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Editorial Note

A snapshot of fundamental geological knowledge to deal with climate change

The 28th meeting of the Conference of the Parties (COP 28) to the United Nations Framework Convention on Climate Change (UNFCCC) in Dubai, United Arab Emirates, concluded in December 2023. The meeting discussed the overarching goal of the legally binding Paris Agreement to limit "global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels". The COP 28 recognised recent findings of Intergovernmental Panel on Climate Change (IPCC) that "limiting global warming to 1.5 °C with no or limited overshoot requires deep, rapid and sustained reductions in global greenhouse gas emissions of 43% by 2030 and 60% by 2035 relative to the 2019 level, and reaching net zero carbon dioxide emissions by 2050".

The IPCC also reports that the impacts from climate change will vary across regions and that risks are expected to be greater for global warming of 1.5 °C than at present, and even higher at 2 °C (IPCC, 2023). In the backdrop of the scientific findings of the IPCC, a landmark decision of COP 28 was "Transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner, accelerating action in this critical decade, so as to achieve net zero by 2050 in keeping with the science." Equally significant is the call for scaling-up renewable energy, phasing down unabated coal power, and "abatement and removal technologies such as carbon capture and utilization and storage, particularly in hard-to-abate sectors." There are also decisions to phase out "inefficient fossil fuel subsidies that do not address energy poverty or just transitions, as soon as possible".

The 77th volume of the Bulletin of the Geological Society of Malaysia comprises eight articles in the milieu of the global decision to fast track the shift away from fossil fuels. The lead article by Everts (2024) focuses on the geothermal energy potential of basement hot springs, an untapped renewable energy source in Malaysia. The following five articles offer means for advancing geological knowledge to support technologies for carbon capture and utilization and storage. Ralanarko *et al*. (2024) and Bashir *et al*. (2024) present seismic modelling approaches with the potential to advance geological storage of carbon. Aznan *et al*. (2024), Khor *et al*. (2024) and Dishong *et al.* (2024) rely on conventional field work and laboratory results to reconstruct structural and depositional histories; techniques that are the foundation for geological assessment of potential rock types for carbon storage. The final two articles by Tampubolon *et al.* (2024) and Widi *et al*. (2024) are on economic minerals in Indonesia, specifically Rare Earth Elements, tin and gold. The call to scale-up on renewable energy is expected to increase the demand for minerals, particularly Rare Earth Elements, which are used in low-carbon energy generation technologies.

Everts (2024) presents an evaluation of the potential for geothermal energy from the Ulu Slim hot spring in Perak, Malaysia. The hot spring is reported to have the highest surface-outflow temperature in Peninsular Malaysia. The evaluation was based on available data and comparative interpretations that were augmented with conceptual hydrodynamic- and thermodynamic-model calculations to delineate subsurface parameters that control extractable heat. The results were used to obtain the heat-extraction and electric power potential of hypothetical wells drilled into the hot-spring source, with support from injector wells. Preliminary findings indicate that the use of geothermal heat from the hot springs for electric power generation may be complicated with the risk of premature cooling due to fluid circulation through narrow fracture systems. It is proposed that the search for high potential geothermal locations be guided by proximity to infrastructure and electricity demand rather than hot-spring locations, with hot-dry rock exploitation in fresh granite being an option to be considered.

Ralanarko *et al*. (2024) used 4-dimensional seismic data over the period of 1991 and 2004 to interpret the reservoir characteristics of the Widuri Field in the Southeast Sumatra Basin, which is one of Indonesia's oldest offshore oil-producing fields. The review was informed by an enhanced oil recovery scheme conducted in 2000 by injecting water into the reservoir to increase oil production. Intervals and areas with an abundance of water were anticipated to be potential zones to store carbon dioxide. Increasing impedance from inversion data between 1991 and 2004 reflects the presence of existing porosity and permeability, indicating reservoir capability for storage of carbon dioxide. This brings forth

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the prospect of transforming the Widuri Field from an oil producer to a geological carbon sequester. Notwithstanding, further work is required to determine the feasibility of the reservoir for storage, including the possibility of carbon dioxide leakage.

Bashir *et al*. (2024) highlight recent advancements in marine seismic technologies and algorithmic development, which primarily focused on improving seismic bandwidth, resulting in enhanced vertical resolution. Technology providers are acknowledged for effectively designed and implemented instrumentation to eliminate ghost notches, yielding improved results from legacy and new datasets. A particular advancement relates to the application of constrained Statistical Elastic Inversion, which is specifically designed to investigate thin pay beds that are common in this region. Improved seismic knowledge has advanced the development of more precise subsurface reservoir models, which have been validated using data from offshore Malaysia. This is crucial for delineating potential hydrocarbon resources, planning their development, and devising the abandonment stage.

Aznan *et al*. (2024) report on regional and local-scale fractures that are prevalent in the limestone of Gunung Keriang, Kedah, Malaysia, using a combination of data from satellite imagery and fieldwork. Three major fracture sets that are steep to vertically dipping have been delineated, trending NW-SE, N-S, and NE-SW. It is reported that the formation of N-S tension gashes and potential conjugate fracture sets in the NW-SE and NE-SW directions is due to E-W compression resulting from the Late Triassic collision between the Sibumasu and Indochina terranes. The succeeding uplift exposed the limestone hill to extensive dissolution, particularly along fractures. Gunung Keriang is a geosite and recreational area, and comprehensive knowledge of the fracture system is critical to minimise the risk of hazards such as rockfalls and sinkholes and ensuring the safety of residents and visitors. Fracture analysis is also critical for carbon capture and storage, and the findings from the study offer an onshore analogue for the evolution of fracture networks within limestone, which could be of use in the future.

Khor *et al*. (2024) present new findings from the Early Miocene Tanjong Formation of Imbak Canyon in Sabah, Malaysia. Previous investigations have provided limited information on the Formation due to its location in remote and protected forests, which is a challenge to access. Formerly interpreted as a shallow marine environment deposit without tidal influence, the evaluation of newly logged sections encountered in 2019 reveals that the Tanjong Formation is indeed a tidal deposit. Correlation of the logged geological sections revealed eight facies that were grouped into three interpreted associations representing intertidal deposits, middle to lower shoreface, and offshore deposits. It is concluded that the Tanjong Formation was deposited in a macrotidal open coast setting with major tidal imprint signatures. The findings now pave the way for potential revisions of current shallow marine models in the region.

Dishong *et al.* (2024) provide an account of the historical setting of Bukit Choras in Kedah, Malaysia, an important archaeological site of the Bujang Valley, which retains the oldest man-made structures in the region. The peak of Bukit Choras is currently located 8 km inland, but its proximity to other pre-14th Century coastal sites in Bujang Valley alludes to a shoreline setting in historic times, serving as the motivation for the current study. Geochemical and microfossil analysis of hand-augered soils samples, in combination with data on sea-level fluctuations and geomorphology, was used to determine whether the area surrounding Bukit Choras was once submerged below sea level. The findings reveal that Bukit Choras was once a coastal site, bordered by a marine and swampy environment, while the archaeological site functioned as a coastal settlement. The coastline was located 3 km to the west of Bukit Choras, while the foothill was likely a mangrove swamp with ancient settlements along the coast and river estuary setting. A more robust investigation of the paleoshoreline has been proposed.

Tampubolon *et al*. (2024) report on the correlation between Rare Earth Elements (REEs) and Sn using data of Sn-W, REEs, Y, Th, and U in granite, quartz veins, and weathered granite samples in South Bangka, Indonesia. The importance of REEs in clean technology makes it an important commodity worldwide. The study intended to establish a possible genetic relationship between Sn and REEs, given that Sn is frequently used as a general indicator for the presence of REEs, giving rise to the view that they form simultaneously, despite limited spatial evidence linking the two elements. Statistical analysis using the Pearson correlation coefficient and multivariate processing revealed a weak negative correlation between Sn and REEs. Chemical and mineralogy characteristics indicate that Sn and REE originated from the same magmatic fluids but at different depositional phases of the magmatic-hydrothermal process. REEs were formed during the early magmatic crystallization as minerals and stannite (Cu-Sn) in granite, while Sn was enriched as cassiterite in the deposition of late-stage hydrothermal fluid in the parental granite. The weak negative correlation between Sn and REEs is a reflection of the variation in deposition stage and temperature during their formation process.

Widi *et al*. (2024) bring focus to the characteristics of the epithermal gold-base metals prospect of the Anggai block, located in Obi Island, North Maluku Province, Indonesia. The Island hosts several mineral prospects with a history of exploration dating back to the late 1900s. Gold and base metal are within quartz veins of the Bacan Formation, enveloped predominantly by argillic alteration and silicic alteration to a lesser extent. A combination of methods such as petrography, Portable Infrared Mineral Analyser (PIMA), Atomic Absorption Spectrometry (AAS), and fluid inclusion micro-thermometry were used to analyse samples of unaltered and altered host rocks and ore bodies. The intention was to obtain a better understanding of the ore forming fluid and its physicochemical condition during the precipitation of metals in the Anggai block. Findings reveal that free gold occurs with argentite, while galena, chalcopyrite, sphalerite, covellite, chalcocite, and pyrite are mainly observed together. There is a strong correlation between Au and other metals to Zn. The metals Cu, P, and Zn show a strong positive correlation with each other. The micro-thermometry analysis of fluid inclusions reveals two modes of homogenization temperature, indicating overprinting and enrichment of the ore bodies with gold and base metals in the quartz veins. The gold and base metals were probably carried by the sulfide complex, which later precipitated during the cooling of the hydrothermal fluid. These additional details shed further light on gold-base metal mineralisation in the Anggai block. While these metals are not critical for the energy transition, they do play a significant role in remote and 'frontier' economies.

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