補海域小地震觀測的不足，建構臺灣東北部海陸域高解析度之三維地震活動模型，以及進一步釐清該區域的孕震構造特徵。未來也期望可藉由DAS技術有即時資料接收的優點，將其運用在臺灣近海的地震監測。

中文關鍵詞：分散式光纖感測、海底電纜、臺灣東北部、孕震構造

【學生壁報比賽】參與者於摘要尾端註記

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(2) 學位：大學部 / 年級：四年級

Student Poster SP119

Preliminary Results of Local Earthquake Location at the MiDAS Site
MiDAS 場址區域地震定位初步成果

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摘　要

花蓮地區位於臺灣東部板塊交界帶，地震活動頻繁，其中米崙斷層為區域內重要構造。地下微震活動對於了解斷層活動特性與地下構造具有重要意義。然而，由於地表測站易受環境雜訊影響，小規模或深層微震事件難以辨識。因此，本研究利用井下地震儀低雜訊與高訊號品質之特性，分析米崙斷層附近地下微震活動，並建立 MStudio 軟體在井下地震資料處理與震源定位分析中的操作流程。

米崙斷層科學鑽井計畫（Milun-fault Drilling and All-inclusive Sensing Project, 簡稱 MiDAS 計畫）於花蓮七星潭地區米崙斷層上、下盤設置 700 公尺深之井 A 與 500 公尺深之井 B，各井於不同深度配置加速度與速度地震儀，資料取樣率為 1000 Hz。本研究使用 MiDAS 井下地震儀網記錄之地震波形，並透過 NORSAR 開發之 MStudio 軟體進行處理與分析。首先以人工判讀挑選 P、S 波到時，並計算 Ts–Tp 到時差；接著利用 Full Grid Search 與 NonLinLoc（NLLoc）進行震源定位，在三維空間求得震源位置。其中 Full Grid Search 透過網格搜尋找出殘差最小之位置，而 NLLoc 則以機率法估計震源空間分布並求得最可能位置及其不確定性。

本研究使用詹京倍（2025）所建立之 MiDAS 場址區域地震 D1 類事件（Ts–Tp 小於 2 秒，且地震波由深部傳向地表），資料時間為 2023 年 3 月 17 日至 9 月 13 日，共 317 個事件用於定位分析，此類地震僅少數於中央氣象署地震目錄中。初步結果顯示，地震主要分布於深度 2000 至 3000 公尺之近垂直區域，可能與米崙斷層淺部構造有關。本研究可作為米崙斷層附近地下地震活動分析之基礎，並提供未來地震監測與地下構造研究之參考。

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(2) 學位: 碩士生 /年級: 一年級

Student Poster SP120

Shipborne Gravity Data Processing and Preliminary Forward Gravity Modeling along the SALITE array in Southern Taiwan

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(3) National Academy of Marine Research, Kaohsiung, Taiwan

Abstract

Southern Taiwan lies at an active tectonic transition from subduction to arc–continent collision, making it a key region for understanding lithospheric dynamics. The Southern Array for the Lithosphere and Uplift of Taiwan Experiment (SALUTE) provides high-resolution seismic images offering a natural framework for integrated geophysical investigation. In this study, we focus on the processing and quality assessment of shipborne gravity data acquired by the gravimeter aboard the R/V *Legend*. As the gravimeter was newly installed, we perform careful gravity tie procedures with the absolute gravity benchmark, applying Eötvös, latitude and free-air corrections to derive free-air anomaly. To evaluate data consistency, we conduct crossover error analysis between R/V *Legend* and R/V *New Ocean Researcher 1*, quantifying systematic inter-vessel differences for data quality control. The resulting free-air anomaly profiles are compared with Sandwell (2023) satellite-derived gravity and Ocean Data Bank (ODB) shipborne compilations: Sandwell shows generally smooth and consistent trends with the ship data, while ODB exhibits larger discrepancies in the eastern profiles, particularly near the Luzon arc region. A composite free-air anomaly profile is then constructed by combining shipborne data with existing land data along SALUTE array corridor. As a preliminary step toward a joint geophysical interpretation, we apply empirical velocity–density relationships to SALUTE seismic velocity model to perform two-dimensional forward gravity modeling and compare the predicted anomalies with observations to evaluate density structure in this collision-subduction transition zone.

Characters count: 1678/1700

Abstract Information

Session: S4 – Seismology

Sub-session: S4 - 觀測地震學 Observational Seismology

Keywords in Chinese: SALUTE 陣列、船載重力測量、交叉誤差分析、順推

Keywords in English: SALUTE array, Shipborne Gravimetry, Crossover error (COE) analysis, Forward Modeling

Remarks:
We hope that SALUTE-related contributions can be scheduled together.

(1) Bachelor's Degree/ junior
(2) University: Department of Earth Sciences, National Taiwan Normal University, Taipei, Taiwan/ Advisor: Pei-Ying Patty Lin
(3) _____

Student Poster SP121

Investigating the Influence of the Low-Velocity Layer on Guided Wave Propagation in the Subducting Plate in Southern Taiwan with 2D Finite-Difference Simulation

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[2]Institute of Oceanography, National Taiwan University, Taipei, Taiwan
[3]Southern Array for the Lithosphere and Uplift of Taiwan Experiment

Abstract

Southern Taiwan lies within a transitional zone of convergence between the Eurasian Plate and the Philippine Sea Plate, where tectonic processes evolve from subduction to arc-continent collision. Constraining the geometry and properties of the subducting plate boundary is therefore important for understanding the tectonic evolution of this region. In this study, we use 2-D finite-difference simulations to investigate the lithospheric structure, emphasizing the role of a low-velocity layer (LVL) located along the upper interface of the subducting slab. Existence of LVL has been a popular explanation for waveguide signatures from intermediate-depth earthquakes in southern Taiwan: a low-frequency P-wave onset followed by a delayed high-frequency coda. To verify this, we conduct a series of 2-D forward simulations at high-resolution, enabling accurate modeling of frequency-dependent wave propagation up to 10 Hz. Results indicate that the presence of an LVL is a necessary condition for the development of guided waves. By comparing synthetic waveforms for models with LVL thicknesses ranging 0–12 km, we fist found that dispersion do not occur in models without an LVL. Spectral analysis further demonstrates that thinner LVLs are more effective at trapping seismic energy within the waveguide, whereas thicker LVLs allow transmission of high-frequency energy but reduce the separation between frequency components. Moreover, pronounced dispersion requires sufficiently long propagation. Future work will incorporate realistic lithospheric models of southern Taiwan and perform waveform fitting with data from the SALUTE array to further constrain the subduction zone structures.

Keywords: Subduction Zone, Guided Waves, 2D Wavefield Simulation, Low-Velocity Layer, Southern Taiwan, SALUTE Array

University / Advisor：Professor Tai-Lin Tseng, Department of Geosciences, National Taiwan University
Degree / Grade：Yu-Han Chen, Department of Geosciences, National Taiwan University / First-year master's student

Student Poster SP122

Observations of sSmS Phases and Implications for Moho Depth Beneath the Taiwan Strait

Hsuan-Ching Hung[1], Kuo-Fong Ma[2], Wen-Tzong Liang[2], and Tai-Lin Tseng[1]

(1) Department of Geosciences, National Taiwan University

(2) Institute of Earth Sciences, Academia Sinica, Taiwan

Abstract

The sSmS phase is a seismic depth phase in which an upgoing S-wave reflects first at the Earth's surface and subsequently at the Moho discontinuity. This Moho-reflected phase provides a valuable constraint on the Moho depth at the reflection point. However, the sSmS phase is rarely reported in the Taiwan region, and the Moho depth beneath the Taiwan Strait remains poorly constrained.

In this study, we identify several intermediate-depth earthquakes (>60 km) in the Ryukyu subduction zone that exhibit clear sSmS waveforms recorded at station VWUC of the Broadband Array in Taiwan for Seismology (BATS), located in Wuqiu Township, Kinmen County. Notable events include those occurring at 2025-12-27T15:05:55, 2025-08-27T13:11:00, and 2026-02-24T04:37:15 (UTC). The observed sSmS phases arrive about 16 seconds after the direct S-wave and display comparable or even larger amplitudes.

These observations indicate that the sSmS phase is detectable in the Taiwan region. This study will utilize sSmS travel times to constrain the Moho depth beneath the Taiwan Strait, and may provide new insights into the Moho geometry.

Keywords: sSmS, Moho depth

(1) University: National Taiwan University

Advisors: Kuo-Fong Ma, and Tai-Lin Tseng

(2) Master's degree/ 1st grade

(3

中文摘要格式範例 中文摘要含空白限定 800 字

以接收函數、P 波極化與表面波頻散進行貝氏聯合反演解析臺灣南部隱沒－碰撞轉換帶剪力波速度構造

柯俊杰[1]、洪淑蕙[1]、SALUTE團隊[1,2,3,4]
(1)國立臺灣大學地質科學系、(2) 國立臺灣師範大學地球科學系、(3) 中央研究院地球科學所、(4)國立中正大學地球與環境科學系

摘　要

本研究旨在解析臺灣南部由大陸岩石圈隱沒轉變為弧陸碰撞構造區的地殼與最上部地函剪力波速度構造。研究利用臺灣南部多個寬頻地震觀測網，包括CWASN、BATS、NCREE 以及自 2021年10月起布設之密集SALUTE陣列，蒐集2020-2024年震央距 30－90° 之遠震P波資料。透過Seispy計算接收函數並施以不同時間窗長度T的低通濾波，分析P波質點運動極化方向用以估算剪力波視速度隨T的變化；同時利用測站對所記錄之連續周遭噪訊互相關擷取雷利波頻散曲線，反演不同週期之相速度模型以建立各測站頻散曲線。根據上述資料對速度構造不同的約制能力，進行聯合反演以解析臺灣南部地殼與最上部地函的S波速度構造。

為提升資料穩定性，依震源深度、方位角及震央距將遠震事件分為26個事件群，並經人工篩選高品質接收函數後進行疊加，建立26個虛擬震源及其對應之剪力波視速度時間曲線。同時，根據不同週期的相速度圖(主要反映約1/3波長深度的S波速度)，計算各虛擬源接收函數入射波線路徑的第一Fresnel區域內平均相速度以取得所對應的的雷利波頻散曲線。隨後整合針對每一測站與虛擬震源組合的接收函數、剪力波視速度曲線與頻散曲線，採用貝式統計方法進行一維剪力波速度反演，並將結果沿射線投影至三維空間，並以Fresnel區域作為敏感範圍，對重疊區域進行平均，建構最終三維S波速度模型。

結果顯示淺層地殼呈現明顯的側向速度變化，由西部海岸平原厚沉積層的低速區向東過渡至中央山脈快速的變質岩帶，再進入臺東平原相對較慢的速度區。此外，莫荷面深度在南北向潮州斷層東西兩側呈現約5-10 km變化，且在中央山脈下方顯示有逐漸向東傾斜的趨勢。此外，在中央山脈深度10 km可辨識出一個速度突然增加的不連續面,而在20-30 的下地殼則存在一顯著低速帶，為理解台灣造山作用與深部動力過程提供重要制約。

↑每一段落請空兩中文字元

【學生壁報比賽】參與者於摘要尾端註記

(1) 國立臺灣大學/洪淑蕙
(2) 博士班/一年級
(3

English abstract form model
The maximum number of characters for an abstract is 1700 (spaces are included)

Shear-Wave Velocity Structure Beneath the Southern Taiwan Subduction–Collision Transition From Bayesian Joint Inversion of Receiver Functions, P-Wave Polarization, and Surface Wave Dispersion

Jun-Jie Ke[1] 、Shu-Huei Hung[1] 、SALUTE team[1,2,3,4]
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(2) Department of Earth Sciences, Nation Taiwan Normal University 、
(3) Institute of Earth Sciences, Academic Sinica 、(4) Department of Earth and Environmental Sciences, National Chung Cheng University

Abstract

We investigate the S-wave velocity (Vs) structure of the crust and uppermost mantle beneath southern Taiwan, where continental subduction transitions into arc–continent collision. Broadband seismic data from CWASN, BATS, NCREE, and the dense SALUTE array are analyzed. Teleseismic P-waves with distances of 30–90° from 2020–2024 are used to compute receiver functions (RFs) using Seispy. P-wave polarization analysis estimates apparent S-wave velocities (Vs,app) , while Rayleigh-wave dispersion extracted from ambient noise cross correlation inverts for frequency-dependent phase velocity maps. These complementary datasets are jointly inverted using a Bayesian framework to constrain the Vs structure.

To improve data robustness, events are grouped by source depth, back-azimuth, and epicentral distance. High-quality RFs are manually selected and stacked to construct 26 virtual sources and corresponding Vs,app curves. Phase-velocity maps are used to estimate average dispersion within the first Fresnel zone of each ray path. The resulting 1-D models are projected into 3-D space to construct the final Vs model.

The results reveal pronounced lateral velocity variations in the shallow crust. Low Vs beneath the western coastal plain transition eastward into the high-Vs metamorphic belt of the Central Range (CR) and slower Vs beneath the Taitung Plain. The Moho depth varies by ~5–10 km across the Chaochou Fault and gently dips eastward beneath the CR. A sharp velocity increase near 10 km depth and a lower-crustal low-Vs zone at 20–30 km depth are identified beneath the CR, providing new constraints on the tectonic evolution and deep geodynamic processes of the Taiwan orogen.

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Please note the information in the bottom of abstract if you choose to attend to "the Students' Poster Competition".

(1) National Taiwan University/Advisor
(2) PhD/Grade I

Student Poster SP124

Can Dual-Layer Crustal Anisotropy Beneath the Southern Taiwan Orogen be Resolved Using SALUTE Data and Adjoint-State Earthquake Travel-time Tomography?

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Abstract

Seismic anisotropy beneath Taiwan's Central Range play key constraints on how strain is partitioned through the crust during arc–continent collision. Seismic tomography studies have suggested a depth-dependent rotation of anisotropic fabrics, with a transition occurring near $\sim 20\ km$. Despite its tectonic significance, the degree to which this dual-layer interpretation is recoverable from regional body-wave travel times remains sensitive to station–event distribution and modeling assumptions.

Here we use data from the SALUTE deployment in southern Taiwan to reassess the resolvability of a two-layer anisotropy model beneath the Central Range over 0–60 km depth. We compiled and quality-controlled arrival-time data from 2021–2023, comprising approximately 10,000 local earthquakes and 130,000 P and S picks each. Given the distinct sensitivities of P and S travel times, we perform separate inversions for the two datasets.

Inversions are carried out with TomoATT, an open-source adjoint-state travel-time tomography framework that solves the eikonal equation for efficient 3-D forward modeling and enables joint updates of earthquake source parameters and Earth structure, including azimuthal anisotropy. To make the inversions computationally feasible, we use TomoATT's fast eikonal solver and its multi-level parallelization over seismic sources and computational domains. Within the target depth range, we assess whether SALUTE ray coverage can robustly distinguish a two-layer anisotropy structure with a transition near ~20 km from simpler alternatives, providing an updated basis for interpreting layered deformation beneath the Taiwan orogen.

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Student Poster SP125

整合機器學習方法分析2022年關山-池上地震序列之餘震分佈與震源機制

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摘　要

本研究以機器學習與深度學習方法為核心，欲建立一套自動化地震資料處理流程以系統性分析2022年關山-池上地震序列之餘震活動特徵與震源機制解。精確的餘震定位與震源機制解可對主震破裂幾何形態、斷層走向及震後應力轉移提供重要的資訊，對理解地震孕震帶與區域構造變形具有關鍵意義。

本研究整合中央氣象署地震觀測網(CWBSN)、臺灣強地動觀測網(TSMIP)與臺灣寬頻地震觀測網(BATS)以及臨時密集SALUTE陣列所記錄三分量連續速度波形觀測資料進行分析。SALUTE資料的加入補強山區永久測站分布不足之限制，顯著提升空間覆蓋與觀測解析度。

在資料處理方面，首先針對各測站原始連續波形資料採用DeepDenoiser進行去噪處理，以抑制環境雜訊並提升訊噪比，改善後續波相辨識之準確性。隨後，利用PhaseNet Plus進行自動化的P波與S波到時判讀，並同步擷取初動P波極性及S波振幅資訊，作為震源機制反演的重要觀測資料。在地震事件建構與定位方面，先以PyOcto進行地震事件聯集並於一維速度模型下進行初步定位，以快速建立完整之地震事件目錄；再利用NonLinLoc於三維速度模型中進行非線性定位(nonlinear location)，以考量地下構造側向速度變化對波相走時之影響，提升震源定位精度。在震源機制解分析方面，則是應用深度學習模型FocoNet，結合P波初動極性、最大S/P振幅比以及測站訊噪比進行震源機制反演，藉以獲得餘震序列的震源機制解。

藉由機器學習與深度學習之自動化處理流程，本研究可有效應對大規模波形資料的處理需求，顯著提升效率與分析結果的一致性，並降低人工判斷的主觀誤差。最終結果將將建立高精度之餘震分佈與震源機制資料庫，可用以進一步探討關山—池上地震序列之破裂行為、應力轉移特徵及其與區域構造之關聯性，為台灣南部活動構造與地震孕震機制提供重要之觀測約束。

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Student Poster SP126

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

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Ocean-bottom seismographs (OBS) exhibit substantial variability in design specifications and instrumental characteristics, causing significant discrepancies across deployments. This heterogeneity poses a fundamental challenge for applying general-purpose deep learning models to OBS data, necessitating instrument-specific approaches. In this study, we utilize continuous seismic data collected from September 2023 to June 2025 by integrating the Southern Array for the Lithosphere and Uplift of Taiwan Experiment (SALUTE) array and the surrounding Broadband Array in Taiwan for Seismology (BATS) network, encompassing both ocean-bottom and onshore seismographs. Focusing on the region between 22°N–23.5°N and 121°E–122°E, we establish a comprehensive processing pipeline comprising EQTransformer and OBSTransformer for seismic phase picking, PyOcto with a 1D velocity model for phase association, and NonLinLoc coupled with a 3D velocity model for hypocenter determination. Detection results are benchmarked against the Central Weather Administration catalog and rigorously verified through manual inspections. Through this workflow, we are constructing a high-quality local earthquake catalog integrating machine-generated picks with manually refined labels. Regional seismic variability and complex marine conditions require localized training; thus, this dataset is used to fine-tune OBSTransformer via transfer learning, improving phase-picking accuracy and adaptability for offshore seismicity. This approach enhances earthquake detection and localization precision while establishing a critical foundation for future high-resolution structural imaging in the eastern offshore Taiwan.

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Student Poster SP127

Improved Monitoring of Coseismic Velocity Changes Associated with the 2022 Guanshan-Chishang Earthquake Sequence Using Ambient Noise Interferometry

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Abstract

Large earthquakes are often accompanied by coseismic and postseismic changes in crustal seismic velocity. Coda interferometry based on ambient noise cross correlations (CCFs) has proven to be an effective approach for monitoring such velocity variations at daily time scales. In this study, we investigate crustal velocity changes associated with the 2022 Guanshan-Chishang earthquake sequence in southern Taiwan using CCFs computed from several seismic networks, including BATS, CWBSN, and the dense SALUTE array. To improve the temporal resolution and stability of subtle time-shift (dt/t) or velocity-change (dv/v) measurements from daily CCFs, and explore potential frequency-dependent dv/v variations, we test and apply an SVD filter to enhance the signal quality of the CCFs and achieve higher waveform correlations with shorter stacking windows. Moreover, we compare the performance of different dv/v measurement algorithms to evaluate their pros and cons in resolving small temporal dv/v changes.

Since seasonal hydrological processes may also contribute to dv/v variations, we collected daily precipitation and groundwater level data from CWBSN and corrected for hydrological effects in the obtained dv/v time series. After removing these seasonal contributions, the remaining signal reflects the true coseismic velocity change induced by the 2022 Guanshan-Chishang earthquake, showing a sudden transient drop in dv/v immediately after the earthquake sequence, followed by a gradual recovery in a logarithmic trend over several months. This behavior is consistent with observations from other large earthquakes and likely reflects damage and subsequent healing processes within the crust.

Keywords: Coda Wave Interferometry, Ambient Noise Cross-Correlation. 2022 Guanshan-Chishang Earthquake Sequence, Coseismic and Postseismic Velocity Change, SALUTE Array

【學生壁報比賽】參與者於摘要尾端註記

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大規模(Mw ≥ 7.0)走向滑移地震之破裂方向性分析
Rupture Directivity Analysis for Large Strike-Slip Earthquakes with Mw ≥ 7.0

邱亦璿、黃瑞德、林瓊瑤、林采儀
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摘要

本研究利用雷利波相位走時分析 2001 年至 2025 年數個 M_W 7.0 以上走向滑移地震的破裂方向性。首先決定主震與其附近中規模參考地震或全球表面波相速圖的雷利波相位走時差異，得到隨測站方位變化的震源歷時，並透過破裂方向性分析推導這些地震的破裂方位、破裂長度、震源歷時及破裂速度。結果顯示除了 2023 年 M_W7.8 土耳其地震與 2025 年 M_W7.7 緬甸地震是非對稱雙向破裂外，其餘地震皆是單向破裂，且破裂方位與斷層走向一致，多數地震呈現超剪力破裂或高速破裂，其中 2001 年 Mw 7.8 崑崙地震有最長的破裂長度(~470 公里)及歷時(~150 秒)。本研究也顯示破裂長度(L)與地震矩(M_0)似乎存在 M_0~L 的關係，而不是 M_0~L^2 或 M_0~L^3。另外，透過餘震的深度分布並配合震源機制評估這些地震的破裂寬度(W)，約落在 10~20 公里，可能是大規模走向滑移地震向下破裂到地殼脆韌轉換帶後受到抑制，而 L/W 的比值變化約在 2~35，且傾向於隨 M_0 增加而增加的趨勢。

關鍵詞：走向滑移地震、雷利波、破裂長度、破裂寬度、地震矩、超剪力破裂

Keywords: strike-slip earthquake, Rayleigh wave, rupture length, rupture width, seismic moment, supershear rupture

Student Poster SP129

Unsupervised Classification of P-Wave Features for Intermediate-Depth Earthquakes under Taiwan Region

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Abstract

The body waves from intermediate- to deep-depth earthquakes exhibit complex patterns and frequency contents, reflecting various propagation effects produced by subduction zone structures. In the past decades, dense-array deployments have provided great opportunities for systematic investigations of subduction-related signals, while challenges remain due to the labor-intensive nature of manual inspection and the reliance on prior pattern recognitions required in conventional analysis. In this study, we aim to classify the subduction zone P-waves with unsupervised clustering algorithms.

We analyze intermediate-depth events in the southern Ryukyu and northern Luzon subduction zones near Taiwan region using P-wave records from the FMA and SALUTE arrays. We calculate spectrograms to characterize 0.5–10 Hz energy distributions on both globally normalized and per-frequency normalized images. We employ K-means and hierarchical clustering methods, both of which only require predefined parameters of clustering numbers and threshold distances. Intra- and inter-cluster similarities are used to evaluate clustering quality . We also apply PCA to reduce the data dimension and examine whether it improves clustering quality. Preliminary results show clustering on globally normalized images better isolates low-quality records and can also retrieve waveform featured by multiple reflections; whereas per-frequency normalization captures dispersive signatures and is more adequate for guided-wave study. Ultimately, we will evaluate candidate mechanisms, including thin low-velocity layers atop the slab, intra-slab heterogeneous scattering and possible attenuation in the mantle wedge.

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Monitoring Erosion of Recreational Trail Using Unmanned Aerial Vehicle (UAV) and GIS Technique in Hengchun Peninsula, Taiwan

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Keywords: Trail erosion; Trail monitoring; UAV photogrammetry; DEM; GIS

Abstract

Recreational trail erosion represents an increasing environmental challenge in protected landscapes subjected to intensive visitor activity. This research investigates trail erosion and degradation on the Hengchun Peninsula in southern Taiwan, focusing on trail systems within and adjacent to Kenting National Park. The study employs historical imagery analysis, Unmanned Aerial Vehicle (UAV) surveys, Geographic Information System (GIS) methodologies, and field observations to evaluate both long-term and short-term landscape dynamics. Long-term trends in trail development, vegetation disturbance, and landscape alteration were assessed using aerial and satellite imagery from 1991, 2000, 2009, and 2019. These datasets facilitated the identification of trail expansion, vegetation clearance, and the emergence of informal trails over nearly thirty years. Short-term monitoring utilized UAV-based photogrammetry to produce high-resolution orthophotos and digital elevation models (DEMs). UAV imagery was processed using Agisoft Metashape and Pix4D, and Ground Control Points (GCPs) collected during fieldwork improved spatial accuracy and enabled the detection of subtle topographic changes associated with erosion and surface instability. The findings demonstrate that the interplay between natural environmental variables and anthropogenic pressures governs trail erosion. Slope gradient, drainage configuration, soil characteristics, rainfall intensity, and vegetation cover affect erosion susceptibility, while concentrated visitor activity and informal trail creation intensify surface degradation.

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Master/Second Year

Student Poster SP131

應用地形指數分析雪山山脈地質區河流型態控制機制

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摘要

台灣北部地區已被認為進入後造山時期（Post-orogenic period）。隨著碰撞點向南遷移、隱沒方向反轉及南沖繩海槽的擴張，部分早期的逆斷層轉化為正斷層，形成台北盆地與宜蘭平原。理論上，當抬升作用減弱，河流縱剖面應趨於平緩穩定，然而觀察顯示，除了北勢溪外，其餘流域仍普遍保有瞬態（transient）特徵，顯示河流尚未達到平衡。

為探討雪山山脈地質區地形演化之核心機制，本研究從河流地形學著手。河流系統為塑造地形起伏的重要營力之一，底岩河道的遷急點（knickpoint）分布、陡峭度（steepness）及集水區面積變化，能反映地區的構造活動、岩層性質、基準面與氣候變化。其中，遷急點是一段離散且陡峭的河段，在河流縱剖面中呈現局部凸起，可能為岩層抗侵蝕能力差異的邊界，或是構造活動或基準面變化訊號向上游傳遞的界線。χ指數（χ index）為考慮河流流域面積的標準化河流長度，對於共用相同分水嶺的不同流域，可指示分水嶺的移動趨勢。標準化河道陡峭度指標（k_{sn}，normalized channel steepness index）由底岩河道高程及χ指數計算而得，可反映河流的侵蝕能力，並作為區域構造抬升速率或岩石可侵蝕能力的代用指標。

本研究綜合研究區域內χ指數、k_{sn}、遷急點、地層及斷層分布、Getis-Ord G_i^*統計分析、長年降水資料及遷急點移動速率模型，探討該區域地形演化之控制機制。初步結果顯示，新店溪兩條主要支流，南勢溪的流域平均標準化河道陡峭度指標（MLS, mean local steepness）不但高出相鄰的北勢溪許多，其高值還大多集中於年雨量最高的烏來地區。其次，在一些流域中，發現部分k_{sn}高值呈現沿著鄰近斷層系統分布的現象。此外，空間熱點分析揭示，在岩性相對均一且遠離活動斷層的大漢溪和大安溪上游，仍可觀察到遷急點的顯著群聚現象。

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP132

基於多期DEM差異分析探討蘭陽溪流域地表侵蝕率

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摘　要

強降雨事件發生後可能會在短時間內形成大量的崩積物，這些土砂再被洪水堆積至更下游處或運移出海，在氣候變遷的背景之下，頻繁發生的極端天氣事件是否對地表侵蝕率造成影響是個值得關注的議題。傳統上用來推估地表侵蝕率的方法，大多仰賴河川懸浮載的觀測紀錄，或輔以河川流量進行經驗公式的推算，但此類方法容易受限於人工採樣的不連續性以及水文測站的設置位置，導致僅能討論單一集水面積的長時間侵蝕量。若是想要突破空間上的限制，使用數值高程模型(Digital Elevation Models, DEMs)或許是探討流域侵蝕量的好方法。然而，DEM會因為原始資料取得方式、後製處理過程而有幾何或是系統上的偏差，本研究為了克服不同時期資料之間的水平及垂直位移，將1990年至今共四期的DEM運用Nuth＆Kääb (2011) 的演算法進行三維空間對位，並引用Perron et al. (2008) 提出的二維傅立葉轉換技術減少模型之間的高程誤差，接著使用DEM差異分析(DEM of Difference, DoD)的方法獲得地表變化。

研究成果提供了10年、20年、30年間的地表高程變化數據，得以討論蘭陽溪流域在包含極端氣候事件、大規模地震事件等不同環境背景下，短期及長期侵蝕率差異。DoD分析的結果顯示出地表變化有明顯的空間異質性：受崩塌影響的天狗溪上游，高程減少量超過120公尺；而在主流河道段，則觀察到40公尺以上的堆積訊號。而與前人研究的長期背景侵蝕率相比，涵蓋極端降雨事件時期的短期侵蝕率明顯較高，顯示出極端事件在驅動蘭陽溪流域的土砂運移過程中扮演重要角色。本研究證實應用多期DEM能夠解析流域尺度的地貌變化並計算侵蝕率，為地形陡峭且降水豐沛的山區流域提供侵蝕測定的研究框架。

關鍵字：蘭陽溪流域、數值高程模型、DEM差異分析、地表侵蝕率

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Student Poster SP133

利用砂箱實驗探討地下水系統中水體流動與水壓傳遞之速度差異

王梓芯[1]、王士榮[1、2]、陳德輝[1]、陳中漢[2]
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摘　要

地下水系統中，水位變化常被用來判斷地下水流動情形。但實際上水位發生變化，並不代表水體粒子已由高水位移動到低水位區，而是透過壓力傳遞作用抬升水位。因此水體流動與水壓傳遞，在反應速度上並不相同。本研究利用砂箱實驗建立可控條件，實驗設計之砂箱外部長、寬、高分別為193公分、5公分及111.5公分，包含填砂區及左右水箱以控制定水頭邊界。砂箱以透明壓克力製成，一面鑽設150個孔洞作為多深度且空間均勻分布之水位觀測點；另一面未鑽孔，以利攝影觀察水流。本研究以均質細砂作為介質，在水力梯度為0.125的穩態流動與條件下，瞬間提升高水頭邊界之水頭0.1 m後，分別以縮時攝影觀察染色水體流動前緣的推進情形，與採用流量計記錄另一側的出流水量，以分析兩者之速度差異。結果顯示，水體流動速度約為6.26×10^{-5} m/s，水壓傳遞速度約為5.00×10^{-2} m/s。另由落水頭試驗所得水力傳導係數推估之理論達西流速約為3.91×10^{-5} m/s。水體流動速度與理論達西流速屬同一數量級，而水壓傳遞速度則比兩者快約三個數量級。研究結果顯示，水壓傳遞作用可以很快地將壓力傳到系統另一側，但水體本身移動非常緩慢。另外，水體流動速度略高於理論達西流速，推測與大尺度砂箱填砂較難完全均勻、局部產生較大孔隙與優勢水流路徑有關；而本研究採用自由含水層系統，可能亦造成部分差異。本研究結果亦清楚展示，達西定律描述的標的為水體顆粒的流動行為，並非壓力傳遞行為，因此理論速度與實際現地觀測到的水位(壓)變化之反應速度不同。研究結果可釐清地下水系統中水體流動與水壓傳遞之速度差異，並可作為抽注水影響分析與後續耦合模擬之驗證。此外，本研究建立自動化影像擷取與判識程式，以定量染色水體的移動速度、水位變化與流量觀測數據，其結果與人工判讀結果趨勢一致，平均絕對誤差(MAE)約0.1 cm，顯示影像分析法具備作為後續大量實驗資料處理工具之可行性。

【學生壁報比賽】參與者於摘要尾端註記

(1) 國立中央大學/王士榮
(2) 碩士/二年級

Student Poster SP134

以多樣監測資料探討臺灣濁水溪沖積扇地下水抽取引致之地層下陷特徵

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(1)國立中央大學應用地質研究所、(2) 中央研究院地球科學研究所

摘　要

全球許多地區因地下水超抽而導致地層下陷，進而威脅當地基礎建設與民生安全。濁水溪沖積扇為臺灣重要農業區，長期因灌溉需求大量抽取地下水，造成嚴重地層下陷，並對當地居民生活及高鐵運行安全構成威脅。

為建立有效的地層下陷減緩策略，需先掌握研究區地層下陷之時空分布特徵，並透過預壓密水頭與比儲水係數等參數，進一步了解地層變形行為。然而，目前對這些關鍵特徵與參數之量化仍相對不足。因此，本研究旨在探討抽水引致地層下陷之機制與時空特徵，並進一步估算相關參數。

此研究整合 2018 年 5 月至 2023 年 4 月之全球導航衛星系統（GNSS）、地層下陷磁環分層監測井（MLCW）及鑽井資料進行分析。結果顯示，GNSS 觀測到之地表位移通常大於 MLCW 所記錄之淺層壓密量，指出深層壓密對總下陷量具有一定貢獻。此外，含水層性質與地層厚度為控制壓密量大小之主要因素。本研究亦根據地層之應力記憶行為，辨識分析期間之最終預壓密水頭為 2021 年 5 月之 -14.46 m，並以此作為區分彈性與非彈性變形之判定依據。於區分變形行為後，計算得到彈性比儲水係數約介於 10^{-5} 至 10^{-4} m^{-1} 之間，而非彈性比儲水係數則約為 10^{-4} m^{-1} 等級。結果顯示，單位水頭下降所對應之壓密量於彈性階段小於非彈性階段。

相關成果將作為未來力學參數反演與區域地層力學特性分析之重要基礎。

【學生壁報比賽】

(1) 就讀學校/指導教授：國立中央大學/倪春發、許雅儒

(2) 學位/年級：碩士/二年級

Student Poster SP135

Detection and Identification of Vessels and Natural Events Using Distributed Acoustic Sensing on a Submarine Fiber-Optic Cable Northeastern Offshore Taiwan

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Abstract

This study develops a system to identify vessels, earthquakes, and volcanic activity by analyzing spatiotemporal wavefield characteristics recorded by distributed acoustic sensing (DAS) on a submarine fiber-optic cable.

DAS provides high spatial coverage and resolution, complementing traditional seismometers that remain important for quantitative seismic and low-frequency observations. Continuous DAS data were collected from a cable in the northeastern offshore area of Taiwan near Guishan Island, an active volcanic region affected by frequent earthquakes due to the northwestward subduction of the Philippine Sea Plate beneath the Eurasian Plate. The region is also influenced by the Kuroshio Current, which supports abundant fisheries and frequent vessel activity.

Event detection was performed using the recursive short-time-average/long-time-average (STA/LTA) method, which compares signal amplitudes within short- and long-time windows; events are detected when the ratio exceeds a threshold and are further manually inspected. Because low signal-to-noise ratios can reduce STA/LTA sensitivity, additional signal-processing adjustments were applied to improve detection. To confirm the event sources, ship-related detections were validated using Automatic Identification System (AIS) records, while earthquake detections were compared with the Taiwan Seismological and Geophysical Data Management System (GDMS) catalog. Results demonstrate that DAS can serve as a valuable complementary tool for offshore geophysical and maritime monitoring.

“Students’ Poster Competition”

(1) University/Advisor: National Central University / Chung Han Chan
(2) Degree/Grade: Master / 1

Student Poster SP136

Reconstructing Submarine Cable Geometry Using DAS-Based Vessel Localization

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Abstract

Distributed Acoustic Sensing (DAS) enables dense acoustic measurements along fiber-optic cables and has recently demonstrated strong potential for marine monitoring. In this study, we leverage the multi-channel nature of DAS to localize vessels by exploiting travel-time differences of vessel-generated acoustic signals recorded along a fiber-optic cable. To overcome the high-noise environment typical of subsea cables, we apply coherent multi-channel stacking. This approach improves the signal-to-noise ratio and makes vessel localization feasible with the dense DAS array, which is challenging for sparse conventional seismometer arrays.

The precise location of the submarine cable is fundamental for subsequent analyses. Unfortunately, only a limited number of cable locations are available. We therefore combine DAS-based vessel localization with ship-track information from the Automatic Identification System (AIS) to estimate vessel positions and reconstruct the cable route and better constrain the georeferenced locations of DAS channels. Results show good agreement between DAS-inferred vessel trajectories and AIS records, with the reconstructed cable location validated using multiple vessels with AIS records, demonstrating the capability of DAS for vessel tracking and cable position reconstruction when cable-location information is limited. The reconstructed cable geometry establishes a foundation for future DAS applications, including object tracing, earthquake monitoring, and subsurface imaging.

(1) National Central University / Prof. Chung-Han Chan
(2) M.S. student/ 1st year

基於分散式聲波感測與機器學習之即時訊號分類與土石流偵測研究：以蘇花鐵路為例

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(1)國立臺灣大學地質科學系、(2) 國立中正大學地球與環境科學系
、(3) 中央研究院地球科學研究所

蘇花鐵路沿線多位於地形陡峭且地質破碎之區域，於強降雨期間易誘發崩塌與土石流災害。尤其在 2024 年 Mw 7.4 花蓮地震後，大量邊坡鬆動與崩塌堆積物增加，進一步提高降雨觸發土石流之潛勢，對鐵路運輸安全構成持續威脅。然而，傳統土石流監測多仰賴點位式感測器，空間覆蓋有限，難以應用於長距離線性基礎設施。基於此，本研究利用鐵路沿線既有的中華電信光纖，結合分散式聲波感測技術（Distributed Acoustic Sensing, DAS）與非監督式學習方法，嘗試建立公里級的土石流即時監測與早期預警系統。本研究使用沿花蓮新城至和平鐵路布放之 28.6 公里光纖，記錄為期兩週的震動訊號，包含列車、雷聲及地震等多種環境訊號。透過非監督式學習對 DAS 瀑布圖進行分群分析，初步辨識出多種不同型態的訊號特徵，其中部分可能與降雨或土石流活動相關。此外，本研究亦將 DAS 瀑布圖視為影像資料，應用 YOLO 目標偵測模型進行訊號辨識，並以 precision、recall 等指標比較不同方法在潛在土石流訊號偵測上的效能。結果顯示，結合既有光纖與機器學習方法具有發展為長距離地質災害監測工具的潛力。

【學生壁報比賽】參與者於摘要尾端註記

(1) 就讀學校/指導教授：國立臺灣大學/黃信樺
(2) 學位/年級：地質科學系/三年級

應用深度學習於光纖與地震儀混合式陣列進行花蓮地區之微震偵測與定位

Yen-Hsin Lee[1] (李妍忻), Hsin-Hua Huang[1,2] (黃信樺), Hsiang-Yu Yang[2] (楊翔宇)
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摘要

受到菲律賓海板塊與歐亞板塊持續擠壓碰撞影響，臺灣地區的地震活動相當頻繁，發展快速且高精度的地震偵測與定位的流程，對於了解發震構造及評估地震危害至關重要。近年來深度學習類神經網路法已在地震波相撿拾取上取得巨大的成功，高度自動化改善過去原本依賴人工經驗與耗時的作業流程，在很多區域的應用上建立了更完整的地震目錄。分散式光纖感測技術(Distributed Acoustic Sensing, DAS)是一種能將光纖纜線轉換成密集地震陣列的新興技術，能提供公尺級的高時空解析度，並對微小的地震動具有較寬頻的敏感度，在微震訊號上可以提供更連續完整的波場資料。本研究基於近期使用地震測站網開發的機器學習工作流程 AutoQuake(Yang et al., 2025)，旨在測試與整合 DAS 資料到此流程中，提升微震偵測與定位能力，進而對淺部斷層構造進行詳細調查與分析。本研究分析花蓮地區為期一年的資料，比較僅使用地震儀與結合 DAS 觀測的混合式陣列之定位結果，顯示由於光纖陣列的加入，能夠更準確地辨識微震訊號，進而提升地震定位的品質，幫助分析淺部構造及研究地震活動。

關鍵字：機器學習、分散式光纖、密集地震網

Student Poster SP139

Scale Effects on Rate- and State-Dependent Friction (RSF) Parameters and Behavior

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Abstract

The rate- and state-dependent friction law serves as the core theoretical framework for describing fault frictional behavior in modern seismology (Dieterich, 1979; Ruina, 1983). Traditionally, its key parameters—a, b, and the critical slip distance (D_c)—have been regarded as pure material constants. However, a discrepancy of approximately six orders of magnitude exists between laboratory-measured D_c (micrometer scale) and estimates from natural faults (meter scale). This long-unresolved scale gap suggests that these parameters may not be scale-independent.

Previous velocity-stepping experiments have predominantly been conducted on centimeter-scale samples, where system stiffness is primarily provided by the loading apparatus. This fundamentally differs from natural faults, where stiffness is governed by the surrounding elastic rock mass. To address this, the present study utilizes the large-scale fault experimental apparatus at the Department of Civil Engineering, National Taiwan University. Using polymethyl methacrylate (PMMA) specimens, velocity-stepping experiments are conducted on a 50-cm-long laboratory fault with systematically varied sample thicknesses (5, 10 cm) and frictional interfaces (Bare PMMA, Teflon, and PE).

By comparing *a*, *b*, and *D*c across sample thicknesses and interface conditions, this study directly tests whether RSF parameters carry a systematic dependence on specimen geometry. The results will constrain the scaling behavior of these parameters and inform whether empirical friction constitutive laws calibrated from small-scale laboratory experiments can be reliably extrapolated to natural fault dimensions.

Keywords: Rate-and-state friction, frictional parameters, characteristic slip distance, scale dependence, laboratory fault, velocity-stepping

(1) National Taiwan University/ Chun-Yu Ke

(2) Bachelor/ Grade 3

Coseismic seismic velocity variations of deep-seated landslide caused by two M6.5+ earthquakes in the eastern Taiwan

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Abstract

Ambient noise-derived seismic velocity changes (dv/v) serve as a proxy for the rigidity of landslide materials. This study investigates the deep-seated Wuhe landslide in eastern Taiwan, an active site with annual cumulative displacements of 6.04, 4.70, 3.64, and 1.67 m in 2021, 2022, 2023 and 2024, respectively. Its kinematics are strongly modulated by external forcings. For instance, a 164.5 mm rainfall event on October 16, 2022, triggered immediate groundwater fluctuations—indicating high infiltration capacity—and accelerated the average displacement rate from 9.7 to 24.6 mm/day. This rapid increase in sliding prompts an investigation into whether the post-October 16 movement is solely rainfall-induced or coupled with delayed co-seismic effects from the preceding September 2022 M_L 6.6 Guanshan and M_L 6.8 Chihshang earthquakes. The Chihshang event induced strong shaking with a peak ground acceleration (PGA) of 408.39 gal at station PA04 and a maximum N-S coseismic displacement of 8.13 cm at station BH03. We applied the single-station cross-component (SC) technique using continuous ambient noise records from one geophone on the sliding mass and three bedrock reference stations. Preliminary results reveal a clear coseismic velocity reduction within the landslide area. By comparing dv/v measurements with RTK GPS and strong-motion records, we demonstrate that velocity drops correlate with strong ground shaking and coseismic displacements. Furthermore, we investigate post-seismic recovery mechanisms captured by dv/v, as the earthquakes did not trigger catastrophic failure.

(1) University/Advisor: National Yang Ming Chiao Tung University / Wei-An Chao
(2) Degree/Grade: Graduate Student

Student Poster SP141

離散元素法於大規模邊坡崩塌分析之應用：以臺七線49.8k大曼崩塌為例

劉倫旭[1]、邱家吉[1]

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摘　要

受極端氣候與複雜地形影響，2022年9月14日，北橫公路臺七線49.8K大曼路段發生了大規模崩塌事件，邊坡土石滑落，嚴重影響當地交通與用路人安全。為探討該崩塌區之工程地質破壞機制，本研究以無人機航測技術獲取多期地形資料，並透過離散元素法數值模擬分析探討崩塌的動態演變過程，以期為後續邊坡落石防治與改善工程提供具體的科學與工程依據。

根據該區工程地質鑽探探查結果，大曼路段地層主要屬漸新世之水長流層（巴陵層），岩性以暗灰色硬頁岩與板岩為主。邊坡表層覆蓋不規則的崩積層，其下方為受長期潛移作用影響的破碎軟弱板岩。鑽探岩心與地表地質調查顯示，該區發育多組板劈理與節理，導致岩盤被切割成獨立的破碎岩塊。現地調查顯示，道路上邊坡底部具有明顯的岩性差異，並且有地下水滲出現象，是可能導致邊坡失穩的因子之一。

本研究以現地灰色頁岩區岩心單軸壓縮試驗結果作為離散元素法數值模擬之微觀參數輸入依據並進行調整。模擬邊坡上層為較堅硬砂岩，下層為軟弱硬頁岩；促崩因子為降雨引致地下水壓上升，促使邊坡下半部分表層弱化，進而引發坍塌。由於本區域在多次降雨事件後持續有多期崩塌現象，故本研究除模擬49.8K崩塌事件外，也一併針對後續事件進行分析，透過不斷弱化邊坡下層區域模擬後續多期崩塌行為。

模擬結果顯示，離散元素法能分析邊坡崩塌之運移行為，並能透過弱化鍵結方式重現邊坡失穩之過程。透過本研究之微觀力學模型能有效模擬複雜地質條件下之崩塌運動歷程，增進對大規模崩塌之運動機制解析。

【學生壁報比賽】參與者於摘要尾端註記

(1) 國立臺北科技大學/邱家吉
(2) 碩士/二年級

Student Poster SP142

Exploring Seismic and Rainfall Coupling Effects on Landslide Hazards in Mainland Southeast Asia Using PlanetScope Imagery

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Abstract

The coupling of seismic ground motion and intense precipitation is a critical factor affecting the cascading landslide hazards. While such effects are well-documented in Taiwan and Japan, they remain poorly constrained in Southeast Asia. To enhance our understanding of the interaction between earthquakes and precipitation in landslide hazards, this study investigates landslides triggered by the 2022 Mw 5.9 Kengtung earthquake and the subsequent Tropical Storm Mulan in the Golden Triangle Area using PlanetScope satellite imagery. We identified over 800 earthquake-induced landslides after the mainshock, all located in the region where the seismic intensity is higher than IV on the Modified Mercalli Intensity (MMI) scale. This result suggests a lower threshold of peak ground motions to trigger landslides than the global dataset. The distribution of these landslides is primarily controlled by topography, lithology, and rupture directivity. We further identified more than 800 rainfall-induced landslides after the Tropical Storm Mulan within our selected areas, showing that the subsequent storm triggered far more widespread mass movements than the antecedent earthquake. Our analysis suggests a positive correlation between the density of rainfall-induced landslides and antecedent earthquake ground motion when the antecedent earthquake intensity exceeds MMI IV. Our result suggests that even moderate-magnitude earthquakes can significantly amplify landslide hazard potential from subsequent rainfall-induced events in Mainland Southeast Asia, causing an unexpected cascade of hazards near the earthquake-affected area.

(1) University/Advisor: National Taiwan University/ Yu Wang
(2) Degree/Grade: Master/ Second grade

Student Poster SP143

Multi-Sensor Satellite Monitoring for Rapid Disaster Response: A Case Study of a Landslide-Dam in Hualien, Taiwan

Yuheng Tai [1]、Chiung-Min Huang [2]、Ya-Chi Yang [2]、Chien-Liang Liu [2]、Kuo-Hsin Tseng [2]、Fuan Tsai [2]、Chung-Pai Chang [2]

(1)Department of Earth Sciences, National Central University, Zhongli, Taoyuan 32001, Taiwan、(2) Center for Space and Remote Sensing Research, National Central University, Zhongli, Taoyuan 32001, Taiwan

Abstract

Remote sensing offers a rapid, all-weather solution for monitoring landslide dams in inaccessible terrain. This study integrates multi-sensor satellite observations, such as optical (Pleiades), high-resolution SAR (TerraSAR-X, Capella), and wide-swath SAR (Sentinel-1), to track the lifecycle of a landslide-dam formed in Wanrung, Hualien, Taiwan, after intense rainfall from Tropical Storm Wipha. Seismic alerts prompted the acquisition of a TerraSAR-X image on July 30, revealing an initial landslide extent of ~16 ha. Stereo Pleiades imagery generated a digital surface model (DSM) from which landslide volume and barrier-lake water volume, derived from lake-surface elevation relative to the DSM, were estimated. Multi-temporal Pleiades images quantified lake-area growth, while deep-learning-assisted scatterer selection enhanced Interferometric SAR (InSAR) analysis of Sentinel-1 data to characterize slope deformation around the landslide body.

On September 23 2025, extreme precipitation from Typhoon Ragasa triggered a rapid rise in lake level, causing a dam breach, downstream flooding, and extensive inundation and sediment deposition affecting ~382 ha in Guangfu Township. Post-failure SAR acquisitions from TerraSAR-X and Capella, benefiting from their day-and-night, all-weather capability, captured embankment and bridge failures, providing critical situational awareness for emergency response.

The integrated workflow demonstrates that fused optical and SAR observations enable continuous monitoring from dam inception through stability assessment, failure detection, and post-event impact evaluation. This operational, transferable framework is especially valuable under increasingly extreme rainfall scenarios and can be readily adapted to future landslide-dams worldwide.

Please note the information in the bottom of abstract if you choose to attend to "the Students' Poster Competition".

(1) University: National Central University / **Advisor:** Chung-Pai Chang
(2) Degree: PhD / **Grade:** 5

Student Poster SP144

Reconstructing the Landslide Evolution Using PlanetScope Imagery: A Case Study from Yusui Stream, Southwestern Taiwan

Zong-Kai Huang[1], Yu Wang[1]

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Abstract

This study utilizes the near-daily revisit PlanetScope optical imagery to investigate the landslide evolution in Yusui Stream, a tributary of the Laonong River. Since 2019, the upstream area of this catchment has experienced multiple large-scale rainfall-induced landslides and debris flows, causing severe damage to Taiwan's Southern Cross-Island Highway. To characterize the spatiotemporal evolution of landslides, including rapid slope-failure events and inter-event surface creeps, we use multi-temporal PlanetScope imagery acquired between 2019 and 2021 to generate a series of Digital Surface Models (DSMs) and ortho-images to analyze the vertical and horizontal changes of landslide bodies, and compare these results to the results derived from the aerial surveys.

Our study suggests the DSMs derived from PlanetScope imagery show good agreement with the LiDAR- and aerial photo-derived digital elevation models. The estimated volume changes for individual landslide events are consistent with those derived from aerial photos and airborne LiDAR surveys, demonstrating the feasibility of quantitative volume assessment using PlanetScope's near-daily revisit imagery. In addition, sub-pixel image correlation analysis reveals continuous downslope displacement of the main landslide body during inter-event periods, showing a positive relationship between pre-failure landslide movement and rainfall variability. These results demonstrate that PlanetScope imagery can effectively capture both rapid mass-wasting events and gradual surface deformation. This approach provides a practical framework for landslide monitoring in remote mountainous regions where frequent airborne surveys are unavailable.

(1) National Taiwan University / Advisor: Prof. Yu Wang

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Evolution of Rainfall-Induced Landslide Thresholds Considering Seismic Disturbance: A Case Study of Watersheds in Eastern Taiwan

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Abstract

Taiwan lies at a convergent plate boundary and within the subtropical monsoon zone. Consequently, the island features fractured geology and experiences frequent extreme rainfall events. These conditions create compound hazards triggered by earthquakes and typhoons, which pose significant challenges to disaster mitigation. Previous studies suggest that seismic energy releases loosen slope materials. This process lowers the threshold for subsequent rainfall-induced landslides.

This study investigates the spatiotemporal evolution of rainfall thresholds following seismic disturbances. We focused on the representative catchments in Eastern Taiwan, a region with high tectonic activity. We compiled a high-resolution catalog of rainfall, earthquake, and landslide events from the past 20 years. First, we classified the catchments based on geomorphological and geological factors to ensure consistent baselines. For each group, we used the intensity-duration (*I–D*) power-law model and established the 5% lower bound as the group-specific *I–D* threshold.

To quantify post-seismic effects, we identified the first rainfall-induced landslide event following each major earthquake and characterized its *I–D* conditions. We then compared these post-seismic events with the historical baseline thresholds. Preliminary results show that the first post-earthquake landslides occur under rainfall conditions below the historical baseline, suggesting elevated landslide susceptibility immediately after seismic shaking. This pattern is consistent with earthquake-induced damage and loosening slope materials, which can effectively lower the critical rainfall intensity and duration required to trigger slope failures. Our findings provide a scientific basis for temporarily adjusting rainfall warning criteria during post-seismic periods, potentially improving the accuracy and timeliness of landslide early warning systems.
Keywords: Rainfall-induced landslides, I–D threshold, Seismic disturbance

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Student Poster SP146

運用多時序衛星資料探討南台灣崩塌地地表活動之特性

Characterizing Surface Activity of Landslides in Southern Taiwan with Multi-Temporal Satellite Data

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摘要

南橫公路（台 20 線）西段位於臺灣南部山區變質岩帶，受地震、豪雨與地形切割等因素共同影響，沿線崩塌與道路災害頻仍。政府每年編列大量預算進行公路邊坡災害整治，顯示該區亟需建立一套穩定且具經濟效益之監測方法，以提升災害應變與治理效率。本研究以 2022 年 9 月 18 日台東池上地震後至 2024 年凱米颱風前為豪雨事件之災前時段，整合多時序 Sentinel-1 雷達影像全球衛星導航系統(GNSS)資料和災前、災後光學衛星影像，建構研究區的地表活動監測與判釋架構。研究採用合成孔徑雷達差分干涉技術中的短基線子集 SBAS 方法，分析長時間序列的 Sentinel-1 雷達衛星影像，並透過後續的相位解纏、時序反演與大氣修正的處理，推算沿衛星視線方向(LOS)的平均速度場與時間序列位移，描繪研究區整體形變之空間分布與災前演化特徵。為檢核 SBAS 速度估算之合理性，本研究引入臺灣大地測量模型(TGM)的 GNSS 位移速率資訊並投影至 LOS 方向作為外部參考，比對區域尺度速度場的量級與趨勢；同時整合 Sentinel-2 光學衛星影像進行災前與災後地表變遷判釋，圈繪可能活動區與崩塌範圍變化。

在區域尺度結果基礎上，本研究進一步選取五處代表性崩塌地進行個案分析，綜合其 LOS 速度場、時間序列位移與光學影像變遷特徵，判斷各崩塌地之主要活動帶位置、變形強度差異與時序變化型態，並討論其對災前風險辨識之指標意義。研究結果顯示，南橫公路西段災前地表形變具有明顯空間異質性，崩塌地因其自身坡向為朝向、背向或垂直衛星 LOS 方向而表現出不同的訊號，但在邊坡尺度依然可以辨識出潛在地表活動範圍。區域尺度之升、降軌 LOS 平均速度場雖受觀測幾何差異影響而呈現不同表現形式，但整體仍反映板塊構造尺度的抬升與向西背景位移趨勢；此外 GNSS 位移速率投影至 LOS 後，與 SBAS 的 LOS 速度場在量級與空間分布具有一致性，顯示 SBAS 時序分析成果可有效掌握研

究區災前之區域性地表位移特徵。並針對局部速度異常與時間序列差異的位置，提供辨識潛在活動邊坡與崩塌地內部差動變形之依據。

中文關鍵字：邊坡穩定監測、短基線子集、光學衛星影像、全球衛星導航系統

英文關鍵字：Slope Stability Monitoring、SBAS、Optical Satellite Image、GNSS

【學生壁報比賽】參與者於摘要尾端註記

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(2) 學位/年級：學士班/四年級

Student Poster SP147

自製式低價位水聲計於人工河道泥砂運移監測之應用與整合多物理量測量分析之成果

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摘要

泥砂運移為控制河川水動力與河床演變之關鍵過程，然於高含砂水流與洪水期間，傳統影像與現地採樣方法難以進行即時連續觀測，故自動化量測技術之發展成為重要課題。水聲量測可透過記錄床載顆粒撞擊所產生之聲學訊號反映泥砂運移，但接觸式水聲計於高能量流況下易受損，增加維運成本，因此本研究發展低成本且具自計式連續記錄能力之水聲量測系統。該系統採用 Aquarian Audio H2a-XLR 水聲計搭配 Zoom AMS-24 音訊介面進行訊號擷取，具備 48 kHz 取樣率與高解析度連續錄音能力。系統整合穩定供電，並由樹莓派作為核心控制單元。本研究建立自動化錄音與資料管理流程，整合定時錄音、檔案分段與資料儲存，使系統可於野外長時間穩定運作並降低人工需求，支援 20 天以上之連續監測。

本研究於惠蓀林場蘭島溪人工河道進行大型水工試驗，河道高 1.8 公尺、寬 2.2 公尺，側壁採砌石邊界；底床條件分為定床與動床，定床鋪設砌石護甲層，動床鋪設約 30 公分細砂層以模擬可移動河床。試驗由上游能高大圳供水，控制入流歷程建立乾床、穩態流與洪峰等流況，並進行兩次試驗以檢驗量測系統之穩定性與一致性。試驗期間同步佈設水聲計、分散式光纖感測系統（DAS）及微地動感測器（SmartSolo），建構多物理量觀測架構，在一致條件下蒐集水聲、地動與光纖應變率資料，並整合不同感測器於空間與時間上的觀測結果，以探討其對水文事件歷程之響應特性。兩次試驗峰值水位分別為 0.48 公尺與 0.33 公尺，反映不同流況強度之差異。

資料分析採用功率譜密度分析頻帶能量特徵，並結合移動式時序窗口追蹤其時間變化，同時透過波形飽和事件之偵測與統計辨識高能量瞬時訊號，以表徵床載顆粒撞擊行為。結果顯示，第一次試驗中水聲頻帶能量與微地動訊號具有良好一致性，其 Pearson 相關係數可達 0.75 以上，顯示水聲計對泥砂運移具高度敏感性；第二次試驗亦顯示系統可穩定捕捉床載相關聲學特徵，驗證其量

測之穩定性與重現性。綜合而言，本研究所開發之低成本自計式水聲量測系統結合頻譜分析與事件偵測方法，可有效反映泥砂運移之時序變化與強度特性，具備應用於人工河道及天然河川長期監測之潛力。

關鍵字： 泥砂運移、自計式低價位水聲計、光纖應變率、微地動訊號

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Developing a National Probabilistic Seismic Risk Assessment Framework for Taiwan

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Abstract

Taiwan faces substantial seismic risk, yet nationwide probabilistic seismic risk assessment remains limited. This study develops a building-level probabilistic seismic risk assessment framework for Taiwan by integrating seismic hazard, building vulnerability, and exposure.

The hazard component is based on the probabilistic seismic hazard assessment developed by the Taiwan Earthquake Model in 2020 (TEM PSHA2020), incorporating updated seismic source characterizations, ground motion models, and site-specific amplification factors. The vulnerability component uses localized fragility and vulnerability functions derived from engineering parameters in the Taiwan Earthquake Loss Estimation System (TELES) and analytical methodologies from the Global Earthquake Model (GEM) framework, allowing damage estimation to better reflect Taiwan's building stock. The exposure component is represented by a national building-level residential database developed using two approaches depending on data availability. First, for most regions, the model relies on high-resolution building footprint datasets, while in specific municipalities official census housing statistics are spatially disaggregated to achieve nationwide coverage. In addition, the mobile-network-based population data is further incorporated to refine population distribution for casualty estimation.

The framework generates high-resolution probabilistic seismic risk maps for Taiwan, including estimates of building damage, reconstruction cost, and casualties. This work provides a reproducible basis for earthquake risk management and resilience planning in Taiwan.

Keywords: Probabilistic Seismic Risk Assessment, Building-Level Exposure Model, Mobile-Network-Based Population Data, Seismic Loss Map

(1) National Central University/Advisor: Chung-Han Chan & Yen-Yu Lin
(2) Master/2nd year

Student Poster SP149

Probabilistic seismic hazard assessments for continental Southeast Asia

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Abstract

This study presents a probabilistic seismic hazard assessment (PSHA) for continental Southeast Asia by integrating regional earthquake catalogs, an active fault database, ground motion prediction equations (GMPEs), and site effects. According to regional tectonic structures, fault distribution, and subduction-related sources, the study area is represented by 18 area sources and one deep source. Seismicity rates are evaluated using multiple models—including the truncated exponential model, the characteristic earthquake model, the Seismic Hazard and Earthquake Rate in Fault Systems (SHERIFS) model, and the Brownian Passage Time (BPT) model—to capture diverse source characteristics and earthquake occurrence behaviors. The hazard model incorporates shallow crustal earthquakes, active fault sources, subduction interface events, and intraslab earthquakes. To account for regional attenuation behavior, appropriate GMPEs for crustal and subduction environments are adopted, while local site effects are incorporated using time-averaged shear-wave velocity in the upper 30 m (V_{s30}). Epistemic uncertainties are treated through a logic-tree framework, and seismic hazard is evaluated in terms of hazard maps, hazard curves, and disaggregation results. The results highlight significant hazard levels along the Sagaing Fault and in nearby urban areas such as Sagaing and Mandalay, reflecting the strong influence of active fault sources in the region. This study

provides an updated regional seismic hazard framework for continental Southeast Asia and offers useful information for seismic risk mitigation, engineering applications, and future development of regional design criteria.

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Student Poster SP150

Development of a High-Temporal-Resolution Smart Rock System Integrating Multi-Modal Observations: Trajectory Reconstruction and Impact Force Inversion

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Abstract

Effective rockfall protection requires accurate estimation of impact forces and trajectories. Current approaches mainly rely on numerical simulations or optical tracking methods. However, optical methods are limited by occlusion, perspective distortion, and insufficient temporal resolution to resolve millisecond-scale impact dynamics. GBSAR and dynamic tracking radar can overcome line-of-sight limitations, but limited measurable velocity still restricts capture of rockfall dynamics and internal impact response. Numerical models are also highly sensitive to assumed collision parameters but lack direct measurements for calibration. This study develops Smart Rock Node (SaRoN), embedded in reinforced concrete shells to mimic natural rock and directly record acceleration, angular velocity, and impact response within the rock. SaRoN operates at 1600Hz and integrates a ±200g accelerometer with a precision IMU (±16g, ±4000dps), providing wide dynamic range. The estimated quaternion rotates body-frame acceleration into the global frame for trajectory reconstruction through double integration. Shaking-table validation was performed to assess the feasibility and measurement reliability of SaRoN under controlled sinusoidal and historical earthquake inputs, showing that it tracks sinusoidal excitations from 1 to 10Hz with clear higher harmonics, achieving peak accelerations of 0.5–3.9g. For historical earthquake inputs (0403Hualien, Kobe, 921, El_Centro), SaRoN showed RMSE of 0.01–0.4g relative to the shaking-table reference, with peak responses of 0.5–1.24 g, and Pearson correlation coefficients above 0.95 for both input types. These results support the use of SaRoN in field-scale rockfall experiments, where its measurements can be integrated with UAV-based trajectory、seismic signals、DAS strain、numerical simulations to calibrate key parameters in rockfall simulations and improve quantitative rockfall hazard assessment.

Keywords: Trajectory Reconstruction, Smart Rock Node (SaRoN), Rockfall Impact force, Distributed Acoustic Sensing (DAS).

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Student Poster SP151

以宜蘭梅花湖沉積物內矽藻及有機物分析來重建其古環境變遷

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摘 要

宜蘭梅花湖位於亞熱帶地區，常年受東北季風及颱風活動影響且處迎風面，過去50年平均年降水量約為2760毫米，年平均氣溫約為22.5°C，該地因地表無明顯逕流，所以湖內沉積物皆是透過降雨事件從周邊山坡帶下來的。

岩芯取樣於宜蘭縣冬山鄉梅花湖，岩芯編號為MHL-09-01，包含深度共78.0公分沉積物樣本之短岩芯，進行矽藻種類鑑定與計數。

因為矽藻的生態特性在全球範圍內相似，且能夠在各種環境中生存，因此矽藻十分適合進行古環境重建的研究。另外，矽藻可以根據殼的表面模樣的不同進行種的鑑定及計數，並可以透過觀查其優勢種的生存環境得知當時可能的環境樣態，為古環境重建提供可靠依據。

本研究期望透過分析宜蘭縣梅花湖的沉積物內矽藻化石與有機物之$\delta^{13}C_{org}$(‰)、總有機碳、磁感率等紀錄，重建近百年來的人類活動及水文變化對當地湖泊生態的影響，更深入理解人類活動如何記錄在沉積記錄中，對於區分自然與人類信號至關重要，也可作為土地利用管理與永續環境治理的重要基礎。

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2.大學部三年級

Student Poster SP152

利用介形蟲及多重指標重建大鵬灣之古氣候與古環境變遷

Paleoclimate and Paleoenvironmental Changes in Dapeng Bay Reconstructed based on Ostracods and Multiple Proxies

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(1)國立中正大學地球與環境科學系

摘　要

大鵬灣位於台灣屏東縣西南部海岸，是台灣目前最大的瀉湖，本研究所使用岩芯採樣於大鵬灣北岸，編號為 DPW-23-05 ，總長 380 公分，其定年結果可顯示近 1000 年的古環境紀錄。介形蟲因殼體微小、數量豐富、化石紀錄良好且其可反應多種環境因素，包含水深、溫度、鹽度和含氧量，利用群聚分析可重建出當地過去的環境變化紀錄。本研究將分析台灣西南部海岸大鵬灣的沉積物內介形蟲化石，並結合各項有機物環境指標如總有機碳(TOC)、總氮含量(TN)、碳氮比(C/N)、穩定碳同位素（$\delta^{13}C_{org}$）、磁感率等，重建近千年大鵬灣的環境與氣候變遷。

根據目前所得到的結果顯示，在 TOC 部分，大部分深度的 TOC 值約在 1% 波動，但在 145 公分到 175 公分深度和 370 公分到 395 公分深度範圍內 TOC 值上升到近 10%，但在 TN 部分僅在 370 公分到 395 公分深度範圍內有上升至 0.4 % 的趨勢，其餘部分皆在 0.1% 上下波動，導致在該區段 C/N ratio 降至 10 以下，推測當時有事件使該地變為水生環境。在 $\delta^{13}C_{org}$ 部分雖然波動較大，但大部分都在約 -33‰ 到 -26‰ 間波動，直到 35 公分深度有明顯下降，且之後回升至 -25‰ 直到現今。

【學生壁報比賽】

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Student Poster SP153

Holocene climate fluctuations in northeastern Taiwan reconstructed through pollen analysis from Shenmihu Lake

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Abstract

Shenmihu Lake is located at an elevation of approximately 1100 meters in northeastern Taiwan, within the transition zone between broadleaf and coniferous forests. The currently dominant plant species surrounding the area is *Pasania*. This study aims to reconstruct the environmental history of the Shenmihu catchment over the past 10,000 years using pollen analysis, a key method for tracing vegetation responses to climatic changes, since pollen grains produced by plants are often preserved in sediments.

The results indicate that *Pasania* is the major dominant vegetation for most of the period, but *Alnus* populations markedly expanded between 5000 and 1000 cal BP, and become the dominant taxon. This change is likely associated with drier climatic conditions or major disturbances such as fires or typhoons that triggered landslides, highlighting the significant influence of climate variability and extreme weather on vegetation dynamics.

Furthermore, black carbon analysis was employed to detect fire events in this study. Black carbon, produced from the incomplete combustion of biomass and fossil fuels, and typically consists of particles smaller than 2.5 μm, can serves as a proxy for past fire events. While intervals of elevated BC broadly coincide with phases of *Alnus* expansion, this relationship is not consistently synchronous and may involve temporal offsets. These patterns suggest a possible link between fire disturbance and *Alnus* establishment. Overall, the results highlight the complex interactions among climate variability, disturbance processes, and vegetation dynamics in Shenmihu Lake.

Keywords: Shemihu Lake, pollen analysis, Paleoclimate, black carbon analysis, fire event, Paleoenvironmet

Student Poster SP154

海岸山脈北段超鎂鐵質岩石的岩象與礦物成分初探

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摘要

本研究針對海岸山脈北段八里灣層水璉礫岩中之超鎂鐵質礫石進行岩象觀察與礦物成分分析。雖然這類岩石出現於水璉礫岩的產狀早有報導(Teng, 1982; Chen, 1988)，但至今尚無基本的岩象與礦物岩石學研究。其岩石物質來源更仍是個謎，因超鎂鐵質岩在海岸山脈的分布主要在東臺灣蛇綠岩系(East Taiwan Ophiolite, ETO)，那是位於海岸山脈遙遠的另一端，南段的利吉混同層。研究樣本外觀仍保持有類似橄欖岩的樣貌，呈暗綠或淺綠色，岩石薄片於偏光顯微鏡下觀察顯示，超鎂鐵質岩主要由蛇紋石組成，附屬礦物有鉻尖晶石、磁鐵礦、及方解石。蛇紋石與磁鐵礦的相對關係呈現典型的網狀組構(mesh texture)，代表是蛇紋石取代先前存在的橄欖石，磁鐵礦沿著先前橄欖石的顆粒邊界分布。鉻尖晶石呈褐色，半透光，半自形至它形，可能原為填充於橄欖石之間隙；方解石為後期裂隙之次生礦物。絹石(bastite)組構局部存在，可能為先前存在之輝石的假象(pseudomorph)。岩象觀察顯示研究之超鎂鐵質岩樣本為蛇紋岩，是從橄欖岩經過完全蛇紋岩化而成，但仍保存橄欖岩時期的鉻尖晶石殘晶。本研究以電子微探儀分析鉻尖晶石之化學成分，並計算 Cr# [= Cr/(Cr+Al)] 為指標以推測超鎂鐵質岩之原始存在環境，期盼探索這類礫石之可能物源。

關鍵詞：水璉礫岩、蛇紋岩、鉻尖晶石

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Student Poster SP155

水熱合成硫複鐵礦之動力學探討：硫源釋放速率對長晶序列的影響

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摘 要

硫複鐵礦（Fe_3S_4, Greigite）為還原沉積環境中常見的亞穩態磁性礦物，亦廣泛分布於台灣西南部泥岩中。為了解其成礦機制與磁學特徵，前人多利用水熱法等途徑進行人工合成。然而，過量硫環境中，硫複鐵礦作為奈米四方硫鐵礦（FeS, Mackinawite）轉化為黃鐵礦途徑上的中間產物，極易因其固態轉化機制而迅速轉成黃鐵礦，導致純相硫複鐵礦之合成極具挑戰性。本研究試圖透過有機硫源（硫代乙醯胺）的緩慢釋放特性，並探討產物的形貌與磁特性演化。

X 光繞射的初步時間序列結果顯示，反應溫度與持溫時間大幅度主導反應進程。在 120℃條件下、反應初期，環境中尚未累積足夠的多硫化物濃度而會在缺硫環境下生成菱硫鐵礦（Fe_9S_{11}, Smythite），隨反應推進至 4 小時以上，成功並穩定生成單一純相的硫複鐵礦。相對地，當溫度提升至 140℃時，硫源釋放加快，僅 2 小時即觀察到硫複鐵礦之過度轉化，進而伴隨生成黃鐵礦與單質硫的混合相。此結果證實適當限制硫源供應速率，能有效抑制其過度轉化為黃鐵礦。

為進一步量化此動力學機制，本研究將透過離子層析儀或可見光-紫外光光譜儀追蹤液相中硫源的釋放速率。同時運用掃描式電子顯微鏡與原子力顯微鏡解析高純度硫複鐵礦樣品之化學計量比與晶體形貌，並搭配磁力顯微鏡探究其磁域分佈及微觀磁特性。本研究不僅突破了純相合成的瓶頸，其成果更可解釋自然界沉積環境中硫複鐵礦的生成制約。

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Student Poster SP156

Thermodynamic Controls on Post-Perovskite Stability within Large Low Shear Velocity Provinces: Insights from Geodynamic Modeling

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Large Low Shear Wave Velocity Provinces (LLSVPs) are distinct, dense, and anomalously hot thermo-chemical structures at the base of the Earth's mantle. Due to its large Clapeyron slope, post-perovskite (pPv) is typically stable only in colder downwelling regions. The existence of the pPv phase within these regions remains highly debated. To determine the physical conditions that could allow pPv to survive within LLSVPs, we conducted thermo-chemical mantle convection numerical experiments in 2-D spherical annulus geometry to investigate the influence of three key thermodynamic constraints: the core-mantle boundary (CMB) temperature (T_{CMB}), the altitude of the phase transition and the Clapeyron slope of the pPv transition (Υ_{pPv}).

Our results reveal that a lower CMB temperature or a higher phase transition altitude allows pPv to form under a wider range of temperatures, enabling pPv to develop a thicker layer that can even extend into the interior of the LLSVPs. Conversely, a higher CMB temperature combined with a larger Clapeyron slope restricts the formation of pPv. Moreover, a large slope prevents the phase change in hot regions, thinning the pPv layer and confining it to the colder areas outside the LLSVPs. Because LLSVPs are prominent thermal anomalies, maintaining a globally uniform pPv layer is physically unlikely. Based on our studies, we define the thermodynamic boundary conditions required for pPv to exist within thermo-chemical piles. These findings provide a theoretical framework for how varying deep-mantle conditions support pPv generation, establishing a foundation for future investigations into the relationship between primordial materials and phase transitions.

Keywords: Post-perovskite, Large Low Shear Wave Velocity Provinces, Clapeyron slope, Thermo-chemical mantle convection

Student Poster SP157

Lattice Thermal Conductivity of Bridgmanite in Lower Mantle

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Bridgmanite, with a composition generally described as (Mg,Fe,Al)(Si,Al,Fe)O_3, is the most abundant mineral in the Earth's lower mantle and therefore plays a key role in affecting mantle dynamics, seismic velocity structure, and thermal evolution of the Earth's lower mantle. The thermal conductivity of bridgmanite especially controls the heat transport in the deep Earth and affects the heat flux across the core-mantle boundary. However, existing estimates of bridgmanite's thermal conductivity with variable composition remain uncertain, with discrepancies among experimental, theoretical, and extrapolated results. Here, we directly measure the thermal conductivity of (Fe,Al)-bearing bridgmanite at lower-mantle pressures and temperatures (up to ~120 GPa and ~2300 K) using time-domain thermoreflectance (TDTR) combined with laser-heated diamond anvil cells (LHDAC). At room temperature, bridgmanite's thermal conductivity initially increases with pressure up to ~40 GPa (with a pressure derivative of ~ 0.25), followed by a gradual decrease and then a plateau above ~60 GPa. High-temperature measurements reveal a monotonic decrease in the thermal conductivity with increasing temperature (T), scaling approximately as $T^{-0.43}$. The observed pressure and temperature dependencies in our results are broadly consistent with previous studies.

Student Poster SP158

Lattice Thermal Conductivity of Wadsleyite with Implications for the Thermal Profile of Mantle Transition Zone

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Abstract

Earth's mantle transition zone (MTZ) at 410-660 km depth features seismic and density discontinuities due to the mineral phase transition of olivine to wadsleyite and then ringwoodite. Given the large water storage capacity of wadsleyite and ringwoodite, the MTZ could host large amounts of water with potential impacts on the mantle convection, slab subduction, and deep volatile cycles. Thermal conductivities of minerals within the MTZ are of particular interest, as they could hold the key to affect the thermal state and dynamics across the interface between upper and lower mantle. Here we investigated the thermal conductivity of hydrous wadsleyite with 0.15 wt% H_2O up to 17 GPa and ~1800 K using time-domain thermoreflectance (TDTR) combined with laser-heated diamond anvil cells (LHDAC). We found that the thermal conductivity of hydrous wadsleyite decreases with increasing temperature. Combined with literature thermal conductivity data for olivine and ringwoodite, our results serve as an essential reference dataset that can be incorporated in geodynamics modeling of mantle convection and slab subduction.

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Student Poster SP159

Testing the link between Panthalassa tectonic evolution and subduction-modified mantle heterogeneity

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Abstract

Subduction zones provide a pathway for transferring surface materials into the mantle, regulating their entry into the convecting upper mantle. Over geological timescales, this process can lead to chemical heterogeneity through the addition and redistribution of slab-derived components.

Recent geochemical studies have suggested that this heterogeneity is expressed as large-scale spatial variations in the upper mantle, with subduction-modified domains prevalent in the Indian and Atlantic Oceans and relatively unmodified domains largely restricted to the Pacific basin. This pattern highlights the critical role of the circum-Pacific region, which has experienced nearly continuous subduction for at least the past 200 Myr and may have acted as a long-lived “subduction shield”, isolating the Pacific mantle from slab-derived materials. However, whether such a classification is geodynamically valid remains an open question.

In this study, we utilize the finite-element geodynamic code CitcomS to simulate thermo-chemical mantle convection in a spherical shell. Constrained by GPlates-derived plate velocities based on published plate reconstruction model, we employ passive tracers to track material in the mantle transport over time. By identifying tracers passing through the mantle wedge, we determine materials acquire subduction signals and evaluate their redistribution within the convective mantle.

This analysis establishes a quantitative framework for assessing how long-term subduction drives global upper-mantle heterogeneity. Our findings offer a new perspective on the dynamic evolution of the circum-Pacific system and its role in shaping Earth’s mantle structure.

Student Poster SP159

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP160

重建中生代以來大西洋之地函異質性時空演化

Reconstructing Atlantic Mantle Heterogeneity Since the Mesozoic

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上部地函在化學組成與物理性質上的不均一性，為地函異質性(Mantle Heterogeneity)的表徵之一。地球化學上常使利用玄武岩之 Sr-Nd-Pb-Hf 放射性同位素組成，作為地函成份不均一的指標，並據此探討隱沒作用與地函熱柱物質加入等可能成因。大西洋中洋脊沿線的同位素變化是最早被辨識的地函異質性案例之一，其中北緯 35°以北呈現相對富集特徵，0°~35°為虧損特徵，而赤道以南又轉為富集。儘管現有地球化學資料以清楚顯示以上的大西洋地函異質性分區，其行程時間仍缺乏約束，進而限制了相關地球動力機制的討論。

為了釐清大西洋自中生代以來地函異質性的時空演化，本研究透過以下步驟進行分析：(1)整合已發表之大西洋海洋地殼玄武岩年齡與地球化學資料；(2)回推其生成時的 Nd 與 Pb 放射性同位素比值；(3)結合數位板塊模型重建模型，重建樣本噴發時的古位置。透過上述方法，本研究重建大西洋張裂過程中地函異質性的時空分佈，並進一步討論地函熱柱活動與大陸岩石圈影響等潛在機制。

關鍵字:中洋脊玄武岩、地函異質性

【學生壁報比賽】參與者於摘要尾端註記

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Student Poster SP161

大屯火山群斜長石晶體中之熔體包裹體研究

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摘 要

熔體包裹體是礦物在生長過程中所保存的微型岩漿系統，透過分析其化學成分，能提供岩漿成分最直接的制約，並有效獲得岩漿來源、演化趨勢及岩漿作用相關的資訊。在世界各地的火山系統中，熔體包裹體被廣泛應用於易揮發元素的測量，成為日益普及的研究手段。

本研究的樣本取自大屯火山群，屬於富含晶體的斑狀安山岩及玄武質安山岩。本研究將對斜長石晶體以及包覆在內的熔體包裹體進行主要元素與微量元素的測定，探討各元素含量的變化範圍與可能的原因，進一步利用斜長石—熔體之間的元素分配關係，推測常規地球化學分析難以測量的岩漿水含量。透過光學顯微鏡觀察岩石薄片、礦物包埋樣本的製備，結合掃描式電子顯微鏡—能量散射X光光譜分析，初步發現可歸納為以下三點。第一，多數樣本中的斜長石晶體均發現有熔體包裹體存在。第二，熔體包裹體大小介於10至50微米之間，且同一樣本中可見多種形態如圓形、箱型、長條形及不規則形狀，這可能與包裹體形成後所經歷溫度及壓力變化的時間尺度有關。第三，在一件採自七星山的樣本中，其熔體包裹體相較於全岩呈現較高的SiO_2及K_2O含量，且宿主斜長石展現極寬的鈣—鈉比值範圍，不同晶體的成分從An_{50}至An_{79}，單晶內不同環帶的成份亦由An_{57}變化至An_{74}，顯示斜長石組成複雜，可能涉及多期晶體在同一岩漿系統中的循環，以及岩漿庫中基性岩漿的補給。後續研究將進行升溫實驗以使熔體包裹體組成均質化，並採用原位分析方法，包括電子微探分析與雷射剝蝕—感應耦合電漿質譜分析，期望能對大屯火山系統的地球化學演化提供更精確的制約。

【學生壁報比賽】

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Student Poster SP162

Aseismic Slip Along Pre-existing Faults: The 2021 Nisyros Seismic Swarm, Southern Aegean

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Abstract

Nisyros, part of the South Aegean Volcanic Arc (SAVA), features both volcanic and tectonic activity due to the subduction of the African plate beneath the Aegean microplate. This study investigates the 2021 Nisyros swarm to determine whether it resulted from magmatic or tectonic processes. Of 1,960 events recorded by 38 permanent HUSN stations during 2019–2025, 1,480 were located using NonLinLoc and subsequently refined to 1,319 precisely relocated events (horizontal and vertical uncertainties <1 km) using the double-difference algorithm. Of the relocated events, 1,188 occurred during the swarm period, with a maximum magnitude of Mw 5.5. Frequency Index (FI) analysis of M < 3.5 events yielded 1,023 and 1,021 events after SNR-based quality filtering for the first (0.5–3 Hz vs. 15–20 Hz) and second (0.3–3 Hz vs. 15–23 Hz) frequency band pairs, respectively. Near-zero FI values suggest predominantly hybrid-type seismicity. Moment tensor inversion of M ≥ 3.5 events yielded 13 stable solutions indicating normal and strike-slip faulting, with a significant isotropic component suggesting volumetric expansion. Pore-pressure diffusion models failed to fit the observed migration pattern, whereas linear migration analysis of two temporal phases with NE–SW strikes yielded statistically significant fits with migration rates (−0.159 and +0.160 km/day), consistent with aseismic slip along pre-existing tectonic faults. These results collectively suggest a predominantly tectonic origin of the 2021 Nisyros swarm, although there may be a possible influence of fluids within the earthquake source.

Keywords: Nisyros, swarm, aseismic slip, moment tensor inversion, frequency index

(1) **National Central University/K. I. Konstantinou**

(2) **Master/Second Year**

Student Poster SP163

Magma Storage and Eruptive History of the Mt. Qixing, Tatun Volcano Group, Taiwan: Insights from Petrology, and Thermobarometry

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The Tatun Volcano Group (TVG) in northern Taiwan has shown increasing evidence for an active magmatic system, raising concerns due to its proximity to metropolitan Taipei. Recent studies suggest that TVG experienced Holocene eruptions (~6 ka, based on ^{14}C dating), particularly at Mt. Qixing. To better constrain the volcanic state of Mt. Qixing during the Holocene, this study uses petrography, mineral chemistry, and multi-mineral thermobarometry (amphibole, and two-pyroxene).

Amphibole thermobarometry (Ridolfi, 2021) indicates the presence of two magma reservoirs beneath Mt. Qixing that supplied Holocene eruptions. A shallow reservoir records pressure–temperature conditions of ~102–241 MPa and ~791–875 °C (~4–9 km in depth) and is characterized by relatively oxidized (up to NNO +3) and moderately water-rich magmas (4–7 wt.% H_2O). A deeper reservoir records higher pressures and temperatures of ~380–597 MPa and ~900–970 °C (~14–22 km in depth) and contains more oxidized and water-rich magmas (7–10 wt.% H_2O).

Two-pyroxene thermobarometry (Putirka, 2008) shows that most clinopyroxene–orthopyroxene pairs pass the subsolidus equilibrium filter (K_D(Fe–Mg) = 0.6–0.9). Calculated pressures are scattered, reaching up to 910 MPa (~38 km in depth), while temperatures range from ~791–930 °C.

These results provide evidence for a complex, multi-level magma plumbing system beneath Mt. Qixing that fed Holocene eruptions.

Keywords: Tatun Volcano Group (TVG), Amphibole thermobarometry, Two-pyroxene thermobarometry

Student Poster SP164

Using novel approaches to investigate the development of the Panzhihua intrusion and its Fe-Ti oxide ores

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The Panzhihua layered gabbroic intrusion (Emeishan Large Igneous Province, SW China) hosts a giant magmatic Fe-Ti oxide deposit, and has attracted wide attention in the community. The relationship among magmatic processes, the timing of oxide saturation and ore formation, however, is still not fully understood. To better understand the factors contributing to the generation of the deposit and similar deposits worldwide, we review the current state of knowledge about the crystallization of Fe-Ti oxides under magmatic environments, compile petrographic observation and geochemical data for the deposit, and undertake novel approaches that shed new lights on the topic including X-ray diffraction (XRD), apatite geochemistry and apatite-hosted melt inclusions, melting experiments on inferred parental magma compositions, and Fe isotopic analysis on mineral separates and whole-rock samples. Preliminary observations and data include: (i) a textural progression from dispersed and net-textured titanomagnetite among cumulus plagioclase + clinopyroxene + olivine + hornblende in the lower zone of the intrusion to massive magnetitite layers with minor ilmenite and apatite in the middle zone of the intrusion, (ii) complex sub-solidus exsolution features, including sandwich and trellis lamellae of ilmenite and/or ulvöspinel, indicating prolonged high-temperature re-equilibration and slow cooling in crystal mush. The XRD data so far obtained indicate magnetite as the dominant mineral, followed by titanomagnetite, ilmenite, apatite, with minor hematite, pyrrhotite, and chalcopyrite. The traditional and novel approaches noted above will be useful to evaluate the crystallization model(s) of the Panzhihua magma, whether ore formation involved gravitational settling of dense, liquidus Fe–Ti oxide crystals or percolation of dense, Fe-rich residual liquid formed through liquid immiscibility, and whether and how volatiles played a role in ore formation. The anticipated outcome is a refined genetic model of the Panzhihua intrusion and its Fe-Ti oxide ores.

Keywords: Panzhihua intrusion, Fe-Ti oxide ores, ELIP, oxide saturation, crystal mush

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Co-Advisor: Chih-Tung Chen, Department of Earth Science, National Central University
Degree: First-year PhD student, 2025

The Potential of *in-situ* Trace Element Geochemistry in Tephrochronology: Revisiting Marine Core MD97-2143, Western Philippine Sea

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Abstract

Tephra layers in marine cores are excellent materials for reconstructing the history of regional paleo-volcanic events. Core MD97-2143 (Western Philippine Sea) preserves 11 tephra layers (172 – 1978 ka), providing a high-resolution record of Luzon Arc eruptions. Previous provenance tracing relied on major elements from electron probe microanalysis (EPMA) and bulk Sr isotopes. However, similar magmatic evolutionary trends within a single arc system cause major-element compositional overlap, making source identification difficult.

To overcome this, high-resolution scanning electron microscopy (SEM) eliminated microlite interference on glass shard analyses. Subsequently, laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) precisely acquired *in-situ* trace element data, providing a more robust geochemical fingerprint sensitive to magmatic evolution.

Analyses reveal typical arc magma signatures: enriched large-ion lithophile (LILE) and light rare earth elements (LREE), with depleted high-field-strength elements (Nb-Ta-Ti). Through statistical methods such as multivariate analysis, the findings indicate

that the tephras originated from at least three distinct sources: (1) medium-K calc-alkaline rhyolites with heavy rare earth element (HREE) depletion (Yb_N = 1.03 – 4.22); (2) high-K calc-alkaline basaltic andesites to dacites with higher enrichments in LILE and LREE (La/Yb = 6.42 – 13.19); and (3) high-K calc-alkaline andesites to dacites with relatively lower LILE and LREE enrichments (La/Yb = 5.46 – 8.68). Incorporating trace elements enhances provenance discrimination, providing rigorous spatiotemporal constraints for regional volcanic hazard assessments.

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Student Poster SP166

深海熱泉貽貝殼體的地球化學應用初探：以南沖繩海槽為例

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摘要

深海熱泉系統是水圈和岩石圈物質交換的重要場合，但受限於深海區域抵達困難且樣本採集不易，探討時空演化的研究機會匱乏。在南沖繩海槽(Okinawa Trough)南緣深海熱泉「石林隆堆(Geolin Mounds)」場址，採撈到深海貽貝(*Bathymodiolus platifrons*)，貽貝具有厚度約 100~150 μm 的方解石外殼層和厚度達 1 mm 的霰石內殼層。本研究將探討深海貽貝碳酸鹽殼生長時記錄的環境訊號 (1) 元素含量、(2) 硼同位素($\delta^{11}B$)，以及 (3) 叢同位素(Clumped isotopes)，分別作為深海熱泉的成分、pH 值以及溫度替代指標，以及隨時間演化的可行性。

微量元素分析採用 LA-ICP-MS，以直徑 85 μm 的雷射束斑沿殼體生長軸剖面進行原位線掃描。常用的微量元素分析矽酸鹽標準品，實驗測試結果指出它們明顯與碳酸鹽物質所得的元素分析靈敏度存在差異，基質效應嚴重。分析測試指示殼體的硼濃度偏低(B/Ca=9.90-125.29 μmol/mol)，而外殼的硼同位素較輕，為 +6.09 - +7.97 (±0.35 (2SD)，n=3)，已超出 pH 值換算公式適用範圍，可能反映了極端的 pH 環境或是與 $B(OH)_3$ 不易結合入方解石有關；內殼層的硼同位素值為 +13.34 ~+13.47 (±0.35(2SD))，分別對應 pH 值 7.29、7.34，與該區海底 1515 公尺深的 pH 量測值 7.290 相近。叢同位素初步測得殼體形成的溫度區間約在 0-12°C，雖受限於不足的分析樣本量(7.5 mg)，但結果仍大致符合現地量測值(4°C)。為了提升數據可信度，引入均質性較佳的天然碳酸鹽奈米顆粒 JCt-1 NP、JCp-1 NP作為參考樣，且提升取樣量，總計穩定同位素單筆分析，共需鑽取約 30 mg 樣本，約占殼體面積 1 cm^2。

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Student Poster SP167

利用多元素與地球化學指標重建大鵬灣沉積環境之變遷

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摘　要

天然示蹤劑是利用自然界中原本存在之物質，用以推估環境中的自然過程。沉積物可長期保存水體環境變化的重要地球化學訊號，因此常被用來重建過去環境條件。本研究以多元素與稀土元素作為天然示蹤劑，分析大鵬灣沉積物的化學組成，以探討大鵬灣過去的環境變化。本研究共分析 74 個沉積物樣本。樣本先以連續萃取法進行前處理，再進行基質轉換，並利用感應耦合電漿質譜儀測定主要元素、微量元素及稀土元素之濃度。

濃度分析結果顯示，在鐵錳氧化物相中，於 2.77 ka cal. BP、5.07 ka cal. BP、5.21 ka cal. BP、5.53 ka cal. BP、6.04 ka cal. BP、6.22 ka cal. BP、8.75 ka cal. BP 及 31.39 ka cal. BP，Na/Fe 比值出現明顯異常高值。稀土元素經上部大陸地殼標準化後並未顯示明顯異常，但整體稀土元素分布模式普遍呈現中稀土元素富集的特徵，此現象可能與沉積物中的早期成岩作用有關。

主成分分析結果顯示，在第五主成分中，Na 為唯一具有高負荷量之元素，顯示其來源可能與其他元素不同。結合稀土元素分布模式未顯示明顯海水訊號，推測上述 Na 異常值可能並非由海水輸入所造成，而較可能與陸源碎屑輸入事件有關。推測在該些沉積時期可能發生洪水或強降雨事件，輸入較多含 Na 之矽酸鹽礦物，進而造成沉積物中 Na 含量的增加。

綜合上述結果，大鵬灣沉積物中的元素分布主要受沉積來源、早期成岩作用及鐵錳氧化物吸附作用所控制，而 Na 的異常值則可能記錄了過去陸源輸入事件所造成的沉積環境變化。

未來研究可進一步結合沉積物的礦物組成分析及粒徑分析，亦可整合連續萃取法中其他相態（如可交換相及碳酸鹽相）之元素地球化學資料，以更精確重建大鵬灣沉積物的沉積歷史與環境演變過程，並釐清陸源輸入事件與區域氣候變化之關聯。

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Student Poster SP168

Slab Tear and Subduction Reinitiation Triggering Magmatism via Mush Short-Circuiting, Petrological Cannibalism, and Crustal Assimilation at Lutao Volcano

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Abstract

The Northern Luzon Arc (NLA) is one of the few active examples of arc-continent collision systems worldwide and is characterized by its unique “double arc” configuration. Lutao, located at the northernmost extent of the Luzon arc, is commonly regarded as the initial expression of the island arc branch. Previous studies on the Lutao debate over the coexistence of fractional crystallization, magma mixing, and crustal contamination remain enigmatic within a traditional liquid-dominated magmatic model. In this study, we re-evaluate the petrogenesis of the Lutao volcano using zircon U-Pb dating, whole-rock geochemistry, and Sr-Nd isotope analyses, within a "transcrustal magmatic system" model. Our results demonstrate that Lutao’s magmatic evolution was driven by three integrated mush-related processes: (1) Mush Short-Circuiting, reflecting rapid melt transport across the mush; (2) Petrological Cannibalism, remobilization and rejuvenation of pre-existing crystal mush; and (3) significant Crustal Assimilation during magma ascent and storage.

We propose that these processes were triggered by a major geodynamic transition associated with the "double arc" evolution. A shift in subduction dynamics—potentially

involving slab shallowing followed by slab rollback—triggered a slab tear within the South China Sea Plate. This tectonic rupture facilitated asthenospheric upwelling, which "re-ignited" the stagnant plumbing system beneath Lutao. This study provides an integrated framework for linking transcrustal mush processes with large-scale tectonic events, offering new insights into the origin of geochemical architecture in arc magmatism at convergent margins undergoing subduction reorganization.

Keywords: Slab tear; Double arc evolution; Transcrustal magmatic system; Lutao volcano; Northern Luzon Arc.

◎the Students' Poster Competition

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