觀測大屯火山地區流體上升現象

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近年，關於大屯火山的構造研究十分多樣化。這些研究的重點，點出了大屯火山淺層的火山構造特性，例如壓力源構造、火山流體上升的位置、火山流體的成份來源、火山流體形成的特殊地動訊號…等。這些研究不但指出了大屯火山的活動性，同時也表明了其可能形成的威脅。與之不同之處，在於本研究將試圖以現有的資料，探討如何監測這些流體的變化。使用的資料有地震與火山噴氣的成份，這些資料的來源為大屯火山觀測站。基於過去的研究可知，大屯火山的大油坑下方可能存在一個壓力源，而大油坑地區的噴氣成份又被推測可能包含了火山特性。基於這個模式，本研究分析大屯火山地區的地震震源機制，進一步將震源機制分成正、逆、走向滑移等三種機制。進一步再分析在壓力源週邊與壓力源上方地區的震源機制型態隨時間的變化，結果發現，在壓力源周邊的逆斷層發生率與壓力源上方的正斷層發生率有極高的相關性與些許的時間差，而這些時間變化又與地表的噴氣成份中的硫含量變化趨勢相仿。基於這些觀測資料，本研究推出了大屯火山地區的火山流體上升模式。而三種觀測資料間的時間差，正好反應了火山流體上升的位置。此結果在火山監測中，具有極高的應用性。因為這些觀測資料可以在可能造成災害的火山流體傳播至地表產生噴發前，約 4 個月前，預先監測到流體活動。這個時間段，讓監測單位有時間可以多方確認各項資料，同時發出預警資訊。

中文關鍵字：大屯火山群、上升流體、震源機制、火山噴氣

深度學習於地震偵測之落地化：連續資料的波相挑選及降低反投影法之計算開銷

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近來，深度學習算法於地震學之嘗試如雨後春筍冒出，而如何將演算法納入連續，甚至是即時的地震資料處理流程是值得被關注的議題。為了提高模型在動態的波形上偵測地震及波相的穩定性，我們提出了 Marching Mosaic Waveform Augmentation (MMWA)。在模型的訓練資料中加入以不同地震波形拼接而成的資料，並使其隨機前後移動，以模擬多組地震訊號同時出現，以及在判釋的時間窗格內被截切的狀況。本研究以在固定時間窗格內判釋地震 P 波及 S 波到時的模型為例，在時間域上對所有資料點進行移動式的重複判釋，取其中位數以作為模型的穩定輸出。此判釋方式能迫使模型判釋每個資料點時，能同時注意其他資料點隨著時間變化的情形，以模擬人類判釋地震波相到時的行為。反投影法(back-projection)藉由在連續資料上針對多個測站所記錄到的特定訊號（如初達 P 波）建構特徵方程式（如 STA/LTA, Kurtosis 等），在時、空間域進行疊加，以尋找潛在的訊號源。使用傳統的線性方法建構特徵方程式，在連續資料的處理上最大的問題有三：(一) 無法分辨 P 波、S 波。(二)無法捕捉在短時間內連續發生之地震，尤其是振幅差異較大之事件。(三)特徵方程式的值無統一單位，偵測閾值設定困難。因此在實務應用上，在地震記錄的三個分量上分別對 P 波及 S 波設計特徵方程式，並使用研究區域的 P 波及 S 波速度模型分別進行演算再疊加是較保守的做法。然而地震波形的變異性甚大，無法以同組參數量化所有地震出現時，所有波相的特徵。本研究以兩百萬餘筆三分量地震記錄(約 5%純噪音，約 25%為 MMWA 所合成的資料)訓練而成的 ARRU (Attention Residual-Residual U-Net) seismic phase picker 進行連續資料的地震偵測及波相判釋，可以很好的緩解上述三個困境。此外，將需要建構並疊加的時間序列函數減少為原本的三分之一，即只輸入模型所產出的 P 波及 S 波偵測函式。其中最大值為 1，最小值為 0，演算法的數值穩定度較高。

中文關鍵字：深度學習、地震偵測、波相挑選、資料增強、連續資料處理

From two-class to one-class classification of tectonic tremor in Taiwan

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In Taiwan, ambient tremors are found to locate underneath a mountain in Southern Central Range. Given that the ambient tremors represent the aseismic slip process at greater depth where no seismicity is present, it is crucial to monitor their activity. To identify tremors, the similarity and time lapse of the arrival tremor bursts from multiple stations are oftentimes demanded, while manual checks of multi-station waveforms are practiced, to exclude loud noise and swarms of regional earthquakes.

We aim at exploring if the advances of machine learning techniques enable an automatic search for patterns to discriminate tremor from regional earthquakes. Using *k*-Nearest Neighbor (*k*-NN, Cover and Hart, 1967) classifier, Liu et al. (2019) successfully separated tremor from local earthquakes and noise at high accuracy of 86.6-98.8%, showing that the possibility of applying ML technique to separate tremors from other types of seismic signals is feasible. However, they also found that the multi-class classification approach is not robust in the real-time monitoring using continuous data. This is mainly due to the fact that in the continuous data, many other types of signals exist without being labeled. In this study, not only two-class but one-class classifier was built to test if tremor can be separated from regional earthquakes and the possibility of continuous tremor detection.

Using 5,796 tremor, 6,746 regional earthquake, and 441,887 noise data collected in 2016, we found the two-class k-NN classifier allows the high classification rate (CR) of 91.8-95.8%. We further demonstrate the performance of one-class Support Vector Data Description (Tax and Duin, 2004) classifier that does not need a collection of other classes' samples. The resulting CR of 71.1-82.8% indicates the capability of one-class classifier on real-time detection of tremor in Taiwan.

Keywords: tectonic tremor, machine learning, real-time detection, Support Vector Data Description

井下地震儀觀測 Pd 與 M_L之關係

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地震預警系統已廣泛應用在台灣、日本及美國等地，為地震發生時拯救生 命財產的一大利器。目前使用之地震預警系統以地表測站觀測資料為基準，利用 P 波位移波形前三秒之最大振幅推估地震規模(以下簡稱 Pd 值)，進而使用此資訊配合強地動衰減式估算各地震度。然地表站觀測波形可能會受到場址效應 的影響，增加估計規模的誤差導致震度估計有所偏差，而井下測站儀器避開了鬆軟之淺層構造，大大降低場址效應的影響，可以有效的增加地震預警的準確性及效率。截至目前為止中央氣象局已於全台灣佈設了 52 個井下地震儀測站，其中包含強震站以及寬頻站。本研究蒐集 2018 年井下地震儀之強震地震資料共 522 個地震(966 筆垂直紀錄)，得到芮氏規模大於 4 之地震，其震源距 50 公里內的 Pd 與規模之迴歸式為 log(Pd)=-2.11log(R)+0.99M-4.12。此迴歸式得到的預測規模 Mpd 與觀測之芮氏規模 M_L有良好的相關性，其關係式為 M_L=1.03Mpd0.02，標準差為 0.15 低於前人的研究 0.18~0.23，未來將投入中央氣象局地震預警系統測試。

中文關鍵字：地震預警系統、Pd、井下地震儀

A comparison of methods for calibration of seismometer orientation

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Many seismological researches rely on precise seismometer orientation. To understand the performance of currently available methods based on teleseismic P-wave, Rayleigh wave, and receiver functions respectively, we have applied them to well calibrated broadband seismic stations in Taiwan. In general, seismic waveform data collected for distant earthquakes distributed at various back-azimuth is required for higher precision and accuracy. It seems that the P-wave particle motion can give a good result if the noise level is acceptable whereas the back-azimuth coverage does not change the orientation significantly. We are going to apply these methods to open data that is collected in Taiwan to enable a complete metadata for borehole or ocean bottom seismometers.

Keywords: seismometer orientation, observational seismology, seismogram, receiver function

Observations of separating first P arrivals as induced by mantle wedge fast anomalies beneath NE Taiwan

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Using data from the Formosa Array (FMA), a dense seismic network covering North Taiwan with r oughly 140 broadband stations, we observed that an earthquake (25.02°N, 121.86°E, 138 km) exhibits distinct two arrivals of P waves (two phases) for stations just above it. Having determined the two phase d elayed times for FMA, results show a spatial radiation pattern decreasing from 1.6 seconds to zero outward the epicenter. In addition, this event is located on the Ryukyu subduction zone, where the Philippine Sea Plate subducts beneath the Eurasian Plate, and both the slab and mantle wedge exhibit the feature of fast P wave anomalies, which is also mentioned by previous publication of high resolution tomography on NE Taiwan (Su et al., 2019). Then, we conducted a study of tracing rays, and visualized them on the 2 D cross sections with multiple azimuth. Therefore, we find a positive correlation between the duration of delayed times and the length of rays passing through the fast P anomaly in the mantle wedge. As a result, we conclude that the two phase arr ivals are induced by the fast anomaly in mantle wedge beneath NE Taiwan. Moreover, after comparing the data and ray paths of other adjacent events with weaker two phase arrivals, we can further confirm the conclusion. To figure out the causes of the two ph ase arrivals, the simulations of wave propagations will be simulated in the future.

Keywords: Formosa Array, northeastern Taiwan, anomalous waveform effects

3-D plate interactions beneath Taiwan orogeny from source-side seismic tomography

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We conducted unconventional joint local and teleseismic traveltime tomography, source-side seismic tomography, for improving regional 3-D *P*-wave velocity (*Vp*) structure beneath the Taiwan region down to ~400 km. The teleseismic data in this study are traveltime residuals of local earthquakes determined at distant stations instead of those from teleseismic events to local stations in the traditional teleseismic tomography. This provides a larger amount of the teleseismic data than before and a better raypath coverage at the upper mantle depths, benefiting from a much larger number and a more even distribution of the local earthquakes compared to those of broadband stations only placed on the surface in the study area. Our results show clear geometry of the subducting Eurasian Plate (EP) and Philippine Sea Plate (PSP) beneath Taiwan. In the south, the top interface of the high-*Vp* anomaly interpreted as the subducting EP extends eastward and downward to reach a depth of 450 km at a longitude of about 123°E. From central to northern Taiwan, the deeper part of the EP subducting beneath the PSP is progressively deformed, while the PSP continuously collides with the shallow part of the EP on the west and gradually subducts northward. The subducting EP becomes sub-vertical beneath northern Taiwan and seems to be detached as the PSP subducts below a depth of about 80 km.

Keywords: Taiwan orogeny, seismic tomography, subduction, tectonics

Three-dimensional Scattering Dominated Attenuation Models in Southern California

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Seismic attenuation is not only a powerful tool to constrain the physical state of the Earth's materials but also a crucial component to improve the accuracy of the ground motion simulations at higher frequencies (f > 1 Hz). Lin and Jordan (2018) indicated that the attenuation at high frequencies is frequency dependent with a power-law rate α=0.4 and dominated by scattering from small-scale crustal heterogeneities in Southern California. In this study, we inverted the spectral-amplitude residuals between observations and synthetics for 3-D *P*- and *S*-wave attenuation structures from 660 regional earthquakes ($3 \leq M \leq 5.7$) recorded at 281 broadband stations of the Southern California Seismic Network (SCSN). The synthetic spectral amplitudes accounted for geometrical spreading, source excitation, and frequency dependence of *Q*. The 3-D Q_P and Q_S variations are inverted by the spectral ratios measured in the band 1-10 Hz. Results from independent inversions of the P and S datasets are strongly correlated. Our results show weaker attenuation in two more homogeneous batholitic blocks including Peninsular Ranges and southern Sierra Nevada and stronger attenuation in the vicinity of the San Andreas Fault and the Garlock Fault systems, which is dominated by the elastic waves scattering from the fracture structures around the faults. The Salton Trough displays the strong attenuation, which consistent with the high heat flow in the Salton Sea area. However, the low Q_P/Q_S indicates that the elastic scattering still dominates the attenuation observations in this region.

Keywords: seismic attenuation, elastic scattering, Southern California

Revealing seasonal crustal seismic velocity variations in Taiwan with single-station cross-component analysis

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Ambient noise interferometry is a promising technique for providing continuous measurements of seismic velocity changes (dv/v) and studying crustal behaviors in relation to various geophysical processes over time. In addition to the tectonic-driven dv/v changes, dv/v is also known to be affected by environmental factors through rainfall-induced pore-pressure changes, air pressure loading changes, thermoelastic effects, and so forth. In this study, benefiting from the long-term continuous data of Broadband Array in Taiwan for Seismology (BATS) that has been operated since 1994, we investigate the evolution of crustal seismic velocity by applying the single-station cross-component (SC) method on the continuous seismic data from 1998 to 2019. We construct the noise correlation functions and compute daily seismic velocity changes by the stretching technique in a frequency band of 0.1 to 0.9 Hz. In our dv/v results, we observe the co-seismic drops associated with inland moderate earthquakes and also the clear seasonal cycles that appear at most stations but with different characteristics. Systematic correlational analyses with the weather data suggest that the rainfall-induced pore-pressure change is likely the main cause of the seasonal variations with high correlations. The observed site-dependency of these seasonal dv/v variations implies spatially-varying complex hydro-mechanical interaction across the orogenic belt in Taiwan.

Keywords: seismic velocity change, single-station cross-component method, stretching technique, seasonal variation

初探台灣高階噪訊表面波的時空特性

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地震學中的噪訊(microseisms)主要源自於海浪與沿岸或是海床的能量交換，其傳遞方式多以基態(fundamental mode)表面波為主，只有在特殊天氣系統或海床構造下，才有機會產生體波或是高階(higher-mode)表面波的噪訊能量。透過噪訊干涉法，除了可以提供高密度的表面波格林函數來進行速度構造相關的研究之外，也可以進一步釐清噪訊源的時空特性。根據研究指出，由於台灣周遭海浪週期約為 7-9 秒，因此可以提供以基態表面波傳遞為主高頻的次級微震(secondary microseism, 2-5 sec)，且激發能量與季風系統與水深有關。近年來將干涉技術應用在多分量的噪訊紀錄上，很多研究發現干涉波形中出現高階(higher-mode)表面波，且其起源可能與沈積層的基盤有關。台灣西部以沈積構造為主，往東進入板塊碰撞造山帶，劇烈的側向構造變化，提供很好釐清噪訊高階表面波起源的試驗場所。為了探討高階噪訊表面波空間分佈特性與地質構造的關係，本研究結合 CWB、BATS 與 TSMIP 三個地震觀測網的資料，以提升干涉波形在空間上的解析能力。透過分析干涉波形的質點運動與表面波頻散曲線，可以清楚分辨基態與高階表面波的訊號。我們將測站依照地理位置加以分組，透過干涉波形的非對稱性與 Beamforming 的結果，發現高階噪訊表面波的空間分佈特性與台灣構造息息相關。未來將結合高階與基模噪訊表面波的 H/V 特性與頻譜特徵，勾勒西部沖積平原基盤的幾何樣貌。

中文關鍵字：噪訊、干涉法、高階表面波

Ambient noise Full Waveform Inversion along Lanyang River, Ilan Plain, Taiwan– Synthetic tests and application

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Full Waveform Inversion (FWI) is a high resolution method capable of inferring detail subsurface structure and velocity variations. FWI emphasis on utilizing the whole waveform information instead of using first- or reflection arrival time in Travel Time Inversion (TTI). However, FWI may suffer from the potential non-linear nature of the seismic data. The FWI community trying to tackle the high non-linearity problem embedded in FWI through multiscale approach and various objective function formulation. A multiscale FWI approach is performed on the synthetic dataset based on the known Taiwan complex geological fold-bend-fault model provided by CPC to test the capability of the FWI application in central Taiwan area. Synthetic data were generated from the test model. The multiscale approach invert the data with the frequency content of 2, 4, 8, 10, 15, 20 Hz. The result shows promising result as the inverted velocity model are sequentially constructed from smooth-to-detail according to the designated frequency bands. For real data application, ambient noise dataset from Ilan 2004 network is analyzed and studied in this project. The initial model is estimated from the conventional multichannel analysis of surface wave (MASW) inversion. Fifty inter-station cross-correlation gathers were used to construct a 2D profile from Land array data. Preliminary inversion shows wedge-shaped sedimentary basin the Ilan plain thicken from the sea (East) toward mountain (West) direction. To understand its potential generation mechanism, ambient noise data simulation is performed to understand noise generation signatures, effect on the cross-correlation results and compare the synthetic responses with the recorded data. Ambient noise synthetic data are simulated by random source distribution with the random duration and activation time. Data preprocessing including body- and surface waves separation through curvelet transform is necessary before FWI.

Keywords: ambient noise, curvelet, Full Waveform Inversion

Ambient wavefield simulation in ILAN2014 array data

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Ambient noise data is generally attributed to primary or secondary microseisms. The primary microseism is the direct coupling between ocean waves and seafloor. The secondary microseism is the ocean waves once hits the coast, reflect back to the ocean and interacts with another incoming ocean waves and and propagate back to the coast. We simulate the primary and secondary microseisms based on the spectral element method (SEM). The current simulation aims to understand how the coupled acoustic-elastic waves responses while interact with sea-land boundary. Mimic the primary and secondary microseisms along the coastline. Coupled elastic-acoustic waves simulation with excitations occurred inland, ocean, and coastline are studied and analyzed. The 2D model is set to 131x81 km with 1001x621 elements. A total of 163 receivers of ILAN2014 observations are simulated and analyzed through many model setup including model proposed by Su et al, 2019. Different types of sources were initiated along the coastline in a sequential and random manner. Simulating ambient wavefield is challenging for obtaining a reasonable simulation responses within a reasonable computational time. To simulate one-hour ambient noise data, the computational cost is high. Therefore, simultaneous excitation of random sources along the coastline were performed first to obtain the desired 1-hour long records. The simulated data are cross-correlated and stacked to increase the signal-to-noise ratio (SNR). The result shows that the clarity of the extracted high SNR green functions increases as the recording time increases. Simulation also indicate that the body wave arrivals become less visible with the increasing recording time and eventually enhancing surface wave arrivals. The simulation results are consistent with the commonly observed ambient noise records. Such responses are dominated by the wave interferences excited from the Sandiaojiao in the north and Nanfangao-Fenniaolin in the south of Ilan.

Keywords: ambient wavefield, spectral element method, synthetic simulation

Modeling the earthquake source process with Langevin's approach

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When dealing with the dynamics in an asymmetric many-body system, analytical solutions are practically unattainable and numerical solutions usually exhibit chaotic behaviors, if interactions between bodies are in concern. To deal with this conundrum, stochastic approaches have been widely applied in modeling the dynamics of many-body systems. Following Langevin's approach, we propose a stochastic dynamic model for the earthquake rupture process where the many degrees of freedom is omitted by introducing the random force that accounts for the collision of structures and uncertainties in the heterogeneity of faulting planes. The model is a one-dimensional Langevin equation of Coulomb friction. It allows fast numerical simulations, and analytical solutions are attainable under the steady-state approximation. Both analytical and numerical results coincide with the truncated exponential (TEX) distribution that is empirically characterized in the rupture models of large earthquake events worldwide, and we relate the scale parameter in the TEX model to the ratio of the driving force and the friction parameter in the Langevin equation given the same noise level. Furthermore, basing on numerical simulation a universal energy-duration scaling relationship is suggested. The proposed Langevin equation provides a simple and physically reasonable picture by regarding the tectonic process as a process of Coulomb friction, where earthquakes are those transient (microscopic) stick-slip events during the process.

Keywords: Langevin equation, earthquake rupture, source process, slip distribution

台灣地震科學資料服務平台

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近年來觀測地震學的進展神速，基礎研究及環境監測均仰賴長期的連續地震觀測紀錄，因此大量連續資料的需求逐漸增加。過去十年來，台灣地震科學資料服務計畫已對十數個地震觀測計畫建立了個別的地震資料庫，地震測站的總數超過 800 部，地震數據量極為龐大。隨著測站密度及資料數量的增加，同時索取多個計畫的資料逐漸成為常態。本計畫旨在提供一個新的資料服務系統，整合所有借用台灣地震科學中心儀器所繳回的地震資料，並提供了測站與資料分佈時間查詢、線上波形繪圖、資料品質管理，以及連續資料下載的功能，使用者可利用單一帳號跨計畫查詢並下載所需的地震波形資料，大幅提升使用效能並擴大資料的價值。本系統開發架構基於前後端分離概念，將系統分成前端介面、訊息傳遞及後端處理共三個模組，並用容器化技術將各模組包裝成微服務，不僅讓資訊人員方便進行測試與維護，也使本系統在必要時，能藉由調整微服務的數量來服務更多使用者。目前這個服務平台的測試版已經上線，歡迎有興趣使用的同仁註冊參與測試。

中文關鍵字：台灣地震科學資料中心、儀器中心、地震波形、網路服務

Revealing orogenic layered deformation by crustal seismic anisotropy in southwestern Taiwan

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Taiwan orogenic belt results from the arc-continental collision of the Philippine Sea plate and the Eurasian plate. The complex collision deformation in the crust has been described by models with various depth extent. To examine those models, we investigate the crustal anisotropy in southwestern Taiwan and present a new shear wave splitting map that shows sophisticated yet systematic anisotropy patterns across the southwestern island. A notable feature is the delay time decrease from the coastal plain to the higher metamorphosed western foothills. Those observations could be modeled by the cooperation of the thickening orogeny-parallel anisotropy above the convergence-parallel mineral fabric at depths. Therefore, we prefer the layered deformation model that both the fold-and-thrust in the upper crust and the shearing in the lower crust control the crustal anisotropy manifested at the surface in southwestern Taiwan.

Keywords: crustal seismic anisotropy, southwestern Taiwan, orogeny, layered deformation

Earthquake Cluster analysis using Nearest Neighbor approach with unsupervised classifiers in Taiwan

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The spatiotemporal characteristics of earthquake clusters can shed light on the triggering process behind and physical properties of the crust. Taiwan is located at one of the most active orogenic belts with a high deformation rate and complex crustal structures and is expected to observe diverse earthquake activities, such as typical tectonic-driven mainshock-aftershock (M-A) sequences and fluid-driven swarms among different tectonic regions. Thus, a proper classification of earthquake clusters is critical for investigating the tectonic complexity and the varying triggering processes of local structures in Taiwan, which contributes to the seismicity hazard analysis. We produce the earthquake cluster catalogs with the combination of statistics-based nearest-neighbor approach (NNA) and density-based spatial clustering of applications with noise (DBSCAN) algorithm from January 1990 to June 2018 and further classify these earthquake clusters into M-A sequences and swarms with an modified k-means methods. In Taiwan, most of the M-A sequences are distributed around the major compression zones. The asperity sizes, time duration, and cluster events all show positive correlations with mainshock magnitudes in the M-A sequences. In contrast, the swarms are mainly distributed in the southern Central Range and the northern Hualien areas, which are spatially correlated with the high-fluid-flow regions. Also, the asperity sizes and cluster events show the low correlation with the mainshock magnitudes in the swarms.

Keywords: declustering, k-means, DBSCAN, classification, swarms

The influence of VP/VS on earthquake b value in the Salton Trough region, Southern California

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Earthquake frequency-magnitude distribution in the crust commonly follows the b value from the empirical Gutenberg-Richter Power Law. Naturally, it is well-known that earthquake b value varies primarily with differential stress and earthquake faulting style and then varies with pore fluid pressure locally. So far, the influence of pore fluid pressure on b value can only be observed in the subsurface crust by injection wells. It remains unclear whether the effect is detectable in the scale of the entire crust. The seismic V_P/V_S ratio is sensitive to crustal crack density and pore fluid saturation to approximate pore fluid pressure in the crust. Southern California existed high-quality earthquake catalogs, velocity models, and similar earthquake faulting style, providing an ideal laboratory investigating how b value varies with V_P/V_S ratio. We find a positive correlation that the b value increases with V_P/V_S ratio in the Salton Trough region. This region with abundant earthquake swarms and creep events may imply high pore fluid pressure to vary the b values. This study highlights that V_P/V_S ratio can be used as an index to monitor b value variations for earthquake mitigation.

Keywords: earthquake b value, Vp/Vs ratio; pore fluid pressure, differential stress, Southern California

New insights in seismic tomographic inversion to evaluate and validate Taiwan reference model

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Over last three decays seismic tomography study in Taiwan is one of the principal geophysical techniques for illuminating 3D distribution of Earth structure across a range of scales. The usefulness of results is dependent on our ability to quantify its uncertainty. The uncertainty arises from the ill-posed nature of the tomographic inversion problem as multiple models are capable of satisfying the data. The assessment of uncertainty remains underdeveloped and is often ignored or given minimal treatment. The factors that control solution non-uniqueness include starting model, picking, ray or data coverage, data noise, parameterization, method used for data prediction and formulation of inverse problem. For those who make use of seismic tomography results may not have a full appreciation on their reliability through rigorously verification and validation. Tracing uncertainties can lead to significant improvement in the quantification of exploring structure imaging.

An effort to evaluate the uncertainty of available 3D models in Taiwan through travel-time calculations and wave propagation were performed. The uncertainty of using passive source data is relatively high compare to the use of active source data. Such result is directly linked to a key issue that without 2D data constraint, 3D inversion from 1D starting model produce considerable uncertainty. Shortest path or circular ray tracing is implemented for unstructured Delaunay triangulation mesh system. Ray tracing through tessellation triangle points for better path coverage can be achieved. The goal is to reduce the geophysical uncertainty when merge different types of data which carry various degree of errors while incorporate accurate geographic information into the model. Thus, mesh system preserves the actual suggestion of velocity distribution, geological boundaries, topography and bathymetry. Forward seismic ray tracing for such mesh system also shows better coverage, convergence and accuracy.

Keywords: uncertainty analysis, inverse problem, triangular mesh, triangular/circular ray tracing

微震監測與應力反演：在 2018 花蓮地震與 2019 地震之前

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2020 年，由於新冠肺炎的流行，使得過去進行地球科學研究的模式，遭遇到很大的困境。本研究希望藉由精確的利用過去於應力研究中常被捨棄不用的微震事件，來獲取一些過去所無法得到的一些資料，近而能夠更為詳細的了解該區域的孕震構造以及背景應力狀態，透過三維速度構造的重定位、波線追跡技術，以及全事件的應力反演方法，本研究能夠更為客觀且更精準的運用地震資料，確保資料非由於人為主觀意識所影響，並引入了信賴區間的概念，近而提高所得結果之可信度。結果顯示，台灣東北部地區其孕震構造皆受到菲律賓海板塊隱沒以及沖繩海槽開張之複合式影響，地震活動複雜，未來可透過微震資料的增加，透過微分區的方式，仔細的去了解該區域之孕震構造於空間上的分佈，並提供未來進行應力轉移研究時，所需相關背景應力資訊。

中文關鍵字：台灣東北部、應力反演、微震監測

利用地震活動分布與 P 波速度構造建置西部麓山帶滑脫面三維幾何模型

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臺灣西部麓山帶的活動斷層構造其地下形貌極其複雜，即使透過地球物理探勘方法與地震學理論模式，仍難以清楚釐清並描繪此區孕震構造位置與活動斷層間之相互關係。有鑒於此，若能建立一套西部麓山帶滑脫面之三維幾何模型，將有助於了解此區複雜的斷層幾何構造形貌。

地質學家建立平衡剖面來重現斷層-褶皺帶的地下形貌及壓縮量，用以解釋淺部地殼變形的演化過程，而臺灣西部褶皺逆衝帶與逆衝斷層系統因受板塊擠壓驅動、由東向西成覆瓦狀排列；在薄皮理論架構下，構造變形多發生於深度約 10 公里內的淺部地層，平衡剖面裡可見一個向東傾斜且低傾角的介面，即為滑脫面，此介面為塊體間的弱面，在壓縮過程中，可能以頻繁的小規模地震釋放能量，Carena et al. (2002)應用當時地震資料庫的小規模地震建置滑脫面的三維幾何，但較為粗略，且未與其他區塊整合成一連續的滑脫面模型。

隨著地震解析技術的提升，現今的地震目錄精度將有助於探討滑脫面的空間位置。本研究嘗試以密集繪製的地震分布剖面並利用網格化的方式建立滑脫面三維空間幾何形貌。研究區域參考南北走向之西部活動斷層的空間分布，在臺灣中部海岸平原區及麓山帶框定東西跨距 90 公里、南北跨距 150 公里的範圍，並在研究區域內以 5 公里等間距繪製 2 組互相垂直的地震分布剖面。前人研究中(Davis et al., 1983；Huang et al., 2004；Mouthereau et al., 2006；Simoes et al., 2007)說明，西部麓山帶的滑脫面係約為一向東傾約 6±1 度的面，本研究依此作為初始模型在前述的地震剖面上套疊，以建置滑脫面的初步模型。為能進一步探討初步模型之合理性，本研究另參考 P 波速度構造分布(Kuo-Chen et al., 2012；Huang et al., 2014)與震源分布一起檢視所有剖面中滑脫面的位置，結果顯示滑脫面位置與 P 波速度約 5.2km/s 分布大致相符(Camanni et al., 2016；Brown et al., 2017；Biete et al., 2018)。雖因地震資料上的限制，滑脫面與 P 波速度構造上存在差異性，但判斷下最終能取得本研究區域內所有剖面中之滑脫面深度數值，最後利用 GIS 軟體建置初版的西部麓山帶連續滑脫面三維幾何模型。

臺灣西部的褶皺逆衝斷層帶，因地質構造複雜，對斷層系統的三維幾何建置充滿挑戰，本研究認為先定義出滑脫面的位置有助於整合研究區域內的斷層幾何模型，不僅可作為斷層幾何在深度方向延伸的邊界，更能有效排除相鄰斷層間幾何形貌的衝突性，後續可與地調所發布的活動斷層作討論，以利更了解臺灣西部麓山帶的活動斷層三維幾何模型。

中文關鍵字：滑脫面、地震分布剖面、西部麓山帶、地理資訊系統

Fate of the Luzon Arc after subduction: Evidence from stress inversion along the Taiwan collision boundary

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The arc–continent collision boundary of Taiwan involves complex deformation that is difficult to visualize using conventional two-dimensional stress analyses. We employed a three-dimensional spatial clustering approach in eastern Taiwan to reveal how stress varies along the collision boundary. Results show that the maximum horizontal compression orientation, SH, is parallel to the plate motion throughout the boundary at all depths except in the crust of the northern segment, where SH exhibits a clockwise rotation from convergence-parallel by up to 30°. Concurrent with the SH rotation, the maximum compressive P-axes steepen in the same crustal segment. We interpret this phenomenon as resulting from the rotation of the stress regime in the crust of the Luzon Arc forced by the bending of the Ryukyu Arc continental sliver. The differential response with depth may signify an initial decoupling of the buoyant volcanic arc from the mantle lithosphere during early subduction.

Keywords: Luzon Arc, collision, subduction, stress inversion, Ryukyu Arc sliver

台灣高精度地震動地圖製作

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地震動地圖（Shake Map）能夠在地震後呈現地震動強度值（如地表運動峰值及不同週期的反應譜值等）的空間分佈狀況，第一時間可提供災損之推估及緊急應變措施之擬定，後續亦可供任意目標工址結構進行耐震能力評估之參考，因此其為地震防災研究與應用的重要工具之一。高精度地震動地圖的製作，仰賴精準的地震源參數與有限斷層模型、精準與足夠的地震動觀測資訊、精準的地震動預估式、及精準的空間內插與外插方式等四大重要元素。本研究旨在發展於建置台灣地震動地圖時用來進行空間內插與外插的空間相關性函數，並以台灣即時強地動觀測站（約一百餘站）的觀測資訊及所發展的空間相關性函數建置地震動地圖，接著再以非即時強地動觀測站的觀測資訊，評估所建置之地震動地圖的精確度，及探討即時強地動觀測站數量、不同地震動預估式、以及空間內插方式等對地震動地圖精確度的影響。本研究的成果可供未來震後第一時間及觀測資訊收集完整後建置高精度的台灣地震動地圖，以利地震防災相關的研究與應用。

中文關鍵字：地震動地圖、地震動預估式、空間相關性函數、空間內插與外插

Development of new parameter (H_R) as a proxy for site conditions (V_{s30})

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The average S-wave velocity (Vs) in the upper 30 m (V_{s30}) is a vital site parameter widely used for many purposes like microzonation, ground motion prediction equation (GMPE), and building codes. In this study, we used a newly developed Vs database inverted by Microtremor Horizontal-to-Vertical Spectra Ratio (MHVSR) including more than 3500 Vs profiles, to develop a new parameter H_R as a proxy for site condition (V_{s30}) in Taiwan. The parameter H_R instead of the predominant frequency (fpeak) as a proxy for V_{s30} reduces the standard deviation and leaves out human judgment and challenging to identify the predominant frequency of MHVSR. Both H_R and modified elevation (E_m) as predictor variables are adopted to regress a predicted equation for V_{s30} can further reduce the uncertainty. The MHVSR and elevation are both obtain, and we suggest that H_R and E_m are optimal parameters to be the V_{s30} proxies in Taiwan.

Keywords: S-wave velocity, microtremor, HVSR, V_{s30}

Modal frequency and damping ratio of TAIPEI 101: The response to environmental factors

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Continuous monitoring the state of buildings provides the information for structural health condition, integrity and reliability. Ambient vibration available of being recorded continuously in time, has been widely used to measure the dynamic properties of the buildings through modal frequencies approaches (e.g., Clinton et al., 2006; Nayeri et al., 2008; Ditommaso et al., 2010; Mikael et al., 2013). Over the past two decades, the globally rapid urbanization demands for the better technology and practice for long-term monitoring of high-rise buildings with seismic vulnerability. The behavior of high-rise building is strongly controlled by wind loads, mass of the building, design of damper and internal structure. The damping ratio of a tall building is found to be generally nonlinear with vibration amplitude under strong winds. As recognized as the tallest building in the world from 2004 to 2010, the TAIPEI 101 is located at the place where earthquakes and strong typhoons frequently occurred. Previous study investigated how the TAIPEI 101 responded to large earthquakes and typhoons (Chen et al., 2013; Li et al, 2011). The long-term history of the vibration characteristics of the TAIPEI 101 however, remain explored. In this study, we aim at using one-year continuous data from sensors on 90th floor to establish the characteristics of natural frequency and damping ratio of TAIPEI 101 and further, discuss the possible controlling factors.

Using the four components of seismogramsin both bending (BLE, BLN) and torsion (BRN, BRZ) modes recorded at the 90th floors, we computed Random Decrement Technique to identify the identify three modes of fundamental frequency. We found that the frequency and damping behavior of horizontal components isrelatively stable with similar amplitude for three different frequency modes. In horizontal components, the normalized frequency and damping isrelatively high between June and September. When we further compare the frequency behavior of the building with the precipitation, air pressure, relative humidity, temperature, wind velocity and wind direction recorded at nearby weather station, we found that the frequency increases with increasing humidity/temperature and decreasing air pressure/wind velocity. In addition to the control of environmental parameters, we also

demonstrated a logarithmic relationship between frequency and amplitude in all components and modes. The damping however, seems to reveal higher order dependency on the amplitude in specifically BLN and BRN components.

Keywords: TAIPEI101, modal frequency, damping ratio

Shallow subsurface structure in the Hualien basin and relevance to the damage pattern and fault rupture during the 2018 Hualien earthquake

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The 2018 Mw6.4 Hualien earthquake generated a large peak-to-peak velocity of over 2 m/s, with a period of 3 s at the south end of the Milun fault, which resulted in the collapse of five buildings. To investigate the shallow subsurface soil structure and evaluate possible effects on the ground motion and building damage, we performed microtremor measurements in the Hualien basin. Based on the velocity structure jointly inverted from both Rayleigh-wave dispersion curves and microtremor horizontal-to-vertical spectral ratio data, we found that the shallow subsurface structure generally deepens from west to east. Close to the Milun fault, the structure becomes shallower, which is consistent with faulting during the 2018 earthquake and the long-term tectonic displacement. There is no significant variation for the site conditions in the north–south direction that can explain the large peak ground velocity in the south. As a result of the dense measurements in the heavily damaged area, where three high-rise buildings totally collapsed, these locations have the average S-wave velocity of the upper 30 m (AVS30) values and are relatively high compared to the more distant area from the Meilun River. This is somewhat unusual, because lower AVS30 values indicating softer ground conditions are expected close to the river. We did not find any characteristic subsurface soil structure that may contribute to the building collapses. The large 3 s pulse was probably generated by source effects, rather than subsurface soil amplification.

Keywords: 2018 Hualien earthquake, microtremor measurement

地震危害度分析之斷層幾何模型－觸口斷層與崙後斷層

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地震危害度評估的第一要務便是建立斷層或孕震構造的幾何模型，斷層幾何形貌對於斷層上盤場址之地震危害度有極高的敏感度，除主控震源至場址的最短距離外，並掌控斷層破裂面積與其透過尺度公式(Scaling law)計算最大可能地震規模之結果。由此可知，斷層幾何在地震危害度評估中舉足輕重的地位。

因此，本研究之目的在蒐集斷層或孕震構造之相關資料，由地表地質調查、地下鑽井、平衡剖面、地電測量、反射震測等地質及地球物理資料之彙整到斷層幾何模型建立與不確定性評估之依據，並利用地理資訊系統(GIS)建立斷層三維模型，用以檢視幾何模型在各參數(長度、走向、傾角及深度)不確定範圍的組合內，向下延伸的斷層面是否會在特定位置產生非預期的截切，造成模型不合理之處。本研究之範圍北起三義斷層南至左鎮斷層，東側為雙冬−大茅埔斷層，西側至彰化斷層，而此簡報內容以觸口與崙後斷層為例，由三維方式呈現斷層幾何，並探討幾何參數組合之狀況。

觸口斷層長約 28 公里，崙後斷層由觸口地區至左鎮斷層長約 50 公里。最終幾何模型為觸口斷層向下之傾角分別為 25/40/50 度，深度停於下方的滑脫面(Décollement)。而觸口斷層與崙後斷層之破裂模型為：觸口斷層與崙後斷層個別單獨破裂(Individual ruptures)、觸口斷層與崙後斷層相連破裂(linked rupture)以及與大尖山斷層南段相連的全段破裂(Entire rupture)。

中文關鍵字：地震危害度、觸口斷層、崙後斷層、滑脫面、破裂模型

2006 年屏東外海地震誘發之恆春斷層慢滑移事件

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本研究藉由中央地質調查所於恆春半島設置之 7 個 GNSS 連續站、37 個移動站及 2 條精密水準測線 2002 年至 2016 年間之觀測資料發現，2006 年屏東外海 M_L 7.0 地震發生後，恆春半島之地表運動型態產生了明顯的轉變，且首次觀察到臺灣地區之慢滑移事件。為了釐清此區域慢滑移事件之活動型態及其在恆春斷層上能量累積與釋放的模式，本研究除了分析時間序列獲得地表速度場外，更透過基線反演模型與斷層錯位模型，推估斷層面上滑移虧損速率與滑移速率之分布型態及數值，再結合地質調查結果進行綜合探討。根據時間序列分析結果，恆春半島之地表速度場以 2006 年屏東外海地震及 2010 年 4 月為界，可區分為 3 個時期：相對於 S01R 測站，2006 年屏東外海地震發生前，西南側水平速度於約 53-58 mm/yr 向西北，垂直沉降速度約 8-15 mm/yr；東側水平速度於約 47-55 mm/yr 向西北西，垂直沉降速度約 5-18 mm/yr。2006 年屏東外海地震發生後至 2010 年 4 月，西南側水平速度於約 53-56 mm/yr 向西南西，垂直沉降速度約 3-10 mm/yr；東側水平速度於約 45-53 mm/yr 西北西，垂直速度轉為抬升為主約 3-9 mm/yr。2010 年 4 月至 2016 年，西南側水平速度於約 50-54 mm/yr 向西南西，垂直沉降速度約 3-8 mm/yr；東側水平速度於約 43-53 mm/yr 西北，垂直速度轉回沉降為主約 1-6 mm/yr。基線反演模型與斷層錯位模型結果則指出，恆春斷層為具有左移分量之逆衝斷層，其於 2006 年屏東外海地震發生前，具有南北兩個地栓（Asperity）；且地震發生後，能量並未停止釋放，而是持續於此兩個地栓由南往北遞進釋放。此外，根據地質調查研究結果，鄰近恆春斷層區域直至 2017 年仍有地表裂隙產生，亦為此區域震後持續潛移之佐證。綜上所述，本研究推論：（1）恆春半島地表運動型態的改變是由 2006 年屏東外海地震所誘發；（2）恆春斷層上盤垂直速度之變化與地質調查研究結果顯示，斷層面上所累積之能量於地震後仍持續緩慢釋放中，亦即此區域有慢滑移事件之發生；（3）恆春斷層之位置可能位於目前劃定範圍之東側約 1-2 公里之位置。

中文關鍵字：恆春斷層、2006 年屏東外海地震、慢滑移事件、斷層滑移虧損速率

Ground deformation along the Chegualin fault between 2018 and 2020 from SBAS DInSAR observation

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The Chegualin fault in southern Taiwan is the major active fault within the Gutinkeng formation in the fold-and-thrust belt. According to Central Geological Survey in Taiwan, the Chegualin fault is considered as the category two active fault documented it as a thrust fault striking N-S in the north and gradually striking NE-SW to the south with various dipping angle. However, several investigations have shown that the southwestern segment of the Chegaulin fault is recently dominated by right-lateral movement with minor thrusting component. This fault also shows creeping behavior which could gradually affect the functions of the infrastructures across the Chegualin fault. This study aims to reveal the surface deformation rate relevant to the Chegualin fault zone from 2018 to 2020 by using multi-temporal InSAR analysis. For this purpose, the Small Baseline (SBAS) DInSAR technique was adopted, which allows efficiently analyze the temporal deformation on the small temporal and spatial baselines interferogram network over a wide area. The reliability of the observation and qualities of the procedures in the SBAS DInSAR workflow were quantitatively evaluated based on the results of continuous GPS measurements. We further remark that this study follows the work of Lin et al. (2021) where a numerical workflow for assessing the fault rupture-engineering structure interaction problems was present. The results of this study could provide reliable free-field ground deformation data for the calibration of the numerical simulations in the future.

Keywords: Chegualin fault, ground deformation, SBAS DInSAR analysis, multi-temporal observation

Numerical tectonic escape models of southwest Taiwan

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This study investigates the tectonic escape in SW Taiwan. The studying area in this research ranges from the Pingtung Plain to the east bound of the Peikang High. GPS data show a counterclockwise rotation in the velocity field in the inland part of the studying area. The velocity vectors are around 5 cm/yr westward in the east of the Pingtung plain and around 5 cm/yr southwestward at the coast of Pingtung and Kaohsiung. Previous studies suggest that Peikang High may act as a western backstop and play a crucial role for the tectonic escape here.

Our experiments are 3D dynamic models under elastoplastic deformation regime with the program DynEarthSol. To construct the circumstances of SW Taiwan, field observation with fault map, Cenozoic sediment isopach and GPS data are considered for model settings. Our model is under lateral shortening in E-W direction with a ramp under Chishan fault, and have a southern open boundary, where materials can escape through. The frictional strength and the orientation of the open boundary are varied in our experiments. Common features in all models are: (1) a counterclockwise rotation in surface velocity field, (2) subsidence around the open boundary, and (3) a dextral thrust along the “Chishan” fault. The strength of the decollement controls the width of the fault zone and the degree of rotation in the velocity field. With a high-strength decollement, the rotation in velocity field is small and the fault zone is narrow. Only when the basal friction is low enough and the open boundary is parallel to the coastline between Kaoping river and Chaochou fault, the velocity field would be able to rotate that much as the observation.

Keywords: numerical simulation, southwest Taiwan, tectonic escape

分析環境背景雜訊探查恆春半島速度構造

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恆春半島位於中央山脈最南端，往南連接巴士海脊，是板塊碰撞所形成的增積岩體，以覆瓦狀褶皺逆衝斷層帶為主，所代表的是臺灣造山帶形成初期之地質構造，亦即現今西部麓山帶之地質雛形。恆春斷層為一向東傾斜的逆斷層，呈北北西-南南東走向，大致位於山麓與平原區交界，斷層兩端可能往海域延伸，認為有較高之斷層活動潛勢。因此，國震中心於恆春半島南端架設 12 個臨時寬頻地震站，測站間距約 5 公里，進行恆春半島斷層活動監測。

近年來，分析環境背景雜訊探求地下速度構造，在經過理論方法驗證，有標準化的資料處理程序，也證實研究結果的可靠性，已經被廣泛接受應用。本研究試著將恆春半島的 12 個測站，結合國震中心 SANTA 寬頻地震網，位於南臺灣的 14 個測站，及 4 個監測萬丹泥火山活動的臨時寬頻地震站，總共約有 30 個寬頻地震站，試著解析恆春半島之淺部地殼速度構造。初步分析西元 2018-2020 年的連續紀錄，取樣率降至 20 Hz，選定的分析週期為 0.5-10 秒。把所有測站對疊加平均的交對比函數，依照測站對距離遠近排列，隱約可見時間域經驗格林函數訊號，大致以視速度 2.1 公里/秒傳播。再進一步試著挑選每組測站對，0.5-10 秒的雷利波相速度頻散曲線。接下來進行三種棋盤格解析度測試，確定側向解析度後，層析成像選擇以 0.05 度格點，獲得 1-5 秒的雷利波相速度分布圖。相關的速度分布特性，與活動斷層及地質構造等資訊相互比對及分析討論。

中文關鍵字：恆春半島、環境背景雜訊、層析成像、速度構造

Recent geohazards in Taiwan caught on seismic stations and multidisciplinary techniques

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Mass-movement events on hillslopes are one of frequent natural geohazards causing fatalities and economic losses. The prevention and mitigation of geohazards should be based on the understanding of dynamic behavior of event. In the past decade, landslide seismology has been applied to rapidly determine information on when, where and how event occur that is useful for hazard assessments. Compared to the conventional geo-engineering-based techniques such as borehole drilling, inclinometer, GPS, and piezometer, seismological technique is low-cost and invasive tool and can be widely adopted. Here, I present the results based on a combined analysis of seismic signals, multidisciplinary geological survey and numerical simulation for a landslide event occurred in the Central Cross-Island Highway. Another landslide site (Landslide Inventory ID: DS160) has been well understood by geological, geophysical, geodetic, geotechnical, hydrological and seismological perspectives, which not only improved our understanding in landslide mechanism and but also advanced in studying the landslide forecasting. Above two case studies have successfully toward a rapid assessment of highway slope disasters and defining certain thresholds for landslide forecasting.

Keywords: landslide seismology, hazard assessment, forecasting

無人飛行載具影像技術在山崩活動性之應用

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無人飛行載具，可在野外地質調查、山崩調查等進行遠距露頭或地形觀察，此外也可利用以 SfM 攝影測量範圍成像技術進行三維地形建模，獲取正射影像與數值地表模型資料，有助於地表地形分析。

本研究前期使用 DJI PHANTOM 4 PRO（P4P）及搭配地面基站 D-RTK 2 的 PHANTOM 4 RTK（P4RTK）兩款搭載不同衛星定位模組之無人飛行載具，於同一地區，利用未加入地面控制點所拍攝的影像產製之正射影像成果，透過質點影像測速法（Particle Image Velocimetry, PIV）進行分析並探討兩者所產製的正射影像成果之穩定性，此外，也與現地 RTK 測量資料進行平面誤差計算，得知透過 P4RTK 所產製出的正射影像之成果，全區均方根誤差約在 10 公分內，在此誤差規模下，透過 P4RTK 進行空拍建模的資料，將可直接應用於地表侵蝕差異分析及地表變動觀測等變動規模在公吋至公尺以上的項目上。

近期桃園市復興區光華地區一處農用道路有崩塌地持續滑動現象，此處過去因有發生崩塌滑動之虞，故將其範圍劃入桃園市山崩與地滑地質敏感區（L0011），並於 104 年 12 月公告之；同時也於本所「潛在大規模崩塌精進判釋既補充調查」計畫中，完成崩塌特徵之調查。基於光華地區崩塌地近期有持續滑動現象，且已透過前期研究評估無人飛行載具空拍建模資料之可行性及應用性，故選定此處進行空拍建模及透過質點影像測速法進行分析，以此得知崩塌地整體移動方向及變量，作為崩塌調查參考資料。

中文關鍵字：無人飛行載具(UAV)、質點影像測速法(PIV)、山崩活動性觀測

Deformation pattern of landslide by long-term monitoring: A dip slope case in northern Taiwan

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A natural hillslope developing into a landslide shows ground cracks and topographic deformation. Geomorphological and subsurface investigations using appropriate methodology are essential to understand the failure mechanisms and stability of a hillslope. Huafan University campus located on a dip slope in northern Taiwan is facing a potential landslide hazard. Slope movement was detected through the development of ground cracks and persistent deformation of campus buildings and facilities. To monitor the sliding behavior of the dip slope, a nail network consisting of 144 ground monitoring points was set in 2001, and its coordinates were measured using conventional traverse surveying twice a year until 2017. The 17-year surficial surveying results were presented as a time series of displacements with constraints of geometry and distribution of ground cracks and underground observations. The long-term surveying results reveal multiple potential sliding blocks within the Huafan University campus. A model of landslide movement with a listric sliding surface is proposed. Additionally, from the velocity field derived from the monitoring points, the horizontal strain rates of the slope are estimated. The pattern of strain rates indicates that a plausible fault passing through the campus may have affected the movement of the dip slope. The long-term surface monitoring of a potential landslide slope in this study provides a reliable and economical way to understand the mechanism of movement behavior of the slope and evaluate slope stability.

Keywords: dip slope, long-term monitoring, time series of displacement, listric sliding surface, landslide deformation

Constraining S-wave velocity structure of a complex large-scale deep-seated landslide at Chunlin, southern Taiwan using Rayleigh wave ellipticity inversion

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Large-scale deep-seated landslides are one of the most catastrophic natural hazards which threaten lives and property in the world. The Chunlin landslide in southern Taiwan is one of such composed of complex morphology, showing multiple sub-blocks with different deformation behaviors, and cut through by possible fault zones. As a result, constraining its subsurface structure is crucial to understand the detailed geometry of sliding interface and fault zones, and potential weak zones prone to failure. For this purpose, a seismic network containing 15 stations was installed relatively uniformly across the Chunlin landslide area in July 2019 to provide comprehensive observations. We apply a method, named DOP-E (Berbellini et al., 2018), to estimate degree-of-polarization (DOP) in time-frequency domain to effectively extract and estimate the Rayleigh wave ellipticity information from seismic noise. We then invert the ellipticity measurements with neighborhood algorithm for each station to spatially map the subsurface velocity structure, so as to understand the possible sliding depth and layering structure of different sub-blocks. This method may also allow the temporal imaging of subsurface properties in the future.

Keywords: large-scale deep-seated landslides, Chunlin landslide, degree-of-polarization, Rayleigh waves, ellipticity curve

台灣中部廬山-能高板岩地區坡體重力變形現象之探討

謝有忠[1]、戴東霖[1]、吳庭瑜[1]、林錫宏[1]、紀宗吉[1]
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經濟部中央地質調查所推動「國土保育之地質敏感地區調查分析計畫」，運用空載光達技術，至民國 105 年底完成全臺高解析度數值地形資料建置與相關之地質災害調查分析工作。此為臺灣首次取得全島高解析度數值地形模型資料，其中一項工作是配合衛星影像與航空照片等資料，中央地質調查所據以自 99 年至 109 年於全臺坡地聚落與重要保全設施分布地區，約 4,500 平方公里範圍內，逐步累積判釋出 2,621 處具有重力邊坡變形現象的潛在大規模(10 公頃以上)崩塌地區，其中 188 處之區位可能會影響到 173 處聚落的安全，為國土計畫、保育規劃、防災應用與土地管理之重要參考資料。

坡面重力變形作用(deep-seated slope gravitational deformation, DSGSD)在 1940 年代開始提出(Agliardi et al., 2001)，主要為坡面上大規模岩體因重力作用造成岩體產生變形作用，常會出現張裂地形特徵如崩崖、陷溝、地塹、多重山脊等，以及壓縮地形特徵如坡面隆起(bulging)、挫曲褶皺(buckling folds)、高度破裂岩體等。過去國際間針對山崩或坡地土砂災害等現象之分類方法眾多，多以移動材料、移動方式、移動速度、發生規模等因子進行分類，常見的分類方法為 Varnes 之分類方法(Varnes, 1978)，以移動物質的材料及移動方式來分類，Hungr 等在 2014 也針對 Varnes 的分類中，在移動方式中增加坡體變形(slope deformation)一類，並依照移動物質材料區分 Mountain slope deformation、Soil slope deformation、Rock slope deformation、Soil creep、Solifluction 等 5 細類 (Hungr et al., 2014)。2009 年莫拉克風災時發生的大規模坡面土砂災害，也使得近年來大規模崩塌的調查研究越來越受關注，而臺灣板岩分布區域易受發達之劈理影響，岩體在長期重力作用下產生重力變形現象，多造成岩體破碎進而發生山崩現象，這些坡面重力變形區域極可能為潛在大規模崩塌之位置(Chen et al., 2015; Chigira et al., 2013; Lin et al., 2013)，所以對於這些坡面重力變形區域的調查研究，有助於對後續崩塌災害的了解，在國內地質災害上之研究也具有其重要性。自從莫拉克颱風災後，藉由空載光達測製技術，所獲得之臺灣全島高解析度數值地形資料，藉由進一步地形計測方法與視覺化加值處理後，專業地質人員可以判釋出植覆之下受崩塌作用影響所致的變形(地形)表徵，進而圈繪出潛在大規模崩塌之範圍，但對於其關鍵的地質本質仍所知有限，這些經由初步地質調查與資料判釋、分析，提供鄰近坡地聚落可能存在之不同規模大小的潛在崩塌的資訊，但如此多數量之潛在大規模崩塌在具有不同地質條件、崩塌類型、規模大小、水文地質等特性下，對於崩塌可能破壞的機制與活動性，仍有許多不確定位置的範圍而需進一步研究。好比缺少醫療專業的人，雖勉強可以察覺患病者外觀的病徵，卻難以確認體內的病灶所在。由於空載光達數值地形測製是以鳥瞰的尺度與角度所進行的地形測繪，獲致的資

料有：去除或包含植覆與地表物之地形(DEM)或地表(DSM)面，對於滑動面深達岩體的潛在大規模崩塌的理解，仍缺乏個案場址的地下地質參考模型。對於坡面尺度下的潛在大規模崩塌的地質模型解釋，多受限於現階段板岩地區僅有的地質資料，主要為地質調查所出版之五萬分之一地質圖，此部分因資料尺度及精度限制下，已不敷現階段潛在大規模崩塌之應用。

中央山脈板岩地區地勢陡峭、交通不易，且受限過去之地形圖資精度及解析度有限，本研究以南投縣仁愛鄉廬山、清境地區，利用 1 米解析度空載光達數值地形資料，並結合高解析度三維地形判釋技術，初步完成區域尺度之地質資訊，圈繪出本區域大規模崩塌分布及細部地形特徵，配合野外調查，釐清區域構造作用抑或重力變形作用所造成之現象，並藉由對於這些地形特徵抑或坡面重力變形所致之岩體破壞狀況及可能機制進行研究，未來也可比對近年來已發生大規模崩塌，增進潛在大規模崩塌的判釋和調查，更能進一步探討坡面地質災害的可能成因和規模或影響範圍，做為未來坡地災害防救災策略上亟需的重要資訊。

中文關鍵字：空載光達、數值地形模型、坡體重力變形、三維地形判釋技術、大規模崩塌

板岩片岩交界帶附近邊坡穩定與岩體工程特性探討－以南橫公路摩天下馬沿線為例

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本文針對近年來南橫公路摩天下馬沿線之邊坡經常性崩塌路段，配合多時期遙測影像邊坡崩塌分佈篩選及查核邊坡失穩類型，再輔以路線地質測繪與岩體特性調查，進行板岩與片岩交界帶附近邊坡失穩與岩體工程特性的關係探討。研究成果顯示，大南澳片岩與板岩交界帶之岩體 Q 值低於兩側圍岩，岩體破碎，為邊坡岩體滑動、岩屑崩滑以及落石好發處，Q 值評分因子中以 RQD 以及 Jr 差異較明顯。而板岩層中，板岩、千枚岩及變質砂岩交界帶，其岩體工程特性變化一般不及褶皺出露處明顯；另，中視尺度褶皺軸部斷層、層間剪裂、密集裂隙等調適構造則造成岩體破碎，易成為岩屑崩滑、落石的發生源。片岩層中不連續面組之持續性不佳或呈波浪狀，填充物蝕變程度不高；中視尺度褶皺軸部與邊坡崩塌位置的關聯性不及板岩層。大比例尺路線地質圖以及褶皺各部岩體工程特性經詳細地質評估及採岩體評分法量化分級，有利於板岩與片岩交界帶邊坡穩定及大地工程等課題深入評估。

中文關鍵字：板岩、片岩、Q 法、岩體評分、岩性交界

Stochastic-based approach to uncertainty quantification of large-scale landslide

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Most assessments of landslide hazards are implemented by building the landslide occurrence risk maps. The levels of uncertainty in investigating the landslide occurrence depend on many significant factors, such as the model of the landslide area, the quality of data. The study presents a case study of the Lantai deep-seated landslide of the Taipingshan National Forest Recreation Area in northern Taiwan. The integration of the digital elevation model (DEM) and the numerical simulation is conducted to establish the three-dimension model, which allows evaluating deterministically landslide hazards based on the stochastic approach. According to the previous researches, the geological profile and hydrogeological profile are selected. Due to the limitation of the data, the study uses the naturally susceptible properties of material characteristics based on spatial distribution. This study provides a framework for assessing the uncertainty of a large-scale landslide.

Keywords: large-scale landslide, numerical simulation, stochastic approach

岩坡上楔型岩塊定位技術結合數位實境開發與應用

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本文運用先進測繪技術，針對岩石邊坡建立數值表面模型，發展一套半自動辨識岩楔空間位置程序：透過不連續面判釋技術取得坡面上不連續面位置資料，藉由對應的數學式計算加以將不連續面分組而後區隔同組不同道平面，據以估計坡體中等值不連續面空間分佈，並研判各平面之相交性，完成邊坡岩楔自動萃取、可能墜落岩楔識別以及其潛在運動方向分析等作業，可於數值表面模型中定位潛在岩楔位置，提供露頭調查成果視覺化展現；繼而將岩坡數值模型中可能墜落岩楔視為特徵單元，應用數位實境技術介接岩楔幾何特性及空間分佈，作為監測作業觀察不連續面持續度延伸、開張狀況變化，以及數值模擬分析評估岩楔穩定度成果之檢核比對，架構岩坡數位實境監測平台雛型。本文並透過台 2 線濱海公路鼻頭路段、台 8 線中橫公路天祥附近邊坡測試所提技術，成效良好並具實務應用性。

中文關鍵字：不連續面、楔型岩塊、視覺化

精細測繪應用於落石邊坡脆弱度評估

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岩坡與地工構造物所處環境多為半無限域空間，結構具高度靜不定特性，破壞前異狀徵兆出現位置難於透過解析力學模態預測；加之岩坡失穩常具突發性，以致傳統點狀或線狀配置的監測作業效果受限。

在落石災害管理中，透過遙測分析敏感性及潛在落石位置至關重要，然將落石分析結果套用至真實邊坡時，難以客觀的定義危險區。本研究將 UAV 或地面光達點雲產製的高精度數值地形應用於視覺化不連續面調查、岩體評分以及數位實境地貌變異分析，應用於台灣東部天祥明隧道附近落石邊坡，透過點雲判釋露頭不連續面位態技術及檢定方法，檢核數值地形的適用性；基於點雲判釋不連續面結果，自動萃取關鍵岩楔，繼而應用岩體評分法-Q-slope 評估坡面脆弱度；最後採視覺化展現監測結果，達到整合岩盤工程地質調查成果、精緻化場址分區、三維視覺化模型展示以及大量數據彙整分析，提昇岩體工程特性調查評估、分析設計、建造以至於運營維管的精度與效能。

中文關鍵字：精細測繪、脆弱度、擴增實境、落石監測

水下文化資產與工程之間的取捨與共存

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台灣全島地狹人稠，經濟成長的代價是過度發展的土地使用，導致島上土地資源寸土寸金，在陸地上能開發的土地逐漸限縮下，也因此，想當然動念轉往擴張海域的土地，進行各項海上的工程開發，例如填海造陸工程、離岸風力機組工程等種種案例。在這樣條件下，水下文化資產保存法規也因應而生，於中華民國一百零四年十二月九日總統華總一義字第 10400143861 號令制定全文 44 條，並自公布日起開始施行。

其法規總則第一章第一條：「為保存、保護及管理水下文化資產，建構國民與歷史之聯繫，發揚海洋國家之特質，並尊重聯合國保護水下文化資產公約與國際相關協議之精神，特制定本法」，據此欲涉及海域之水體、海床及其底土，以及陸域內自然形成水域、人工湖庫及運河下之水體、水底及其底土，所有可能干擾與破壞水下文化資產的開發行為，都須依照水下文化資產保存法第 9 條：「應先行調查所涉水域有無水下文化資產或疑似水下文化資產…」。

本文將依據「水域開發利用前水下文化資產調查及處理辦法」，介紹常見於海域工程中，針對工程場址範圍內的水下文化資產調查方法，包含技術上的高精度水深、側掃聲納、地層剖面、磁力探測等調查，以及人文上的歷史資料文獻、了解周圍區域人文歷史環境、歷史的演變等等，進而探查可能被埋覆的水下文化資產與其存在的真實性，且在必要的情況下，甚至安排專業潛水考古人員，進行水下攝影、水下考古，建構完備的水下遺跡之分布與保存方式，融合了工程與人文之間的交流。

中文關鍵字：水下文化資產保存法、填海造陸、水下考古

Stochastic groundwater flow and land subsidence modeling in heterogeneous hydrogeological models in Huwei Town, Yunlin County

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Taiwan High Speed Rail (THSR) is an important infrastructure in Taiwan. It passes through the Choushui-River Alluvial Fan (CRAF), where has suffered land subsidence. The distribution of hydrogeological material plays a major role on heterogeneous aquifer system responsed to groundwater flow and land subsidence. How to quantify the hydrogeological model uncertaitny in the heterogeneous aquifer system is another challenge. Therefore, this study adopted the transition probability/Markov chain model to conduct the realization of 3D heterogeneous hydrogeology. Huwei Town located in the southern CRAF was chosen as the study area. 46 boreholes, collected from Central Geological Survey, multi-layer compaction monitoring wells, and irrigation association, were used to construct the heterogeneous hydrogeological models. Based on the realization number assessment results, 36 realizations were generated based on honoring the geological data. Monte Carlo simulations for groundwater flow and land subsidence were conducted to discuss how hydrogeological models reflects the geological model uncertainty. The result showed that the coefficient of variations at the 90th percentile of the CDF is 0.295 in the subsidence simulation. An appropriate realization was selected as the representative hydrogeological model and use to calibrate the groundwater flow model. A transient model of groundwater flow and land subsidence in the period of 2015-2020 was conducted based on the observation data. Different pumping scenarios were employed to assess the long-term land subsidence. The assessment results showed that after 50% cese of pumping, land subsidence quantity is largely inproved, compared with the zero scenario. The proposed criterion for the selection of representative hydrogeological model can provide the best model for the simulations. The study results can be used for the safety assessment of THSR and a conscious groundwater management in Huwei Town, Yunlin County.

Keywords: groundwater flow, land subsidence, Markov Chain model, stochastic analysis, Choushui-River alluvial fan

對 1997 林肯大郡順向坡滑動與其結構物災損的新見解

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1997 年 8 月 18 日汐止林肯大郡社區北側順向坡在溫妮颱風期間發生滑動，滑動塊體直接衝擊下邊坡五樓建築群，同時造成 28 名人員罹難。過去針對本處順向坡滑動之肇因與機制雖已有諸多調查研究報告，然而對於順向坡滑動引致結構物損壞的行為，因缺乏有效的分析工具仍未有深入探討；另外，林肯大郡事件後在相同地質區中仍有嚴重順向坡災害發生，且近年利用高精度地形資料在研究範圍內圈繪出許多順向坡地形。因此本研究回顧歷史航空影像、災害前後地形測繪資料、災後調查報告與勘災影像，重新定位林肯大郡事件中順向坡滑動與結構群破壞之空間位置，並透過不同比例尺地質圖、LiDAR 陰影圖與補充地表地質調查，釐清區域尺度之地層岩性分布與場址尺度中節理線型之關係，進而建立三維地質模式。最後本研究利用離散元素分析方法允許元素分離、斷裂與位移之優勢，建立模擬順向坡與結構物互制行為之三維力學模型。模擬成果顯示災害過程中順向坡塊體將裂解形成二次滑動，且結構物因空間分布與配置方式將有不同程度的損害。未來將運用此數值模型量化分析順向坡滑動與衝擊結構物之動態過程，以提供針對順向坡破壞引致結構物損害之評估參考。

中文關鍵字：岩石邊坡、林肯大郡順向坡滑動、山崩與結構物互制、離散元素法分析、三維地質力學模型

多平面分析法於三維邊坡穩定性分析之研究–以霧鹿場址為例

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本文以台東縣霧鹿場址為例，採用 SoilVision 軟體中的 Multi-Plane Analysis (簡稱 MPA) 分析方法，透過極限平衡法進行多平面分析，用以探討區域尺度之邊坡穩定性。霧鹿場址的分析模型係利用研究區域內的鑽探及地物探勘資料，建出 AA’及 BB’剖面，並將此區域材料劃切為五層，分別為土壤層、舊崩積層、階地堆積層、剪裂帶、黑色片岩，再以內插方式，將二維剖面分層往第三維度方向延伸，以建立出分析所使用的三維模型。本文除依照觀測水位資料，設定常時水位、高水位兩種分析情境外，並於常時水位加入地震力作用影響，作為第三種分析情境，藉此根據霧鹿場址於上述三種分析情境下之安全係數分布情況，進而探討霧鹿場址之安定性與易致災山崩熱區。

由三維模擬分析結果，得以初步評估霧鹿場址邊坡安全係數分布情況，因觀測期間水位變化不大，故常時水位及高水位情境差異較不明顯，分析成果皆顯示場址大致上處於穩定情況。但地震力的加入，使邊坡安全係數值大幅下降，於階地堆積層及舊崩積層區域穩定性相對較低，需多加留意。整體而言，透過 MPA 技術進行邊坡穩定性分析，能夠有效且快速瞭解邊坡的安全係數三維等值圖，讓研究者能視覺化感受研究區域內的安全係數分布狀態、易崩塌區域、塊體大小及運動方向，有利於研判易致災山崩熱區，並進行後續防減災對策之研擬。

中文關鍵字：大規模崩塌、情境模擬、多平面分析法、霧鹿場址

Developing modified Bi-viscosity model for studying the mudslide fluid dynamics

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This paper incorporates Bingham and bi-viscosity rheology models with the Navier–Stokes solver to simulate the dynamics and kinematics processes of slumps for tsunami generation. The rheology models are integrated into a computational fluid dynamics code, Splash3D, to solve the incompressible Navier–Stokes equations with volume of fluid surface tracking algorithm. The change between un-yield and yield phases of the slide material is controlled by the yield stress and yield strain rate in Bingham and bi-viscosity models, respectively. The integrated model is carefully validated by the theoretical results and laboratory data with good agreements. This validated model is then used to simulate the benchmark problem of the failure of the gypsum tailings dam in East Texas in 1966. The accuracy of predicted flood distances simulated by both models is about 73% of the observation data. To improve the prediction, a fixed large viscosity is introduced to describe the un-yield behavior of tailings material. The yield strain rate is obtained by comparing the simulated inundation boundary to the field data. This modified bi-viscosity model improves not only the accuracy of the spreading distance to about 97% but also the accuracy of the spreading width. The un-yield region in the modified bi-viscosity model is sturdier than that described in the Bingham model. However, once the tailing material yields, the material returns to the Bingham property. This model can be used to simulate landslide tsunamis.

Keywords: mudslide, Bingham, bi-viscus model, rheology, landslide tsunami, local scour

大規模崩塌的場址調查－以宜蘭縣大同鄉 D007 梵梵場址為例

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自 2009 莫拉克颱風挾帶的豪雨誘發台灣中南部多處崩塌，其中尤以小林村最為周知，大規模崩塌的崩塌機制與可能影響範圍成為重要議題。經濟部中央地質調查所利用 LiDAR 高精度數值地形資料資料圈繪全台潛在大規模崩塌範圍，為能釐清坡地之破壞機制選擇以宜蘭縣大同鄉 D007 梵梵潛在大規模崩塌地為本研究場址，本場址位於蘭陽溪西側，出露地層為四稜砂岩及廬山層板岩，而牛鬥斷層為經過本研究場址的主要地質構造。

本研究試圖以多期航照立體像對判釋梵梵地區近 40 年的地表地形變化及崩塌歷史，並蒐集近年坡地災害歷史，以釐清可能的崩塌範圍。地下地質部份則進行地質鑽探及地球物理探勘，鑽探部份共進行 4 孔，鑽孔深度自 70 公尺至 100 公尺不等，總進尺達 340 公尺，提供地下岩性、崩積層、岩層分布資訊；地電阻剖面探勘共 3 條，合計長度達 1300 公尺，可參考地下崩積層與岩層界限位置，以及可能破碎帶位置。最後統整遙測判釋結果、地下調查與地表地質調查結果，建立本場址地質模式、崩塌模式及推判本區的可能崩塌歷史。

中文關鍵字：大規模崩塌

多元測繪技術於山區公路易致災邊坡應用－以臺 20 線 178K+450~178K+819 路段為例

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近年來受氣候異常影響，強降雨頻率增高，南橫公路崩塌頻傳且規模漸趨擴大。而山區公路因常伴峽谷及溪流而行，邊坡陡峭人力不易抵達，故巡檢視角有限。若無法精確的獲取邊坡環境調查資訊，即無法有效的瞭解崩塌災害成因與風險，協助崩塌風險分級及管理，進而降低崩塌災害發生機率。

本文針對南橫公路 178K+450~178K+819 路段，藉由包含 UAV/UAS(無人飛行載具)、LiDAR(地面光達掃瞄)及大尺度 LiDAR(空載光達掃瞄)等多元尺度測繪技術設備，獲取高解析度地形樣貌與產製高精度三維數值地表模型。同時蒐集近五年高解析度衛星或航空影像圖資，準確掌握區域地形構造位置與變化範圍，並輔以 Coltop3D 軟體進行不連續面位態分析，進而評估該易致災邊坡路段崩塌風險分級及提出改善方案建議。

中文關鍵字：多元尺度測繪技術、無人飛行載具、光達掃瞄

Determination of platinum-group elements and Re–Os isotopes using ID-MC-ICP-MS and N-TIMS from a single digestion of geological samples

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A comprehensive method for the precise determination of Re and PGE (i.e., Os, Ir, Ru, Pt and Pd) concentrations as well as Re-Os isotopic compositions following Chu et al. (2015) is set up at IESAS in Taipei. About 2 g powder each sample were digested by the Carius tube method, and the Os was extracted by conventional CCl_4 method. The Re, Ir, Ru, Pt, and Pd were first subgroup separated from the matrix elements into Re-Ru, Ir-Pt, and Pd by a 2-ml anion exchange column. Subsequently, the Re-Ru was further purified by a secondary 0.25 ml anion exchange column to separate Re. The Pd and Ir-Pt were further successively purified by an Eichrom-LN column to completely remove Zr and Hf, respectively. Rhenium, Ir, Ru, Pt and Pd were individually measured by multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS) NuPlasma II, except for Os after microdistillation purification was analyzed by negative thermal ionization mass spectrometry (N-TIMS), Finnigan Triton TIMS, both instruments installed at IESAS. The measured Os isotopic ratios were corrected for mass fractionation using $^{192}Os/^{188}Os$ = 3.08271 after interference corrections and oxygen corrections using $^{18}O/^{16}O$ = 0.002045 and $^{17}O/^{16}O$ = 0.0003708 (Creaser et al. 1991). The in-run precisions for Os isotopic measurements were better than 0.3% (2 RSD). During the analytical session in this study, the $^{187}Os/^{188}Os$ ratio of DROsS reference material was 0.1609±1 (2σ, n=25) on nanogram-sized loads measured with Faraday cups and 0.1607±6 (2σ, n=11) on 3.5–175 pg-sized loads measured with the electron multiplier; both agreed well with the previously reported value (0.16092; Luguet et al., 2008).

Keywords: Re–Os isotopes, platinum-group elements, ID-MC-ICP-MS, N-TIMS

Improvement of U-Th dating by refining uranium isotopic measuring techniques on MC-ICP-MS

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Over the past decades, the development of speleothem U-Th (^{238}U-^{234}U-^{230}Th) dating techniques on multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS) has shed light for precisely reconstructing paleoenvironmental records back to 600 thousand years ago (ka). However, there are still two difficulties to build precise chronology for speleothem-based paleo-records with age >500 kyr. (1) For most 100s-kyr-old carbonates with only 100-200-ppb U, to determine precise ages is a challenge and a large sample size > 1-2 g is required. (2) Even for sample with high ppm-level U, it is difficult to apply U-Th dating to material with age older than 500 kyr, mostly hindered by the current analytical limitation of ±0.2-0.4‰ (2σ) on $^{234}U/^{238}U$. To measure precise $^{234}U/^{238}U$ ratio on a Thermo-Scientific Neptune MC-ICP-MS, we developed two new protocols with 2-sigma external errors of ±0.7‰ for 0.5 g carbonate with 100-200-ppb uranium and of ±0.1-0.2‰ for 0.5 g carbonate with 1-2-ppm uranium. Dynamic jumping modes with Faraday cups and a secondary electron multiplier were designed. The determined 2-sigma age errors are ±1 kyr at 400 ka, ±3 kyr at 500 ka, ±5 kyr at 600 ka, ±10 kyr at 700 ka and ±20 kyr at 800 ka. The refined isotopic techniques offer the possible extension of speleothem-based proxy records to 800 ka.

Keywords: U-Th dating, U isotope measurement

In-situ LA-MC-ICPMS Si isotopic measurement for meteorites and terrestrial samples

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In-situ laser ablation multiple-collector inductively-coupled-plasma mass spectrometry (LA-MC-ICPMS) for Si isotopic measurement has been set up at the Institute of Earth Sciences, Academia Sinica, in order to test the possibility of using Si isotopes to search for Ca-Al-rich inclusions (CAIs, the earliest condensates of the solar system) with fractionated unknown nuclear (FUN) isotopic effects. With identical petrographic and chemical compositions as the other CAIs, FUN CAIs exhibit ‰ to sub-‰ levels of this FUN isotopic effects, e.g., O, Mg, Si, Ca, Ti, and some other elements, which makes it extremely difficult to look for and to study the petrogenesis of FUN CAIs. We have previously set up *in-situ* LA-MC-ICPMS for Mg isotopes to search for FUN CAIs with good success, and thus decided to also set up *in-situ* LA-MC-ICPMS Si isotopes for the task. A 193 nm Analyte G2 excimer laser is coupled with a Nu-Plasma II, with a typical spot size of 50 micron and 50 sec integration time for each analysis, we are able to reproduce precise and accurate Si isotopic compositions of BHVO-2, while using the NIST612 as a standard. Preliminary *in-situ* LA-MC-ICPMS Si isotopic data for Allende CAIs are also consistent with the published results. Besides meteorites, with proper matrix-matching standards, this set up can also apply to terrestrial samples.

Keywords: LA-MC-ICPMS, Si isotope, CAI, meteorite, isotopic composition

Reveal the devil in the detail: Nanometer-scale secondary ion mass spectrometry (Nano-SIMS)

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Nanometer-scale secondary ion mass spectrometry (NanoSIMS) has been used for frontier researches in many field including life, material, earth and planetary sciences. It can be used to study the spatial distributions of elements and stable isotope composition by very high spatial resolution (down to 50 nm per pixel) on the surface of solid samples. The only one NanoSIMS in Taiwan is setup in the core laboratory of interdisciplinary building of science and technology in Academia Sinica. It equips both cesium(Cs^+) and duoplasmatron oxygen(O^- or O_2^-) ion source that enable to analyze most metal and non-metal elements. And the trolley detectors (electron multicollector or faraday cup) can acquire signals of 7 specific isotopes simultaneously. Welcome to contact us for more collaborations.

Keywords: secondary ion mass spectrometry, stable isotope

國立臺灣師範大學地球科學系氬氬定年實驗室之分析儀器配置，實驗步驟流程之簡介

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年代的探索與追尋一直是地質學非常獨樹一格的研究面向。$^{40}Ar/^{39}Ar$ 定年法演伸自 K-Ar 定年法，是分析岩石礦物形成年代的方法之一。鉀元素廣泛存在於多種岩石與礦物之中，而氬氣則是惰性氣體，不易與其他化學物質反應，使得此兩種元素非常適合用來分析。固態鉀在經過中子照射之後，藉由同位素退變的關係，可轉化成氬，藉由高溫氣化或雷射燒熔的方式，將礦物與岩石中的氬氣釋放出來，進而量測岩石或礦物的「絕對年代」。國立臺灣師範大學地球科學系的氬氬定年實驗室承襲於過去國立臺灣大學地質學系的氬氬定年實驗室。共有三套質譜儀分別搭配可階段加溫式高溫爐，CO_2 雷射與 193 nm 準分子雷射，並於 2017 年移交至師大。階段加溫定年系統：此系統以 VG1200S 質譜儀為分析主體，搭配雙真空，可升溫至 1600ºC Mo 高溫爐與超真空樣本腔為採樣系統，採樣系統與質譜儀間則有一套超高真空不銹鋼全自動氣體純化系統。VG1200S 運用法拉第杯來偵測帶電粒子，通過測量 ^{40}Ar、^{39}Ar、^{38}Ar、^{37}Ar 與 ^{36}Ar 的訊號而計算出樣本之年代。適用於年代老，變質或構造事件複雜之礦物與岩石。雷射燒熔定年系統：此系統以 VG3600 質譜儀為分析主體，搭配新銳 CO_2(二氧化碳)雷射並配合超真空樣本腔為採樣系統－可以連續或脈衝形式使用於單顆粒標本燒結定年及階段加溫分析之用。VG3600 運用法拉第杯與倍增管來偵測帶電粒子，由於倍增管的偵測靈敏度為法拉第杯的 100 倍，因此本分析系統適用於地質事件單一，年代年輕，樣本量小，但可能需要大量數量分析之礦物與岩石。雷射探針定年系統：此系統以 Nu Noblesse 質譜儀為主體，利用專利的聚焦設備進行同位素的多重接收，並配合 UP193-FX 準分子雷射與超真空樣本腔為採樣系統，可進行定點微區定年及單礦物燒熔定年實驗分析。此技術提供了一個直接量測礦物內氬同位素分布最方便直接的方法，進而可以求得礦物內的年代剖面。可進行構造、變質岩溫壓及年代之直接比對與連結。本實驗室所分析之礦物與全岩樣本之純化皆於師大地科之礦物分離實驗室進行，而後序之中子照射於清華大學水池式反應器（THOR）進行。並以 Fish Canyon Sanidine（28 Ma）及 MMhb-1 (519.8 Ma)為標準礦物與樣本共同照射。質譜儀之大氣校正值則依據 Lee 等人（2006）所提出的 $^{40}Ar/^{36}Ar = 298.5$。儀器控制軟體則有美國地質調查所所發展之 Ar AUTO 與台大原來之控制系統並行。數據分析與圖表輸出軟體則為美國地質調查所所發展之 ARAR*與 ISOPLOT。

中文關鍵字：氬 ^{39}-氬 ^{40}定年法、分析儀器、分析步驟

Triple oxygen isotope compositions of Taiwan precipitation

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In this report the results of the triple oxygen isotope compositions, including $\delta^{17}O$, $\delta^{18}O$, and ^{17}O excess defined by $\ln(\delta^{17}O+1) - 0.528 \times \ln(\delta^{18}O+1)$, of Taiwanese monsoon precipitation are presented. The samples are collected in Daliao (S. Taiwan), Yi-Lan (N. Taiwan), and Wuling (C. Taiwan), respectively, and are analyzed using Picarro L2140-i isotopic water analyzer (IWA). The analytical precisions of the IWA expressed as 1s for the laboratory standards are better than 0.018‰ for $\delta^{17}O$ and 0.028‰ for $\delta^{18}O$, respectively. Some critical hydro-climatological implications of $^{17}O_{excess}$ regarding Taiwan are briefly listed below: (1) Humidity conditions in the air mass source areas of summer and winter precipitation are similar. (2) Both summer and winter precipitating vapors are almost formed under isotopic equilibrium, but winter precipitating vapor encounter additional kinetic fractionation. (3) Most precipitations are significantly affected by secondary evaporation. Follow-up research is to establish the dual indicators of *d*-excess and ^{17}O-excess of water bodies in Taiwan as the basis for subsequent application research in hydrology and climate.

Keywords: ^{17}Oexcess, monsoon precipitation, Taiwan

利用原位動態拉曼串聯在線式質譜儀觀察含銅/二氧化鈦與一氧化碳反應之結構變化

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礦物的晶相會隨受到外界的溫度與壓力的影響，進而產生所謂的晶相轉變，可是礦物在自然環境中的晶相轉變則遠比我們所認知的更為複雜，尤其當有水氣介入或是在不同的氣體組成條件下，其變化的行為仍猶未可知。

在本研究中，我們利用質子流量控制器協助模擬煙道環境，並通入裝有含銅之二氧化鈦粉(Cu/TiO_2)末之反應器中(heating stage (Linkam))，利用原位動態拉曼光譜儀(Operando Raman)觀察 Cu/TiO_2材料隨著反應溫度上升與一氧化碳(CO)的催化行為模式，並將反應後之氣體利用在線式質譜儀觀察其變化情形，以利協助釐清反應過程中材料與反應氣體間的交互作用，此舉不僅可以建構可能的反應途徑與機制，更可以用於提升材料的反應性。

實驗結果顯示 CO 藉由 Cu/TiO_2催化氧化為二氧化碳，此過程中 TiO_2的結構隨溫度變化有明顯的拉伸情形，但並未改變其晶相，是由於反應過程中 TiO_2出現氧空缺，並由環境中的氧來補給。本研究藉由原位動態拉曼光譜有效的觀察到材料與反應過程之相關性，並有助於發展一氧化碳低溫去除裝置。

中文關鍵字：原位動態拉曼、在線式質譜儀

科技部地化儀器平台-大體積壓力機及現地高溫高壓拉曼

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成大礦物物理實驗室在科技部地化平台計畫及成功大學支持下，安置 1000 噸大體積壓力機及拉曼光譜儀。目前 1000 噸大體積壓力機做為提供高溫高壓的實驗環境來模擬地球內部環境合成地函樣品，以供不同的實驗研究。另一方面也提供不同領域,如材料、物理及化學，延伸「壓力」維度在合成/研究新穎材料。除了合成實驗，大體積壓力機也可用於一些現地高壓實驗如電阻量測。拉曼光譜儀提供物質快速鑑定便利及可以提供非破壞的檢測，這儀器在許多地質實驗室多有安置。我們藉拉曼光譜反映晶體結構的關係，也可在無 X 光單晶繞射儀裝置，對自型或半自型單晶的晶軸快速鑑定，應用在單晶物理性量測。也將拉曼光譜儀結合鑽石高壓砧和高溫加熱台，來研究物質在高溫高壓下的晶體動力學和相變行為的現地實驗。這些研究結果可用來探討化學成分和物質性質與其如何影響地球內部之行為或材料之物理性質。我們將在本會議介紹大體積壓力機及高溫、高壓拉曼光譜實驗及報告實驗結果應用。

中文關鍵字：大體積壓力機、拉曼、晶體動力學、相變

Evaluation of nano-particulate pressed pellet reference materials of igneous rocks by micro-X-ray fluorescence spectrometry

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Micro-X-ray fluorescence spectrometry offers a potentially efficient way of quantification of major and minor elements in rock samples. However, variables like accuracy, precision and lower limit of detection have not been widely addressed, hampering its direct application. In this study, I evaluate six nano-particulate pressed pellet reference materials of igneous rocks manufactured by myStandard GmbH, including OKUM (komatiite), BHVO-2 (basalt), BCR-2 (basalt), BIR-1 (basalt), GH (granite) and AC-E (granite), by bench-top micro-X-ray fluorescence spectrometry (Bruker M4 Tornado Plus). Analyses were performed with X-ray beam size of ~20 μm in a controlled vacuum by two different ways: (i) averaging >15 spots in a grid on the sample with measurement time of 120 seconds per spot, and (ii) averaging X-ray spectra collected over a rectangular area on the sample with measurement time of 20 milliseconds per pixel. X-ray intensity was converted to elemental concentration by fundamental parameter-based standardless quantification, and data obtained by both ways correlate very well. I also find that fundamental parameter-based standardless quantification is only accurate for some elements, as reported in recent investigations, with P_2O_5 showing the greatest discrepancy among the ten major oxides commonly reported for igneous rocks. Accuracy, however, could be improved by calibration based on the reference materials analyzed, as demonstrated by analysis of samples independently verified by conventional major element analysis. Precision, which is examined by deviation from the mean of the spot analyses noted above, is good for all reference materials analyzed, and lower limit of detection is found to be element-dependent. Overall, micro-X-ray fluorescence spectrometry is promising for rapid determination of major and some minor elements in igneous rocks, particularly when sample quantity is limited.

Keywords: micro-X-ray fluorescence, geochemistry, igneous rocks, pressed pellet, quantification

泥炭岩心 ^{14}C 定年以及地球化學指標問題

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泥炭岩心是重建古氣候和古環境以及研究碳循環的重要材料。儘管過去有研究建議泥炭岩心的定年樣本應該選用生長在空氣中（而非水面下的）的苔蘚，但實際上苔蘚很容易分解，在岩心中不易選到，要選到特定長在水面之上的苔蘚更是難上加難。因此，絕大多數泥炭定年是將混合植物殘體用於 ^{14}C 定年。通常泥炭 ^{14}C 定年結果基本符合年齡層序，一根幾米長的岩心用 4-5 個定年結果計算岩心柱年代。然而，在我們近幾年的研究中常常發現高密度泥炭岩心定年發生年齡倒序。同時，許多過去的泥炭同位素記錄都是採用總植物中提取的纖維素測量來重建古氣候和古環境。泥炭植物中不僅包括苔蘚、草本、木本三大類，而且每一類中又有多種不同種類的植物，其同位素值相差很大。古氣候和古環境指標是否能用這種混合植物的泥炭同位素記錄代表，是值得商榷的。為此，我們從中國長春哈尼和金川泥炭地獲得不同種類的泥炭植物進行 ^{14}C 定年、碳氮含量和 ^{13}C 測試，討論泥炭定年和指標問題。2018 年從哈尼泥炭地採集的 18 種現生不同植物包括 5 種苔蘚，5 種草本和 8 種木本。這些植物分析結果顯示，F^{14}C、N%、C%, C/N and ^{13}C (‰ VPDB)的平均值和標準偏差分別為 5 種苔蘚 1.0159±0.0082、0.90±0.10、44.39±1.41、49.5±4.5、-27.20±0.58；5 種草本 1.0104±0.0141、2.06±0.88、47.85±2.95、25.7±8.5、-21.18±5.26 和 8 種木本 1.0082±0.0092、2.52±0.98、53.34±2.10、25.0±12、-25.79±4.91。2018 年從金川泥炭地採集的 85 公分的岩心，在 0-1 公分處取 9 種不同植物樣本以及 35-36 公分處取 6 種不同植物樣本。同一層位的不同植物樣本的 ^{14}C 年齡可以相差幾百年。在表層的 9 種植物的 ^{14}C 年齡範圍從-1332±79 (現代)到 140±85 yr BP，而在 35-36 公分處 6 種植物的 ^{14}C 年齡範圍從 180±74 yr BP 到 611±106 yr BP。由此可見，泥炭 ^{14}C 定年並非很簡單，不同植物的 ^{13}C 值也變化很大，需要謹慎地對待泥炭定年和穩定同位素分析。本研究顯示，盡量不要選擇泥炭中 *Carex* seed、*Carex rhizome*、*Cyperaceae* root、*Carex angustior* Mac.、*Drosera rotundifolia Linn.*、*Potentilla fruticosa L.* 和 *Ericacese branch* 等進行 ^{14}C 定年。同時，因為岩心取樣時，容易將較粗大的草、木本植物從上層插到下層，應避免選擇這樣的植物定年。另外在每 0.5 米的岩心段落應該取上、中、下三層樣本定年。

中文關鍵字：泥炭、植物種類、^{14}C 定年、^{13}C、C/N

Two-end-member mixing in the fluids emitted from mud volcano Lei-Gong-Huo, Eastern Taiwan: Evidence from Sr isotopes

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Mud volcanoes are one of the most important conduits for deep seated materials to migrate upward in sedimentary basins, convergent margin, and subduction zones. Mud volcano Lei-Gong-Huo (MV LGH) is a unique mud volcano which is located on the mélange formation lying on the andesitic volcanic arc. Fluids emitted from 47 setalite mud volcanoes in MV LGH were sampled and measured their major, trace elements with $^{87}Sr/^{86}Sr$ ratios. Major elements of the fluids are Cl, Na, and Ca, which are distributed between 291 and 376 mM, 131 and 289 mM, and 48.9 and 313 mM, respectively. High content of B, Ba, Mn, and Sr with relative low concentration of S and alkalinity are also detected. Comparing with seawater, LGH fluids have lower Na/Cl, K/Cl, and Mg/Cl but higher Ca/Cl ratios, indicating water-rock interaction of igneous rock and paleo-seawater at source region. This interpretation has further supported by Sr isotopes, which show low value of $^{87}Sr/^{86}Sr$ ratio down to 0.70710. The result of spatial distribution showing strong negative correlation between Na, Ca concentration and Ca, $^{87}Sr/^{86}Sr$ ratios indicates two end-member mixing is the major chemical characteristic. The fluid interacts with igneous rock carrying high Ca, low Na and low $^{87}Sr/^{86}Sr$ ratio while those interact with sedimentary rock carrying low Ca, high Na and high $^{87}Sr/^{86}Sr$ ratio. The source from igneous region dominates eastern part of the mud volcanoes in LGH while sedimentary source dominates western part. Most mud volcanoes show mixing behavior between two sources. The most possible geolgical structure to perform the spatial distribution on the surface is the negative flower structure induced by a strike slip fault. In summary, fluids emitted from mud volcanoes in LGH are originated from two sources, which are water-rock interaction of paleoseater and igneous rock from the east and sedimentary rock from the west at depth, resulting from complex geologic background of mélange formation and migrating through the conduit provided by the fault.

Keywords: mud volcano, Mud volcano Lei-Gong-Huo, Sr isotopes

Linking the Wrangellia flood basalts to the Galápagos hotspot

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The Triassic volcanic rocks of Wrangellia erupted at an equatorial to tropical latitude that was within 3000 km of western North America. The mafic and ultramafic volcanic rocks are compositionally and isotopically similar to those of oceanic plateaux that were generated from a Pacific mantle plume-type source. The thermal conditions, estimated from the primitive rocks, indicate that it was a high temperature regime (TP > 1550°C) consistent with elevated temperatures expected for a mantle plume. The only active hotspot currently located near the equator of the eastern Pacific Ocean that was active during the Mesozoic and produced ultramafic volcanic rocks is the Galápagos hotspot. The calculated mantle potential temperatures, trace elemental ratios, and Sr-Nd-Pb isotopes of the Wrangellia volcanic rocks are within the range of those from the Caribbean Plateau and Galápagos Islands, and collectively have similar internal variability as the Hawaii-Emperor island chain. The paleogeographic constraints, thermal estimates, and geochemistry suggests that it is possible that the Galápagos hotspot generated the volcanic rocks of Wrangellia and the Caribbean plateau or, more broadly, that the eastern Pacific (Panthalassa) Ocean was a unique region where anomalously high thermal conditions either periodically or continually existed from ~230 Ma to the present day.

Keywords: Wrangellia, Triassic, Galápagos hotspot, Caribbean plateau, ultramafic volcanic rocks

Geochemical investigation of mafic–ultramafic rocks from the Archean Olondo greenstone belt on the Aldan Shield, Siberian Craton

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The Archean Olondo greenstone belt (OGB) is located in the Aldan shield, which is the largest basement of Siberia craton. Well-preserved abundant mafic-ultramafic rocks make the OGB unique to other greenstone belts worldwide. The ultramafic rocks are mainly dunites with minor serpentinites. They are highly refractory, showing U-shape Rare Earth element patterns with positive to negative Nb anomalies. Platinum Group Element chemistry suggests they are residual mantle phase. Re-Os isotope compositions yield mantle model age (TMA) of 2960-3020 Ma. These isotopic and geochemical features suggest that the OGB dunites are mantle residual after a high degree of partial melting (>30%) then interacted with subduction-related melt/fluid. The OGB mafic rocks (komatiitic and tholeiitic basalts) have been metamorphosed from greenschist to amphibolite facies. Komatiitic basalts are slightly depleted in both LREE and HREE, suggesting a garnet–bearing source. Tholeiitic basalts are divided into three groups: depleted, undepleted, and enriched tholeiites. The depleted group is proposed similar to that of modern N-MORB but lower trace-element abundance, whereas the enriched group is more like that of modern boninite. The undepleted group has flat patterns, close to the primitive mantle. The compositional variation of these mafic rocks is comparable to that of Suprasubduction Zone ophiolites. εNd(t) values of the OGB mafic rocks range from +0.1 to +3.9, with no variation of Nd isotope compositions among different rock types. The lower εNd values with negative Nb-Ta-Ti anomalies could result from either subduction component or crustal contamination. However, Nb depletion is also revealed in residual dunites, which are unable to be affected by crustal processes. These overall geochemical data suggest that plate– and plume–tectonic processes could be involved in the OGB formation and evolution during Mesoarchean. Therefore, typical modern plate tectonics are likely to operate at 3 Ga.

Keywords: Archean greenstone belt, plate tectonics, geochemistry, mafic-ultramafic rocks

Supercontinent breakup mechanisms inferred from the thermal state of Large Igneous Provinces

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The primary magma solutions and mantle potential temperatures (TP) determined for flood basalts of LIPs that are associated with Pangea and its breakup. Among the Pangean LIPs the Oslo rift, Permian Emeishan LIP, and Siberian trap are consistent with a mantle plume thermal regime. The early-Permian Himalayan LIP exhibit ambient mantle TP and consistent with melt derivation from a shallow mantle source. The Post-Pangean LIPs, however, exhibit complex TP relations, and such complexities in the mantle source can be correlated with the dispersal stages of Pangea. The TP estimates on 200 Ma. Central Atlantic Magmatic Province (CAMP) and Miocene Columbia River Basalt are consistent with non-plume sources and the slightly elevated TP relative to the ambient mantle is attributed to the process like continental insulation and subduction delamination. The Early Jurassic Karoo-Ferrar LIP, Early Cretaceous Etendeka LIP, and Paleocene North Atlantic LIP (NALIP) exhibit both mantle plume and ambient mantle thermal regimes. The TP estimates of Deccan LIP (DLIP) and Madagascar LIP are consistent with a mantle plume related origin. The mantle plume-related LIPs and the LIPs that exhibit both lithospheric and sub-lithospheric components point out that they were emplaced into an already thinned lithosphere. Despite the mantle plume origin, the plume-induced continental rifting is absent in the Pangean LIPs like Siberian trap and Emieshan. The LIPs like Himalayan, CAMP, and Columbia River Basalt Group exhibit significant melt generation and continental rifting without mantle plumes. The Karoo-Ferrar LIP, Etendeka LIP, and NALIP show evidence for prior thinned lithosphere and lithosphere-controlled rifting events before the onset of plume magmatism. We posit, based on the thermal state of the LIPs, that mantle plumes act as the source of thermal energy rather than the primary driving mechanism of supercontinent rifting, which is controlled by lithospheric processes.

Keywords: Large Igneous Province, mantle potential temperature, mantle plumes

Tectonic implications of Mesozoic magmatism to initiation of Cenozoic Basin Development within the passive South China Sea margin

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The South China Sea (SCS) is one of the most active exploration regions for oil and gas over the past decades. This marginal sea situated within three major tectonic plates of the Eurasian, Indo-Australian and Philippine plate that exhibited various types of plate boundaries and complex tectonic evolutions due to subsequent subduction and convergences of numerous micro blocks and accretionary prisms during the Cenozoic time. In order to decipher the evolution and their tectonic framework, correlation between the temporal and geographical distribution of Cenozoic magmatism, and the development histories of major basins within and surrounding the SCS were conducted. Four major tectonic episodes can be recognized. (Charvet) The SE ward younging trend of A type granite and high-K calc-alkaline magmatic rock in SE Asia during Paleogen indicated the initiation of continent extension by eastward retreating of subduction of the Pacific plate to Asia. This also induced episodic rifting within the basins along the Asia continental shelf NW of SCS marked by rift onset unconformities. The SCS begin to spread in N-S direction from the NE region along the E-W trending ridge (C11-7) around 34-33 Ma possibly response to southward slab pull during the subduction of proto-South China Sea oceanic crust, which is also marked by the beak up unconformity within surrounding basins. (3) The left lateral shearing activity of the Red River Shear zone (27~16 Ma) due to collision of India into Eurasia trigger a southward ridge jump event (C6b~5c) and the development of the SW sub-region of SCS. The clockwise rotation of Indochina accompanying the left-lateral shearing event induced asymmetric graben and half graben development within the basins west of the SCS. (4) The SCS seized spreading around 15.5 Ma as the Pacific sea plate continued subducted westward. However, this compressional setting reinforced the subsidence of basins to the maximum depth till Pliocene.

Keywords: South China Sea, Mesozoic magmatism, basin development, tectonic reconstruction

一件三角龍屬新頭骨標本的形態描述與初步分類

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自 19 世紀末的化石大戰（Bone Wars）開始，E.D. Cope 與 O.C. Marsh 兩人命名了上百種的恐龍。其中，最有名的恐龍就是在侏儸紀公園系列便風光亮相的三角龍屬（*Triceratops*），而且絕大多數的三角龍屬化石都出土於美國。然而，現今多數標本仍有保存不佳與部分缺失的問題。本研究描述一件挖掘自美國蒙大拿州地獄溪層（Hell Creek Formation）的三角龍屬新頭骨標本，並參考 Forster 於 1996 年根據數件三角龍屬標本所得到的形態統整，討論此新頭骨標本的分類地位。根據其頭骨縫合線、眶前角與鼻角的形態等差異，顯示本研究之頭骨標本同時具有 *T. horridus* 與 *T. prorsus* 之特徵，可能為新的三角龍屬物種，然而確立新種尚需進一步的分類學研究。此外，此新頭骨標本上有一些撞擊、爪痕等疑似受傷後癒合的記錄，透過未來的病理組織學與爪痕對比，此新頭骨標本可幫助古生物學家進一步瞭解三角龍屬過去與其它物種的交互作用與其生活型態。

中文關鍵字：病理組織學、侏儸紀公園、蒙大拿州、地獄溪層、爪痕

以魚耳石討論臺灣更新世以來大黃魚(*Larimichthys crocea*)成長速率與年齡結構之變化

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漁業活動所造成的海洋生態衝擊已明顯改變了魚類群聚構造以及不同物種內的生活史策略，但如何將之量化並評估其影響範圍仍是現今海洋保育、生態管理上重要的挑戰。硬骨魚類的耳石由於能夠長期保存在地層中，其外部形態不僅 能作為分類依據，亦可藉由定齡技術重建其生活史特徵，因此耳石是分析魚類在長時間尺度下受環境變遷壓力所產生生活史變化極有潛力的研究材料。本研究首先重建更新世之古魚類群聚構造，並針對數量豐富，但目前卻因漁業壓力導致野外瀕危之大黃魚(*Larimichthys crocea*)，由化石露頭、臺南科學園區新石器時代早期至鐵器時代考古遺址與現生族群耳石年齡成長及穩定性碳氧同位素分析，探討其族群結構及生活史自更新世以來，隨人類漁業壓力增加，如何出現生活史策略上年齡成長的改變。初步結果指出大黃魚的成長與過去有顯著差異的現象，推斷與漁業壓力逐漸增加有關。

中文關鍵字：嘉義牛埔、台南科學園區遺址、古生物學、碳氧同位素分析、魚類硬組織定齡學

墾丁石灰岩洞穴內鼠類化石之研究

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墾丁森林遊樂區一處石灰岩洞穴中發現大量陸相哺乳動物化石，該化石群落埋藏了以骨質為主的本體化石，未受明顯之風化作用，亦無被礦物置換或取代。本研究針對具有特定環境選擇偏好且數量眾多、繁衍速度快的小型嚙齒動物，透過臼齒形態特徵建立形態模型，並與現生種比對其中之差異。可用於比對之現生種，一為在臺灣一屬一種的高山田鼠（*Microtus kikuchii*）目前棲息於海拔兩千公尺以上的高山，其生理條件不適合生存於熱帶氣候，受限於高山島嶼之上，喜愛草原棲地。另一白腹鼠屬現有兩種，分別為分布於低海拔的刺鼠（*Niviventer coninga*）與高海拔的高山白腹鼠（*Niviventer culturatus*），皆為森林型物種，但刺鼠可以適應森林邊緣過渡至草原的環境。化石標本經過形態描述對比以及量測數據統計判斷較接近高山田鼠與刺鼠，上述兩種化石之發現，推測臺灣南部更新世晚期之環境以草原為主，高山田鼠在當時尚存於恆春地區，直到氣候變遷，競爭失利的牠們才播遷至高山地區。

中文關鍵字：形態學、墾丁、石灰岩洞穴、囓齒目、化石

Fossil scleractinian community in Taiwan

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Taiwanese reefs are among the most diverse marine ecosystems on earth, hosting 558 scleractinian species and over 1400 reef fish species. However, the multiple anthropogenic pressures along with the highly active typhoon regime and recurrent heat stress anomalies have induced major local degradations of the reefs. While modern Taiwanese reef biota have been relatively well characterized, little is known on their past long-term evolutionary trajectory which led to the diversification of this particularly highly diverse scleractinian coral communities. Furthermore, there is an important scarcity in research investigating functional aspects of Taiwan's fossil reefs. Individual coral fossils from diverse locations in the island have been reported since the 1940s. However, specimens and reports are scatter in diverse organizations and nearly all of them are not available online. We aim to inventory the existing information on fossil corals and, further identify potential spatial and temporal knowledge gaps to reconstruct, at geological scale, the development of the scleractinian coral communities in Taiwan. Here, using our recent find on late Miocene *Dendrophyllia* specimens in northern Taiwan as an example, we demonstrate the fact that fossil corals are highly underrepresented to the regional paleontological community. In addition, our project aims to investigate past functioning of coral reef ecosystems in Taiwan by extending the specimen descriptions to the other taxonomic groups associated with fossil corals. Ultimately, with this knowledge, we will be able to better predict coral reef's survival capacities under the ongoing climate change and anthropogenic pressures.

Keywords: paleo-ecology, coral reef, fossil scleractinian diversity, Taiwan

Investigation of the stiffness of dinosaur eggs and the feasibility in contact-incubation in the aspect of mechanics

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Extant avian egg may be regarded as a naturally perfect design. It has to be fragile enough to let the chick out, meanwhile, it has to be stiff enough to bear the load induced by its parents during contact incubation. In our previous work, we studied the eggshells of over 1000 avian species, and defined a dimensionless number *C* (also called C number) to quantify the shell stiffness across a wide range of egg size. We found that C number was largely constant among Aves. The lowest limit of contact-incubation was also defined in the aforementioned study. In this paper, we applied the same method to fossil dinosaur eggs to analyze if contact incubation is possible for these dinosaurs. Our finite element analysis allows us to create egg models in the computer and simulates how the eggs deform and break under the contact-incubation scenario. We focus on the clutch specimens with relatively better preservation (such as troodontid and oviraptorosaurian clutches). Our study may shed new light on the incubation behavior of non-avian dinosaurs and the evolution of contact incubation of amniote eggs.

Keywords: dinosaur egg, eggshell, dimensionless number, contact-incubation

臺灣南部晚更新世金鯛(鯛形目鯛科)之化石紀錄

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本研究針對恆春地區晚更新世發現之鯛魚結核化石進行形態描述與分類鑑定。化石樣本採集於恆春鎮頭溝里的溪溝中，層位屬於四溝層，由富含陸源矽質碎屑的泥質砂岩與海洋生物碎屑岩所組成，年代約在 9-14 萬年前。四溝層沉積環境屬於瀉湖至河口灣，水深約在 0 至 20 公尺間。此件鯛魚結核化石長約 21 公分，寬約 11.5 公分；魚體長約 15.8 公分，寬約 8.2 公分，出露面為原始風化面，出露骨骼多位於魚體左側，上下顎牙齒形態清楚，有利於後續鑑種辨識。本次研究透過牙齒形態學與臺灣現生所有鯛科魚類比較分析，發現其與現生鯛形目鯛科的金鯛(*Chrysophrys auratus*)相同，為臺灣首次化石記錄。此標本目前典藏於中央研究院生物多樣性博物館，館藏編號為：ASIZF0100141。

中文關鍵字：齒列、牙齒形態、魚化石、結核、化石紀錄分析、金鯛

Late Miocene otoliths from northern Taiwan: insights into the rarely known Neogene coastal fish community of the subtropical northwest Pacific

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Knowledge of Neogene fish diversity in Taiwan is extremely limited. In this paper, we present a collection of 1716 fish otoliths recovered from the late Miocene lower-most Kueichulin Formation along the Dahan River in Shulin, New Taipei City; the collection provides insights into the past fish fauna of the subtropical northwest Pacific. The abundance and density of otoliths vary across the sites. Although the preservation of samples is considerably limited, our sample coverage is sufficient and reveals the presence of at least 34 otolith-based taxa belonging to 13 families. Four new species are introduced: *Larimichthys koae* sp. nov., *Nibea chaoi* sp. nov., *Taosciaena jiangi* sp. nov., and *T. hui* sp. nov. The assemblage is dominated by otoliths of Sciaenidae, Gobiidae, and Soleidae. Among the earliest fossil records, this collection features a remarkable abundance of *Larimichthys* spp. All otolith samples are indicative of a coastal shallow-water palaeoenvironment with muddy to sandy bottoms. Furthermore, the fish assemblages were perhaps adjacent to a river mouth. We hypothesize that the differences in the taxonomic composition between the Shulin assemblage and modern fauna are mainly chronological and evolutionary, and a mild turnover of certain lineages has occurred since the Miocene.

Keywords: Kueichulin Formation, palaeodiversity, taxonomy, *Larimichthys*, Sciaenidae, palaeoecology

First report of ichnogenus *Phymatoderma* from Miocene Taliao Formation (NE Taiwan): Systematic ichnology, behavioral ecology and paleoenvironmental linkages

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In the Northeast Coast of Taiwan, the ichnogenus *Phymatoderma* is first reported in the yellowish sandstone units of the Yehliu Member, Miocene Taliao Formation. In order to unravel its ichnological identity, ethology and its linkage to paleoenvironment, several different methods including overall observation (field and hand specimen), profile sectioning, thin section, micro-CT scanning and X-ray diffraction analysis are implemented. Interestingly, despite the trace being found within shoreface environment along with other *Skolithos* ichnofacies-trace fossils, the morphological analyses show that the trace fossil strongly resembles the ichnogenus *Phymatoderma*, which is previously considered to only appear in deeper marine environments (outer shelf/inner slope; *Zoophycus* ichnofacies). In terms of the ethology, some adaptations to the shoreface environment are presented, including densely packed pelletal active fillings and the lined wall in central shaft. Furthermore, the goethite which was found in the pelletal active fillings has implications for the possible diet of the trace maker. The result reveals not only the diversified ancient iconological activities but also the appearance of deep-sea trace fossil in shallow marine environment. Moreover, it implies that the appearance of Phymatoderma is not substantially controlled by the energy level, food resources, oxygen level and substrate stability behind the outer shelf/inner slope environment, but by other unknown environmental factors.

Keywords: *Phymatoderma*, northeast coast, Miocene Taliao Formation, shoreface, trace fossil, Taiwan

Stereomic microstructures of *Scaphechinus mirabilis* from Pleistocene strata in western Taiwan

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Problem: Stereomic microstructures known as stereom are the fundamental building blocks of echinoderm ossicles and they are key features to interpret the function(s) of echinoderm ossicles since Cambrian (~541 Ma). Stereom consists of three-dimensional mesh of trabeculae filled with interconnecting pores. Trabeculae is composed of high-magnesium calcite which behaves as a single crystal in each ossicle. Stereom studies are crucial to understand the phylogeny, growth and soft tissue of Echinoidea. Fossil echinoids from Taiwan have been studied for decades and many impressive collections are housed in both public and private museums in Taiwan, but no report of fossil stereom before.

Goal: The main purpose of this study is to document and report the fossil stereom preservation of a fossil clypeasteroid *Scaphechinus mirabilis* recovered from the Pleistocene strata in the western Taiwan. To understand better the stereom preservation of *S. mirabilis*, a total of 971 specimens deposited at the Department of Geosciences, National Taiwan University (NTUG) were examined. An additional 572 specimens were studied also.

Methods: Well-preserved specimens were prepared for thin sections, allowing interpretations of stereom types under polarized light microscope (PLM). Under PLM, echinoid ossicles boundaries can be recognized easily with open nicol and cross nicol settings. In order to enhance the contrast, an accessory plate (gypsum plate in this case) was inserted. Modern specimens of *S. mirabilis* from Japan were studied also under scanning electron microscope (SEM) for comparison.

Result: A total of 65 well-preserved fossil specimens and one modern sample were selected for making thin sections. Among the 86 thin sections, 68 sections were prepared and cut through the bilateral symmetry, and the other 18 thin sections were cut through different regions of the test, including apical system, petaloid, and interambulacral areas. Types of stereom and the associated tissues are determined by calculating the pore size and minimum thickness of trabeculae. Under SEM, tubercles of modern S. mirabilis can be subdivided into six regions. Our data show that plate boundaries, growth lines and stereom are clear and identifiable under PLM.

Remark: Dominant types of stereom include labyrinthic, rectilinear and galleried stereom. The average coarseness of tubercle boss is 10.9 μm, and the trabecular thickness is 12.3 μm. The porosity of tubercle boss is 0.89. The average coarseness of

tubercle areole is 18.6 μm, and the trabecular thickness is 10.2 μm. The porosity of tubercle areole is 1.8. On the oral-plate, some stronger radial trabecules penetrate into the adjacent plate in order to strengthen the connection in plates. The average trabecular thickness of this soild stereom spikes is 20.3 μm.

Keywords: Paleontology and stratigraphy, Stereom, Echinodermata, Sand dollars, Toukoshan Formation

Application of geometric morphometric methodologies to assess convergence in discoidal morphology in the sand dollar genera Dendraster and Arachnoides occurring from geographically isolated regions

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Clypeasteroids, sand dollars, have obtained a unique discoidal perimeter morphology along the curvature or ambitus. This distinctive flattened and rounded morphology appears adaptive to their shallow water life habitat, implying importance in the evolution of this trait. Currently, there is little understanding on how this morphology was obtained within some clypeasteroids. This study uses geometric morphometrics to examine fossil clypeasteroid specimens of *Dendraster ashleyi* from the western United States and compares with extant *Arachnoides placenta* material from Taiwan. The goals of this analysis are: 1) To quantify morphological, ontogenetic, and developmental variation for the examined clypeasteroid genera; 2) To quantify how discoidal morphology is developed in the examined genera; 3) To quantify lateral and posterior morphological variation for the examined genera; and 4) Examining how regional endemicity and geographic isolation may effect morphological, developmental, and ontogenetic variation in Clypeasteroids.

This analysis forms the foundation for quantifying how this distinctive discoidal morphology evolved by assessing morphological variation and comparing developmental ontogeny between different clypeasteroids. Results demonstrate strong morphological variation and ontogenetic controls in the aboral/oral surfaces for ambitus and curvature change. Other examined morphologic features like the petaloid structures and the lateral and posterior profiles do not demonstrate apparent ontogenetic trends. Explanations for these trends includes interspecific variation or morphological variation controlled by environmental factors. Lastly, the results demonstrate the utility of geometric morphometric methods for assessing morphological and evolutionary questions within clypeasteroids. This work builds a foundation for broader study of the development of discoidal morphologies within clypeasteroids and their morphological and evolutionary history.

Keywords: *Clypeasteroida*, ontogeny, landmarks, Taiwan, paleobiogeography

Generic-level identification of *Astriclypeidae* based on onsite incomplete specimens from Yehliu Geopark, Taiwan

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Problem: Yehliu Geopark is famous with its Queen's Head made out of Miocene fossiliferous sandstone. Based on previous studies, there are two distinct forms of fossil echinoids with lunules: *Astriclypeus* sp. and *Echinodiscus* sp. Although they can be distinguished easily based on the number of lunules if complete, they are difficult to tell apart when they are disarticulate and fragmentary. In addition, fossils are located in national park, thus, all studies have to be done on site. Thus, it is hard to access the ecologic interaction between the two genera.

Goal: The main purpose of this study is developed a method to test if we can distinguish the two genera apart based on disarticulated specimens on site. The main advantage is that there are numerous specimens available to be tested and measurements with good statistical supports can be obtained.

Method: Landmark analysis is a great tool that can be used to understand the variations in different organismal factors based on morphology. Hence, it can reveal information about the evolutionary and biological processes as well as the morphological deviations. The first attempt is to take capture good digital images with scales, then perform landmark analyses with them afterward.

Result: Three and seven landmark points were taken from each specimen image. A total of 55 specimens, including both Astriclypeus and Echinodiscus genera, were examined for the study. The results of the three landmark point data set reveal generic level distinct clustering of data during the principal component analysis (PCA) for the two possible genera present, which are Astriclypeus and Echinodiscus of the Astriclypeidae family. A much similar trend with distinct clusters for the two different genera was displayed even in the results of the seven landmark point data set.

Remark: This study shows that the landmark analysis can be used efficiently for a generic level identification despite the specimen incompleteness, and the minimum number of landmark points. Hence this analysis could also be applicable for broader population studies in more likely settings. In addition, ratio measurements with a digital calibrator were made and will be analysed with PCA method for comparison.

Keywords: paleontology and stratigraphy, *Echinodermata*, *Echinoidea*, *Astriclypeidae*, landmark analysis, PCA

臺南曾文溪剖面六重溪層的沉積環境及其構造意義

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臺灣位於歐亞大陸板塊與菲律賓海板塊交界處，碰撞造山使得臺灣島生成，並在造山帶西緣形成前陸盆地，而隨著造山帶持續向西演進，早先堆積在盆地中的沉積物便被擠壓與抬升。為了解前述自盆地下陷堆積與擠壓抬升的過程，本年度的自行研究選定臺南曾文溪烏山頭斷層下盤的澐水溪層、六重溪層與崁下寮層進行調查，期望藉由沉積相分析與磁生物地層資料，建置高解析的沉積地層柱以作為區域性對比的基礎，其中六重溪層可依沉積循環的特徵區分為六重溪層下段與上段。沉積相分析顯示澐水溪層、六重溪層及崁下寮層為一淺海大陸棚的沉積環境，可再次分出遠濱相、遠濱過渡帶相、濱面相、下蝕水道相以及海底峽谷相等 5 個沉積相。綜觀沉積相的垂直變化，指示澐水溪層由遠濱變淺至遠濱過渡帶相，六重溪層下段由遠濱與下蝕水道相向上變淺，轉以遠濱過渡帶與濱面相為主的上段。六重溪層上段由遠濱過渡帶至濱面相組成，上部被海底峽谷截切，並堆積海底峽谷相及其上覆的遠濱相沉積物。六重溪層的沉積循環週期約為 2.6-3.7 萬年，較此時期以 4.1 萬年週期主導的米蘭科維奇循環短，我們認為這可能與前陸盆地下陷或氣候循環之週期改變有關。

中文關鍵字：六重溪層、前陸盆地、烏山頭斷層、沉積環境

解密太平洋最大規模史前遺址

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現代人 (智人，*Homo sapiens*) 出走非洲後，最後抵達太平洋島嶼，幾千年來，發展出多樣的文化，現今許多海島上還保存許多史前遺蹟，例如復活節島上的巨石人像群、科斯雷島上的珊瑚金字塔等，而在密克羅尼西亞的波納佩島 (Pohnpei) 的東部海岸，則有一座稱為南馬都爾 (Nan Madol) 的廢棄古城，占地約 18 平方公里。由於它是以超過 100 座皆使用柱狀玄武岩和珊瑚砌造而成的人工島與運河所組成，因此也被暱稱為「太平洋的威尼斯」。這個人類在太平洋上最大規模的遺址，於 2016 年 7 月由聯合國教科文組織正式認定為世界文化遺產。

南馬都爾是紹德雷爾王朝 (Saudeleur Dynasty) 的首都，自 1965 年第一批碳十四定年報告出爐，迄今已累積超過 50 年的定年資料。據此推論該王朝可能興建於 1100-1200 年之間；並在 1500-1600 年間，因王朝被推翻，遭到棄用而荒廢。但是確切的建造和廢棄時間，學界則尚無定論。

為了解開南馬都爾的謎團，我們團隊在 2016 年 7 月和 2018 年 1 月，於 14 個有代表性的人工島上採集超過 150 個珊瑚標本，篩選 148 個新鮮標本進行鈾釷定年。結果顯示南馬都爾的建造經過兩期大型工程，第一期約在 900-1100 年之間，規模較大的第二期則約落在 1150-1350 年。3 個最年輕的標本年齡為 1403±4 年、1410±9 年、及 1411±3 年，顯示該城最後工程時間約在 15 世紀初。

國王居住的 Pahnkadira 島，測定的 11 個珊瑚年齡落在 930-1403 年之間，且分布狀況與所有標本的年齡特性一致；有 4 個標本在 930-1140 年之間，6 個標本集中在 1220-1340 年，最年輕的標本則是 1403±4 年。珊瑚鈾釷年齡與過去發表的遺址碳十四年齡分布相符，說明珊瑚年齡應可代表南馬都爾的歷史。

綜合分析後推論，該址的大規模建造約始於 10 世紀，比過去的認知早了 200 年，第二次大型工程在 12 世紀中葉到 14 世紀，持續約 200 多年。王朝崩落，南馬都爾被棄用的時間應在 15 世紀初期，比先前的推估早了 100-200 年。

中文關鍵字：太平洋的威尼斯、南馬都爾、鈾釷定年

左營舊城附近區域的古環境變遷研究

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國立成功大學考古學研究所在 2019 年的「高雄市左營區鳳山縣舊城(城內空間)考古調查發掘暨展示研究計畫」中，於小龜山西南側探坑裡發現清代鳳山舊城的夯土磚土城結構與上覆的人為擾動層間，有一厚度約半公尺的塊狀砂層，由此所採集的碳屑年代約為距今二百年前，故推論砂層的堆積年代應是在土城廢棄到新建磚石城之間。由於此砂層無明顯層理並夾有許多貝殼、碳屑和陶片碎塊，疑似為洪水事件所造成，並且也與南部地區盛傳的「加藤港」古海嘯事件年代相近，因此本研究透過地質鑽探取得的六支 8 公尺長岩芯，進行沉積特徵判釋、粒徑分析、micro XRF 分析、岩象分析和放射性碳十四定年等工作，解釋沉積環境變化及進行古環境指標分析，重建左營舊城區域的古環境變遷過程、解釋環境變遷的原因，進一步探討土城上覆的砂層來源、成因，以及討論是否和《台灣采訪冊》記載「加藤港暴漲」事件有關。

中文關鍵字：左營舊城、古環境變遷、加藤港暴漲

台北陽明山夢幻湖沉積物所紀錄的古湖沼變遷

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本研究分析於 2017 年鑽取於陽明山國家公園夢幻湖長達 300 公分沉積物內的花粉與炭屑紀錄，以重建該區古植群與古火災紀錄。根據岩性、放射性碳十四定年、與花粉含量結果推測，岩心下部 120 公分厚（180-300 公分）的沉積物為單次事件所堆積，可能與在 4360 cal BP 所發生的山崩或土石流事件有關。花粉以禾本科與莎草科花粉為主，顯示夢幻湖周圍自 4360 cal BP 以來為陸生草地植物與濕生草地植物相互演替，森林覆蓋度低。台灣水韭孢子在 1950-1530 cal BP 與近 1000 cal BP 連續存在於沉積物內，顯示當時穩定淺水溼地狀態。炭屑分析顯示較為頻繁火災主要出現在 4000 cal BP 之前與 2000 cal BP 以來，可能反應相對乾燥的氣候。

中文關鍵字：花粉、碳屑、古火災

重建一萬一千年來三星妹池之古氣候

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三星妹池位於宜蘭縣南澳鄉，為三星池旁的濕地。海拔 2100m，鄰近山地植群隨海拔高度變化明顯分帶。分別為高山植被帶（3500m 以上）、亞高山植被帶（3000~3500m）、上部山地植被帶（2000~3000m）、山地植被帶（1000~2000m）及下部山地植被帶等。由於百年來森林砍伐，目前三星妹池周圍森林樹種組成以人工造林的紅檜與扁柏為主。

本研究使用三星妹池中 2.5 公尺的沉積物，沉積物中花粉含量豐富，並擁有良好定年控制的 11 個 ^{14}C 定年資料以及 16 個 ^{210}Pb 的定年資料，顯示三星妹池為研究並分析過去一萬一千年來台灣東北部的環境變化的良好地點。其中 ^{14}C 定年使用日曆年校準曲線 INTCAL20，校正後的年代為 cal BP (0 cal BP=1950 AD)。花粉圖譜使用深度對應花粉百分比製作，花粉百分比則是陸生花粉總數為分母。

除了使用花粉資料以外，本研究也使用碳屑資料，根據前人研究，碳屑可以反應當地的火災事件，透過 CharAnalysis，可以將連續碳屑資料中的火災事件以及火災頻率計算出來。

使用 stratigraphically constrained cluster analysis 分析花粉百分比，可劃分為五個孢粉帶，其中 Zone 3 可分為兩個子帶。(Zone 5：11130-10420 cal BP、Zone 4：10420-7960 cal BP、Zone 3-B：7960-4000 cal BP、Zone 3-A：4000-3410 cal BP、Zone 2：3410-790 cal BP、Zone 1：790 cal BP−現代)。結果顯示，三星妹池沉積物內所保存花粉約有 42 種，其中木本植物以 *Alnus*、*Quercus*、*Tusga*、*Pinus*、*Trochodendron* 為常見樹種，草本植物與蕨類則以 *Cyperaceae*、*Poaceae*、*Monolete* 及 *Trilete* 最為常見。

本研究中使用主成分分析花粉百分比，可以得出 PC1 這個指標，代表溫度。根據主成分分析結果、各孢粉帶的組合以及碳屑分析的結果，可以得知在 11140 cal BP 後，氣溫逐漸降低，濕度一直都很低，且有火災事件的發生。直到 10400 cal BP，氣溫持續降低且溼度還是很低，在 9900 cal BP，達到最冷的時期，後持續變暖變濕到 7900 cal BP，而這段時間中都無火災事件。而 7900-4000 cal BP 持續了一段穩定且溫暖且潮濕的時期但這段期間內無火災事件。直到 4000 cal BP 有溫度急遽下降後急遽上升但濕度維持在高值，溫度較 4000 cal BP 之前高，且溼度依然很高，而這段期間內無火災事件。3410 cal BP 後氣溫維持穩定但濕度降至極低，此時火災事件頻率增加，而濕度則是 1620 cal BP 後開始維持定值。到了接近現代，火災事件有大幅增加的趨勢。

中文關鍵字：氣溫、濕度、花粉、孢粉分析、孢粉帶

滄海桑田話南科

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國立台灣史前文化博物館南科考古館為了配合南部科學園區成長管理及科技產業發展，評估台南園區未來發展擴建之可行性，依據文化資產保存法第 58 條規定，就目前評估擴建範圍進行地質土層調查，了解該區域有無相關考古遺址及文化歷史內涵，以作為園區發展擴建或籌設之參考依據及重要評估指標。因此受託在看西農場進行地質鑽探研究，除了了解是否地下保存史前文化相關文資或界定史前遺址的範圍，亦可藉鑽探土芯的研究重建看西農場的古環境變遷。本計畫共進行 100 孔岩芯鑽探，每孔深度 20 公尺，除了確認岩芯是否含有文物遺留進行文化遺址調查之外，也利用岩芯進行詳細的岩芯紀錄以及碳十四定年，配合全區已完成調查與發掘之史前遺址位置及文化內涵，探討南科地區 6 千年來古海岸變遷及其對史前文化人土地利用之影響。

中文關鍵字：古環境重建、考古遺址、南科園區

千年以來南海的巨波浪事件：澎湖海岸的地層記錄之三

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台灣海峽經常受到颱風與海嘯津波等巨波浪事件侵襲，但是缺乏足夠的歷史事件紀錄與災害描述，仍然難以有效評估溢淹規模與再發生間隔。有鑒於此，選取面向馬尼拉隱沒帶與南中國海的台灣海峽南部海岸，包括澎湖諸島與嘉南海岸平原，進行上部全新統海相事件地層學與沈積學的調查與分析，在本年度（三年期程第三年）已經首先完成中屯嶼、白沙嶼、西嶼的海岸露頭調查，並發現十一個含有海相事件堆積層的剖面。

在中屯嶼四個剖面共發現三層海相事件礫石層，白沙嶼六個剖面共發現五層海相事件礫石層，西嶼東南邊牛心山一個剖面發現一層海相事件礫石層。這些事件層多具有侵蝕底面、海相化石碎屑、圓形岩礫等特徵，並可分為二大類。一類事件層的高程都在 2 公尺以上，遠高於颱風暴潮水位，基質支持反映高濃度沈積物碎屑流的堆積作用，可能與海嘯作用比較相關，碳十四定年結果中，年代指向五個區間：五－六世紀、晚十三世紀、十五－十六世紀、十七－十八世紀、與二十世紀。另一類高程都在 2 公尺左右，接近於颱風暴潮水位，顆粒支持、具有層理，反映高濃度沈積物拖曳流的堆積作用，可能與颱風暴潮作用比較相關，碳十四年代指向二個區間：從十八－十九世紀、現代。

第一類疑似古海嘯堆積層可以比對前二年的研究成果，第二類疑似古颱風堆積層，也可以比對前二年的研究成果，呼應歷史與現代颱風的紀錄，包括澎湖廳志與中央氣象局。

中文關鍵字：颱風暴潮、海嘯、海相事件堆積層、上部全新統、中屯、白沙，
西嶼

Machine learning for facies classification: a new approach based on high-resolution element data from shallow marine sediment cores (East Frisian Wadden Sea, Germany)

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Sediment facies classification is an important first step to investigate depositional environments and provides primary information for further analyses and interpretations. The conventional method relies on sedimentological observations and experience, which include a macroscopical description of color and sediment structure, basic chemical and physical tests, and the evaluation of biological remains. Without time- and labor-consuming quantitative measurements, these classifications are not objective and not easy to re-evaluate. We propose high-resolution core scanning as an alternative of human observation and an automatic facies classification model that was trained by a subset of conventionally identified facies to minimize the disadvantages of standard core descriptions and facies classification. For this study, we make use of 92 sediment cores that have been retrieved from the coastal area around the island of Norderney, Germany. These sediments were classified by a group of sedimentologists into 12 facies, including marine (e.g. shoreface, channel and sand flat sediments) and terrestrial (e.g. peat and moraine deposit) sediments. Our approach is based on 2 mm resolution profiles of 12 elements from these sediment cores, acquired from an Itrax X-ray fluorescence (XRF) core scanner. These measurements are expected to correspond with human observations. Machine learning algorithms (Logistic regression, Random forest and Support vector machine) have been applied and cross-validation was used to determine the optimal model. The performance of the best model reaches 61% prediction accuracy in a test set, which is promising compared to a random guess from the same 12 facies. Two matrices (confusion matrix and conjunction matrix) are provided to understand the performance in more detail. Our result is a further step to introduce machine learning techniques into the field of geosciences and gives a broader coverage of sediment in diversity and quantity.

Keywords: sediment facies classification, Wadden Sea, μ-XRF core scanning, machine learning

山區裂隙岩層風化帶之水文地質特性

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台灣位於造山運動活躍的板塊交界處，山區的岩層多經板塊擠壓而破裂，這些破裂及風化帶常是山區地下水存在之處。本研究選定卑南溪流域上游支流之新武呂溪及大崙溪為研究地點，該區沿主流設置數個河川水位與流量測站、雨量站及地下水位站，提供了新武呂溪集水區域之降雨、河川水位、河川流量與地下水位變化情形之紀錄。此外，於大崙溪與新武呂溪之匯流處，建置了大崙水文地質試驗井場，井場內設有四口深度範圍介於 45 公尺至 150 公尺不等的試驗井。該區地表下崩積層深度範圍約小於 10 公尺，岩盤之岩性以片岩為主，依據岩芯資料，特定深度有明顯的裂隙構造存在，推測是地下水流動的主要通道。本研究分析大崙水文地質井場選定井位的長期地下水位資料，探討地下水位變化和集水區域降雨量之間的相關性，並透過抽水試驗，推估大崙水文地質試驗井場的水力參數，分析地下水在岩層風化帶或裂隙中的可能流動路徑。此外，針對新武呂溪流域的河川流量進行基流分離（baseflow separation），初步推估地下水對於河川之補注量，以增進對該區域的水文特性的瞭解。本研究嘗試使用多種水文資料探討山區裂隙岩層風化帶的地下水變化，建立中、小尺度的高山水文地質特性。

中文關鍵字：高山水文地質、地下水、抽水試驗、基流分離、裂隙岩層

The fate of petrogenic organic carbon in Beinan River catchment

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Petrogenic organic carbon (OC_{petro}) had been regarded as non-degradable and excluded from carbon cycle due to its graphite-like structure. Recently, OC_{petro} was inferred to be oxidized by microbial activities in large river systems, hence contributing CO_2 to atmosphere. However, the fate of OC_{petro} in small mountainous river systems where fresh bedrocks rapidly expose to weathering front but with short transport distance is still uncertain. To provide additional constraints, Raman spectroscopy was applied to rocks, soils and river sediments in Beinan catchment and marine sediments alongside Taitung submarine canyon. The degree of graphitization of OC_{petro} was distinguished based on the peak metamorphic temperature versus total full widths (at half maximum). Data derived from bedrocks clustered mostly between lower- and mildly-graphitized level and some in highly-graphitized level. The graphitization degrees of suspended loads and most of bedloads were similar to bedrocks, indicating mechanical mixture of detritus without substantial alteration. However, data points from bedloads in the estuary and soil samples scattered towards disordered level. For marine sediments, the graphitization degrees of samples increase with the travel distance from land. Comparison of Raman parameters demonstrates the impact of long residence time on OC_{petro} in soils and bedload sediments in the estuary, causing degradation of graphitized OC_{petro}. Contrarily, disordered OC_{petro} is preferentially consumed during long transporting; therefore, graphitized OC_{petro} remains in marine sediments at distant location.

Keywords: petrogenic organic carbon, Raman spectroscopy, weathering process

卑南溪流域地下變質岩層破碎帶之化學風化作用

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化學風化為岩石與水的交互作用，得以調節大氣二氧化碳含量。過去關於化學風化的研究主要聚焦於大河系統，透過量測河水的溶質濃度，建立流域尺度的化學風化速率，並探討不同因素對風化速率的影響。除了近地表環境外，化學風化作用亦可能藉由地表水流經裂隙或破裂帶入滲，與地下岩石反應。然而透過河水反推的風化機制並無法解析風化作用進行的確實位置，更鮮有研究探討以變質岩為主之活動造山帶地下化學風化作用。

有鑑於此，本研究藉由大崙溪流域(卑南溪上游)鑽取的岩心，進行岩心產狀的觀察、淋溶試驗、岩石元素豐度的分析，探討於造山帶、片岩為主體的小河流域之地下化學風化作用。透過岩心產狀得知，岩性變化由淺至深依序為地表至 10 公尺深的土壤與崩積層、10 至 60 公尺區段屬黑色片岩夾雜多處厚度不等、破碎、未膠結、粒徑不一的岩屑構成的破碎帶、60 公尺以下以緻密綠色或矽質片岩為主。元素分析顯示破碎帶的總有機碳含量高於圍岩；由淋溶實驗溶質分析結果顯示 SO_4^{2-}是最主要的陰離子成分，破碎帶樣本平均濃度達 5.12± 4.5 mmol g^{-1}，為相鄰圍岩產率的 2 倍以上。破碎帶與圍岩的淋溶產生的陽離子組成有顯著差異，由 Ca^{2+}/N^{a+}和 Mg^{2+}/Na^{+}的關係圖顯示，圍岩產生的溶質多集中於矽酸鹽礦物風化的端成分，而破碎帶淋溶得到的溶質則介於矽酸鹽礦物與碳酸鹽礦物的端成分間。綜合上述，本研究推測大崙溪地下的風化作用主要由黃鐵礦氧化產生的硫酸根所驅動，又因構造作用形成地層的破碎帶，增加礦物與地下水的反應面積，由此可知地下破碎帶對化學風化作用有重要的貢獻，並影響碳循環的收支。

中文關鍵字：卑南溪、化學風化、硫酸根、破碎帶、變質岩

Global distribution of chemical weathering rate: potential shift from erosion and climate change

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Chemical weathering, which draws much attention due to its capacity of atmospheric CO_2 drawdown, exhibits a tight interplay between physical erosion and runoff, but its global distribution remains unclear due to its (de) coupling with physical erosion. Here we use data from 211 rivers globally and a modified hydrologic regulation model to quantitatively simulate global distributed SiO_2 yield. Modeling results infer that the sediment concentration of 100 mg L^{-1} could separate coupling between chemical weathering and physical erosion reasonably and applicably. Under climate scenarios, kinetically-limited weathering in high- and low-mountains account for 29.3 and 24.3% of the increased SiO_2 export, whereas supply-limited weathering in high- and low-mountains contribute 13.4 and 23.0%, respectively. Conclusively, kinetically-limited weathering in mountains predominately responds to SiO_2 increase under climate change, even solely enhanced by runoff; however, the chemical weathering in low-mountains, where both supply- and kinetically-limited weathering are accelerated simultaneously, are more efficiently responsible to climate change.

Keywords: chemical weathering, physical erosion, supply-limited, kinetically-limited, atmospheric CO_2 drawdown

Geochemical characteristics of chemical weathering and elemental cycle in a mountainous catchment in eastern Taiwan

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Chemical weathering plays a critical role in the global carbon cycle. A balance among silicate weathering, biospheric POC erosion, sulfide oxidation, petrogenic OC oxidation determines the atmospheric CO_2 fluctuation in different time scales. However, the contribution of each process is highly variable depending on climatic or tectonic forcings. As small rivers in active orogens across Asia and Oceania deliver solutes and sediments at a rate surpassing large rivers on the per-area basis, the reaction pathway of chemical weathering and elemental cycling remain poorly clarified. This study aims to investigate the spatial and temporal variations in patterns of chemical weathering along the Beinan river system in eastern Taiwan where fluxes of both carbon and sediment export are the largest in Taiwan. Analyses of river water collected from different tributaries yielded Ca^{2+}, SO_4^{2-} and dissolved inorganic carbon (DIC) as the major constitutes. In particular, SO_4^{2-} concentrations are two to sixteen times higher than the average world value. Dual isotopic compositions of sulfate combined with the solute pattern and geological occurrence indicated that the sulfate is primarily attributed to being produced from pyrite oxidation. While carbon isotopic compositions indicate multiple sources of DIC, partial pressures of CO_2 often exceed the atmospheric equilibrium saturation state. Elemental and isotopic compositions of suspended particle and bedload suggest the petrogenic OC may be dominant in most samples except for the upstream site. Using a computational approach, we demonstrate that the short-termed CO_2 efflux was correlated with the flux of pyrite-derived carbonate weathering with spatial and seasonal variations. Further examination is still wanted for discriminating biogenic and petrogenic organic carbon sources and their fates in such a mountainous catchment.

Keywords: chemical weathering, elemental cycle, mountainous catchment

Behavior of radiogenic and stable Sr isotopes of river water and groundwater collected from Hsinwulu River

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Traditional radiogenic Sr isotope is a robust tool as a tracer for water mass in the hydrosphere. However, the variation of stable Sr isotope in the surface water is presently considered controlling by the source, incongruent weathering, and secondary mineral precipitation. River water from main stream and major tributaries of Hsin-wu-lu River and groundwater were collected and measured their major constitution and dual Sr isotopes. The results of major elements indicate fresh upstream water with high sulfate, calcium, and sodium tributary (Da-Lun River). Ca/Na ratio also indicates a carbonate dominated river water at upstream and shifted to silicate dominated river water after converge with Da-Lun River. Radiogenic Sr isotopes ($^{87}Sr/^{86}Sr$) indicate that all tributaries has higher $^{87}Sr/^{86}Sr$ than main stream but only Da-Lun River is big enough to increase the main stream siginificantly. Groundwater in Site DL shows decreasing $^{87}Sr/^{86}Sr$ ratio with depth and deep groundwater has the lowest $^{87}Sr/^{86}Sr$ ratio among all samples. Stable Sr isotopes ($\delta^{88}Sr$) show relatively small variation, possible resulting from incongruent weathering and/or minor carbonate precipitation. The limited data indicates the complexity end member of river water in Hsinwulu River and more samples from springs, tributaries, and different seasons are needed to get better understanding of the catchment.

Keywords: Sr isotopes, chemical weathering, river water

井下原地深層地熱流體取樣設備：GTFSampler

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本團隊已成功研發一套井下原地(in-situ)深層地熱流體取樣設備，名為GTFSampler (Geothermal Fluid Sampler)，並建立流體分樣與組成分析流程。GTFSampler 主要由一個不鏽鋼取樣瓶與一組氣體驅動閥門(shut-in valve)所組成，並安裝在不鏽鋼保護護套中；氣體驅動閥門與不鏽鋼管連接，不鏽鋼管除了用來懸吊取樣器，另一個重要功能為由地表控制管內氣壓，來打開與關閉氣體驅動閥門，進行流體取樣；GTFSampler 另有搭配一支留點溫度計，以量測記錄井下最高溫度。GTFSampler 已於 2013-2014 在宜蘭清水地熱 IC-19 號井深度 800 m 處測試，進階改良版亦於 2020 年於清水 IC-13 號井深度 1100 m 處測試，以上測試皆成功取得原地地熱流體，並完成地化組成分析。為了要確認取出的原地深層地熱流體保留了位於該深度的特性，本團隊利用 IC-19 號井的地熱流體地化組成分析結果，來計算 800 m 取樣深度的理論熱力學平衡溫度，並與留點溫度計實際量測的溫度進行比對。比對結果顯示，清水 IC-19 號井在噴流狀態下 800 m 處的現地量測溫度落在約 190~198°C，而理論計算溫度則落在約 185~210°C，相符的結果證實了 GTFSampler 取樣地熱流體的代表性。測試結果另顯示在閉井狀態下無法獲得合理的理論平衡溫度，推測是閉井時井內流體所產生之自然對流，影響了該深度的地熱流體原始化學組成，故建議進行原地深層地熱流體取樣時，應在噴流狀態下進行。目前 GTFSampler 的最深成功取樣深度為 1100 m，應可推進到 2000 m 深，但限於目前所使用的 O-ring 耐溫限值，取樣環境溫度極限為 250°C。GTFSampler 除了應用在地熱資源開發，也可在一般溫度的井下進行深層流體原地取樣，應用的領域包括：二氧化碳地質封存、核廢料地質處置、地下水探勘等。

中文關鍵字：井下取樣、地熱流體、清水地熱

整合井測與震波逆推方法應用於查德礦區 A 區塊

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非洲查德礦區為本公司積極探勘、佐證可採蘊藏量的海外經營礦區，並已進入開發生產階段。本計畫主要研究礦區中的 A 區塊，根據先前已有的探勘資料及近期新鑽探佐證與生產井的結果，經由多礦物組成分析、岩石物理模擬、類神經網路模擬橫波、岩石物理模板等井測資料分析，並利用新鑽井之鑽遇地層深度與井測進行合成震波比對、震測重新解釋、震波逆推（包含重合前/後及確定性/隨機性）等方法，進行滾動式更新地質模式。並搭配探勘資料庫設計與建立，以增加油藏量評估的可信度，結果可作為查德礦區生產開發與探勘永續經營方針訂定之重要依據。

中文關鍵字：井測分析、震波逆推、岩石物理模擬

三維離散裂隙網路模擬－以大屯火山區為例

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地熱潛勢區的熱水儲集層大多為高孔隙率或是裂隙發達的岩層，上方則有能封存熱能的緻密岩體做為蓋層，熱水或高溫蒸氣往往經由斷層及裂隙通道進行傳輸遷移，當熱水(氣)傳遞至地表則成為地熱徵兆區；因此，如何透過地表及井下裂隙分布等有限的資訊，推測大範圍地下裂隙空間分布，作為後續地熱概念模式建置及潛能開發評估的參考，是地熱探勘的關鍵性工作之一。

離散裂隙網路(Discrete Fracture Network, DFN)模擬係針對特定空間範圍內，藉由統計方法分析地表及井下裂隙的參數特性，建立三維裂隙網路的空間分布。DFN 模型除了可滿足現地露頭及井下的裂隙特徵之外，更可將裂隙空間分布擴大至尚未進行鑽井的區域，亦可藉由剔除不連通的裂隙，僅就連通至地表的裂隙群及現有調查結果所推測的地下水流連通構造(如正斷層系統等)進行分析，對比於地表地下水出露位置或是地熱徵兆區，評估熱流可能的傳輸路徑。

大屯山地區共完成 12 處地表裂隙參數量測，並繪製相對應的位態極點投影圖及裂隙軌跡分布圖，其中裂隙位態經 K-S 檢定後均可使用費雪分布描述，地表露頭及井下分析的裂隙強度則可藉由理論方法的計算方式，將裂隙線強度及裂隙面強度轉換為裂隙體密度，並可藉由分析地表裂隙軌跡長度及大尺度地表線型判識成果，分析大屯火山區裂隙尺寸的冪方律函數。依照現有的裂隙軌跡長度計算的冪方律指數及相對應的裂隙位態、裂隙強度，分別建立磺嘴山及大磺嘴地區的 DFN 模型，模擬結果說明研究區域內主要仍為斷層或是其它大型導水構造主導地下水及熱流傳輸，裂隙面則代表除了主要通道之外連結至地表的次要通道，出露地表可能形成地熱徵兆區或是降水入滲的區域。

中文關鍵字：離散裂隙網路、裂隙參數、冪方律函數

Influences of stress variation on the evolution of 3D fracture system: An example in NE Taiwan Influences of stress variation on the evolution of 3D fracture system: An example in NE Taiwan

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Fractures can be nucleated and/or reactivated by appropriated stress state. It is well established that NE Taiwan has been experienced the tectonic evolution from oblique collision to backarc extension in the view of stress variation during late Cenozoic. In this study, we will verify whether fractures in NE Taiwan can be manipulated by the stress change along the NE coastline of Taiwan.

3D fracture maps and stress state are two essential elements in this experiment. We recognized 120 of 187 reliable fractures based on DEM analysis and interpretation and further calculated their attitudes. Stress inversion was conducted from focal mechanism data of 1991 to 2016. Inferred stress state can be divided into 3 domains with 12 cells from north to south. After evaluating the fracture instabilities with corresponded stress path, it is realized that surface fractures in DEM could be nucleated with the applied stress field in the evolution of the tectonic setting from the south to the north along the coastline area at NE Taiwan. We also examined the slip tendency to explore the reactivation tendency of nucleated surface fractures. The results confirmed the important role of the back-arc extension of Okinawa Trough opening to reactivate surface fractures in NE Taiwan. Therefore, correlation between 3D fracture map and stress state can afford vital applications in terms of the landslide, groundwater, site characteristics and scientific research issues.

Keywords: fracture instability, 3D fracture system, stress, NE Taiwan

The remaining exploration potential of onshore Taiwan as evidenced by the evolution of oil and gas discoveries in the Llanos basin, Colombia

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Onshore Taiwan exploration had enjoyed some major successes in the Chu-Miao area in the 1960s and early 1970s by exploiting deeper reservoir targets and drilling prominent anticlines defined mainly by surface mapping. This high degree of success began tapering off after the late 1970s, with just a few smaller fault trap and biogenic gas discoveries made south of the Peikang High. On the other hand, Llanos basin has been the most important oil producing basin in Colombia for decades where new discoveries have been made continuously since the 1960s.

When comparing exploration history of onshore Taiwan to the Llanos basin, one can notice that both places had started their exploration effort in a similar humble fashion. Subsequent development of new exploration concepts and implementation of modern technologies in the Llanos basin by various oil companies, however, have not progressed satisfactorily in Taiwan.

With further application of 3D seismic, depth imaging, dynamic petroleum system modeling, reservoir facies analysis, and directional and horizontal drilling, most of the successful plays in Llanos like sub-thrust duplex structures, subtle fault and stratigraphic traps, downthrown fault closures, can have good chance to be duplicated in Taiwan. Adding turbidite channel-fan and mud diapir plays existing in southern Taiwan but not in Llanos, exploring onshore Taiwan by testing high-potential but low-risk prospects is expected to produce significant amount of new hydrocarbon reserves.

Keywords: exploration history, exploration potential, Llanos basin, onshore Taiwan

中東碳酸鹽岩礦區封閉構造研究

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碳酸鹽岩儲集層在全世界的產油氣量佔 60%以上，本公司過去多著重於碎屑岩沈積環境的油氣探勘，對碳酸鹽岩石油系統與油氣探勘均缺乏相關經驗。因此，本研究計畫針對中東碳酸鹽岩礦區進行研究，分析礦區內二維與三維震測資料，並搭配井測資料，嘗試找出研究區域具有油氣潛能之封閉構造。期望藉由分析實際碳酸鹽岩礦區資料，增進碳酸鹽岩類型油氣探勘經驗。本研究先利用井測資料計算的合成震波與震測資料進行比對，找出目標地層在震測剖面所對應的訊號，藉以延伸解釋目標地層頂部構造圖。由震測剖面可知，震波訊號有明顯的側向變化，應是此區域存在許多小型礁體所造成。根據 K、M 和 B 三個三維測區與礦區東部二維測線之震測解釋結果，確認 K 測區之淺部地層有 2 個封閉，分別為背斜構造形成之四方圈合封閉與地層尖滅封閉；M 測區之深部地層有 2 個封閉，分別為深部斷層封閉及淺部背斜構造形成之四方圈合封閉；B 測區之深部地層有 3 個背斜構造形成之四方圈合封閉；礦區東部二維測線的淺部有 1 個背斜構造。除此之外，本研究也針對深部構造結合屬性分析，找出 3 個可能探勘標的。本研究分析的碳酸鹽岩封閉構造類型，可提供做為未來探勘之參考。

中文關鍵字：碳酸鹽岩、震測解釋、四方圈合、斷層封閉

Re-examine the active volcanoes in Taiwan

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Volcanic Hazards have been fitted into the Central Disaster Prevention and Response Council of the Central Emergency Operation Center (CEOC), which need to build up the warning system and emergent plans in 2018. It, thus, needs to know where the active volcano is for preventing volcanic disasters. Volcanologically, two criteria, the empirical and phenomenal have been used to define an active volcano. The former is a volcano having erupted during the last 10,000 yrs, while the latter is a magmatic plumbing system still being working underneath (Szakacs, 1994). Currently, two active volcanoes have been identified. One is the Tatun Volcano Group, while the other is the Kueishantao volcano. However, based on the geological information of inland and offshore of Taiwan, several potentially active volcanoes.have been recognized. They are located in the offshore islands and submarine of north and east Taiwan. Historically, four submarine eruptive events have been recorded in captain log, which occurred in 1853, 1854, 1867 and 1916. Meanwhile, three volcanic islands, the Pengchiahsu, Mienhuahsu and Huapinghsu in north Taiwan and one, the Hsialanyu in the southeast offshore may also be the active ones, based on the preliminary field surveys, occurrences and dating. However, they still study in detail for building up the warning system and emergent plans in the future.

Keywords: active volcano, volcanic hazard, Taiwan

溫泉水之微量元素分析

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溫泉水之地球化學研究是地熱流體探索的重要基礎，可提供區域的水文分布資訊—包括來源與傳輸；對於活躍的火山源(active volcanogenic)地熱區而言，則亦提供了岩漿源氣體的資訊，長期的溫泉水地化監測更是岩漿活動/氣體通道時空變化的重要證據；而上述地化研究首先需要的就是好的化學分析數據。本文即透過分析大屯火山區溫泉水的經驗，整理出溫泉水分析的流程與方法，分析項目包含主要元素與微量元素，微量元素包括 IA 族的 Rb, Cs、IIA 族的 Sr、Ba、IIIA~VIIA 的 B、Ga、Tl、Ge、Sn、Pb、As、Sb、Se，以及 B 族的 V、Cr、Co、Ni、Cu、Zn、Zr、Ag、Cd、Au 和稀土(REEs)元素，涵蓋的元素範圍很廣；透過光譜儀(e.g. ICP-OES)和質譜儀(e.g. ICP-MS)分析，擬定相關的 QA/QC(品管品保)程序，並依溫泉水特性做干擾的測試，以檢驗數據的正確性，訂定有效率的分析標準流程。

中文關鍵字：溫泉水、微量元素分析

非彈性應變回復法現地應力評估的統計分析與精進

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隨著科技水平不斷進步，為提升生活品質，人們對於交通網路建設、天然資源開採、廢棄物處置與空間開發及擴建等需求與日俱增。在這些工程發展的促使下，現地應力在工程及研究上相當重要的參數。現地應力不僅影響開發中結構物的穩定性，對於地下岩盤壓力、水文環境及對不同深淺層岩盤的開挖破壞行為強度控制有著相當關聯性，因此，近年來現地應力狀態的研究日趨重要及重視。現地應力測量有多種不同方法，如套鑽法、水力破裂和非彈性應變回復法等，其中又以非彈性應變回復法(Anelastic Strain Recovery，ASR)為目前的耗費成本較低、效率較高的現地應力測量方法(孫東生等人，2014)。ASR 法是利用地下深處岩石因應力解壓後所產生的應變回復來推算三維現地應力方向和規模的方法。

前人使用的非彈性應變回復分析程式是以 18 個應變計測量 9 個方向的回復正應變規模，重建三維應變張量，進行三維主應變場的演算，轉換成主應力方向與規模，但結果只獲得一組平均數值，並未分析各方向與規模的偏差量，以致無法提出可信的數據供工程單位參考使用。本研究預計進行原程式的改進，將原本 9 個方向改以 6 個獨立方向為一組單位，並於每個獨立方向使用 4 個應變計進行量測，運用抽樣的方式進行重複演算，將比對每一組結果之應力方向與規模的異同，完整地獲得統計意義與誤差範圍的結果。

統計分析方法之樣本取於臺東南橫大崙溪，深度 140 米之片岩樣本。ASR 初步初步分析結果顯示為非典型安德森斷層應力場形式。最大、次大和最小主應變之位態分別為 141.14˚/45.79˚E、36.22˚/14.05˚E 和 293.74˚/40.81˚W，水平最大應力的擠壓方向為西北-東南向，主應力由大到小分別為 3.66、2.22 和 2.06 MPa。葉理傾向和傾角分別為 296.18˚和 65.31˚，葉理面的法向量與三軸主應變相距較遠，推測本樣本可能沒受到葉理面力學異相性的影響。未來工作將會進行抽樣與統計分析，將這些新資料運用新的改良方式進行演算，得到較高可信度的應力場大小。冀望未來此新技術可以廣泛運用於各項工程開發與地質科學學術研究。

中文關鍵字：非彈性應變回復法、現地應力場

台灣瑞穗地區地熱探勘的初步進展與挑戰

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學術單位的研究報告指出，地熱資源在台灣非常豐富，且極具開發潛力。由於國內地熱蘊藏具開發之潛力且與地熱資源開發利用相關之法規、技術、環境等方面之發展日漸成熟，另能源白皮書預定在 2025 年時要達到地熱發電裝置容量 200MWe 之目標，倍速羅得股份有限公司(以下簡稱本公司)將配合政策積極開發國內地熱資源，期能以團隊之經驗、能力與專長合作投入地熱發電產業之發展。目前本公司於花蓮瑞穗地區已完成初步地質調查，並選定一合適場址進行鑽探調查。由於台灣東部地區之地熱模式主要係由地質構造所控制，因此針對斷層及裂隙的掌握是本區域開發的關鍵。於花蓮瑞穗地區，地層主要為玉里層，岩性主要屬黑色至灰色片岩偶夾石英岩脈。於本案基地有加星斷層通過，基地位於斷層破碎帶上，為地下之熱液提供良好的通道。

中文關鍵字：地熱、裂隙、斷層

大屯山地熱區之三維地電阻模型及其含義

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為瞭解大屯山地區的地熱地質構造，本研究於 2020 年進行了寬頻大地電磁探測，探測範圍擴大涵蓋西北側山腳斷層及東南崁腳斷層，以便能獲取較完整的地熱構造空間資訊。本研究採取階段逆推程序及 nested modeling 技巧，獲得水平網格為 250 m 的三維地電阻模型，與空中磁測、地表線型、微震震源分布及既有鑽井礦物分布等資訊對比良好，故能作為後續建構地熱構造之基礎。由國際間類似地質區的大地電磁探測經驗及本區既有鑽井資訊，顯示大屯火山區下伏的沉積岩基盤內有侵入火成岩體存在，具有中和酸性熱液的功能。而安山岩體內電阻率接近 1 ohm-m 的區域可對應受偏中性熱水換質後富集的蒙脫石，是安山岩地熱田重要的指標黏土蓋層。依據三維地電阻模型，本研究共篩選出 8 處潛在地熱區，但若考量未來開發難易與國內地熱開發時程，則可進一步篩選出 5 處場址，可作為後續進一步精查的對象。

中文關鍵字：大屯山、地熱、大地電磁、三維地電阻模型、地熱構造

大屯火山群小油坑區域之無人機高解析度熱影像成果

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傳統熱影像儀多半用於軍事、防災、醫學及工程等用途；拜科技日益新穎所賜，熱影像儀已縮小至無人機可乘載之重量且解析度日趨精細，因此可以將熱影像儀結合無人機進行拍攝任務，再將獲取之熱影像進行建模分析，而我們所使用之熱影像儀也有結合可見光相機，執行任務時可同時獲取可見光影像與熱影像，在天氣狀況不同時，兩種影像可以互補。本研究探討無人機結合熱影像儀後，所生成之熱影像模型之用途。本研究使用無人機掛載熱影像儀進行拍攝。現場執行任務前要先布置航空標以利日後模型建置，但此處航空標與一般可見光影像的航空標有所不同，需在航空標上貼上鋁箔，因為鋁箔的放射率較低，才能在熱影像上明顯看到航空標位置。而熱影像儀的解析度較低，因此航線規劃上，相對於一般可見光影像需要較高的重疊率。任務完成後再回到室內使用軟體生成熱影像模型。本研究區域為陽明山國家公園的小油坑，小油坑位於七星山西北麓，海拔約805 公尺，此研究區域因後火山作用，有許多的噴氣孔形成，這些噴氣孔終年有硫氣與蒸氣噴出且維持一定的溫度，因此選擇小油坑作為無人機與熱影像測試區塊。本研究使用高解析度熱影像儀搭配無人機近距離拍攝可產製出高解析度熱影像模型，從熱影像模型中可以得知噴氣孔的溫度，未來可由熱通量計算進而估略出該區塊之地熱能，期許此方法有助於未來能源開採的前期作業。

中文關鍵字：無人機、熱影像、小油坑區域

大屯山硫磺子坪地熱發電示範區地熱潛能調查分析

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根據以往學研單位估計全台地熱潛能區的調查相關研究顯示，大屯火山地區地熱潛能高達 514 MW。政府再生能源的既定政策目前設定 2025 年，達成地熱發電累積設置 200MWe 的目標。爰此，能源局在 2018 年積極推動新北市硫磺子坪地熱發電示範區計畫案招商，此示範案由結元能源開發股份有限公司(結元公司)奉核執行，示範場址位於陽明山國家公園東北側的硫磺子坪地區(LHZP site)，大致於磺嘴火山錐北側靠近天籟溫泉區。結元公司於 2019 年起啟動硫磺子坪地熱發電示範區內一系列場址調查研究(簡稱探勘階段)，項目包含地電阻率影像剖面調查(RIP)、兩口淺部調查井鑽探(S1 井 80 米，L1 井 200 米)、岩屑取樣分析、地熱流體取樣分析等，並同時委託日本 GERD 公司於場址周邊地區進行大地電磁(MT)分析調查，分析範圍長寬各約 4 公里。

本文概述本案探勘階段，調查試驗與 MT 分析成果的綜合研判。兩口淺部調查井鑽探岩屑分析結果顯示：四磺子坪地區的 S1 井淺部安山岩已受到強烈的熱水換質作用；硫磺子坪地區的 L1 井，較淺部局部裂隙發達處有明顯熱水換質作用，且熱水換質區段 pH 值相當低。根據 RIP 影像剖面、調查井水位，比較位於北側鄰近能源局委託工研院 2014 年所鑽地熱井(E303)的地質剖面與地下水面差異推測，硫磺子坪場址東側邊緣有一水文邊界。此外，從 MT 分析結果可推測海拔 300 公尺處，四磺子坪至硫磺子坪有一西北-東南走向的呈帶狀分布的低阻帶，初判為熱儲層之蓋岩(Cap rock)；海拔 100 公尺處，L1 井西北方有一高阻帶，推測可能為乾蒸氣聚集的區段。綜合各項資料推估，探勘地區熱源可能來自磺嘴山底下的岩漿庫。本文利用大地電磁試驗結果，以 USGS 體積評估法估算目標區(4x4 平方公里)熱儲層的總熱能，再以有效回收熱能轉換電能來評估發電潛能約為 24.38 MWe。

中文關鍵字：地熱發電、硫磺子坪、地電阻率影像剖面(RIP)、大地電磁(MT)

陽明山國家公園地區地熱開發可行性規劃

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台灣地區位於歐亞板塊與菲律賓海板塊相互碰撞的板塊邊緣，處於環太平洋島弧帶，火山與地震活動頻繁。主要的火山分布於北部的大屯火山群，有明顯的火山地形與地表地熱徵兆，加上特有的地理條件，成為陽明山國家公園內獨特的地質地形景觀。經由前人以各類探勘方法的評估研究，台灣北部大屯火山地區的地熱潛能可達 500 MWe 以上。依循政府能源發展綱領，為達成 2025 再生能源發電占比達 20%的政策，近年經濟部能源局已在大屯火山區的陽明山國家公園外圍，協同地方政府選擇適當的地熱潛能區，進行地熱發電示範廠區及其他地熱利用計畫的開發。有鑑於大屯火山區地熱潛能範圍仍有廣大區域分布在國家公園境內，為兼顧經濟發展與環境永續，順利推動綠色能源轉型，達成國家再生能源發展目標，可以思考並參照其他國家的做法，或許有條件的鬆綁陽明山國家公園內某些土地分區的天然資源開發使用規範，亦可進一步的由鑽探研究來了解並監測火山活動及環境指標，在最不影響生態環境的前提下來達成多贏的共識。我們針對在最低限度開放國家公園土地使用的前提下，預先分析地熱開發的可行性評估，套用有利探勘標的分析法則，將地底地質條件，人文環境保育規範，自然災害敏感度作為分析因子，製作數位圖層類別，使用前人的地熱潛能分布，加上陽明山國家公園的各級土地分區，以及過去的陽明山國家公園的地質災害敏感區分級調查及山崩地滑地質敏感區研究報告，以疊圖方式來檢視在陽明山國家公園內的潛在地熱探勘地點，待相關法令鬆綁，即可著手進行國家公園內的地熱探勘，利用天然地熱資源，亦可監測與研究火山相關活動，防患於未然。

中文關鍵字：地熱探勘、國家公園、人文法規、大屯火山群、有利探勘標的法

Petrel Reservoir Modeling – Integrated workflow on geothermal reservoir characterization

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The Petrel E&P software platform is the standard tool in the oil and gas industry, it brings various disciplines together, such as geosciences, reservoir engineering, production engineering, and drilling. This shared earth approach enables companies to standardize workflows from exploration to production, so they can make better decisions based on a clear understanding of both opportunities and risks. In the presentation, we are applying the integrated workflow from oil and gas to geothermal reservoir characterization. In the proposed workflow using Petrel, it allows the combination of all the geological and geophysical data to characterize the geothermal reservoir and create a 3D model to visualize all features of the hot water system.

Keywords: Petrel E&P software platform; 3D reservoir modeling; geothermal reservoir characterization

Wireline openhole logging for geothermal reservoir

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Schlumberger provide the advanced technology to reveal the geologic details in oil and gas industry. Wireline openhole logging deploying sensors to measure all aspects of the reservoir in real time. CPC Corporation, Taiwan adopted our wireline logging services into geothermal reservoir from 2018 to 2020.

We had provided several openhole logging services in geothermal reservoir. From PEX-HRLA-DSLT (triple-combo neutron, density, resistivity and slowness), FMI (Fullbore formation microimager), DSI (Dipole Shear Sonic Imager) to MAST (Multimode Array Sonic Tool, Sonic Scanner).

In the presentation, we are demonstrating the various data we acquired from wireline openhole logging in the reservoir. We provide the answers for informed decision making and risk reduction from precise and accurate downhole logging measurements. Understanding local and field-wide structure and variability helps to achieve optimal reservoir contact and guide well paths to avoid hazards. Combine with Petrel software, Schlumberger set an example for the exploration in geothermal reservoir.

Keywords: wireline openhole logging, geothermal reservoir

The magnetic inversion by using the velocity-based initial model

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Non-uniqueness is a problem encountered while imaging subsurface susceptibility by inverting magnetic field surveys. We propose a novel method to construct velocity-susceptibility initial models using Vp together with the Vp/Vs ratio from seismic tomography to improve the model which satisfies more information and better identifies locations of high-susceptibility materials. For comparison, two recovered susceptibility structures are derived from two distinct initials (homogeneous and velocity-susceptibility) models through the standard inversion process. Two profiles with the intense undulation of magnetic anomalies over sedimentary areas in central-west Taiwan and complex geological structures at the rim of the subduction zone in northeast Taiwan are used as examples to compare the results of the initial models. The inversion results suggest that the susceptibility structures from both models agree in terms of the location of the fault zones, specifically at depth < 10 km. Recovered susceptibility structures derived from the velocity-susceptibility initial model agree with the geological structure that reduces uncertainty at depth > 10 km. Consequently, the initial model with velocity constraints lowers the non-uniqueness associated with the inversion of magnetic anomalies.

Keywords: magnetic anomaly, geothermal energy, velocity tomography

A role of geothermal heat on energy conservation: Implications for Green (low-carbon) campus in Taiwan

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Energy policy includes production, conservation and storage, which the geothermal heat can play all of the roles. For example, the geothermal heats can construct a power plant for electricity supply, to build up heat pump for district heating and cooling on saving energy, and to store the energy underground for future utilization. The direct utilization of shallower geothermal energy, the heat pump is the most widely uses in the world, which may be up to over 70.32 GWt currently. It can be applied on district heating in high latitude, and on local cooling in low latitude. Based on the cooling experiments of heat pumps in tropical and subtropical countries, i.e. Vietnam, Thailand and Indonesia etc., the energy conservation of those testing can save the power up to 50%. Therefore, the International Energy Agency (IEA)-Geothermal promotes the direct uses of geothermal heat in last decade in the world. Taiwan is located in tropical and subtropical areas, which the average season temperatures are 28^{O}C and 16^{O}C in summer and winter, respectively. Based on the statistics of Taipower, the summer need more about 2.2 billion KWh extra-electricity monthly for cooling than winter. Meanwhile, the cooling system uses air as media and discharge heat out to street to induce the temperature up and phenomena of heat island in most Taiwan metropolitan cities. Moreover, the Executive Yuan announced to install air conditioners for all of the elemental and high schools in Taiwan that will increase the usages of electricity and power structures in the future. The heat pump for cooling may provide a solution for not only to save energy and reduce the electricity shortage, but also lower temperature and heat island of a city in Taiwan. Furthermore, the heat pump can also play a role on green (low carbon) campus of university or industrial parks, which is the world trend for reducing carbon emissions.

Keywords: geothermal energy, heat pump, Green campus, Taiwan

日月潭沉積物中的 Ca 指標顯示之自然災害與人類活動紀錄

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日月潭是 1934 年日治時期於臺灣建造的第一個水庫，也是主要的水力發電來源。在 1944-1945 年第二次世界大戰期間，發電廠曾遭遇美軍轟炸，接著又在 1999 年經歷 921 集集大地震的重創。本研究於 2016 年在日月潭鑽取湖泊沉積物岩芯，試圖從岩芯紀錄中尋覓這些天然災害或人類活動所留下的紀錄。首先我們在日月潭進行聲納震測底質剖面掃描，分析自 1934 年建壩之後的沉積物空間分佈，並決定鑽探岩芯的鑽取位置，然後以震盪岩芯採樣器取得 3 公尺以內的沉積物。我們使用 MSCL 分析磁感率、沉積物密度，也使用 X 光攝影、反射式可見光譜儀、X 光螢光掃描分析、X 光粉末繞射分析等方法，以了解沉積物中的組成變化和濁流層可能的位置。此外，定年方法採用沉積物的 ^{210}Pb 和 ^{137}Cs，以及有機碳採用 AMS^{14}C 等方法以求得沉積物年代。結果發現在颱風頻繁與水庫快速沉積的環境下，^{210}Pb 無法判斷沉積速率，僅有 ^{137}Cs 可以指示 1963 年的時間點。

對比沉積物中的黃色指標 b*高峰、X 光攝影影像指示的濁流層，與 ^{137}Cs 高峰點，顯示出較大的濁流層訊號恰巧為發生在 1963 年的 Gloria 颱風。此外，高解析度的 XRF 掃描結果，顯示 Ca 含量低點可以完整對應到 1934 年以來重大的颱風災害事件所形成的濁流層，而 Ca 含量高峰也可以指出日月潭水庫建造初期、第二次世界大戰重建與 921 大地震災後重建的水泥使用訊號。未來近代沉積物的研究或歷史紀錄對比，可以思考使用類似的方法或手段進行相關研究。

中文關鍵字：人類活動、災害、地震、颱風、XRF、沉積物

Marine evidence for Holocene flooding and climate change off SW Taiwan (EAGER core MD18-3548/MD18-3552)

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Taiwan, regularly affected by both climatic forcing (East Asian Monsoon, typhoons, and extreme climate/weather events) and tectonic origin (intense seismicity, and marine landslides), provides significant scientific topics and excellent material for testing past climate change and tectonic hypotheses. The EAGER's marine core MD18-3548/MD18-3552 (21.879°N; 119.953°E; water depth 1752 m) off SW Taiwan was investigated in order to reconstruct late Quaternary paleoceanographic changes and regional flooding events based on non-destructive technique. In contrast to traditional technique of stable oxygen isotope stratigraphy, the age model of core MD18-3552 was constructed using four AMS C^{14} dating and visible color reflectance data with/no MSCL physical properties. These extra-high sedimentation rates estimated for the top 16 m (equal to ~10 ka) could provide for clay mineral composition and associated paleoclimatic/paleoceanographic variations on centennial-to-millennial time scales. Besides, our results indicate that illite and goethite would represent a long-trend humid condition off SW Taiwan during the Holocene, which coincides with local insolation. The frequency of high illite would imply that heavy rainfall over SW Taiwan caused Holocene floodings. Moreover, we observed that Hematite existed large amplitude changes with ~1500 yr cyclical fluctuations, suggesting a plausible dynamic climate tele-connection between local process and extra-tropical forcing in the Holocene.

Keywords: EAGER cruise, off SW Taiwan, non-destructive technique, paleoceanographic changes, Holocene flooding events

中全新世早期台北盆地牡蠣的詳細 ^{14}C 定年以及氧碳同位素分析

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2002 年 3 月在臺北盆地東緣，位於台北市政府東側的新光三越臺北信義天地 A11 館基地開挖時，發現早-中全新世台北盆地的沉積地層中有大量的貝殼和牡蠣堆積。剖面地面的海拔高度為 10 米，從地面往下 9.5 米處採集的窗貝(Plancenta)用貝塔液閃法 ^{14}C 定年得到的年齡為 7640±60 yr BP。從地面往下 14.9 米處有一個 2 米見方的牡蠣礁體(oyster reef)，在此礁體中採集了一枚長約 40 公分的牡蠣殼。在此牡蠣殼上採集了 8 處樣品進行 AMS ^{14}C 定年，年齡範圍從 8130 ±200 yr BP 至 8435±155 yr BP。雖然定年精度無法分別年齡層序，但可以確定這個牡蠣礁的形成年齡是在 8130~8435 年前，比上層貝殼年齡要老 800 年左右。從 ^{14}C 定年結果看，從 8435 年前到 7600 年前台北盆地遭受海侵。由於牡蠣為鹹水生物，判斷海平面較長時間停留在剖面之上。在該牡蠣殼的頭部（最老部分）沿著生長軸在 5.5 公分內鑽取了 79 個粉末樣品，進行碳氧同位素分析。在這 5.5 公分內，氧同位素值變化範圍是-6.03‰ ~ -1.33‰ (VPDB)，顯示大約 4 年的變化；碳同位素值變化範圍是-2.21‰ ~ -0.31‰ (VPDB)。碳、氧同位素都指示該牡蠣礁體的生長環境是鹽度較高的海水環境。本研究結果將對描述台北盆地早-中全新世的歷史提供新的證據。

中文關鍵字：台北盆地、早-中全新世、牡蠣殼、碳十四定年、穩定同位素

上帝之子(女)在搗蛋：台灣西半部乾旱的潛在因素？

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今年(2021 年)台灣正面臨嚴峻的缺水問題，究其原因，前一年(2020 年)沒有颱風登陸使得豐水期的儲水不足，又逢隨後的秋冬春季節降雨量減少，因此最終導致台灣西半部陷入缺水危機。台灣位在東亞季風區，除了颱風之外，冷暖季節轉換的鋒面(例如梅雨鋒面)也是重要的降雨機制，然而造成季風波動的原因十分複雜，聖嬰現象便是其中重要的大尺度長週期變化因素之一。

聖嬰-南方震盪(ENSO)主要發生在赤道太平洋附近，並透過大氣與海洋循環而對全球氣候造成影響。根據美國國家海洋暨大氣總署(NOAA)的監測資料顯示，在 2020 年夏秋之際赤道太平洋地區出現了強烈反聖嬰現象並持續至今，這次反聖嬰現象對於台灣降雨的實質影響值得關注。過去研究指出台灣在聖嬰現象期間的冬季至隔年春季往往出現降雨量多於平均的情形，在反聖嬰現象期間則台灣東北部經常降下秋季豪雨，然而對於 ENSO 事件與台灣乾旱現象的連結目前並無定論。過去筆者曾經透過宜蘭湖泊沉積物中的古氣候紀錄，指出台灣東北部豪雨事件與古代 ENSO 活動之間的對應關係，進而連結宜蘭秋季共伴豪雨與 ENSO 活動的遙相關，相對於今日台灣西半部的乾旱現象，除了利用近代儀器觀測紀錄之外，古氣候資料或許也能提供有用的線索。

中文關鍵字：乾旱現象、聖嬰-南方震盪、古氣候、台灣西半部

跨井熱示蹤劑試驗結合分散式光纖溫度感測器量測特徵化裂隙岩體之優勢水流路徑

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地下水在裂隙岩體中之流動有別於在傳統孔隙介質之中，其流動行為不再遵循傳統的孔隙介質理論。裂隙岩體中的特定透水裂隙常被認定為地下水流及污染傳輸之主要優勢路徑，然而，由於裂隙本身之複雜性與外在不確定性因素，導致在調查裂隙岩體中之水流極具困難性，僅利用傳統之調查方式判釋地下水流向與流速，並推估透水裂隙之水文地質參數相當不易。本研究選用熱作為地下水示蹤劑，並搭配井下跨孔水力試驗，判釋透水裂隙位置及連通性，並同時推估其相對應之水力參數，用以特徵化透水裂隙之水力特性。研究區域選定於南投和社水文地質試驗場址進行現地試驗，選定一組跨孔觀測井作為試驗井，除了以傳統溫度陣列進行溫度量測之外，並同時利用高解析度之分散式溫度感測器（fiber optic distributed temperature sensor, FO-DTS）蒐集空間中連續性之溫度資料。本研究之試驗結果顯示，透過溫度變化分析及溫度破透曲線的描繪，可準確判釋井下導水裂隙之位置及連通性，而數值模式之模擬，則進一步量化導水裂隙之水力傳導係數。試驗結果亦顯示，在不同的流場條件下，對於裂隙位置判釋將產生差異，而導水裂隙與井下裸孔之交錯，將造成井內強烈的垂向水流。利用熱水搭配鹽水進行試驗，透過熱衰減（thermal attenuation）及熱與鹽水峰值之時間延遲（lag time），可更進一步推估導水裂隙之隙寬。本研究之成果顯示，熱-鹽水示蹤劑試驗搭配高解析度分散式溫度感測器量測，在特徵化裂隙岩體中的優勢水流極具潛力，可提供未來裂隙岩體中優勢水流路徑調查技術提供參考依據。

中文關鍵字：熱示蹤劑、鹽水示蹤劑、導水裂隙、分散式溫度感測器、南投和社

孔內多層式光纖光柵水壓與溫度感測系統研發與測試

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含水層常作為地下水使用的來源，一旦遭受地下水污染將立即影響供水安全性，同時地下水復育亦將面臨極大的挑戰。為了預測整治藥劑與污染團在深層含水層的移動路徑，了解地下水系統的狀態是很重要的(如地下水質、水位與水溫等)，然而傳統環保署觀測井多僅在特定深度開孔，且只能觀測含水層的平均狀態，因此提供的地下水相關資訊相當有限。有鑒於此，本研究使用光纖布拉格光柵(Fiber Bragg Grating, FBG)研發出多層地下水壓與溫度量測系統，可以在同一 鑽孔內同時進行多個不同深度的水壓與溫度量測。光纖具有可遠距離穩定傳輸訊號、訊號不易受水與電磁波干擾與無火花安全性高等優點，而本研究所開發之 FBG 多深度水壓與溫度量測系統則進一步透過室內測試與現地測試，以展現本系統之觀測能力。

中文關鍵字：多層式光纖光柵感測系統、地下水壓、地下水溫

利用主動式光纖溫度感測器解析地下水污染場址之地下水流速

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傳統的水文地質調查方式，僅能針對大區域的環境進行試驗，在地下含水層極為複雜的情形下，由於現地資料空間解析度的不足，將導致水文地質狀況掌握不易，產生含水層透水區段及地下水流速、流向推估上的誤判。本研究利用分散式光纖溫度感測器（fiber optical distributed temperature sensing, FO-DTS）量測技術，針對台灣南部地下水污染場址，進行井下的高解析度（high resolution）水文地質調查，同時以複合式光纖纜線搭配主動式線性熱源加熱法，推估地下水流速在垂直方向上之分佈。分散式光纖溫度感測器之量測原理為藉由分析雷射光束在光纜中的雷曼散射（Raman scattering）訊號而獲得環境中的感測溫度，其最大優勢為在空間上與時間上的連續性量測。本研究針對場址內的 15 口監測井進行試驗，並透過熱傳輸的原理分析，解析井下透水區段及推估地下水流速在垂直上之分佈，細部的水文地質分層亦可透過上述資訊獲得進一步的解析。經由視熱傳導（apparent thermal conduction）的解析，可進一步將岩層的熱傳導與地下水流熱對流效應予以區分。本研究之成果顯示，利用分散式光纖溫度感測器在環境溫度感測上的高解析度優勢，搭配主動式的線性熱源加熱，可產出具有時間及空間上優勢的高解析度成果，提供地下環境細部分層狀況的進一步評析，未來土壤與地下水污染場址在水文地質調查、甚至污染整治成效評估之參考依據。

中文關鍵字：分散式光纖溫度感測器、熱示蹤劑試驗、井下水文地質調查、地下水流速

低衝擊開發之生態滯洪單元非飽和入滲形態對排水量之影響

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低衝擊開發的理念已經廣為大眾所推崇，並落實於土地規劃及景觀設計，以友善環境的作法就源處理，透過入滲、過濾、滯留、蒸發延緩雨水排水量，達到消減洪峰流量、改善水質的目標。文獻指出透過設置生態滯洪單元能有效地減少逕流排出量，並且多以飽和入滲或穩定入滲率探討其效益。但是，生態滯洪單元內部的非飽和入滲過程及形態對於排水量，仍然缺乏相關研究。本研究在生態滯洪單元(槽池長 4m、寬 1.5m、深 2.3m)內部設置時域反射計(TDR)、張力計及溫度計觀測非飽和入滲過程之體積水分含量、基質勢能及土壤溫度之變化，並以地球物理探勘的地電阻技術測量入滲剖面，觀測入滲濕峰移動及水分分布，討論不同的供水方式(點源供水與降雨)所形成的入滲形態，以及影響生態滯洪單元的排水量。結果顯示，透過二維地電阻影像剖面能呈現出生態滯洪單元內部的非飽和入滲過程，入滲濕峰的移動受供水方式與地下水位的邊界條件所影響。再配合體積水分含量及溫度資料，發現剖面中層及深層高溫訊號落後於低溫訊號，顯示不同深度的濕峰移動，所混合的入滲新水及殘留舊水之比例明顯不同，而且舊水反應波速可達新水流速的兩倍以上。

中文關鍵字：入滲、體積水分含量、地電阻、新舊水互動

ArcGIS 地下地質三維模型建置－以桃園市地下水分層為例

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近年來，由於全球氣候快速變遷下，導致水庫蓄水量不定，造成工業、民生等用水極大問題與挑戰。長年以來，桃園市境內利用埤塘作為次要儲水使用外，而蘊藏之地下水是另一個相當重要的用水資源。從前人研究之水文地質剖面顯示，位於桃園地區之主要含水層分別位於晚更新世以來之階地礫石層及下伏之更新世楊梅層砂岩等，故為了解桃園地區之地下水分布，本研究蒐集且篩濾區域內 32 孔水文地質鑽孔，將岩心記錄中分為礫岩與砂岩之透水層，及粉砂岩與泥岩之阻水層，進行含水層判釋，參考既有平面地質圖及地質剖面圖，繪製 8 條岩性地層地質剖面，做為三維地質柵狀圖之依據。

而本研究則利用計畫區周緣設置三維模式邊界後，透過 ArcGIS 軟體將上述之岩性地質剖面圖，以三維空間處理模組建置三維地質柵狀圖，並擷取各透水層及阻水層面用以產製三維曲面資料，再依各曲面之空間分布狀況進行衝突修正後，建立實體水文地質模型。最後，此模型可將大量且複雜之地質資料以視覺化方式呈現，有利於地質專業人員進行判讀及檢核，更可以增進民眾及政府機關閱覽能力，並增進雙方溝通效率等益處，進而可即時且快速探討區域之水文地質架構。

中文關鍵字：三維地質模型、地理資訊系統(GIS)、水文地質