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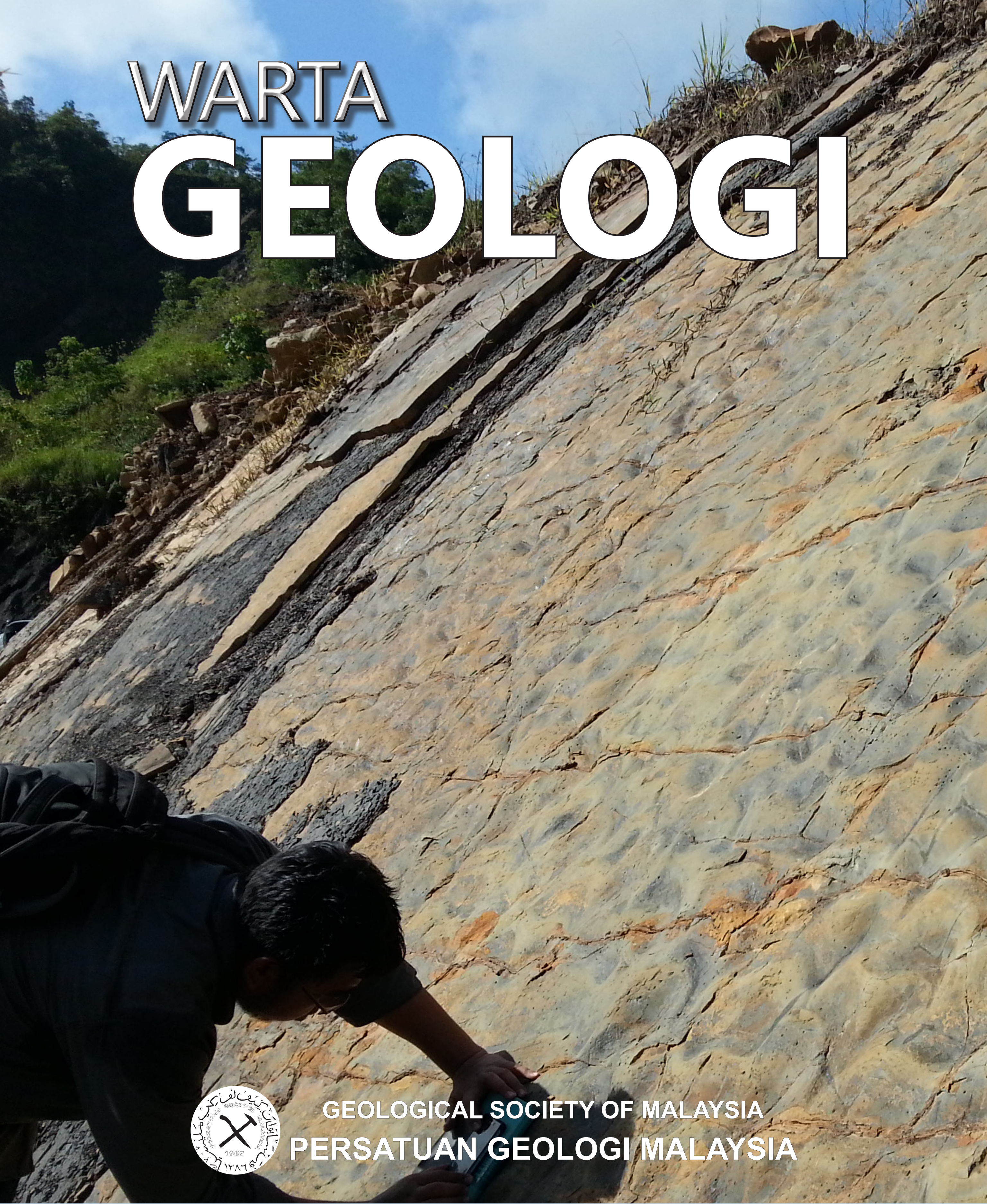

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Warta Geologi

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Cover photo: Current ripples on sandstone bedding plane. Temburong Formation near Lawas, Sarawak. Photo by: Meor Hakif Bin Amir Hassan

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Characterizing mudstones and fault structure in Bumita Quarry, Perlis through integrated geophysical techniques

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Abstract: The parameters of seismic refraction and electrical resistivity play a crucial role in geological studies, as they provide insights into the composition of rocks or soil beneath the Earth's surface. Previous researchers have established reference ranges for seismic velocity and resistivity values based on different rock types, which are presented in tabulated forms. However, the wide variability in these values sometimes leads to challenges in interpretation due to overlapping ranges. In the region of Perlis, Malaysia, a comprehensive geophysical investigation involving seismic refraction and electrical resistivity methods was conducted within the Chepor Member of the Kubang Pasu Formation at the Bumita Quarry and Utan Aji. The results were then correlated with porosity and permeability data. The Chepor Member primarily comprises both red mudstone and grey mudstone. Interestingly, the seismic velocities of these two mudstone types are quite similar, differing only by a small margin of approximately 200 m/s. The resistivity method employed utilized a pole-dipole array configuration. In terms of resistivity values, the red mudstone exhibited lower readings (ranging from 15 to 100 Ωm) compared to the grey mudstone (ranging from 120 to 500 Ωm). Assessing porosity, the red mudstone displayed a value of 0.95%, alongside a permeability of 5.58×10^{-5} µd, while the grey mudstone indicated a slightly higher porosity value of 1.9% and a permeability of 2.06×10^{-5} µd. Consequently, the study successfully established seismic velocity and resistivity benchmarks for the mudstones within the Chepor Member geological unit.

Keywords: Chepor Member, sedimentary rocks, seismic refraction, electrical resistivity, mudstone, porosity

INTRODUCTION

The Earth's intricate composition, stemming from its lack of uniformity, hinders the complete exploitation of its resources. Therefore, it's crucial to extensively grasp the physical and chemical attributes of the Earth to thoroughly investigate its underground layers and components. Employing geophysical techniques to delve into the Earth's interior necessitates gathering measurements either at the surface or in its proximity. Geophysical analysis outcomes can provide insights into both the vertical and lateral fluctuations in the physical characteristics of the Earth's subsurface. Among the measurable attributes are the porosity and permeability of rocks, which hold significant importance in the field of earth exploration, particularly within the oil and gas industry.

The seismic velocity and resistivity range established by various geophysicists gives a wide range of values subject to the type of rocks. A type of rock having different type of facies will have its own specific range of values. Having a smaller range of values would help researchers to interpret the type of rock in a specific way thus accurately.

An outcrop is characterized as a visible section of bedrock that emerges on the Earth's surface; however, it

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Table 1: Geophysical parameters pertaining to mudstone encompassing seismic velocity and resistivity values.

Geophysical parameter of mudstone	Values
Seismic velocity (Reynolds, 1997)	1000 – 4100 m/s
Electrical resistivity (Loke, 1999)	20 – 2000 Ωm

is not widespread across the land as a significant portion is concealed by vegetation. The presence of outcrops enables the direct observation and collection of bedrock samples, facilitating in-depth geological analysis. They provide exceptionally detailed and spatially consistent insights into various aspects such as sedimentary structure, texture, petrology, facies, grain types, morphometric properties, joint patterns, fractures and their orientations, diagenetic alterations, compaction, and petrophysical as well as physicochemical properties (Van Dam *et al*., 2015). Geologists often map the geological features of an area by observing the geomorphology of the area. Sometimes, the use of logging is applied to study the subsurface lithology. The earth surface is 70% of sedimentary origin; it is formed through physical, chemical and biological processes (Tucker, 1981). This study identifies the geological outcrop of the Chepor Member at Bumita Quarry, Utan Aji, integrating seismic refraction and electrical resistivity parameters with mudstone porosity and permeability.

In general, the seismic velocity and resistivity values of mudstone, as presented by Reynold (1997) and Loke (1999) respectively, exhibit a broad range (Table 1). This study specifically focuses on characterizing the resistivity and seismic values of both red and grey mudstone within the Chepor Member at Utan Aji.

Literature review

Basic geological knowledge is indispensable for evaluation and interpretation of the substrate which is important for civil engineering. Geology provides information of the exposed area while geotechnical investigations is useful to provide information of the Earth's interior but mostly involving costly destructive methods. To avoid unnecessary loss, all methods of the geosciences was taken into consideration, and recently geophysics methods have widely contributed in providing information to probe properties of the subsurface, properties of soils, sediment and rock outcrops, cost effectively and mostly related to the environmental surveys. Geophysical exploration comprises several methods and unique tools to investigate the subsurface. The methods are used for geological surveying to derive the Earth's internal physical properties. Hence, geophysical exploration is of importance to geologists and engineers, and not limited to geophysicists (Kearey *et al*., 2002). The seismic refraction method employs wave propagation through the Earth, a process influenced by the elastic properties of rocks. This quality, defined as elasticity (Telford *et al*., 1990), describes the rock's ability to resist alterations in size or shape and to revert to an undeformed state once external forces are eliminated. Seismic waves can be divided into two waves; P-wave and S-wave. P-wave travels by compressional and dilational uniaxial strain in the direction of propagation whereas S-wave travels perpendicularly to the direction of propagation (Kearey *et al*., 2002; Mohamad *et al*., 2015). Seismic refraction relies on the requirement that the velocity of sound in a deeper layer surpasses that of the layer above it. Upon fulfilling this condition, refracted waves reach the Earth's surface, detectable by a geophone. This geophone generates an electrical signal which is then transmitted to a seismograph (Haeni, 1986). Rahmouni *et al*. (2013) employed P-wave velocity (Vp) to assess the geotechnical characteristics of rock materials. The P-wave velocity of a rock exhibits a strong correlation with the properties of the rock in its natural state. In order to estimate the porosity and density of calcarenite rocks, which hold significance as historical monuments, they employed a straightforward ultrasonic velocity technique. This ultrasonic test relies on measuring the time taken for a P-wave to propagate in the longitudinal direction. Electrical imaging is a survey method developed to investigates areas of complex geology (Griffiths & Barker, 1993). The electrical survey operates by measuring the potential difference at various points in the Earth, which is generated by injecting current into the ground (Burger, 1992). Electrical resistivity tomography has proven effective in mapping the stratigraphy of sedimentary, limestone, and granite formations (Muztaza *et al*., 2013).

The quantification of empty spaces is referred to as the porosity of rock, while the assessment of a rock's capacity to facilitate fluid movement is known as permeability. Analyzing these fundamental rock characteristics is crucial prior to addressing factors such as fluid types, quantities, flow rates, and estimates of fluid recovery. The predominant characteristics of sedimentary rock texture are primarily influenced by factors such as the roundness and shape of grains, the size and sorting of grains, the orientation and arrangement of grains, as well as the chemical composition (Tiab & Donaldson, 2015). The porosity is measured in percentage (%) while the unit for permeability is in microdarcy (µd).

Previous researchers, Ismail *et al*. (2013) and Muztaza *et al*. (2013) conducted seismic refraction and electrical resistivity respectively at Kaki Bukit, Perlis to characterize the geological outcrop of limestone formation. This study focusses on Chepor Member of Kubang Pasu Formation at Bumita Quarry, Utan Aji. Both seismic refraction and electrical resistivity were conducted simultaneously on the same survey line. In their study, Meor & Lee (2004) examined the depositional setting of the Mid-Paleozoic red beds at Utan Aji, Perlis, and its implications for global eustatic sea level fluctuations. The area in the northwest of the Peninsula Malaysia features widespread Late Devonian to Early Carboniferous red-colored mudstones and sandstones. A well-preserved sequence is found at Bumita Quarry, Utan Aji, Perlis, and is detailed in this report. The identified facies suggest a marine prodelta-delta front environment for the Mid-Paleozoic red beds. Within the Bumita Quarry sequence, a relatively thin (9 m) black mudstone facies could potentially signify the occurrence of the Latest Devonian Hangenberg Anoxic Event. The presence of a Mid-Paleozoic orogeny is ruled out. It is proposed that a significant regression immediately following the transgressive episode of the global Hangenberg Event is responsible for the notable pre-Carboniferous paraconformity observed in the mid-Paleozoic successions of the Sibumasu/Shan-Thai Terrane.

Geological setting

The northwestern region of Peninsula Malaysia holds an almost uninterrupted sedimentary sequence from the Cambrian to the Permian period, encompassing the entire Paleozoic era (Jones (1981); Meor & Lee (2005); Cocks *et al*. (2005); Lee (2009)). In Perlis, the arrangement of rock layers follows a pattern of gradually increasing age from west to east, commencing at the Setul Boundary Range (Jones, 1981; Meor, 2013). The lowermost segment of the Kubang Pasu Formation (KPF) is referred to as the Chepor Member. This Chepor Member is situated in areas such as Utan Aji, Guar Jentik, and Bukit Tuntung, which were previously identified as formations characterized by reddish sediments (Meor & Lee, 2005). The Chepor Member is comprised of substantial layers of mudstone ranging in color from grey to red, interspersed with flat layers of quartzitic and feldspathic sandstone, and occasionally containing stratified diamictite beds (Meor, 2013). The depositional environment for Chepor Member is of glacial marine shelf system. Figure 1 shows the geological map of Kubang Pasu Formation and Bumita Quarry, Utan Aji.

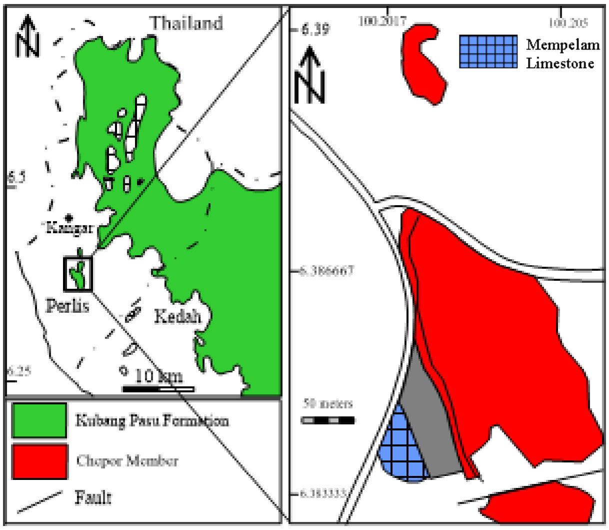

Figure 1: Geological map of Kubang Pasu Formation and Bumita Quarry, Utan Aji (Meor, 2013).

Figure 2 shows the exposed bedrock at Bumita Quarry, Utan Aji. The beds approximately dip 70 degrees eastward and complicated with folding and thrusted strata. The Chepor Member succession exposed in Utan Aji is like that exist in Guar Jentik (Meor, 2013). Figure 2 clearly shows that the rocks are tilted towards the ground and two types of mudstone exists at the area which are red mudstone and grey mudstone.

METHODOLOGY

Data acquisition took place at Bumita Quarry in Utan Aji. The survey line at this location was oriented perpendicular to the visible bedrock (Figure 3). Geophones were positioned at intervals of 2 meters, while the electrode spacing for the electrical resistivity method was set at 1 meter. Both techniques were executed simultaneously on the same survey line.

In this geophysical survey, hammer is used as the source to generate the sound waves. Geophone with frequency 14Hz is used to detect the seismic waves.

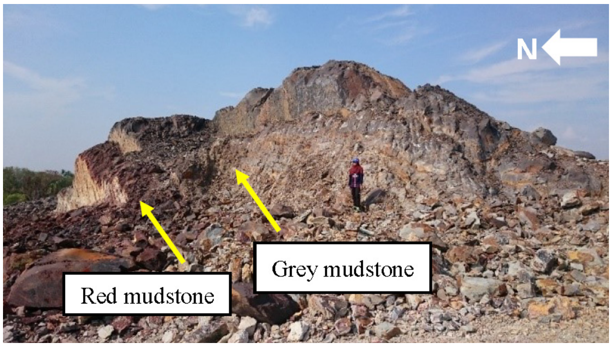

Figure 2: Outcrop at Bumita Quarry, Utan Aji. The beds approximately dip 70 degrees eastward with 40 m length.

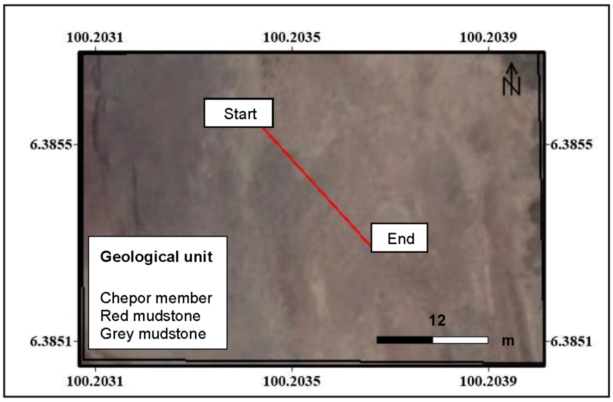

Figure 3: Location of the survey line from top view (Google earth, 2016).

Seismic refraction tomography (SRT) employs the transmission of waves through the Earth's subsurface. This wave propagation is contingent upon the elastic characteristics of the underlying rock formations (Telford *et al*., 1990). At its core, seismic exploration operates on a fundamental concept: it involves the creation of seismic waves and the subsequent measurement of the travel time for these waves as they traverse from emission points to an array of geophones, typically arranged linearly in alignment with the source (Figure 4).

In electrical resistivity survey, the pole-dipole array was employed due to its capacity for deeper current penetration and its effectiveness in providing extensive horizontal coverage (Loke, 1999).

Resistivity measurements entail the injection of electrical current into the Earth through a pair of current electrodes, labeled as C1 and C2. Consequently, the resulting potential difference is recorded by two potential electrodes, designated as P1 and P2. Figure 5 depicts the representation of electric current distribution within a uniform subsurface. In this scenario, when electric current is introduced into the ground through a pair of current electrodes, it disperses outward from the electrodes in a radial manner and also travels between them. By employing voltmeters, the potential differences between two potential electrodes are measured. It's important to note that as the distance between the electrodes increases, the depth at which the current penetrates also increases.

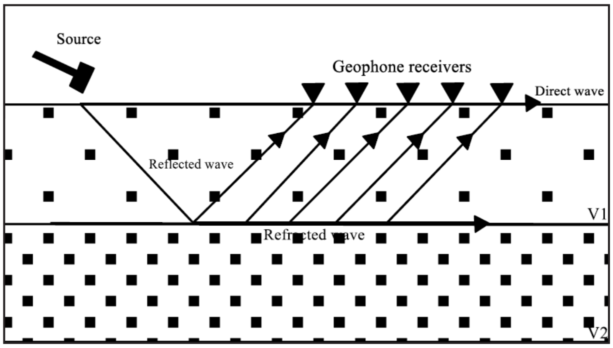

Figure 4: Ray paths for seismic waves (after Anderson &Croxton, 2008).

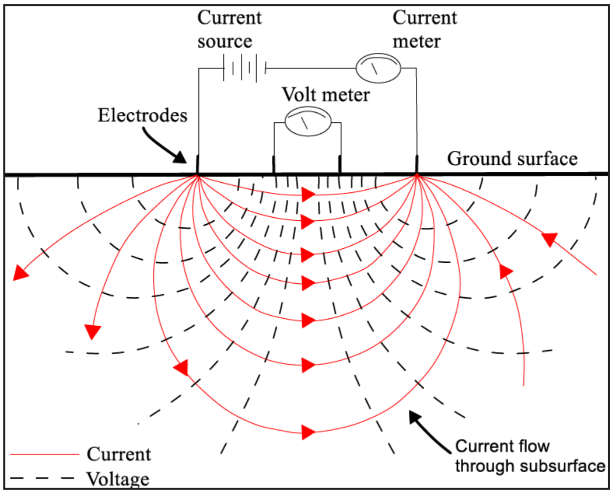

Figure 5: Electric current is generated between the paired electrodes, as indicated by the red lines. The potential difference between the potential electrodes, which are also paired, is then measured (after Anderson & Croxton, 2008).

The raw data from seismic refraction is processed using several software. Firstly, IXRefraX is used to transfer the data from seismograph to the computer. The software is also used to filter the noises of the seismic wavelets. After the filters, it is imported to FIRSTPIX v4.21 for picking the first break of each of the seismic traces. Lastly, the time of the first break is imported to SeisOpt2D for imaging the depth versus distance. For electrical resistivity, the data is automatically processed using Res2Dinv software. Both seismic refraction and electrical resistivity imaging section are imported to Surfer8 software for final editing.

Rock samples are extracted from the visible outcrop using a rock hammer, after which they are transported to the laboratory for further testing. The conducted test involves determining the porosity and permeability values of the rocks. Prior to conducting any tests, the rock specimens were shaped into cylindrical forms using a diamond drill bit core driller (Figure 6). The nitrogen permeability test was employed for measuring

Figure 6: Cutting the rock sample into cylindrical shapes. a) the sample is placed in a jig specifically designed to hold the sample in place for both the trimming and facing, b) trimming the sample and c) cylindrical blocks.

permeability, while water immersion under vacuum was utilized for porosity determination. Additionally, the rock samples were transported to the Department of Mineral and Geosciences Malaysia (JMG) in Ipoh for the creation of thin sections.

RESULTS AND DISCUSSION

The lowermost segment of the Kubang Pasu Formation (KPF) is referred to as the Chepor Member (CM). This specific unit, known as the Chepor Member, is situated at Utan Aji and Guar Jentik. In earlier descriptions by Meor & Lee (2005), these locations were categorized as formations characterized by 'red bed' deposits. The Chepor Member is composed of substantial layers of mudstone ranging in color from gray to red. These mudstone layers are interspersed with flat, tabular deposits of sandstone that are rich in quartz and feldspar. In certain instances, bedded diamictite can also be observed within this member (Meor, 2013). The depositional environment for Chepor Member is of glacial marine shelf system. Both red mudstone and grey mudstone are fresh rock which exist under the survey line contrast to the beds of quartzitic and feldspathic sandstone which shows moderately weathered condition on the outcrop.

Figure 7 shows the seismic refraction (SR) at Bumita Quarry, Utan Aji. The tomography gives depth of approximately 15 m. At the right side of the section, the velocity is slightly higher compared to the left. The SR value for red mudstone is between 1500 m/s – 2100 m/s whereas for grey mudstone also from 1500 m/s to 2300 m/s. At the center of the line, the layering starts to fall which might indicate the contact or fault line between red mudstone and grey mudstone. The difference in seismic velocity of the red mudstone to grey mudstone is within 200 m/s.

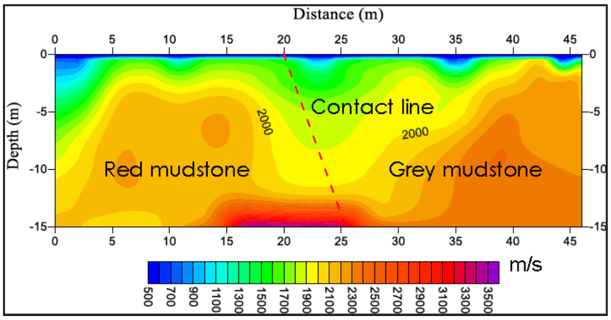

Figure 7: Seismic refraction profile at Bumita Quarry, Utan Aji.

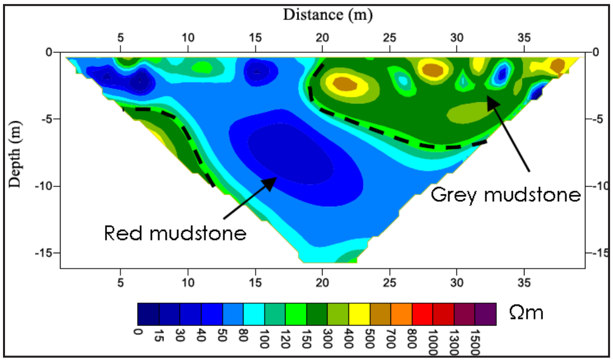

Figure 8: 2-D inversion model of Pole – dipole array at Bumita Quarry, Utan Aji.

Figure 8 depicts the inversion model of electrical resistivity (ER) obtained from the pole-dipole array survey conducted at Bumita Quarry, Utan Aji. The boundary between the red mudstone and grey mudstone is indicated by the black dashed line. As inferred from the results, the rock is observed to be inclined or dipping beneath the ground surface. It can be directly deduced that the two major colors which are blue and green in the inversion model resistivity represents two types of mudstone. The green color having higher resistivity (120 – 500 Ωm) value is the grey mudstone, while the low resistivity value (15 – 100 Ωm) with blue color is the red mudstone. The depth of the result is approximately 16 m.

Figure 9 shows the SR and ER results are compared together. The red dashed line shows the centre of the survey line as at distance 22 m of SR is equivalent to 20 m ER survey line. Observing the possible fault or contact line between red mudstone and grey mudstone indicated by black dashed line, both SR and ER results shows quite good correlation. Correlation between seismic refraction and electrical resistivity results shows the subsurface imaging is agreeable to one another.

The difference of seismic velocity between red mudstone and grey mudstone is within 200 m/s, the range for red mudstone is slightly lesser than the grey mudstone.

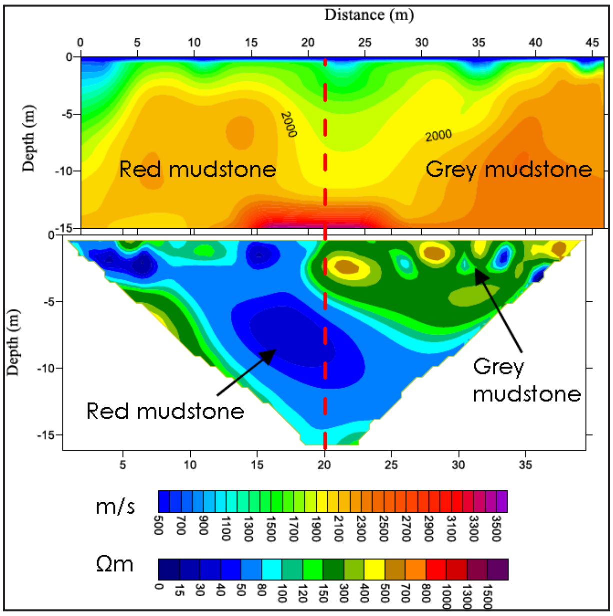

Figure 9: Comparison between seismic refraction and Pole – dipole array of electrical resistivity.

Table 2: Table describing geophysical parameters and their corresponding facies of the Chepor Member at Bumita Quarry, Utan Aji.

Facies	Velocity (m/s)	Resistivity (Ωm)
Red mudstone	1500 – 2100	15 – 100
Grey mudstone	1500 – 2300	120 – 500

Whereby resistivity results show a great distinct value between the two mudstones. Table 2 shows the mudstone facies with its respective geophysical parameter.

Mudstone are brittle rocks that needs a hammer to remove the sample from quarry faces or any rock exposures. The color of mudrock is related to its mineralogy and geochemistry. The color can be quite useful in field mapping to differentiate between mudrock formations. The main controls of the color are the organic matter and pyrite content and the oxidation state of the iron (Tucker, 1981).

The mudstones can be divided into two referring to its color; red mudstone and grey mudstone as shown in Figure 10. The difference in color of the mudstone is because of the chemical weathering processes of each of the mudstone has undergone. Brown or red mudstone typically consist of oxidized ferric iron minerals like hematite (Fe_2O_3), primarily present as coatings on grains and intertwined with clay particles. On the other hand, mudstone exhibiting shades of grey generally suggest a substantial clay content along with a limited presence of non-oxidized ferrous minerals. As the clay content increases, there tends to be a higher proportion of organic matter and pyrite in such grey-hued mudstone (Tucker, 1981; Merriman *et al*., 2003).

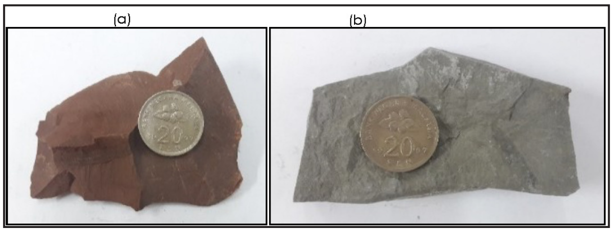

Figure 10: Rock samples representing (a) red mudstone and (b) grey mudstone of the Chepor Member.

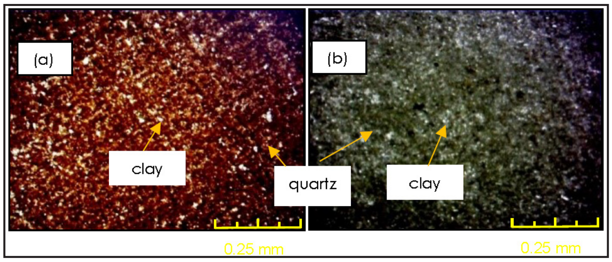

Figure 11: Thin section photomicrograph of (a) red mudstone and (b) grey mudstone.

Figure 11 illustrates the thin sections of red mudstone and grey mudstone from the Chepor Member located at Bumita Quarry, Utan Aji. Looking at both thin sections, the mineral crystals are extremely fine, making it very difficult to identify the type of minerals present with the petrological microscope (Tucker, 1981). Generally, the minerals present in a mudstone are clay minerals and quartz.

Both mudstone of Chepor Member has nearly the same seismic velocity because of its physical properties. Generally, mudstone is a fined grain encompassed of clay minerals and silt-grade quartz. The only difference that can be seen clearly is the color of the mudstone. Seismic velocity does not get affected by the difference in color, since both mudstone show the same physical properties therefore the seismic velocity shows nearly the same.

The main reason on why the low resistivity values of red mudstone is because of the chemical processes it had undergone which is oxidation and the ferromagnetic properties itself. The chemical composition of the red mudstone is iron (III) oxide (Fe_2O_3) which can be seen by the red color. Dynamically, the ferromagnetic property of Fe_2O_3 creates an environment which caused electrons to easily move around the material, this reduces the resistivity properties as current can move through the mudstone easily.

The resistivity of grey mudstone is higher because of the deficient in iron compared to the iron content in red mudstone which is higher. The chemical composition of grey mudstone is iron (II) oxide (FeO). Resistivity value greater than the resistivity of mudstones is consider as sandstone.

Upon integrating the porosity and permeability values derived from the laboratory tests, it has been observed that the results for both red mudstone and grey mudstone are nearly the same. The porosity of red mudstone is 0.95% compared to grey mudstone which is 1.9% (Table 3). The permeability value for red mudstone is 5.58×10^{-5} µd while grey mudstone is 2.06×10^{-5} µd.

CONCLUSION

The study has effectively employed seismic refraction and electrical resistivity surveys to investigate the geological exposure of the Chepor Member at Bumita Quarry, Utan Aji. The seismic velocity and resistivity values of both red mudstone and grey mudstone from the Chepor

Table 3: Comparing parameters between red mudstone and grey mudstone.

Parameters	Red mudstone	Grey mudstone
Seismic velocity (m/s)	1500 – 2100	1500 – 2300
Resistivity (Ωm)	15 – 100	120 – 500
Porosity (%)	0.95	1.9
Permeability (µd)	5.58×10^{-5}	2.06×10^{-5}

Member were combined with their respective porosity and permeability values. These are useful benchmarks for the mudstones within the Chepor Member geological unit.

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AUTHOR CONTRIBUTIONS

NMM: Investigation, data curation, writing original draft. HH: Investigation, data curation, formal analysis, writing – editing. TYJ: Validation, formal analysis. MTZ: Conceptualization, formal analysis, methodology, software. NAI: Conceptualization, formal analysis, methodology, software. MFMD @ AMDMFM: Conceptualization, validation. TA: Review and editing.

CONFLICT OF INTEREST

The authors affirm that there are no conflicts of interest in relation to this research, nor are there any personal relationships that could be perceived as potentially exerting influence on the findings presented in this paper.

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Slake durability indices of shales from the Batu Arang Beds, Selangor Darul Ehsan

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Abstract: The Eocene to Oligocene Batu Arang Beds outcrop within an approximately triangular basin covering some 15 km^2 and comprise stiff, structureless clays to well laminated and fissile shales inter-bedded with fine to coarse sandstones and several coal layers. The shales are often silty and even sandy and contain abundant carbonaceous material. The coal mostly occurs as thin laminae, though two thick seams, mined by open-cast and under-ground methods from 1915 to 1960, are found in the eastern part of the basin. To determine the weatherability characteristics of the shales, three samples (A, B and C) were collected at the western wall, and one sample (D) at the eastern wall, of an open-cast shale pit. Samples A and D are located some 10 m, and 5 m, below the ground surface, whilst samples B and C are 10 m, and 16 m, stratigraphically below sample A. Samples A, B and C, and D have average dry unit weights of 16.64, 14.49, and 15.40, kN/m^3 and average apparent porosities of 26.2%, 35.7% and 31.7%, respectively. Slake durability indices of all samples for one standard cycle of wetting and drying (Id_1) are between 98.3% and 99.3%, and for two standard cycles (Id_2), between 96.7% and 98.9%. Durability indices for three standard cycles (Id_3) are between 95.1% and 98.2%, and for four standard cycles (Id_4), between 93.3% and 97.6%. The indices lead to the conclusion that the shales are of high to extremely high durability and suitable for use as highway embankment or construction material. The high durability classification is supported by recent excavations at an overburden dump where relatively fresh shale blocks with little disaggregation or disintegration are exposed even after being buried for 78 to 85 years.

Keywords: Batu Arang Beds, Eocene to Oligocene strata, shales, slake durability indices

INTRODUCTION

Several earth materials, especially those with a high clay content, are prone to swelling, weakening or disintegration when exposed to short-term weathering processes of a wetting and drying nature. Such slaking characteristics or weatherability are of practical importance in engineering projects for they can influence the stability of excavations with time as well as the surface durability of canal and tunnel walls (Morgenstern & Eigenbrod, 1974).

The weatherability of clay-rick rock materials probably presents the most problems because their degree of induration may cause observers to be misled concerning their performance when exposed to the elements (Johnson & DeGraff, 1988). In view of this, the slake durability test was devised as a means of assessing the resistance offered by a rock material to weakening and disintegration when subjected to two standard cycles of drying and wetting (Franklin & Chandra, 1972). Standardized procedures for the slake durability test are provided in ISRM (1979) and AIT (1981).

The Colorado Department of Transport (CDOT, 2015) has recommended that shales used for highway embankments or as construction material be classified as being soil-like (non-durable) or rock-like (durable). Two methods of test were recommended to distinguish durable shales that can be used in rock fills from non-durable shales that must be placed and compacted as soil. The first method is the qualitative jar-slake test which involves six descriptive degrees of slaking determined from visual observation. The second method employs the slake durability apparatus where a number of oven-dried rock blocks are submerged in water and rotated in a wire drum cage. The jar-slake test is recommended as the basic screening test, whilst the slake durability test is considered to be the main index test. Identification of shales as being soil-like (non-durable) or rock-like (durable) is based on the slake durability index (Id)

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and the character of the retained wet rock materials (CDOT, 2015).

In Malaysia, there is limited published data on the durability of rock materials with (Azman Kassim & Edy Tonnizam Mohamad, 2007) stating that the slake durability index (Id_2) for two standard cycles of testing decreased with an increase in the weathering grade of sandstones and shales from the Mersing area. Zainab Mohamed *et al.* (2007) discussed the characterization and classification of weathered Kenny Hill Formation rocks and presented results of jar-slake tests as well as tests with the slake durability apparatus. Edy Tonnizam Mohamad *et al.* (2011) reported that jar slaking tests were more suitable for determining the durability of highly (Grade IV), and completely (Grade V), weathered sandstone from the Mersing area rather than tests with the standard slake durability apparatus.

Wong *et al.* (2018) concluded that the slake durability index (Id_2) for two cycles of wetting and drying is the ideal test to characterize the weathering grade of rocks from the Kati Formation of Carboniferous to Permian age in Perak State. The Formation comprises inter-bedded sandstones, siltstones and mudstones with Id_2 values <15% indicating completely weathered rocks, 22% to 67% highly weathered rocks, 68% to 83% moderately weathered rocks, and 87% to 98% slightly weathered to fresh rocks.

In a recent publication, Raj (2020) has discussed the slake durability indices of shales and fine grained sandstones from the Middle to Upper Triassic Gemas Formation. Durability indices (Id_2) for two standard cycles of wetting and drying were between 99.1% and 99.6% for the shales, and between 99.2% and 99.3% for the sandstones. Durability indices (Id_4) for four standard cycles of wetting and drying furthermore, were between 99.0% and 99.5% for the shales, and between 98.4% and 98.5% for the sandstones. It was thus concluded that fresh (unaltered) shales and sandstones from the Gemas Formation are of extremely high durability and suitable for use as highway embankment or construction material (rock fill).

As part of a study to determine the geotechnical properties of earth materials in Malaysia, were investigated outcrops of Tertiary sedimentary rocks in the Batu Arang area. Uniaxial compressive strengths of these rocks have been earlier discussed (Raj, 1994) as have been their point load strengths (Raj, 1995). In this short note are presented the results of laboratory tests carried out to determine the slake durability indices of shales from the Batu Arang Beds.

GENERAL SETTING OF STUDY AREA

Tertiary sediments at Batu Arang (Figure 1) form an approximately triangular basin, encompassing an area of about 15 km^2 and overlie with marked unconformity, much older and steeply dipping meta-sediments, mainly quartzites and phyllites, of the Kenny Hill Formation (Stauffer, 1973; Raj *et al.*, 2009). The Tertiary sediments, known as the Batu Arang Beds (Stauffer, 1973) or the Coal Measures (Roe, 1951) are also unconformably overlain by a thick sequence of semi-consolidated, sandy to gravelly and bouldery sediments of a probable Pleistocene age (Raj *et al.*, 2009). The Tertiary sediments proper have a maximum recorded thickness of 265 m in the center of the basin, but where the beds outcrop along the eastern and northern sides, the sequence is some 183 to 244 m thick (Raj *et al.*, 2009).

The Batu Arang Beds consist mainly of fine grained strata that range from stiff, structureless clays to well laminated and fissile shales inter-bedded with some sandstone and coal beds. The shales contain abundant carbonaceous material and are often silty and even sandy, with colors ranging from light grey through dark greyish brown to blackish brown and black. The interbedded sandstones are mostly fine grained, though ranging up to coarse grained, and even pebbly with colors of white to

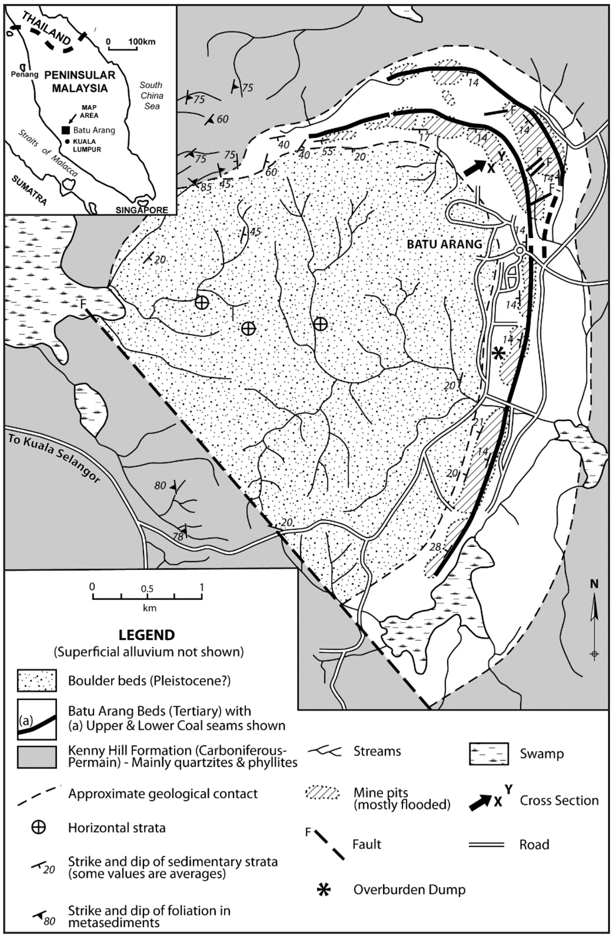

Figure 1: Geology map of the Batu Arang area, Selangor Darul Ehsan. (After Roe, 1951; Law, 1961; Stauffer, 1973; Raj, 1998; Raj *et al.*, 2009).

various shades of brown depending upon the amount of carbonaceous matter. Small-scale cross-bedding is very common, while pebbly beds sometimes contain rounded clay pebbles. The coal mostly occurs as thin laminae, though two thick seams are found in the eastern part of the basin; the Upper Seam with a thickness of up to 15 m, and the Lower Seam averaging 8 m in thickness. The two seams are some 65 m stratigraphically apart and have been mined by open-cast and under-ground methods from 1915 to 1960 (Renwick & Rishworth, 1966).

Fossil leaves and other plant fragments within the coal-bearing sediments indicate a young, possibly Late Tertiary or younger, age and also suggest a drier climate than at present, or a partly upland source for the transported plant material (Roe, 1951). More recent work utilizing palynomorph assemblages indicates that the coals are of a probable Eocene to Oligocene age and were deposited in a lacustrine environment under somewhat seasonal climatic conditions (Ahmad, 1993).

The Tertiary sediments show a synclinal structure that plunges southwestwards, though this is considered to reflect the basin of deposition, rather than tectonic activity (Stauffer, 1973). Two to three sets of joints are found in the silty to sandy shales; the two more prominent sets showing steep dip angles and striking perpendicular to bedding with variable spacings of 0.1 to 0.5 m. Joints (cleats) are also present in the coal seams, though their orientations are more variable and their spacings closer, ranging from 0.03 to 0.06 m.

METHODOLOGY OF STUDY

In view of the need for fresh (unaltered) samples, sampling points were limited to accessible sites at an open-cast shale pit where excavation was being actively carried out (Figure 2). Three sampling points were located on the west wall of the pit; sample A at a depth of 10 m below the ground surface, and samples B and C some 10 m, and 16 m, stratigraphically below sample A (Figure 3). The fourth sampling point (sample D) was located on the east wall of the pit at a depth of 5 m below the ground surface (Figure 4). Several large blocks (each about 0.03 m^3 in volume) of fresh shale were collected at each of the sampling points and taken to the laboratory where they were diamond-sawn into smaller tetrahedral blocks. The visible textural and structural features of each of the blocks was then described before the densities, unit weights and apparent porosities of representative, wax coated specimens determined following the saturation and bouyancy technique described in ISRM (1979) and AIT (1981).

The corners of the tetrahedral blocks were rounded off, and about ten of them (each weighing about 40 to 60 g) selected to give a total weight of some 400 to 600 g

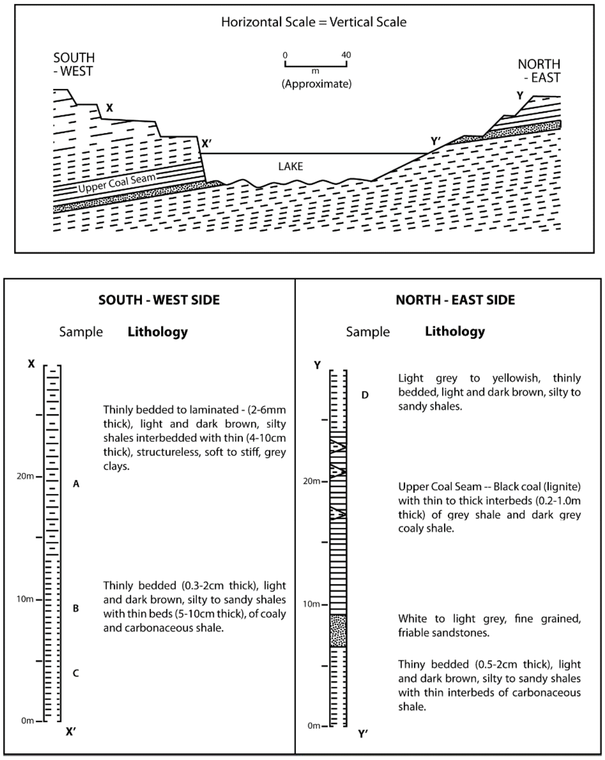

Figure 2: Geological cross-sections and locations of samples. (Points X and Y are shown in Figure 1).

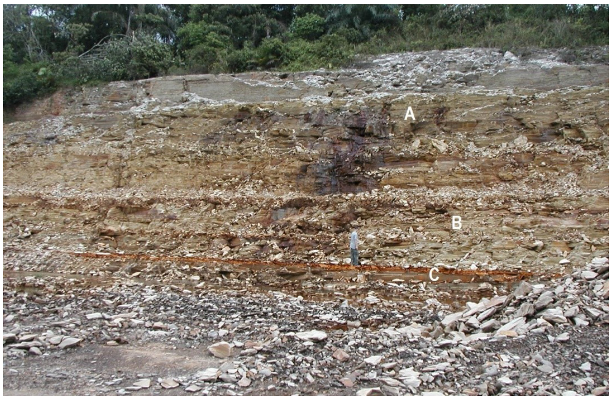

Figure 3: View of sampling points A, B and C.

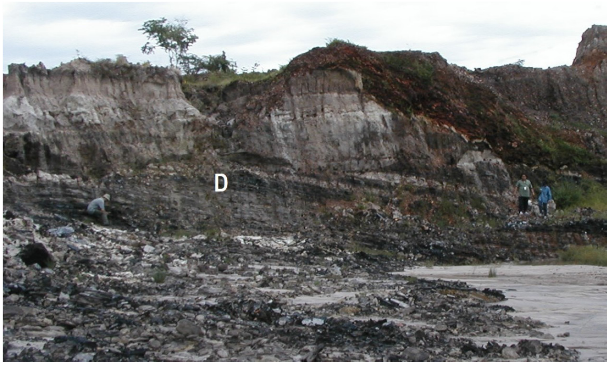

Figure 4: View of sampling point D.

for each test sample. Each sample (comprising some ten individual blocks) was oven-dried at 105°C overnight, and then placed in the drum of the slake durability apparatus. The weight of the drum and test specimen was then determined (Weight A) before the drum was covered with a lid and placed in the trough attached to the motor-drive unit. The trough was filled with tap water to a level some 20 mm below the drum axis, and the drum rotated at 20 rev/min for a period of 10 minutes. The drum (with the retained specimen) was then removed from the trough and oven-dried (over-night) at 105°C before the weight was measured (Weight B). The same process was repeated and the oven-dried weight of the drum and retained specimen determined (Weight C). The drum was then oven-dried (over-night) at 105°C and its weight determined (Weight D). The slake durability index (Id_2) for the two cycles of wetting and drying was then calculated as a percentage ratio of the final to initial dry specimen weight as follows:

$$\text{Slake durability index } (Id_2)\ \% = ((C-D)/(A-D)) \times 100$$

Repetition of the wetting and drying cycles with determination of oven-dry weights then gave slake durability indices for increasing numbers of cycles.

The apparatus used for the slake durability tests was manufactured by ELE (Engineering Laboratory Equipment) and consisted of a base-mounted, motor-drive unit that allowed rotation of drums at 20 revolutions per minute. Four mesh drums and four water tanks could be attached to the motor-drive unit with quick-release assemblies to allow for the simultaneous testing of four samples.

RESULTS

Physical properties of shales

Densities, unit weights and apparent porosities of representative specimens of the tested samples A, B, C and D are shown in Table 1. The laminated, dark brown shale (sample A) is the densest shale with an average dry unit weight of 16.64 kN/m^3, dry density of 1698 kg/m^3 and apparent porosity of 26.2 %. The thinly bedded, light brown, sandy shale (sample D) is the next most dense one with an average dry unit weight of 15.40 kN/m^3, dry density of 1574 kg/m^3, and apparent porosity of 31.7%. The thinly bedded, brown, silty shale (samples C and D) is the least dense shale with an average dry unit weight of 14.49 kN/m^3, dry density of 1479 kg/m^3, and apparent porosity of 35.7%.

Slake durability indices

Slake durability indices show some variability; the single cycle index (Id_1) of the laminated, dark brown shale (sample A) being 99.3%, and that of the other shales (samples B, C and D) between 98.3% and 98.6% (Table 2). The durability index (Id_2) for two standard cycles of wetting and drying of the laminated, dark brown shale (sample A) is 98.9%, and that of the other shales (samples B, C and D) between 96.7% and 97.4% (Table 2).

The slake durability index (Id_3) for three standard cycles of wetting and drying is more variable; the laminated, dark brown shale (sample A) with an index of 98.2%, the brown, silty shale (samples B and C) with an average index of 95.3%, and the light brown, sandy shale (sample D) with an index of 96.2% (Table 2). The durability index (Id_4) for four standard cycles of wetting

Table 1: Physical properties of selected shales from the Batu Arang Beds.

Sample	Lithology	Dry Unit Weight (kN/m^3)	Apparent Porosity (%)	Dry Density (kg/m^3)
A (1)	Laminated, dark brown, shale	16.95	24.8	1730
A (2)		16.52	26.7	1686
A (3)		16.45	27.0	1679
Average		16.64	26.2	1698
B (1)	Thinly bedded, brown, silty shale	14.73	34.6	1503
B (2)		14.30	36.6	1459
C (1)		14.45	35.9	1474
Average		14.49	35.7	1479
D (1)	Thinly bedded, light brown, sandy shale	15.49	31.3	1581
D (2)		15.50	31.2	1582
D (3)		15.19	32.6	1550
Average		15.40	31.7	1574

Table 2: Slake durability indices of selected shales from the Batu Arang Beds.

Sample	Lithology	Slake Durability Index			
		Cycle 1 (Id_1)	Cycle 2 (Id_2)	Cycle 3 (Id_3)	Cycle 4 (Id_4)
A	Dark brown, shale	99.3	98.9	98.2	97.6
B	Brown, silty shale	98.3	97.1	95.5	93.3
C		98.6	96.7	95.1	93.8
D	Light brown, sandy shale	98.6	97.4	96.2	95.0

and drying is most variable; the laminated, dark brown shale (sample A) with an index of 97.6%, whilst the brown, silty shale (samples B and C) has an average index of 93.6%, and the light brown, sandy shale (sample D) an index of 95.0% (Table 2).

DISCUSSION

Variations in slake durability indices

As the samples were collected at different stratigraphic positions and depths below the ground surface, there can be expected some differences in slake durability indices. The indices for different cycles of wetting and drying, however, are quite close with some correlation between the physical properties and durability indices (Tables 1 and 2). The laminated, dark brown shale (sample A) with the largest values of dry unit weight and dry density but lowest apparent porosity has the highest durability indices for different cycles, whilst the thinly bedded, brown, silty shale (samples B and C) with the lowest values of dry unit weight and dry density, but highest apparent porosity, has the lowest indices. The thinly bedded, light brown, sandy shale (sample D) with intermediate values of dry unit weight and density as well as apparent porosity furthermore, has intermediate values of durability indices. Increasing density and unit weight but decreasing apparent porosity thus results in increasing durability of the shales.

Comparison with published data

The durability indices for two cycles of wetting and drying (Id_2) of the Batu Arang shales are between 96.7% and 98.9%; a range that is comparable with the durability indices (Id_2) of 91.6%, and between 82.5% and 87.1%, reported for slightly weathered (grade II), and moderately weathered (grade III) shale. Details on the age of the investigated shale are, however, not provided (Azman Kassim & Edy Tonnizam Mohammad, 2007).

The single cycle durability indices (Id_1) of between 98.3% and 99.3% for the Batu Arang shales are furthermore, compatible with the indices (Id_1) of 98%, and 92%, reported for a slightly weathered sandstone, and a highly weathered shale, from the Kenny Hill Formation (Zainab Mohamed *et al.*, 2007).

The durability indices for two standard cycles of wetting and drying (Id_2) of the Batu Arang shales between 96.7% and 98.9% can also be considered comparable with the indices (Id_2) of 87% to 98%, and 68%, reported for slightly weathered to fresh sandstones, and moderately weathered mudstone, from the Carboniferous to Permian Kati Formation in Perak State (Wong *et al.*, 2018).

The single cycle durability indices (Id_1) of between 98.3% and 99.3% of the Batu Arang shales are directly comparable with the indices (Id_1) of between 99.8% and 99.9% of shales from the Middle to Upper Triassic Gemas Formation (Raj, 2020). The slake durability indices for two standard cycles of wetting and drying (Id_2) of between 96.7% and 98.9% are also comparable with the indices (Id_2) of 99.1% to 99.7% of shales from the Gemas Formation (Raj, 2020).

Durability classification of shales

The shales from the Batu Arang Beds have slake durability indices for two cycles of wetting and drying (Id_2) of between 97.1% and 98.9%. These indices thus allow the shales to be classified as being of extremely high durability in terms of the classification proposed by Franklin & Chandra (1972).

In terms of the Colorado Department of Transportation classification (CDOT, 2015) furthermore, the laminated. dark brown shale (sample A) would be classified as being of very high durability, whilst the other shales (samples B, C and D) would be classified as being of high durability. This high to very high durability classification thus indicates that shales of the Batu Arang Beds are suitable for use as highway embankment or construction material (CDOT, 2015). Problems with ground settlement at overburden dumps associated with coal mining in the Batu Arang area can therefore, not be attributed to disaggregation or disintegration of shale blocks.

Validity of durability classification of shales

The large durability indices for two cycles of wetting and drying (Id_2) of the shales and their classification as being of high to extremely high durability is somewhat surprising in view of their relatively young geological age (Eocene to Oligocene). Over-burden loads on the Batu

Figure 5: Recent excavation in overburden dump (25.03.2023) - Dumping 1937-1945 with coal extraction at Open-Cast No. 8 in Upper Coal Seam. (30 cm ruler for scale)

Figure 6: Relatively fresh shale blocks at overburden dump (25.03.2023) - Overburden dumping from 1937 to 1945. (30 cm ruler for scale)

Arang Beds are also not expected to be large in view of their present exposure at the ground surface.

Recent excavations at an overburden dump from the early days of coal mining expose relatively fresh shale blocks that have experienced little disaggregation or disintegration over the years (Figures 5 and 6). This overburden dump, with a minimum thickness of 4 m, is located some 20 m from the west edge of former Open Cast Coal Mine No. 8, and some 100 m south of the adit to the old underground Centre Mine No. 3 (Figure 1). Open Cast Mine No. 8 in the Upper Coal Seam was started with over-burden stripping in 1936 and followed by coal extraction in 1937 and subsequent years till about the start of the Second World War (Roe, 1951; Renwick & Rishworth, 1966). The over-burden earth materials at the dump are thus some 78 to 85 years of age.

CONCLUSION

It is concluded that slake durability tests allow shales from the Eocene to Oligocene Batu Arang Beds to be classified as being of high to extremely high durability and thus suitable for use as highway embankment or construction material. Four shale samples were tested; three of them (A, B and C) from the western wall of an open-cast shale pit, and one sample (D) from the eastern wall. Samples A and D are located some 10 m, and 5 m, below the ground surface whilst samples B and C are 10 m, and 16 m, stratigraphically below sample A. Samples A, B and C, and D have average dry unit weights of 16.64, 14.49, and 15.40, kN/m^3 and average apparent porosities of 26.2 %, 35.7% and 31/7%, respectively.

Slake durability indices for one standard cycle of wetting and drying (Id_1) of all samples are between 98.3% and 99.3%, whilst indices for two standard cycles (Id_2) are between 96.7% and 98.9%. Durability indices for three standard cycles (Id_3) are between 95.1% and 98.2%, and indices for four standard cycles (Id_4) between 93.3% and 97.6%. The high to extremely high durability classification of the shales is validated by recent excavations at an overburden dump where relatively fresh shale blocks with little disaggregation nor disintegration are exposed even though they have been buried for some 78 to 85 years.

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CONFLICT OF INTEREST

The author has no conflicts of interest to declare that are relevant to the content of this article.

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Aplikasi isotop sebagai teknik nuklear dalam pentaksiran pencemaran air tanah disebabkan oleh aktiviti manusia

Application of isotope as a nuclear technique in groundwater pollution assessment due to human activities

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Abstrak: Air tanah yang bersih dan lestari adalah aset yang penting untuk kehidupan manusia dan ekosistem. Namun, ancaman pencemaran air tanah semakin meningkat akibat aktiviti manusia seperti perindustrian, pertanian, dan perbandaran. Objektif artikel tinjauan ini adalah untuk meneliti bagaimana teknik isotop, sebagai salah satu teknik nuklear berfungsi sebagai alat yang berkesan dalam mengkaji, mengesan, dan memahami isu pencemaran air tanah berpunca dari aktiviti antropogenik di permukaan. Artikel ini merangkumi penerangan dan perbincangan mengenai jenis-jenis isotop yang digunakan dalam pengesanan pencemaran air tanah dan faktor-faktor yang mempengaruhi variasi komposisi isotop di dalam air tanah berdasarkan dapatan kajian-kajian terdahulu. Selain itu, artikel ini juga memberi ulasan mengenai kajian pencemaran air tanah menggunakan isotop dalam konteks pentaksiran pencemaran air tanah di Malaysia. Artikel ini berfungsi sebagai panduan atau rujukan kepada penyelidik, profesional alam sekitar, dan pengurus sumber air yang ingin memahami dan melaksanakan teknik nuklear dalam pemantauan dan pentaksiran pencemaran air tanah. Artikel ini juga menggariskan satu pandangan holistik terhadap penyelesaian isu pencemaran air tanah melalui aplikasi teknik nuklear dan isotop berperanan sebagai alat yang signifikan dalam menjamin pengurusan alam sekitar yang lestari.

Kata kunci: Teknik nuklear, isotop, air tanah, sumber pencemaran

Abstract: Clean and sustainable groundwater is an important asset for human life and ecosystems. However, the threat of groundwater pollution is increasing as a result of human activities such as industrial, agricultural, and municipal. The objective of this review article is to examine how isotope techniques, as one of the nuclear techniques serve as an effective tool in studying, detecting, and understanding the issue of groundwater pollution stemming from anthropogenic activity on the surface. This article covers the description and discussion of the types of isotopes used in the detection of groundwater pollution and factors that influence the variation in the composition of isotopes in groundwater based on the findings of previous studies. In addition, this article also comments on the study of groundwater pollution using isotopes in the context of groundwater pollution assessment in Malaysia. This article serves as a guide or reference to researchers, environmental professionals, and water resources managers who want to understand and implement nuclear techniques in the monitoring and assessment of groundwater pollution. This article also outlines a holistic view on the resolution of groundwater pollution issues through the application of nuclear techniques and isotopes as a significant tool in ensuring sustainable environmental management.

Keywords: Isotope techniques, isotopes, groundwater, source of pollution

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PENGENALAN

Air merupakan nadi kehidupan manusia. Air tanah merupakan salah satu sumber air utama dalam kehidupan manusia merangkumi lebih 50% keseluruhan sumber air tawar di dunia (Mahamat Nour *et al*., 2022; Ansari *et al*., 2023; Gupta *et al*., 2023). Air tanah merupakan air yang terdapat di dalam lapisan tanah atau batuan di bawah permukaan bumi yang meresap ke dalam tanah melalui retakan dan liang-liang. Sumber air tanah ini digunakan secara meluas untuk tujuan domestik, pertanian dan perindustrian (Cao *et al*., 2022; Carrión-Mero *et al*., 2022; Chander *et al*., 2023; Tanui *et al*., 2023). Sejak abad ke-20, air tanah telah memainkan peranan penting dalam pertambahan populasi manusia dan pembangunan sosioekonomi (Zhang *et al*., 2018; Zhang *et al*., 2023). Walau bagaimanapun, kualiti air tanah telah terjejas teruk pada masa kini disebabkan oleh peningkatan aktiviti-aktiviti manusia seperti pembangunan bandar, pelupusan air sisa yang tidak mengikuti piawaian yang telah ditetapkan, penggunaan baja pertanian yang berlebihan, tumpahan minyak dan perubahan guna tanah. Secara tidak langsung, aktiviti-aktiviti berikut telah menyumbang kepada penambahan bahan cemar seperti bahan kimia beracun, logam berat, atau sisa toksik (Rodushkin *et al*., 2022; Sankoh *et al*., 2022; Gupta *et al*., 2023; Zhang *et al*., 2023). Usaha untuk merawat air tanah tercemar bagi mengembalikan kualiti asal air tanah adalah sangat sukar dan mencabar (Jakóbczyk-Karpierz & Ślósarczyk, 2022; Zhang *et al*., 2023). Impak sinergistik aktiviti manusia yang intensif serta perubahan iklim turut memberi kesan yang kompleks kepada penurunan kualiti air tanah (Xia *et al*., 2023).

Bagi menangani masalah pencemaran air tanah yang semakin meruncing, pelbagai kaedah telah digunakan bagi mengenal pasti punca pencemaran air tanah di seluruh dunia. Antara kaedah tersebut ialah hidrokimia, geofizik, hidrogeologi, dan hidrogeokimia (Ouhamdouch *et al*., 2022; Sankoh *et al*., 2022; Ansari *et al*., 2023; Zhu *et al*., 2023). Namun, bagi memperoleh maklumat yang lebih tepat mengenai punca pencemaran air tanah, teknik nuklear telah digunakan. Penggunaan teknologi nuklear terutamanya teknik isotop dalam pentaksiran pencemaran air telah mendapat perhatian yang meluas oleh penyelidik-penyelidik dari seluruh dunia. Menurut mereka, penggunaan teknologi nuklear ini berupaya menghasilkan maklumat yang lebih komprehensif dan sebagai pelengkap kepada kaedah konvensional dalam menyelesaikan isu-isu pengurusan sumber air (Blarasin *et al*., 2021; Jakóbczyk-Karpierz & Ślósarczyk, 2022; Rodushkin *et al*., 2022). Oleh itu, terdapat keperluan untuk memberi penekanan serius terhadap pemantauan dan kajian yang teliti mengenai punca pencemaran air tanah bagi memastikan sumber air ini kekal lestari (Xie *et al*., 2023).

Objektif artikel tinjauan ini ialah untuk merungkai penggunaan teknik nuklear iaitu teknik isotop dalam mengenal pasti sumber pencemaran air tanah yang berpunca daripada aktiviti manusia. Artikel ini mengandungi lima bahagian. Bahagian pertama artikel merangkumi pengenalan tentang keperluan pentaksiran pencemaran air tanah yang lebih tepat dengan menggunakan teknik isotop. Penerangan mengenai jenis isotop dalam penjejakan punca pencemaran air tanah diterangkan pada bahagian dua. Seterusnya, faktor-faktor yang mempengaruhi variasi komposisi isotop di dalam air tanah dibincangkan di bahagian tiga. Bahagian empat pula membincangkan hala tuju kajian pencemaran air tanah di Malaysia menggunakan teknik isotop ini. Bahagian lima pula adalah kesimpulan yang dapat diperolehi daripada penggunaan isotop dalam pentaksiran pencemaran air tanah. Artikel ini akan membantu pembaca memahami dengan lebih mendalam konsep isotop dan bagaimana ia digunakan dalam mengenal pasti punca pencemaran air tanah oleh aktiviti manusia. Kefahaman yang menyeluruh mengenai penggunaan isotop akan meningkatkan kebolehan penyelidik dan pihak bertanggungjawab dalam bidang alam sekitar untuk mengesan dan memantau pencemaran air tanah dengan lebih efektif. Secara tidak langsung, ia dapat membantu dalam menangani masalah pencemaran air tanah melalui tindakan pencegahan dan pemulihan yang lebih cepat dan berkesan.

JENIS ISOTOP DALAM PENGESANAN PUNCA PENCEMARAN AIR TANAH

Isotop merujuk kepada variasi atom dalam unsur kimia yang memiliki jumlah proton yang sama tetapi memiliki nombor neutron yang berbeza, menyebabkan berat atom yang berbeza (IAEA, 2022). Isotop-isotop ini mempunyai sifat kimia yang sama kerana masing-masing mempunyai bilangan dan susunan elektron yang sama, namun sifat fizik isotop seperti ketumpatan dan takat didih adalah berbeza (IAEA, 2022). Isotop boleh dibahagikan kepada dua jenis iaitu isotop stabil dan isotop radioaktif (Sankoh *et al*., 2022). Menurut Agensi Tenaga Atom Antarabangsa (IAEA, 2022), 80 elemen pertama dalam Jadual Berkala mempunyai isotop stabil. Isotop stabil mempunyai jangka separuh hayat (*half-life*) yang sangat panjang sehingga mencecah ratusan juta tahun. Manakala isotop radioaktif ialah isotop yang mempunyai nukleus atom yang tidak stabil yang melalui proses pereputan radioaktif. Contoh isotop radioaktif ialah tritium yang mempunyai separuh hayat 12.33 tahun (Malkova *et al*., 2023; Tanui *et al*., 2023).

Dalam konteks penyelidikan sumber pencemaran air tanah, penggunaan isotop stabil dan radioaktif menjadi satu alat pengesanan pencemaran yang efektif. Ciri-ciri khusus yang dimiliki oleh setiap isotop telah membolehkan ia untuk memberikan petunjuk yang tepat tentang asal usul dan pergerakan air serta punca bahan pencemar seperti nitrat, sebatian klorin, karbonat dan sebatian-sebatian antropogenik lain dalam sistem hidrologi. Ini secara tidak langsung telah meningkatkan kualiti dapatan kajian seterusnya meningkatkan pemahaman mengenai pelbagai proses hidrologi dan hidrogeologi yang terlibat (Mohamed *et al*., 2021; Heiderscheidt *et al*., 2022; IAEA, 2022; Ouhamdouch *et al*., 2022; Sankoh *et al*., 2022; Dee *et al*., 2023; Malkova *et al*., 2023; Pandey *et al*., 2023; Tanui *et al*., 2023; Zhang *et al*., 2023; Zhu *et al*., 2023). Proses-proses tersebut merangkumi interaksi air permukaan dengan air tanah, punca dan sumbangannya dalam alir masuk semula (*recharge*) air tanah dan proses alir masuk semula air tanah (Malkova *et al*., 2023; Pandey *et al*., 2023). Antara isotop yang paling banyak digunakan adalah oksigen (^{18}O), hidrogen (^{2}H, atau D), karbon (^{13}C), sulfur (^{34}S) dan nitrogen (^{15}N) (Mohamed *et al*., 2021; Hosono *et al*., 2023).

Aktiviti manusia di permukaan tanah mempunyai kesan yang signifikan terhadap kandungan isotop di dalam air tanah. Kegiatan seperti pertanian, perindustrian, penggunaan bahan api fosil dan pengeluaran sisa kimia merupakan antara aktiviti manusia yang dapat mempengaruhi komposisi isotop di dalam air tanah. Campuran pelbagai bahan pencemar yang terhasil dari kegiatan aktiviti-aktiviti tersebut boleh mencemar sumber air tanah. Maka, adalah menjadi satu keperluan untuk mengesan punca pencemaran air tanah ini dengan mengaplikasi teknologi nuklear yang menjamin penghasilan dapatan kajian yang lebih tepat. Berdasarkan kajian-kajian yang lepas, terdapat pelbagai jenis isotop yang digunakan dalam mengesan punca pencemaran air tanah di seluruh dunia seperti rumusan pada Jadual 1. Julat-julat kandungan isotop ini berbeza mengikut lokasi kajian dan faktor-faktor yang dibincangkan di bahagian seterusnya. Untuk skop artikel ini, hanya beberapa jenis isotop yang diberi perhatian iaitu isotop hidrogen (deuterium dan tritium), oksigen, karbon, nitrat, sulfat, ammonium, dan boron. Ini kerana isotop-isotop ini adalah isotop yang biasa digunakan dalam kajian pengesanan pencemaran air tanah oleh aktiviti manusia.

Isotop hidrogen

Secara semulajadi, hidrogen yang membentuk molekul air mempunyai tiga isotop yang utama iaitu hidrogen (^{1}H), deuterium (^{2}H) dan tritium (^{3}H). Hidrogen (^{1}H) atau juga dikenali sebagai protium merupakan isotop utama yang mudah dibebaskan melalui proses penyejatan (Malkova *et al*., 2023). Isotop ^{1}H hanya terdiri daripada satu atom dan mempunyai ketumpatan lebih daripada 99.98%. Isotop deuterium (^{2}H) terdiri daripada satu proton dan satu neutron di dalam nukleusnya. Deuterium tidak radioaktif dan tidak mendatangkan bahaya toksik yang tinggi.

Tritium (^{3}H) pula merupakan isotop radioaktif yang mengandungi satu proton dan dua neutron di dalam nukleusnya. Ia mereput melalui pereputan β^- untuk membentuk helium-3, dan mempunyai separuh hayat selama 12.32 tahun (Malkova *et al*., 2023; Tanui *et al*., 2023). Tritium digunakan sebagai pengesan dalam penentuan usia air tanah semasa dan punca pencemaran air tanah (Tanui *et al*., 2023). Penentuan usia air tanah menggunakan tritium membantu mengenal pasti zon akuifer yang rentan terhadap pencemaran. Tritium terbentuk dalam atmosfera akibat pengaruh partikel radiasi kosmik, semasa operasi loji nuklear dan reaktor penyelidikan, dan sisa dari ujian nuklear di udara terbuka pada masa lalu (Malkova *et al*., 2023). Menurut Ouhamdouch *et al*. (2022), kandungan tritium yang melebihi 1 TU (*Tritium Unit*) (Unit Tritium) menunjukkan penambahan semua air tanah selepas nuklear (*post-nuclear recharge*) dan kandungan tritium yang kurang daripada 1 TU mewakili penambahan semula pra-nuklear (*pre-nuclear recharge*) atau campuran antara air baru dan air lama. Selain itu, tritium telah digunakan sebagai pengesan air larut resapan yang berkesan. Ini kerana tritium tidak wujud di dalam air laut mahupun baja. Fakta tersebut telah menetapkan asas dalam membezakan air tanah dan air larut resapan. Ciri-ciri unik ini menjadikan tritium lebih digemari berbanding parameter kimia dan isotop yang lain dalam proses membezakan air larut resapan tapak pelupusan dari sisa septik dan baja (Sankoh *et al*., 2022).

Isotop oksigen

Isotop oksigen mempunyai tiga isotop stabil dengan jisim atom 16, 17, dan 18 (^{16}O, ^{17}O dan ^{18}O), dengan nisbah relatif 99.76%, 0.04% dan 0.2%. Oleh kerana pemeringkatan (*fractionation*) ^{17}O dan ^{18}O berkadaran dengan ^{16}O, dan jumlah ^{17}O yang kecil, maka nisbah isotop dikira menggunakan $^{18}O/^{16}O$ (~1/500). Kebiasaannya, pengiraan tersebut digunakan untuk mengira nisbah isotop di dalam sampel air (contohnya, air tanah dan ais), sedimen karbonat ($CaCO_3$), gas oksigen (O_2), karbon dioksida (CO_2), dan bahan organik. Manakala, nisbah $^{18}O/^{16}O$ adalah berbeza dengan melebihi 100‰ (Delaygue, 2009). Kandungan ^{16}O lebih mudah terbebas berbanding dengan ^{18}O kerana perbezaan berat unsur. Proses fizikal seperti penyejatan boleh merubah variasi nisbah isotop-isotop stabil $^{2}H/^{1}H$ dan $^{18}O/^{16}O$ di dalam sampel air yang mewakili lokasi tertentu. Secara tidak langsung, variasi sedemikian berkemungkinan membolehkan "fingerprint" air dapat dikaitkan dengan asal usul (*origins*) dan perkaitannya dapat dikenal pasti (Li *et al*., 2019a; Yaacup *et al*., 2002). Isotop oksigen dan hidrogen adalah pengesan yang sesuai dalam menentukan sumber air dan juga pergerakan air kerana ia merupakan molekul-molekul air (Li *et al*., 2019a). Namun, terdapat pelbagai faktor yang berpotensi untuk mengubah komposisi isotop-isotop ini di dalam pemendakan sebelum sampai ke akuifer. Antara faktor yang berkaitan termasuklah geologi batu asas, jenis aquifer dan kedalamannya (Wright & Novakowski, 2020).

Isotop karbon

Isotop karbon adalah variasi atom karbon yang mempunyai nombor jisim yang berbeza. Terdapat tiga isotop karbon utama yang biasa dijumpai, iaitu karbon-12 (^{12}C), karbon-13 (^{13}C) dan karbon-14 (^{14}C). ^{12}C adalah isotop paling lazim dengan nombor jisim 12. Ia membentuk sebahagian besar karbon yang ada di alam semulajadi, iaitu lebih daripada 98%. Isotop karbon sering digunakan untuk menilai transformasi karbon dan untuk mengikuti pergerakan karbon bukan organik terlarut (*dissolved inorganic carbon,* DIC). Pertukaran atau kehilangan karbon memberi kesan pada perubahan $\delta^{13}C$-DIC disebabkan oleh degradasi isotop yang berlaku di setiap proses (Huang *et al*., 2023).

Apabila penguraian CO_2 di dalam tanah menjadi faktor utama yang mempengaruhi penguraian mineral karbonat, nilai bagi isotop karbon DIC ($\delta^{13}C_{DIC}$) adalah kira-kira – 8.5‰. Manakala, nilai $\delta^{13}C_{DIC}$ yang dihasilkan oleh penguraian bahan organik adalah lebih kurang – 14‰ apabila air tanah dicemari oleh najis haiwan dan aktiviti manusia. Seterusnya, nilai $\delta^{13}C_{DIC}$ adalah pada 0‰ yang menggambarkan berlakunya proses pelarutan (*dissolution*) mineral karbonat, kesan pengaruh asid kuat atau CO_2 di udara (Huang *et al*., 2023).

Pelepasan karbon biogenik yang isotopik ringan boleh dikaitkan dengan proses pengoksidaan dan penguraian bahan organik labil dalam air sisa. Penguraian bahan organik ini membawa kepada penurunan nilai $\delta^{13}C_{DIC}$ dengan peningkatan DIC. Oleh itu, hubungan antara $\delta^{13}C_{DIC}$ dan ion antropogenik seperti Na, K, NO_3 and Cl, di dalam air tanah cetek yang terjejas oleh air sisa menunjukkan bahawa aktiviti manusia (karbon dalam bahan organik dalam air sisa) boleh memberi kesan kepada pencemaran air tanah, dengan mengurangkan nilai $\delta^{13}C_{DIC}$ dan meningkatkan fluorida dan kemasinan air tanah (Li *et al*., 2019b). Selain itu, pengeluaran air tanah yang intensif bagi kegunaan industri, pertanian, dan domestik selama beberapa dekad telah mengganggu keseimbangan dinamik air tawar dan air masin. Senario tersebut telah menyumbang kepada kemasukan air masin ke dalam sistem akuifer dan seterusnya merosakkan kualiti air tanah (Li *et al*., 2019b).

Isotop nitrat

Pencemaran nitrat di dalam air tanah merupakan masalah serius yang di hadapi oleh majoriti pengguna air tanah di seluruh dunia. Nitrat merupakan sebatian yang mempunyai sifat yang stabil, keterlarutan yang tinggi dan mudah bermigrasi yang menjadikan ia antara pencemar utama air tanah (Zhang *et al*., 2023). Kandungan nitrat yang tinggi dalam air tanah yang dijadikan sumber air minuman berpotensi untuk mendatangkan risiko kesihatan (Huang *et al*., 2021; He *et al*., 2022). Antara risiko kesihatan akibat pendedahan kepada kandungan nitrat yang tinggi di dalam sumber air ialah penyakit *methemoglobinemia* atau 'sindrom bayi biru', keguguran, dan penyakit tiroid (Huang *et al*., 2021; Shamsuddin *et al*., 2023). Sehubungan dengan itu, Pertubuhan Kesihatan Sedunia (WHO) telah menetapkan garis dasar kepekatan tertinggi (*Maximum Contaminant Level, MCL*) bagi nitrat di dalam air minuman ialah pada 10 mg/L NO_3-N (Huang *et al*., 2021). Di samping itu, pelepasan air tanah yang mengandungi nitrat yang tinggi ke air permukaan boleh menyebabkan pelbagai masalah ekologi dan alam sekitar, termasuklah eutrofikasi dan hipoksia bermusim (Zhang *et al*., 2018). Kajian terdahulu turut melaporkan keberkesanan aplikasi teknik isotop nitrat dalam penentuan punca pencemaran nitrat yang disebabkan oleh ciri-ciri komposisi isotopnya yang spesifik atau berbeza (Sankoh *et al*., 2022; Hermawan *et al*., 2023).

Nitrat terdiri daripada pelbagai isotop stabil nitrogen (N) dan oksigen (O) dengan komposisi kedua-dua isotop ini adalah berbeza di dalam sistem air permukaan dan air tanah (Snow, 2018). Transformasi nitrogen di persekitaran, seperti proses nitrifikasi dan denitrifikasi boleh mengubah komposisi isotop nitrat disebabkan oleh proses pemecahan fizikal, kimia dan biologi (Zhang *et al*., 2018; Huang *et al*., 2021). Oleh itu, kombinasi dua isotop ini $\delta^{15}N\text{-}NO_3^-$ dan $\delta^{18}O\text{-}NO_3^-$ telah digunakan untuk mengenal pasti punca nitrat di dalam sistem air tanah (Zhang *et al*., 2018; Huang *et al*., 2021; Li *et al*., 2021). Denitrifikasi merupakan satu proses penurunan semulajadi yang mengurangkan tahap nitrat dalam persekitaran air tanah. Kebiasaanya, proses tersebut dapat dikenal pasti dengan baik melalui kedua isotop ini, $\delta^{15}N\text{-}NO_3^-$ dan $\delta^{18}O\text{-}NO_3^-$ kerana nisbah pemeringkatan $\delta^{15}N\text{-}NO_3^-$:$\delta^{18}O\text{-}NO_3^-$ semasa denitrifikasi berada dalam julat antara 1.3:1 dan 2.1:1 (Huang *et al*., 2021; Li *et al*., 2021). Selain itu, jumlah komposisi $\delta^{18}O\text{-}NO_3^-$ dapat digunakan untuk membezakan punca nitrat sama ada berasal daripada penyerapan atmosfera yang mempunyai nilai yang tinggi (>50‰) atau dihasilkan secara biologi di dalam tanah dan air (0.8–5.8‰) (Chen *et al*., 2019).

Penemuan kajian terkini yang dijalankan oleh Zhang *et al*. (2023) telah menggunakan isotop $\delta^{15}N\text{-}NO_3^-$ dan $\delta^{18}O\text{-}NO_3^-$ untuk menentukan punca utama pencemaran nitrat di dalam air tanah di lembangan Sungai Beichuan, China. Dapatan kajian ini menunjukkan bahawa komposisi nitrat adalah berbeza mengikut kepelbagaian tujuan guna tanah seperti kawasan hutan, bandar, perindustrian, pertanian dan perkampungan. Dapatan kajian ini menunjukkan bahawa punca pencemaran air tanah di kawasan-kawasan yang dinyatakan itu adalah daripada tanah bernitrogen ($\delta^{15}N$: 0–8$^0/_{00}$, $\delta^{18}O$: 0–15$^0/_{00}$) di kawasan hutan, sisa kumbahan domestik di kawasan bandar ($\delta^{15}N$: 4–25$^0/_{00}$, $\delta^{18}O$: 0–10$^0/_{00}$) dan di kawasan industri ($\delta^{15}N$: 4–25$^0/_{00}$, $\delta^{18}O$: 0–10$^0/_{00}$), campuran punca (baja ammonia, kumbahan dan baja ternakan) di kawasan pertanian ($\delta^{15}N$: 6–6$^0/_{00}$, $\delta^{18}O$: 10–10$^0/_{00}$) dan kumbahan dan baja ternakan di kawasan perkampungan (Zhang *et al*., 2023).

Isotop sulfat

Sulfat merupakan salah satu unsur utama dalam air tanah dan memainkan peranan penting dalam kitaran biogeokimia (Zhang *et al*., 2023). Walau bagaimanapun, kandungan sulfat yang tinggi boleh menyebabkan pencemaran sulfat di dalam air tanah dan situasi ini sering diabaikan. Sulfat di dalam air tanah berasal dari pelarutan penyejatan (contohnya, gipsum), pengoksidaan mineral sulfida, zon luluhawa, bakteria penurun sulfat, penyerapan atmosfera, baja, sisa kumbahan, dan air lombong, dan lain-lain (Jakóbczyk-Karpierz & Ślósarczyk, 2022; Jiang *et al*., 2022; Huang *et al*., 2023; Zhang *et al*., 2023). Sama seperti nitrat, sulfat di dalam air tanah juga berasal daripada pebagai punca.

Banyak kajian yang telah dijalankan bagi menentukan tahap pencemaran sulfat di dalam air tanah. Antaranya ialah Huang *et al*. (2023) yang menentukan kandungan sulfat di dalam air tanah di kawasan lombong arang batu. Dapatan isotop sulfat di kawasan kajian mendapati punca utama pencemaran sulfat di dalam air tanah adalah disebabkan oleh pengoksidaan sulfat. Aktiviti perlombongan telah memusnahkan struktur batuan dan menutup hubungan hidraulik di antara akuifer-akuifer. Selain itu, pengoksidaan pirit (*pyrite*), bahan organik dan bahan lain yang kaya dengan arang batu menyebabkan pengasidan lantai batu kapur, dan secara tidak langsung meningkatkan keupayaan pelarutan (*dissolution*). Kesan daripada kewujudan kepelbagaian mineral di dalam strata terlarut telah meningkatkan kandungan sulfat di dalam air tanah (Huang *et al*., 2023).

Isotop ammonium

Ammonium adalah salah satu isotop nitrogen. Ammonium merupakan bahan pencemar alam sekitar yang kebiasaannya terkandung dalam air tanah. Penghasilan kandungan ammonium dalam air tanah tidak terhad kepada proses semulajadi sahaja namun turut dipengaruhi oleh aktiviti manusia. Kepekatan ammonium semulajadi yang tinggi sebanyak 390 mg/L telah ditemui di dalam air tanah di akuifer pada kedalaman 20 - 50 m di beberapa dataran di China (Liu *et al*., 2023). Sementara itu, kehadiran air tanah dengan kepekatan ammonium yang tinggi (juga dirujuk sebagai air bawah tanah HANC) secara amnya disebabkan oleh pencemaran antropogenik iaitu kesan penggunaan baja pertanian, baja haiwan, kumbahan domestik bandar, dan kumbahan industri (Böhlke *et al*., 2006; Norrman *et al*., 2015; Liu *et al*., 2023). Kepekatan NH_4^+ dalam julat 1–10 mmol/L telah dikenalpasti dalam akuifer yang tercemar akibat kewujudan tapak pelupusan dan amalan pelupusan air sisa pekat (Böhlke *et al*., 2006). Selain daripada itu, NH_4^+ antropogenik turut dikenal pasti sebagai satu komponen terlarut utama dalam beberapa jenis plum bahan cemar air tanah. Sistem septik dan amalan pertanian juga turut menyumbang kepada kadar cas semula NH_4^+ yang tinggi di kawasan setempat. Kemerosotan kualiti dan kebolehgunaan air tanah juga berpunca dari kewujudan NH_4^+ dalam akuifer dan seterusnya memberi kesan yang besar terhadap interaksi batuan air, dan ia boleh menjadi sumber besar N di perairan permukaan yang menerima pelepasan air bawah tanah.

Di sebalik kepentingan kandungan NH_4^+ kepada alam sekitar, terdapat beberapa kajian yang turut memfokuskan kepada proses pengangkutan dan tindak balas NH_4^+ dalam akuifer (Böhlke *et al*., 2006). Pergerakan ammonium boleh terganggu oleh proses fizikal-kimia seperti penyerapan (termasuk pertukaran kation), atau proses biologi seperti transformasi yang disebabkan oleh mikrob. Namun, proses tersebut turut bergantung kepada geokimia akuifer dan sifat sistem aliran air bawah tanah. Kerencatan pengangkutan NH_4^+ telah diperhatikan di dalam air bawah tanah yang tercemar, dan ia boleh membawa kepada masa pembilasan akuifer yang lebih lama untuk NH_4^+ daripada spesies aquous mudah alih yang lain, dengan faktor terencat relatif berpotensi merangkumi lebih daripada 3 turutan magnitud (10^0 hingga 10^3) (Böhlke *et al*., 2006). Pengoksidaan ammonium biasanya berlaku bersamaan dengan pengurangan O_2 (nitrifikasi) dan mungkin dikaitkan dengan pengurangan Mn-oksida (Böhlke *et al*., 2006).

Selain daripada aktiviti antropogenik, kandungan ammonium dalam air tanah turut berpunca dari sumber ammonium semulajadi iaitu kesan mineralisasi protein dan komponen asid amino dalam bahan organik semulajadi (Liu *et al*., 2023). Kemerosotan anaerobik bahan organik dan kesan pembuangan sisa organik telah menyumbang kepada kandungan ammonium semulajadi dalam air tanah.

Isotop boron

Isotop boron, khususnya boron-11 (^{11}B) dan boron-10 (^{10}B), adalah antara alat penting dalam mengesan pencemaran air tanah. Ciri-ciri isotopik yang unik telah menjadikan isotop ini alat yang berguna dalam mengenalpasti punca pencemaran dalam sistem air tanah.

Dalam konteks pengesanan pencemaran air tanah, isotop boron digunakan untuk beberapa tujuan. Pertama, isotop boron diaplikasikan dalam mengenalpasti punca asal pencemaran dalam air tanah. Secara amnya, boron terdapat dalam pelbagai sumber, termasuk bahan kimia industri, pertanian, dan kumbahan. Melalui analisis isotop, penyelidik boleh membezakan samada kandungan boron yang dikenalpasti pada lokasi kajian berpunca dari sumber boron sumber semula jadi atau sumber buatan manusia. Kedua, isotop boron turut membantu dalam analisis pengukuran kesan pencemaran dalam air tanah. Perubahan dalam nisbah isotop boron dalam air tanah boleh memberikan petunjuk tentang sejauh mana pencemaran telah berlaku. Ini berguna dalam menilai tahap pencemaran dan menentukan tindakan yang diperlukan untuk membersihkan air tanah. Ketiga, analisis isotop boron juga digunakan untuk mengesan pergerakan air tanah. Boron dalam air bawah tanah boleh mengalami pertukaran isotop dengan batuan sekitarnya. Oleh itu, dengan mengukur nisbah isotop boron di beberapa lokasi, penyelidik dapat menentukan arah aliran air bawah tanah dan mendapat gambaran sistem akuifer.

Huraian diatas menunjukkan bahawa penggunaan Isotop boron adalah sangat penting dalam skop pemantauan dan pemahaman pencemaran air tanah. Berdasarkan ciri-ciri isotopik boron, kita dapat mengenal pasti punca pencemaran, mengukur kesan pencemaran, dan memahami pergerakan air bawah tanah dengan lebih baik. Ini membolehkan tindakan yang tepat diambil untuk menjaga kualiti air bawah tanah yang penting bagi kesihatan manusia dan alam sekitar.

Jadual 1: Contoh kajian-kajian terdahulu yang menggunakan isotop dalam pentaksiran punca pencemaran air tanah.

Isotop	Jenis isotop	Julat	Punca pencemaran	Rujukan
Oksigen	$\delta^{18}O-H_2O$	–8.9‰ hingga 8.8‰	Saliran lombong	Jiang *et al.* (2022);
		–4.5‰ hingga 3.7‰	Air larut resap	Sankoh *et al.* (2022)
Hidrogen	δD	–65.7‰ hingga 63.5‰	Saliran lombong	Jiang *et al.* (2022);
		–22‰ hingga +60‰	Air larut lesap	Sankoh *et al.* (2022)
Karbon	$\delta^{13}C$-DIC	–28‰	Penguraian bahan organik	Huang *et al.* (2021);
		–14.6‰ hingga +1.1‰	Pelarutan calcite dan mineral karbonat lain	Sankoh *et al.* (2022)
		+16‰ hingga +21.2‰	Air larut lesap	
		+5‰ hingga +38‰	Air tanah tercemar dengan air larut lesap	
Sulfat	$\delta^{34}S$	25‰ hingga 16.2‰	Pengoksidaan mineral sulfida	Jiang *et al.* (2022);
		2 ‰ hingga 12.5‰	Kumbahan	Jakóbczyk-Karpierz & Ślósarczyk (2022);
		7‰ hingga 21‰	Baja kimia	
		+12‰ hingga +35‰	Penyejatan biasa (gipsum)	Huang *et al.* (2023);
		–18‰ hingga +12‰	Dibentuk oleh sulfida (*pyrite*)	
		–5‰ hingga +6‰	Pemendakan atmosfera	Zhang *et al.* (2023)
	$\delta^{18}O-SO_4^{2-}$	+6‰ hingga +20‰	Penyejatan biasa (gipsum)	
		–5‰ hingga +5‰	Dibentuk oleh sulfida (*pyrite*)	
		+6‰ hingga +18‰	Pemendakan atmosfera	
Nitrat	$\delta^{15}N-NO_3$	–13‰ hingga +13‰	Pemendakan atmosfera	Zhang *et al.* (2018); Carrey *et al.* (2021); Huang *et al.* (2021); Li *et al.* (2021); He *et al.* (2022); Biddau *et al.* (2023); Hosono *et al.* (2023); Hussein *et al.* (2023); Ren *et al.* (2023); Zhang *et al.* (2023)
		0‰ hingga +8‰/ –3‰ hingga +9‰	Nitrogen tanah	
		+4‰ hingga +25‰	Kumbahan dan baja	
		–6‰ hingga +6‰	Baja nitrogen kimia dan urea	
			Nitrogen tanah	
	$\delta^{18}O-NO_3$	–10‰ hingga +10‰	Nitrifikasi (seperti, NO_3^- dari tanah N, NH_4^+ dalam baja dan hujan, dan kumbahan dan baja)	
		+17‰ hingga +25‰	Baja sintetik	
		+25‰ hingga +75‰	Pemendakan atmosfera	
Ammonium	$\delta^{15}N-NH_4^+$	+10‰ hingga +25‰	Baja haiwan	Böhlke *et al.* (2006);
		–3‰ hingga +1‰	Penetapan nitrogen	Liu *et al.*(2023)
		+2‰ hingga +7‰	Bahan organik	
Boron	$\delta^{11}B$	+33‰ hingga +70‰	Air laut	Sankoh *et al.* (2022)
		–6‰ hingga +5‰	Baja sintetik	
		+7.2‰ hingga +42.5‰	Baja najis babi	
		+22.3‰ hingga +24‰	Baja najis lembu	
		+5‰ hingga +25‰	Kumbahan, tapak pelupusan dan larut septik	
Tritium	$\delta^{3}H$	50.9 hingga 159,316 TU	Air larut lesap	Sankoh *et al.* (2022);
		2.3 hingga 76.6 TU	Air bawah tanah tercemar oleh air larut lesap	Malkova *et al.* (2023);
		0.04 hingga 10 TU	Air yang tidak tercemar	
		<10 TU	Kerpasan (*precipitation*)	Tanui *et al.* (2023)

TU = unit tritium, yang sama dengan 1 atom tritium untuk setiap 10^{18} atom hidrogen.

FAKTOR YANG MEMPENGARUHI KOMPOSISI ISOTOP DALAM AIR TANAH

Variasi komposisi isotop di dalam air tanah dipengaruhi oleh keadaan persekitaran. Skop artikel ini akan memberi fokus kepada beberapa faktor keadaan persekitaran termasuklah (i) kawasan kajian, (ii) meteorologi atau iklim kawasan kajian, dan (iii) hidrogeologi kawasan kajian.

Kawasan kajian

Kawasan kajian memainkan peranan yang penting dalam mempengaruhi komposisi isotop di dalam air tanah. Sebagai contoh, status negara iaitu negara maju, membangun dan juga kurang membangun (mundur) akan mempunyai kandungan komposisi isotop yang berbeza antara satu sama lain. Faktor penyumbang kepada perbezaan komposisi isotop ini termasuklah faktor penggunaan tanah dan kepelbagaian aktiviti manusia yang dilaksanakan di negara-negara tersebut.

Di negara maju, pertumbuhan bandar biasanya adalah pesat. Terdapat pembinaan bangunan komersial yang pesat, perumahan yang padat, dan industri besar. Aktiviti pembinaan dan industri boleh menyebabkan pencemaran air tanah. Selain itu, kepesatan industri, penggunaan bahan kimia dalam pertanian dan perindustrian, pengurusan sisa dan air sisa bandar juga dapat mempengaruhi komposisi isotop di dalam air tanah. Ini berlaku apabila bahan pencemar yang terhasil daripada aktiviti tersebut meresap ke dalam air tanah. Bagi negara membangun pula, ia mungkin juga mengalami pertumbuhan bandar yang pesat, walaupun mungkin pada tahap pembangunan infrastruktur yang lebih rendah berbanding negara maju. Selain itu juga, aktiviti pertanian masih menjadi sumber utama pendapatan negara dan kebarangkalian penggunaan bahan kima pertanian mungkin kurang intensif berbanding negara maju. Pengurusan bahan kimia pertanian masih pada tahap kurang canggih, dan ini boleh menyebabkan pencemaran air tanah yang terhasil daripada sisa domestik dan pertanian. Manakala bagi negara kurang membangun atau mundur, industri pertanian tradisional masih menjadi aktiviti utama penduduk. Penggunaan bahan kimia dalam industri tersebut sedikit sebanyak akan mempengaruhi komposisi isotop yang terkandung di dalam air tanah. Faktor pertumbuhan bandar yang terhad dan pengurusan sisa yang tidak cekap juga turut menyumbang kepada perubahan komposisi isotop air tanah di negara kurang membangun.

Eksploitasi penggunaan tanah yang tidak terkawal untuk pelbagai tujuan telah memberi kesan kepada kualiti air tanah. Senario tersebut berlaku akibat perkembangan pesat industri dan bidang pertanian, seterusnya menyumbang kepada manipulasi penggunaan sumber air tanah secara berleluasa tanpa kawalan (Zhang *et al*., 2018). Beberapa penemuan kajian terdahulu membuktikan bahawa imbuhan air tanah di kawasan lembap dan gersang sangat dipengaruhi oleh aktiviti manusia di permukaan (Liu *et al*., 2020).

Meteorologi

Meteorologi merujuk kepada keadaan cuaca dan iklim dalam sesuatu kawasan pada masa tertentu. Faktor-faktor meteorologi atau iklim seperti intensiti hujan, suhu udara, kelembapan udara, corak angin dan jarak perjalanan wap air sebelum jatuh sebagai hujan, akan memberi kesan kepada kandungan isotop di dalam air tanah (Jung *et al*., 2022). Ini bermakna setiap kawasan dengan iklim yang berbeza akan mempunyai komposisi isotop air hujan yang berbeza mengikut musim dan taburan hujan tahunan (Mohamed *et al*., 2021; Vystavna *et al*., 2021). Menurut Vystavna *et al*. (2021), isotop stabil seperti $\delta^{18}O$ dan $\delta^{2}H$ adalah isotop yang biasanya dikesan di dalam air hujan. Ketika hujan terjadi, air hujan akan meresap ke dalam tanah dan mengisi ruang atau zon air tanah, dan komposisi isotop ini akan berubah bergantung kepada suhu dan zon geografi di mana air itu terperangkap.

Suhu udara juga boleh mempengaruhi kandungan isotop terutama sekali isotop hidrogen di dalam air tanah. Pada suhu rendah, air cenderung mengandungi lebih banyak isotop hidrogen yang berat (deuterium), manakala pada suhu yang tinggi, air cenderung mengandungi lebih banyak isotop hidrogen yang ringan (Christofi *et al*., 2020). Mohamed *et al*. (2021) menyatakan kandungan isotop stabil berat dalam air hujan meningkat dengan suhu atmosfera, yang mempengaruhi proses penyejatan semasa kerpasan (*precipitation).* Selain itu, kandungan isotop stabil berat dalam hujan menurun dengan peningkatan ketinggian altitud yang disebabkan oleh penurunan suhu (Christofi *et al*., 2020; Mohamed *et al*., 2021). Kesan ini dikenali sebagai pemeringkatan isotop yang sangat bergantung pada suhu. Pemeringkatan isotop semasa proses perubahan fasa seperti penyejatan dan pemendakan lebih ketara pada suhu yang lebih rendah. Gabungan penurunan suhu dengan ketinggian altitud menghasilkan kesan ke atas komposisi isotop di dalam pemendakan (Christofi *et al*., 2020). Namun begitu, aktiviti-aktiviti manusia seperti aktiviti pertanian yang meluas di kawasan beraltitud tinggi contohnya di Cameron Highland, Pahang, juga mempengaruhi kandungan isotop dalam air tanah seperti isotop sulfat, nitrat, ammonium dan karbon akibat daripada penggunaan baja dan racun perosak yang tinggi. Penggunaan racun perosak dan baja ini juga mempengaruhi aktiviti mikroorganisma di dalam tanah yang terlibat dalam kitar biogeokimia. Proses ini mengubah komposisi isotop dalam air tanah sebagai tindakbalas kepada perubahan dalam pertukaran unsur-unsur tertentu dalam sistem ekologi. Selain itu, dapatan kajian oleh Jung *et al*. (2022) turut melaporkan nilai $\delta^{18}O$ dan $\delta^{2}H$ di dalam air tanah mempunyai hubung kait dengan latitud dan suhu, dengan penurunan nilai $\delta^{18}O$ and $\delta^{2}H$ secara beransur-ansur dalam air tanah dari barat daya ke timur laut Semenanjung Korea.

Selain suhu yang rendah disebabkan oleh altitud kawasan yang tinggi, iklim juga mempengaruhi kandungan isotop di dalam air tanah (Wright & Novakowski, 2020; Jódar *et al*., 2021). Iklim yang sejuk cenderung untuk menyebabkan isotop-isotop berat seperti $\delta^{18}O$ and $\delta^{2}H$ terperangkap dalam kepekatan yang lebih tinggi dalam air tanah. Ini kerana semasa proses penyejatan ketika musim sejuk, molekul-molekul berat lebih sukar untuk berpindah ke fasa wap, sehingga molekul-molekul yang tinggal di air yang terperangkap dalam kepekatan yang lebih tinggi mempunyai isotop-isotop yang lebih berat. Kajian oleh Huang *et al*. (2021) memaparkan nilai median $\delta^{15}N$ cenderung untuk lebih positif pada musim monsun berbanding pada musim sejuk. Peningkatan nilai $\delta^{15}N$ dan penurunan nitrat di dalam air tanah tidak berkurang ketika musim monsun adalah disebabkan oleh proses denitrifikasi dalam tempoh cuaca panas (Huang *et al*., 2021). Dapatan daripada Jung *et al*. (2022) menunjukkan spasial nilai $\delta^{18}O$ dan $\delta^{2}H$ di dalam air bergantung kepada pemeringkatan isotop dengan pergerakan aliran udara pada musim panas.

Hidrogeologi

Hidrogeologi juga memainkan peranan penting dalam menentukan komposisi isotop dalam air tanah. Antaranya ialah geologi kawasan tersebut. Batuan yang membentuk lapisan bawah tanah mengandungi mineral tertentu yang mempengaruhi isotop di dalam air. Apabila air meresap dan mengalir dari kawasan imbuhan ke kawasan pelepasan, interaksi air dengan mineral di dalam batuan mempengaruhi komposisi kimia air tanah termasuklah komposisi isotop (Gupta *et al*., 2023). Antara proses semulajadi yang terlibat dalam proses interaksi air dan batuan ialah pelarutan gas atmosfera, pelarutan mineral utama di dalam batuan, mineral daripada kerpasan, pertukaran ion, dan pencampuran air tersekap (Li *et al*., 2019c; Christofi *et al*., 2020). Selain itu, jenis batuan dalam lapisan air tanah juga akan mempengaruhi keupayaan batuan untuk menyimpan air dan mempengaruhi pergerakan air tanah. Batuan yang mempunyai rongga dan rekahan (seperti batu gamping atau kapur) mempunyai lebih banyak ruang untuk menyimpan air dan memberikan ruang untuk proses pencampuran yang berbeza. Manakala kadar keupayaan penyerapan adalah lebih rendah bagi batuan yang rapat (seperti granit) (Huang *et al*., 2021).

Akuifer *karst* dan batu kapur adalah antara akuifer yang paling terdedah kepada pencemaran disebabkan oleh kememancarannya (*transmissivity*) yang tinggi (Hermawan *et al*., 2023; Ren *et al*., 2023). Kebiasaannya, akuifer kars berkarbonat ditemui di kawasan bukit dan pergunungan. Akuifer ini mempunyai ciri-ciri yang berbeza berbanding akuifer yang lain seperti keheterogenan yang tinggi, aliran air tanah yang berhalaju tinggi di dalam rongga-rongga, dan masa tinggal air yang pendek (Jódar *et al*., 2021; Ren *et al*., 2023). Ciri-ciri hidrodinamik yang dimiliki ini membolehkan penghantaran cepat isyarat aliran masuk imbuhan, termasuk variasi pengesan alam sekitar seperti $\delta^{18}O$, ke titik pelepasan air tanah (Jódar *et al*., 2021).

Komposisi isotop juga dipengaruhi oleh kedalaman air tanah melalui beberapa cara yang berbeza. Akuifer cetek cenderung mempunyai kandungan isotop yang lebih tinggi, berbanding akuifer dalam yang lebih cenderung untuk mempunyai kandungan isotop yang lebih rendah dan stabil. Kebiasaannya, air tanah yang cetek mempunyai kerentanan (*vulnerability*) yang lebih tinggi terhadap pencemaran yang disebabkan oleh aktiviti manusia berbanding air tanah yang lebih dalam (Li *et al*., 2019b; Jung *et al*., 2022; Tanui *et al*., 2023). Kajian oleh Jung *et al*., (2022) turut menunjukkan kandungan isotop tritium lebih tinggi direkodkan di dalam air tanah cetek yang disebabkan oleh kesan imbuhan air tanah melalui akuifer alluvium. Namun, kandungan tritium yang rendah dilaporkan di dalam air tanah dalam iaitu kesan aliran air melalui batuan hampar berhablur.

HALA TUJU KAJIAN PENCEMARAN AIR TANAH DI MALAYSIA MENGGUNAKAN TEKNIK ISOTOP

Pencemaran air tanah merupakan isu alam sekitar yang signifikan di Malaysia. Dalam usaha untuk mencari penyelesaian dan pengurusan isu global ini, para penyelidik telah mula mengaplikasikan teknik isotop dalam skop kajian mengenal pasti punca pencemaran. Isotop seperti isotop stabil hidrogen ($\delta^{2}H$) dan oksigen ($\delta^{18}O$), telah digunakan untuk mengenalpasti hubungan dinamik di antara air tanah dan air permukaan di akuifer pantai, bahagian timur semenanjung Malaysia (Mostapa *et al*., 2022). Kajian tersebut menunjukkan tiada hubungan di antara air tanah yang separa dalam dan air tanah yang dalam. Penemuan data tersebut telah membuktikan bahawa sumber-sumber itu hadir dari akuifier yang berbeza. Selain itu, dapatan kajian tersebut turut melaporkan bahawa kombinasi 12% air tanah dan 88% air masin adalah datang dari sumber air hujan dan kemasukan air masin dari laut. Hal ini kerana, isotop-isotop ini dapat memberikan maklumat penting tentang asal usul dan punca penambahan air tanah, serta kemungkinan pencemaran dan penyerapan air masin ke dalam akuifer.

Dari segi sektor pertanian pula, kajian-kajian menunjukkan bahawa aktiviti pertanian, seperti penggunaan baja komersial boleh menyebabkan pencemaran nitrat dalam air tanah (Fadhullah *et al*., 2020). Kajian tersebut melibatkan persampelan air tanah dari Pusat Takungan Air Bukit Merah yang dianalisis menggunakan kombinasi kimia air, isotop air stabil ($\delta^{2}H$-H_2O dan $\delta^{18}O$-H_2O) dan isotop nitrat stabil ($\delta^{15}N$-NO_3^- dan $\delta^{18}O$-NO_3^-). Kajian tersebut memberi fokus kepada penentuan sumber nitrat dan proses yang berlaku di dalam pusat takungan air yang tertua di Malaysia iaitu Pusat Takungan Bukit Merah. Dapatan kajian menunjukkan bahawa nilai $\delta^{15}N\text{-}NO_3^-$ di dalam sampel air sungai dan pusat takungan air adalah berada dalam julat +0.4 ke 14.9%, manakala nilai $\delta^{18}O\text{-}NO_3^-$ berada dalam julat antara -0.01 dan +39.4%, masing-masing. Bagi tujuan mengenalpasti sumber pencemaran, hasil kajian tersebut mendapati bahawa campuran sumber dari atmosfera, baja ammonia, nitrogen tanah, tinja dan sisa buangan telah menyumbang kepada sumber nitrat yang terkandung dalam sampel takungan air di Bukit Merah.

Teknik isotop yang sama termasuk isotop stabil nitrogen ($\delta^{15}N$) dan oksigen ($\delta^{18}O$) juga telah digunakan untuk menjejaki punca pencemaran nitrat dalam persekitaran air tawar yang telah dijalankan oleh Niu *et al*. (2021). Isotop-isotop ini dapat membantu membezakan antara sumber nitrogen yang berlainan, seperti sumber nitrogen sintetik dan organik, serta memberikan maklumat penting untuk mengawal pencemaran nitrat. Air dari tapak pelupusan dan air sisa domestik atau kumbahan juga merupakan punca pencemaran air tanah. Teknik isotop, seperti isotop stabil karbon ($\delta^{13}C$) dan oksigen ($\delta^{18}O$), telah digunakan untuk mengesan pencemaran air tanah berdekatan dengan tapak pelupusan bandar seperti di dalam tinjauan kajian oleh Sankoh *et al*. (2022). Berdasarkan kajian tersebut, hasil penemuan kajian membuktikan bahawa pasangan isotop ^{11}B dengan $\delta^{15}N\text{-}NO_3^-$ dan $\delta^{18}O\text{-}NO_3^-$ serta parameter hidrokimia lain adalah berkesan dalam membezakan antara baja nitrat, baja ternakan, pencemaran air laut, dan sisa kumbahan. Oleh itu, adalah penting untuk menggabungkan teknik hidrokimia dan isotop dalam pengesanan punca pencemaran air tanah secara berkesan di negara membangun termasuk Malaysia. Dalam meneliti skop tersebut, penekanan seharusnya diberikan terutamanya di kawasan yang terjejas oleh aktiviti pertanian, air larutan dari tapak pembuangan, sisa domestik atau sisa kumbahan, dan pencemaran air laut.

Secara keseluruhannya, teknik isotop telah terbukti menjadi salah satu cara yang penting dan efisien dalam mengkaji dan mengenal pasti punca pencemaran air tanah di Malaysia. Teknik-teknik ini dapat memberikan maklumat tentang asal usul, punca pencemaran, kesan kepelbagaian punca pencemaran serta metodologi dalam penambahbaikan kualiti air tanah negara. Dengan memahami punca pencemaran dan teknik pengesan pencemaran yang lebih efisien, langkah-langkah yang efektif boleh dilaksanakan oleh pihak berwajib dalam menguruskan dan mengendalikan isu pencemaran air tanah di Malaysia.

Walau bagaimanapun, penggunaan teknik isotop ini melibatkan kos yang tinggi yang merangkumi pelbagai aspek seperti peralatan analisis, penyelidikan lapangan, dan juga interpretasi data. Pembelian dan penyelenggaraan peralatan analisis isotop memerlukan kos perbelanjaan yang lebih tinggi jika dibandingkan dengan peralatan analisis teknik konvensional yang lain. Selain itu, proses persediaan sampel dan analisis di makmal bagi mengukur kandungan isotop memerlukan kemahiran pakar dan tenaga kerja yang berkualiti, yang juga memberikan sumbangan kepada kos keseluruhan. Penyelidikan lapangan bagi mengumpul sampel air tanah serta ujian di lapangan, juga memerlukan sumber kewangan yang mencukupi. Meskipun kos teknologi ini boleh menjadi tinggi, manfaatnya termasuk pemahaman yang mendalam terhadap pencemaran air tanah dan kemampuan untuk merancang langkah-langkah pemulihan dan pengurusan secara efektif.

KESIMPULAN

Secara kesimpulannya, penggunaan teknik nuklear banyak memberi manfaat dalam penyiasatan forensik alam sekitar. Ini membolehkan lebih banyak penyiasatan berfokuskan penyiasatan makmal dan menghasilkan penyiasatan yang lebih pantas dan sewajarnya dalam sesuatu insiden alam sekitar. Selain itu, penggunaan teknik nuklear terutamanya teknik isotop mampu diaplikasikan untuk mengesan sebarang pergerakan bahan cemar sekiranya punca bahan cemar dapat dikenal pasti. Dengan kewujudan data asas kandungan isotop bahan buangan bagi sesuatu industri atau aktiviti manusia, secara tidak langsung, ianya dapat membantu pihak berkuasa dalam mengesan pihak yang bertanggungjawab terhadap sebarang insiden pencemaran alam sekitar dan seterusnya dapat melaksanakan langkah-langkah pengurusan yang efektif dalam mengatasi dan mengawal isu berkaitan alam sekitar. Pada akhirnya, ini akan memastikan perlindungan alam sekitar yang lebih lestari dan menjamin kesihatan dan kesejahteraan manusia yang lebih baik.

Artikel ulasan ini menyumbang dalam memperkukuhkan pengetahuan mengenai cara teknologi nuklear terutamanya teknik isotop sebagai alat yang berkesan dalam menangani masalah pencemaran air tanah. Dengan pemahaman yang lebih mendalam terhadap impak aktiviti manusia terhadap sumber air tanah, kita dapat membangunkan pendekatan-pendekatan yang lebih berkesan dalam melestarikan dan melindungi kualiti air tanah untuk generasi masa depan.

PENGHARGAAN

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SUMBANGAN PENGARANG

ASS: Perkonseptualan, penyiasatan, penulisan-draf asal, semakan dan penyuntingan. NM: Semakan dan penyuntingan. AZ: Visualisasi, semakan dan penyuntingan. NMIO: Penulisan-draf asal, semakan dan penyuntingan.

KONFLIK KEPENTINGAN

Semua pengarang mengisytiharkan bahawa mereka tidak mempunyai sebarang kepentingan kewangan serta hubungan peribadi yang boleh mempengaruhi hasil kerja yang dilaporkan di dalam artikel ini.

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CERAMAH TEKNIK TECHNICAL TALK

Innovative approach in risk and stability assessment of an engineered rock slope

Koay Leong Thye
Minconsult Sdn. Bhd.
Date: 24 January 2024
Platform: Zoom

The above talk was delivered by P. Geol. Koay Leong Thye (Minconsult Sdn. Bhd.) on 24th January, 2024 via Zoom. Some 80 members participated. An abstract of the talk is given below:

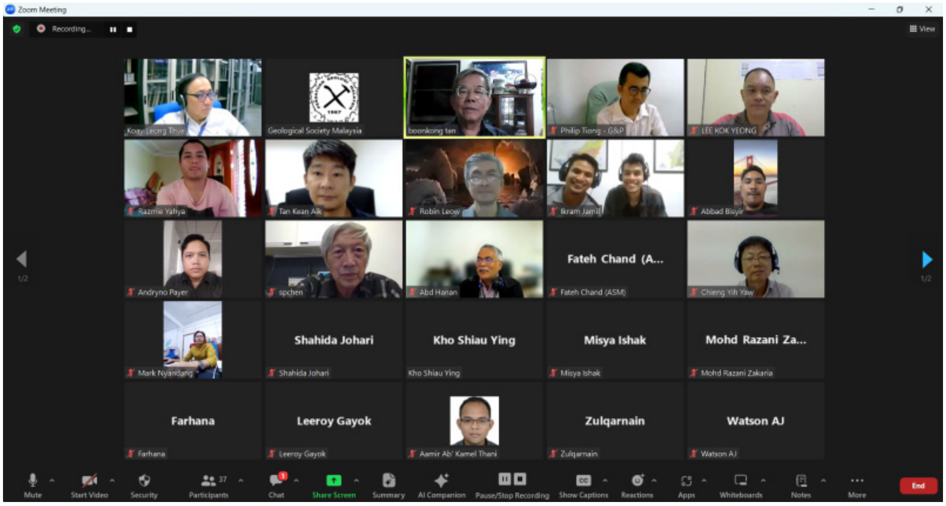
Abstract: The effects of weathering of rock mass and its discontinuities is well known in the highly humid Malaysian climate. A pilot study was carried out to assess the stability and risk categorization of rock slopes at a major expressway. The expressway operator was interested to ascertain the risks of slope instability and identification of priority areas for maintenance planning of remedial or mitigation works.

The principal methods to identify potentially unstable rock mass are geological and rock discontinuity mapping, LiDAR survey, kinematic analysis, stability and risk assessment of the slopes. At inaccessible areas, fieldworks were facilitated using roped access technique and a sky lift crane.

Geo-structural and discontinuity mapping was carried out to assess the rock mass condition and joint orientations at the slope face. Topographic contours and cross-sections, obtained from LiDAR survey, were used to evaluate the geometric profile of slopes while kinematic analyses were performed to verify the stability of rock face. The likelihood of a slope failure is caused by instability factors such as rock mass and joint conditions, slope angle and kinematic analysis. The related consequence factors are influenced by slope geometry, height of potential instability and safety features available at the slope.

High risk slopes were prioritised for future remedial works. With visual conditions and mapping data recorded in the base photographs, it is possible to continuously monitor the slopes over time, thereby providing a versatile tool in the long-term asset management of Expressway.

We thank Sdr Koay for his support and contribution to the Society's activities.



Prepared by,
Tan Boon Kong
Chairman, Working Group on Engineering Geology
25th January 2024

CERAMAH TEKNIK TECHNICAL TALK

Appraisal of the geology of Boya Quarry, Western Australia

Ramli Mohd Osman
Former Geoscientist of JMG, Malaysia
Date: 31 January 2024
Platform: Zoom

Moderators: Assoc. Prof. Dr. Mohd Hariri Arifin (President of GSM) and Mr. Mohammad Noor Akmal Anuar.
Audience: Members who would like to get acquainted with the geology of Australia while reflecting on the geology of Malaysia.

Abstract: The talk is a follow-up of the Boya Event, a fieldtrip we organised for the public in Western Australia to appraise the geology of Boya Quarry. Since it is for the public, expect a geology 301 fieldtrip. However, the geological interpretation requires the basic understanding of the geology of Australia, geology of Western Australia, and geology of SW Yilgarn Craton. The latter is where the Boya Event was held. Much of the geology at Boya Quarry will be rocks and geological processes in Precambrian Eon (from Neoarchean to Neoproterozoic Eras). The geology is interpreted in term of the assemblies and breakups of the supercontinents Kenorland, Nuna, Rodinia, and Pannotia. Overlying the Precambrian rocks are the all-important Oligocene to Early Miocene lateritic profiles and present-day scenario.

Content of presentation:
Part 1 [1.5hr]
1. Welcome to Australia (in geological and geographical perspective)
2. A brief introduction to the geology of Australia

Part 2 [1.5hr]
1. A brief introduction to the geology of Western Australia
2. A brief introduction to the geology of SW Yilgarn Craton
3. Appraisal of the geology of Boya Quarry, WA

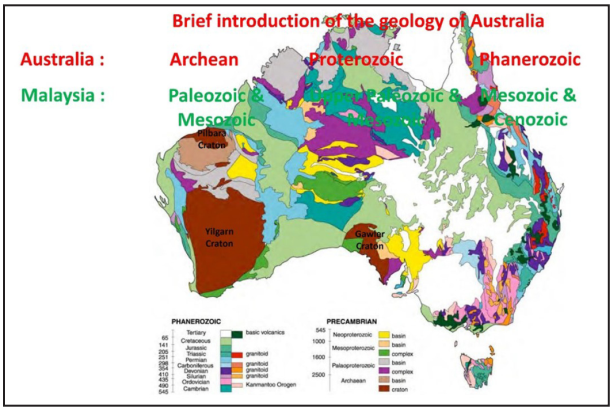
Summary of presentation

1. Welcome to Australia

Australia is:
1. Big ≈ 23 x Malaysia
2. Old ≈ 9 x Malaysia
3. Flat
4. Red
5. Hot
6. Dry
7. Uninhabitable ≈ 11.5/km^2 (habitable zone)

Whereas Malaysia is:
1. Small
2. Young
3. Mountainous
4. Green
5. Hot
6. Wet
7. Populous ≈ 101/km^2

2. A brief introduction to the geology of Australia



Generally speaking, continental Australia grew from west to east, with Archean (4.0 to 2.5 Ga ago) rocks mostly in the west, Proterozoic (2.5 Ga to 540 Ma ago) rocks in the centre, and Phanerozoic (540 to 0 Ma ago) rocks in the east. Sort of similar to Malaysia. Paleozoic and Mesozoic in the west coast of Peninsula, Upper Paleozoic and Mesozoic in the east coast of Peninsula, and Mesozoic and Cenozoic in East Malaysia.

3. A brief introduction to the geology of Western Australia

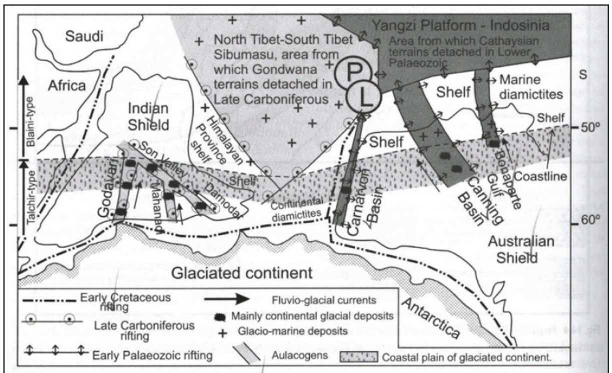
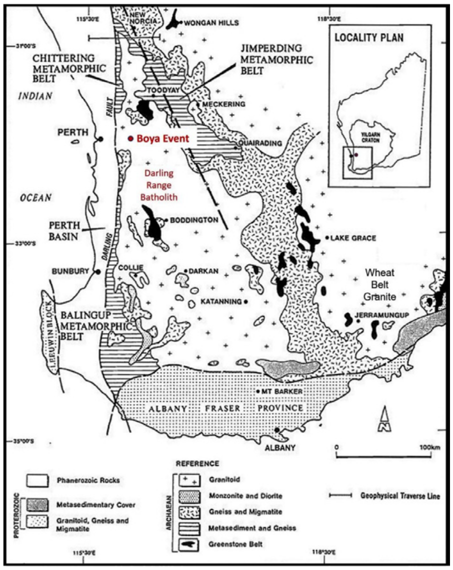


Fig. 14.5: Schematic diagram to illustrate possible northern margin of Gondwanaland in the Late Carboniferous–Early Permian. It shows the distinction between continental fluvio-glacial deposits (Talchir Beds) and marine glacial deposits (Blaini-type) of Tibet and Sibumasu. The aulocogens of India and Australia contain the Talchir Beds. Positions of Phuket (P) and Langkawi (L) are suggested near the Canning Basin because of similar fossils. From Hutchison (1989a).

During Permo-Carboniferous (300 Ma ago) during ice-house Earth, Australia was connected to ancient Malaya. Both Bonaparte and Canning Basins were attached to the Indochina Terrain (East Malaya Block), while Carnarvon Basin was attached to Langkawi (Sibumasu Block). During the Carboniferous, Singa Formation in Langkawi was deposited with layers of dropped stones (carried by icebergs). These dropped stones were dated to be 1 Ga old (Neoproterozoic), the source of which was the then the glaciated Australia.

4. A brief introduction to the geology of SW Yilgarn Craton



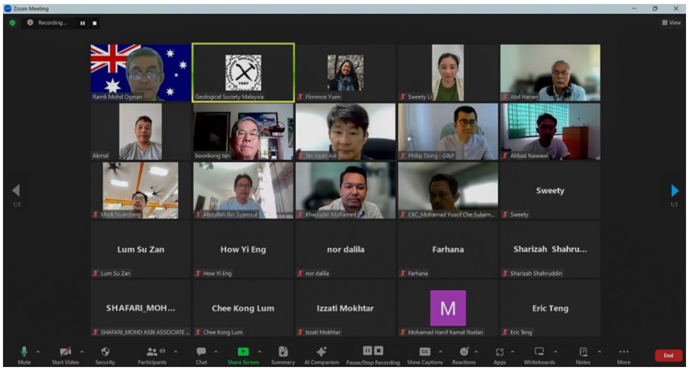
The presence of these schist, gneiss, migmatite, greenstone, granitoid, and dolerite dykes indicate that the SW Yilgarn Craton had been subjected to continental collisions, subductions, and riftings throughout the Archean and Proterozoic eons during the assemblies and break-up of the supercontinents Vaalbara (3.6 to 2.8 Ga ago), Kenorland (2.7 to 2.1 Ga ago), Nuna (1.8 to 1.5 Ga ago), and Rodinia (1.3 Ga to 750 Ma ago).

5. Appraisal of the geology of Boya Quarry, WA

Geological history

1. Communities of plants, animals, and microbes colonized the saprolith forming soils.
2. Erosion of lateritic profiles resulted in truncated lateritic profiles seen at Boya Quarry.
3. Lateritic profiles formed during Oligocene to Early Miocene.
4. Uplift and erosion of sediment cover during the Paleozoic and Mesozoic.
5. The assembly of supercontinent Pannotia probably caused the sheared margin between coarse-grained granite and porphyritic dolerite dyke.
6. Supercontinent Pannotia assembled between 600 and 540 Ma ago.
7. At the same time xenoliths of coarse-grained granite was included into the porphyritic dolerite dyke.
8. Between 750 and 700 Ma ago (Neoproterozoic) porphyritic dolerite dykes (with white plagioclase phenocrysts) intruded along fractures and joins in the coarse-grained granite and non-porphyritic dolerite dykes during the breakup of supercontinent Rodinia.
9. Supercontinent Rodinia assembled from 1.3 Ga to 750 Ma ago.
10. About 1.5 Ma ago (Mesoproterozoic) mafic magma was injected into the solidified granitic rock massive as a result of increasing fracturing of the Earth's crust during the breakup of the supercontinent Nuna. This magma intruded along fractures and joins in the granite to form dykes of non-porphyritic dolerite.
11. Shearing of coarse-grained granite probably occurred during the assembly of the supercontinent Kenorland.
12. The coarse-grained granite formed ≈ 2.6 Ga ago (Neoarchean) when large volumes of granitic magma were injected into the Earth's crust many kilometres below the surface during the formation of the supercontinent Kenorland.

Participants of Boya Quarry Event.



Part of the participants of "Appraisal of the geology of Boya Quarry, WA" online presentation. Total number of audiences attended were 98 members.

Prepared by,
Ramli Mohd Osman

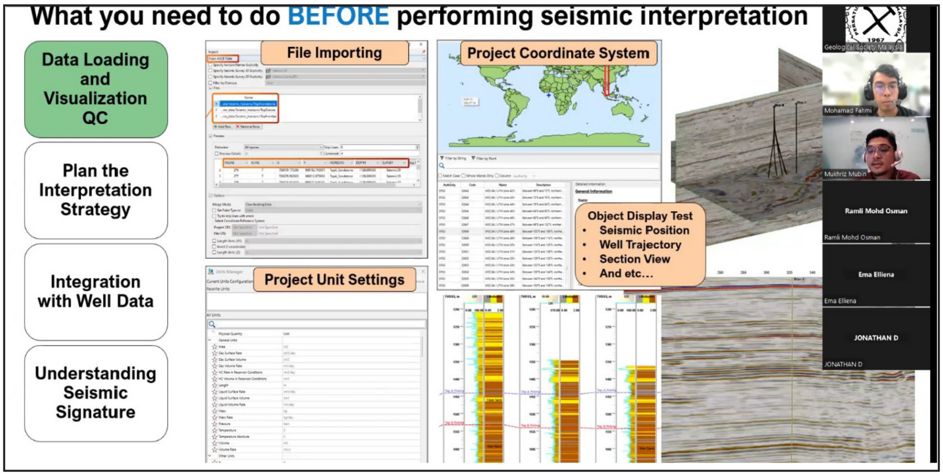
CERAMAH TEKNIK TECHNICAL TALK

What do you need to do when performing seismic interpretation?

Mukhriz Mubin
Rock Flow Dynamics
Date: 5 February 2024
Platform: Zoom

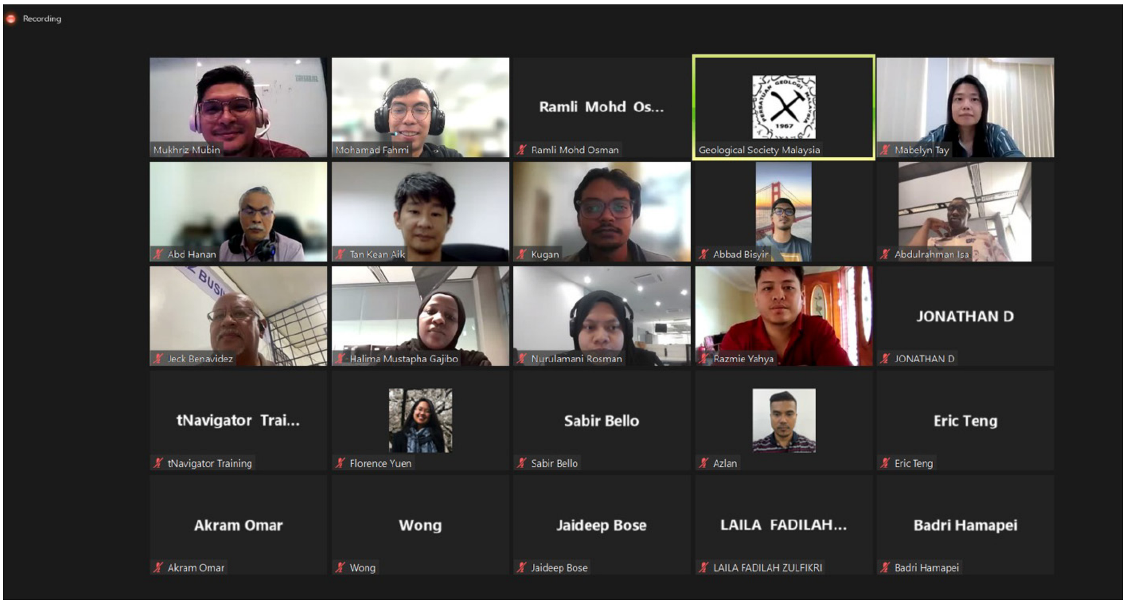
On February 5th, 2024, the Geological Society of Malaysia, in partnership with Rock Flow Dynamics (RFD) through their tNavigator flagship, hosted a virtual technical talk titled "What do you need to do when performing seismic interpretation?" This event was organized by the Geophysics Working Group within the Geological Society of Malaysia (GSM). The talk provided insights and guidance for professionals and students involved in the geoscience domain, particularly seismic interpretation, addressing various aspects such as methodologies, tools, and best practices when conducting seismic interpretations. The collaboration between GSM and RFD highlights the importance of industry partnerships in fostering knowledge sharing and advancement within the geological and geophysical community in Malaysia. The talk was delivered by Mr. Mukhriz bin Mubin, a Geologist-Technical Support at Rock Flow Dynamics.

The talk was held using the Zoom platform and was attended by around 80 participants. Mr. Mukhriz delivered insights on optimal approaches and methodologies for seismic interpretation, guiding interpreters on understanding the process flow and recommended practices during interpretation. The talk emphasizes practices undertaken prior to, dur-



ing, and following seismic interpretation to ensure comprehensive understanding and effective interpretation. For example, performing data loading and visualisation quality checks prior to seismic interpretation and comprehending the seismic signature. Methods such as horizon tracking and seismic attribute creation are also highlighted as techniques that can be performed during seismic interpretation. Geobody extractions, structural frameworks and stratigraphic analysis are also some examples that can be done after a seismic interpretation that were highlighted during the talk.

At the end of the talk, several questions from the audience were addressed to the speaker on a variety of topic such as seismic processing, Carbon Capture Storage application and seismic interpretation on carbonate environments. Mr. Mukhriz provided a thorough response to the questions and most of the audiences received a solid understanding of the topic they were asking. The audience was well engaged and interacted with him during the session, which provided valuable outcomes that are useful and beneficial to the existing and future geologists and geophysicists.



The participants of GSM technical talk with Mr. Mukhriz Mubin (top left).

Prepared by,
Dr. Siti Nur Fathiyah Jamaludin
Chairperson, Geophysics Working Group
8th February 2024

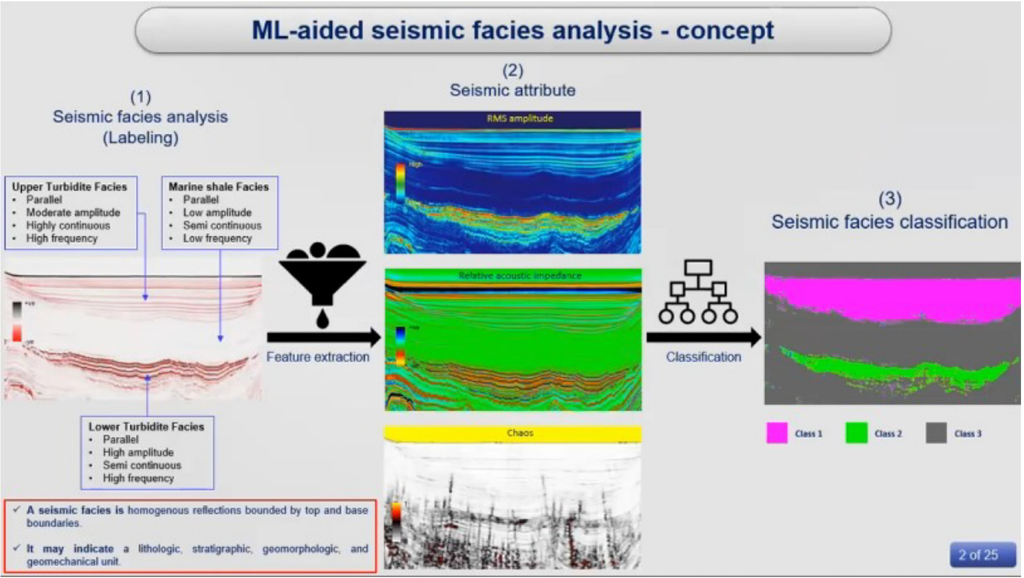
CERAMAH TEKNIK TECHNICAL TALK

Improving seismic facies classification through attribute selection and sample size analysis: Examples from Malay and Sabah basins, offshore Malaysia

Ismailalwali Babikir
Universiti Teknologi PETRONAS (UTP)
Date: 7 February 2024
Platform: Zoom

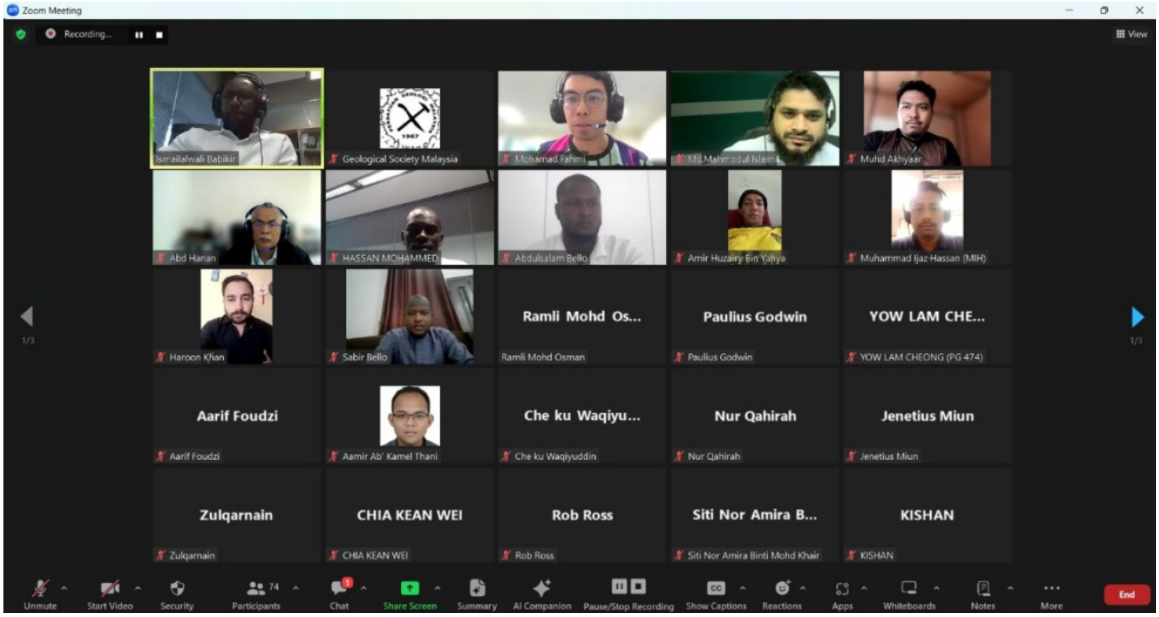
On February 7th, 2024, the Geological Society of Malaysia, in partnership with the Centre for Subsurface Imaging from University Technology PETRONAS (UTP), hosted a virtual technical talk titled "Improving Seismic Facies Classification through Attribute Selection and Sample Size Analysis: Examples from Malay and Sabah Basins, Offshore Malaysia" which was held using the Zoom platform and attended by 80 participants. This event was organized by the Geophysics Working Group within the Geological Society of Malaysia (GSM). The talk was presented by Dr Ismailalwali Babikir, a post-doctoral researcher from UTP where the talk provides some knowledges regarding on seismic facies classification using attribute selection that involved machine learning and deep learning techniques that increase the effectiveness of attribute selection and solved diverse seismic facies classification problems. There were several concepts shown by the speaker which are labelling techniques, feature extraction, classifier techniques and prediction.

Dr Ismailwali presented an insightful presentation that involved the workflow of the machine learning from data collection until deployment of selected machine learning models produced the best output for the facies volumes. Presentation also included with future work that can be done such as to study more complex classifications with more classes and subtle geologic features.



At the end of the session, the audience asked the speaker a range of questions about dataset size and machine learning methods. Dr. Ismail delivered extensive solutions to the queries. The audience was actively engaged and interacted with throughout the session. The emergence of machine learning and deep learning techniques may be unfamiliar to some within the field of geoscience, yet it presents a fresh outlook on interpretation methods that aid geologists in their research purpose.

Poster for the talk.



The participants of GSM technical talk with Dr Ismailwali (top left).

Prepared by,
Dr. Siti Nur Fathiyah Jamaludin
Chairman, Geophysics Working Group
8th February 2024

CERAMAH TEKNIK TECHNICAL TALK

Memudahkan proses rekabentuk (geoteknik) pada tanah lembut: Model resistiviti elektrik untuk meramal nilai-N dan sifat-sifat tanah

Zakiah Binti Razak
Perbadanan Kemajuan Negeri Selangor
Tarikh: 21 Februari 2024
Platform: Zoom dan Facebook Live

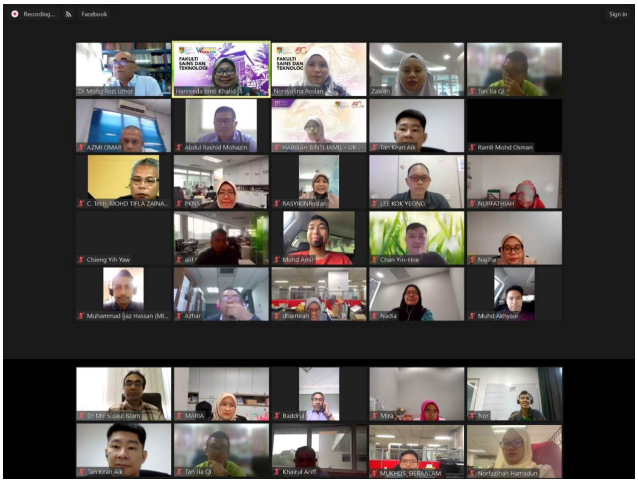
Ceramah teknik ini disampaikan oleh Ir. Ts. Zakiah Binti Razak pada 21 Februari 2024, secara atas talian di platform Zoom/Facebook Live Fakulti Sains dan Teknologi, UKM. Jumlah peserta adalah seramai 136 orang.

Berikut merupakan abstrak pembentangan:

Cabaran geoteknik bagi membuat binaan di atas tanah lembut adalah terutamanya disebabkan oleh kekuatan tanah, yang boleh menghalang proses rekabentuk struktur akibat penyiasatan tapak dan prosedur penyelidikan yang tidak mencukupi. Permukaan tanah yang tidak rata boleh menyebabkan ketidakstabilan dalam struktur yang disokong. Kaedah Kerintangan Elektrik ialah teknik geofizik yang mampu untuk menghasilkan ciri-ciri profil bawah permukaan, walaupun data daripadanya tidak dapat menentukan ciri fizikal dan kejuruteraan tanah. Kajian ini menyiasat hubungan antara tingkah laku rintangan tanah dan sifat fizikal, termasuk data siasatan tapak (SI) di Seksyen 23 Shah Alam, Selangor. Menggunakan MINITAB, analisis menunjukkan korelasi yang baik antara nilai-N untuk sifat kekuatan dan kerintangan. Model berjaya dibentuk untuk menentukan nilai-N berdasarkan nilai kerintangan, menjadikannya lebih cepat dan lebih mudah untuk dikumpulkan. Parameter ini penting dalam kebanyakan penyelesaian reka bentuk geoteknikal dan struktur. Kajian ini juga mampu menawarkan garis panduan untuk mengisi jurang dalam penyelidikan terdahulu, menonjolkan keupayaan teknik pengkomputeran dalam pelbagai disiplin kejuruteraan, khususnya kejuruteraan awam dan kejuruteraan geoteknik.

Kata kunci: Tanah lembut, kekuatan tanah, Kaedah Kerintangan Elektrik (ERM)

Setinggi-tinggi ucapan terima kasih diucapkan kepada pembentang atas sokongan dan sumbangan kepada UKM dan aktiviti persatuan.



Gambar 1: Ir. Zakiah bersama moderator dan para hadirin

Disediakan oleh,
Dr. Norsyafina Roslan
Moderator Slot Ceramah Teknik (UKM)
12hb Mac 2024

CERAMAH TEKNIK TECHNICAL TALK

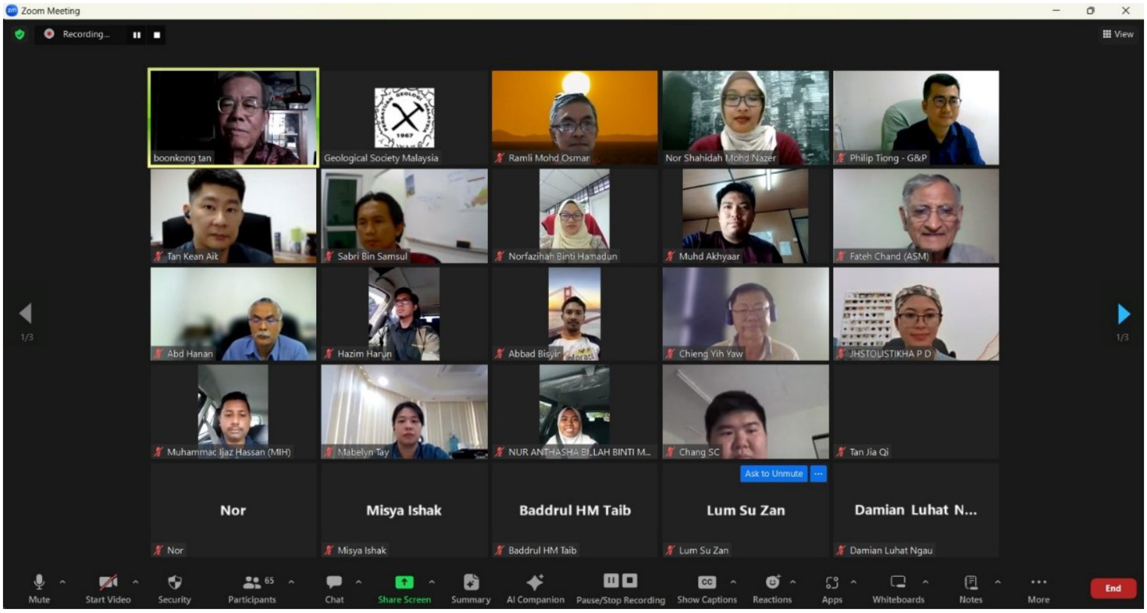
Problematic behaviour of dispersive soil: Evidence from landslide events in Malaysia

Nor Shahidah Mohd Nazer
Universiti Kebangsaan Malaysia
Date: 21 February 2024
Platform: Zoom

The above talk was delivered by P.Geol. Dr. Nor Shahidah Mohd Nazer (UKM) on 21st February, 2024 via Zoom. Some 90 members participated. An abstract of the talk is given below:

Abstract: Dispersive soils, characterized by their susceptibility to erosion and the dispersion of clay particles in the presence of water, have emerged as a significant geological hazard, with far-reaching implications for slope stability and landslide initiation. Dispersive soils, often referred to as “erosion-prone” or “dispersive clay,” pose a substantial threat due to their unique response to water infiltration. The presence of dispersive clay minerals, such as sodium montmorillonite, enhances soil erodibility and leads to the breakdown of soil aggregates, resulting in increased susceptibility to erosion. The interplay between dispersive soils and landslides is further exacerbated by the intricate balance of soil composition, topography, and climatic conditions. The combined effect of these factors can lead to a sudden loss of slope stability, triggering landslides that may cause devastating consequences for both human settlements and the natural environment. Regions with dispersive soils, particularly those undergoing urbanization or deforestation, are particularly vulnerable to landslide events, making it imperative to understand and mitigate the associated risks. This paper synthesizes current research findings from recent landslide events in Malaysia including Gunung Jerai Debris Flow, Batang Kali, Taman Bukit Mewah, Ampang, and Kemensah Height, and highlights the need for comprehensive studies that address the underlying mechanisms linking dispersive soils to landslide initiation.

We thank Sdri Shahidah for her support and contribution to the Society’s activities.



Prepared by,
Tan Boon Kong
Chairman, Working Group on Engineering Geology
22nd February 2024

CERAMAH TEKNIK TECHNICAL TALK

Groundwater and surface water interaction revealed by multi-tracer method in Klang River watershed, Malaysia

Saito Mariko
University of Tsukuba, Japan
Date: 6 March 2024
Venue: Webex and Facebook Live

The above talk was delivered by Dr. Saito Mariko on 6th March 2024 via Webex and Facebook Live of Faculty Science and Technology UKM. The total attendees were 137 persons.

Below is the synopsis of the presentation:

We investigate the groundwater flow system in the Klang River watershed, Malaysia, which has high precipitation and large topographic gradients, using multi-tracer methods such as dissolved ion constituents and stable isotope components of hydrogen and oxygen (δ^2H and $\delta^{18}O$). We conducted five sampling campaigns between September 2019 and December 2022, collecting 44 river water and 34 groundwater samples from upstream to downstream of the watershed. Water samples were analyzed in the laboratory for dissolved ion constituents, δ^2H and $\delta^{18}O$. In addition, existing data on the $\delta^{18}O$ of the precipitation in the downstream area and the hydraulic head of the groundwater were collected. As a result, the $\delta^{18}O$ of the river water at the headwaters and that of the deeper groundwater downstream ranged between -8.3‰ to -7.9‰ and -8.1‰ to -7.6‰, respectively, suggesting that the deeper groundwater downstream recharged at the headwaters. The $\delta^{18}O$ in the mainstem of the Klang River decreased from -7.2‰ to -7.6‰ as the river flowed from the midstream to the downstream, which is lower than the precipitation weighted average of -7.2‰ in the downstream. The hydraulic head of deep groundwater is higher than that of shallow groundwater downstream, indicating that the direction of groundwater flow is upward. These results suggest that deep groundwater recharged in the headwaters, which is composed of low $\delta^{18}O$, is discharged to the downstream river with high flux. Thus, our study demonstrates the importance of the groundwater discharge in downstream river under conditions of high precipitation and large topographic gradients.

We would like to thank the invited speaker for the support to UKM and to the Geological Society of Malaysia.

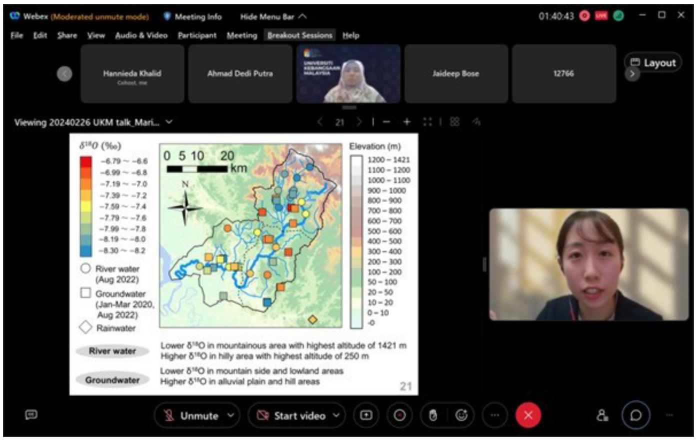


Figure 1: The invited speaker with the moderator and some of the participants that attended the session.

Prepared by,
Dr. Norsyafina Roslan
Moderator of Technical Talk (UKM)
12th March 2024

CERAMAH TEKNIK TECHNICAL TALK

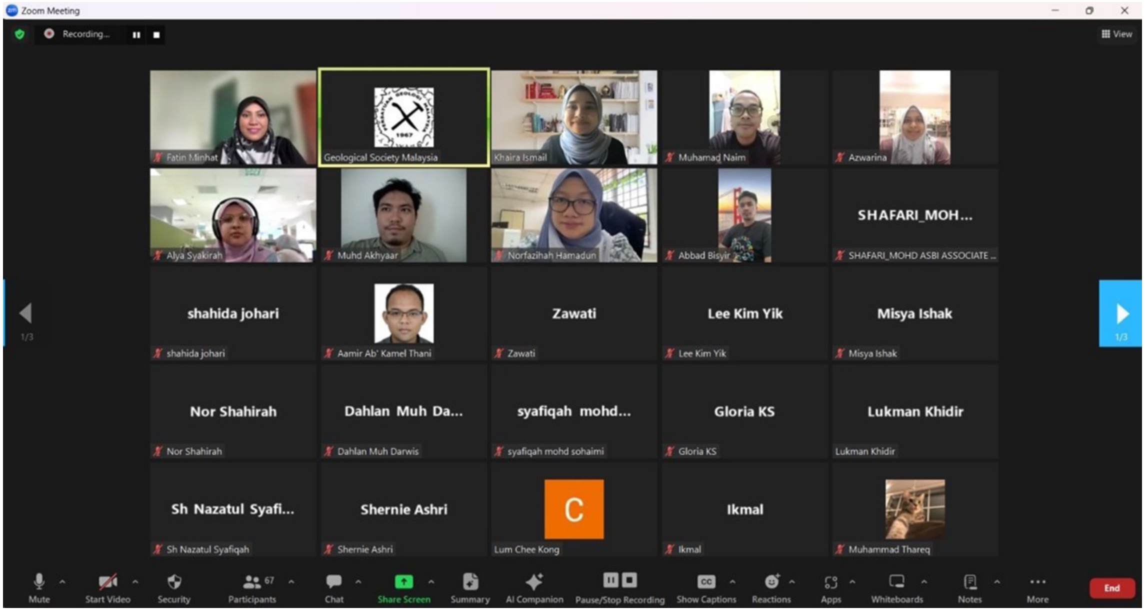
Modern foraminifera and their application

Fatin Izzati Minhat
Universiti Malaysia Terengganu
Date: 6 March 2024
Platform: Zoom

The above talk was delivered by Associate Professor Dr. Fatin Izzati Minhat (Universiti Malaysia Terengganu) on 6th March, 2024 via Zoom. Some 67 members participated. An abstract of the talk is given below:

Abstract: Foraminifera, unicellular organisms in marine environments, are vital bioindicators and proxies for understanding ecological dynamics and environmental changes. Their applications span ecology, paleoceanography, palaeoclimatology, and environmental monitoring. They play diverse roles, from primary producers to water quality and habitat health indicators. Foraminifera also acts as a sensitive recorder of past environmental conditions, shedding light on historical climate variability, ocean circulation patterns, and ecosystem dynamics. Recent methodological advancements, such as molecular techniques and stable isotopic analysis, enhance our interpretation of past climate based on the foraminiferal assemblages and their environmental significance. Large benthic foraminifera (LBF) are noteworthy for their conspicuous size and complex morphologies. They serve as crucial indicators of reef health, sedimentary environments, and carbonate production. Their symbiotic relationship with photosynthetic algae makes them sensitive to environmental changes, especially in coral reef ecosystems. Integrating findings from modern foraminiferal research, including LBFs, into environmental management strategies can better protect and preserve marine ecosystems. This talk examines the multifaceted applications of foraminifera, highlighting the importance of LBFs in understanding and managing marine environments.

We thank AP Dr. Fatin Izzati Minhat for her support and contribution to the Society's activities.



Prepared by,
Dr. Khaira Ismail
Chairman, Working Group on Quaternary & Marine Geology
31st March, 2024

CERAMAH TEKNIK TECHNICAL TALK

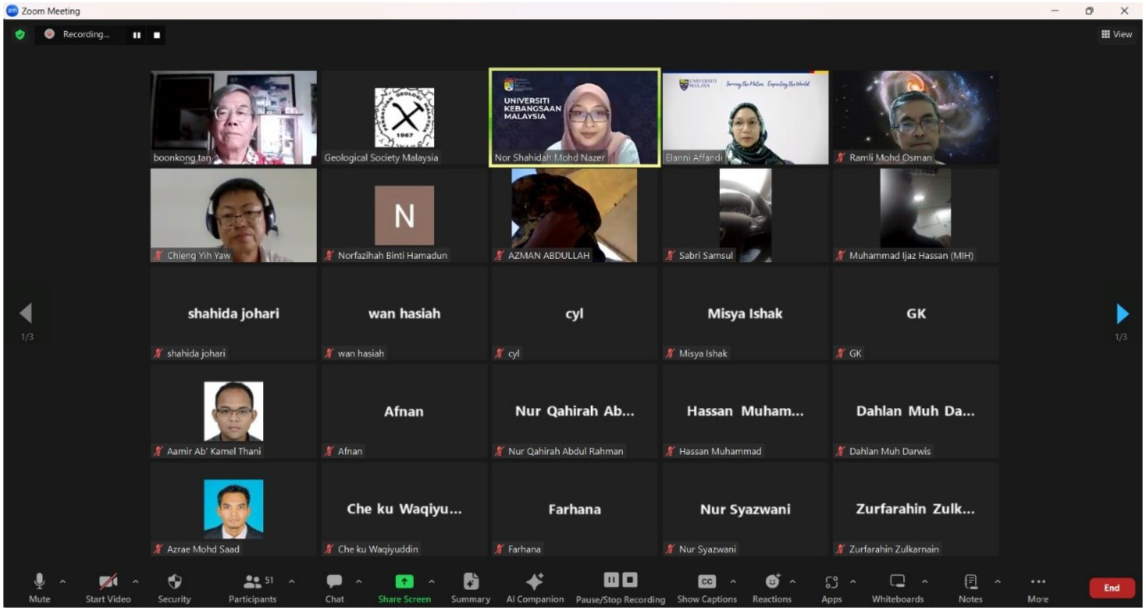
Mapping Kuala Lumpur's resilience: Urban geology for sustainable development

Elanni Md Affandi
Universiti Malaya
Date: 6 March 2024
Platform: Zoom

The above talk was delivered by Dr. Elanni Md Affandi (Universiti Malaya) on 6th March, 2024 via Zoom. Some 75 members participated. An abstract of the talk is given below:

Abstract: Urbanization and the effects of climate change are a challenge towards the building of Kuala Lumpur into a safe, sustainable and disaster – resilient city. The urban geology study gathers geoscientific information that is critical to address local issue that will assist future development and disaster risk reduction strategies from planning and engineering perspective. This research embarks on gathering available geological and geotechnical data across different organization, conducting evaluation on the geology, engineering geology and geohazard then reinterpreting them into practical outputs using geospatial data assessment. Geoscience information supports strategic development planning for building disaster resilience in Kuala Lumpur, Malaysia, which is a city challenged by issues such as landslides, floods and unfavourable ground conditions. Aspects such as the subsurface setting and susceptibility to hazards offer insights to resolve risks that are expected to worsen with climate change. The information on engineering ground conditions and susceptibility to geohazards was then combine to demarcate zones that are suitable for urban development. This approach can be applied to other cities so that relevant geoscience information is integrated for planning and decision making in a changing climate. Additional development should be limited in such areas, and where already developed, targeted hazard-specific measures can be taken to build resilience.

We thank Sdri Elanni for her support and contribution to the Society's activities.



Prepared by,
Tan Boon Kong
Chairman, Working Group on Engineering Geology
8th March 2024

CERAMAH TEKNIK TECHNICAL TALK

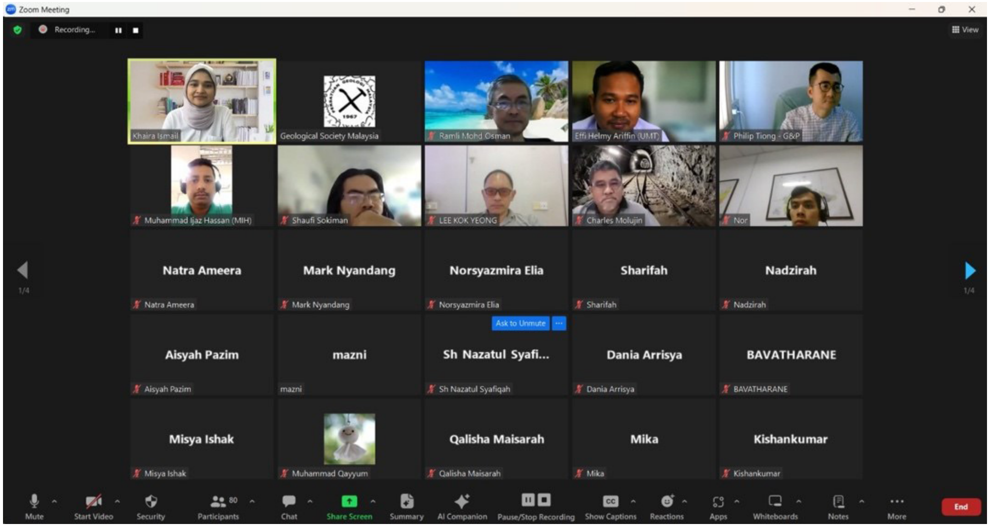
A multi-hazards coastal vulnerability index of the East Coast of Peninsular Malaysia

Effi Helmy Ariffin
Universiti Malaysia Terengganu
Date: 19 March 2024
Platform: Zoom

The above talk was delivered by Associate Professor Dr. Effi Helmy Ariffin (Universiti Malaysia Terengganu) on 19th March, 2024 via Zoom. Some 80 members participated. An abstract of the talk is given below:

Abstract: In Southeast Asia, an increase of 20 million people in the coastal zone have accentuated the infrastructure risk. In Malaysia, littoral erosion due to seasonal monsoons can critically affect the coastal population and the country lacks practical plans to attenuate coastal erosion. In this study, a systematic coastal vulnerability assessment that covers 10 physical and 5 socio-economic variables has been conducted at 16 districts from 4 states. The aim is to highlight the most vulnerable districts with respect to a potential catastrophic event. Multivariate statistical analyses facilitated realistic and meaningful interpretations for optimal coastal zone planning. We show that socio-economic variables are extremely relevant in all states except in southern Terengganu because it faces a direct impact of monsoon waves. Gender composition was found to be the most dominant coastal vulnerability factor for two states: Kelantan and Terengganu (north) due to the abundance of women involved in coastal trade and commerce. Besides, agriculture indicates a primary concern in the district of Johor. The results were categorized from very low to very high of vulnerability. The northern states of the east coast of Peninsular Malaysia show very high to high vulnerability relative to the southern states, which reveal moderate to very low vulnerability. In statistical analysis, it is shown that there is a similarity of 81.25% between Coastal Vulnerability Index (CVI) and Hierarchical Agglomerative Cluster Analysis (HACA). The authorities could utilize the findings of this study to forecast potential shoreline recession and establish adaptation measures to their coastal erosion adaptation plan.

We thank AP Dr. Effi Helmy Ariffin for his support and contribution to the Society's activities.



Prepared by,
Dr. Khaira Ismail
Chairman, Working Group on Quaternary & Marine Geology
31st March, 2024

CERAMAH TEKNIK TECHNICAL TALK

Seismic geomorphology: From the Earth's ocean depths to beyond Earth, a revolution in reconstructing landscape form and process

Lesli J. Wood
Colorado School of Mines
Date: 19 March 2024
Venue: Main Lecture Hall, Department of Geology, Faculty of Science, Universiti Malaya

Abstract: A walk through 20 years of Dr. Lesli Wood's research in quantitative seismic geomorphology, from Morocco to Australia to Indonesia and elsewhere, and a touch on applications to planetary studies and the need for us, as students of paleo-landscapes to understand the geography of the past and how we can engineer a safe and economical future. It is time to revisit the Moon and Mars a bit, and the latest landings impress upon us the importance of understanding where the rocks are.

We thank Prof. Wood for her support and contribution to the Society's activities. Thank you to Allan Filipov, Mohd Shafiq Firdauz and Maradona Mansyur from the KL Geoscience Group (KLGG) for help in organizing the talk.

Prepared by,
Dr. Meor Hakif Amir Hassan
Chairman, Working Group on Regional Geology and Stratigraphy
27th March 2024

Acknowledgement to Peer Reviewers (2023)

In appreciation of the enormous contribution they make to the Society's publications, we would like to thank the scholars and experts below who have participated in the peer review process of manuscripts submitted for consideration for publication in the Bulletin of the Geological Society of Malaysia and Warta Geologi in 2023:

Abdul Hadi Hashim
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GSM-UMS Geology Club Programmes

Summary report on GSM-UMS Geology Club programmes held in December 2023

KOTA KINABALU – On December 8, 2023, the GSM UMS – Geology Club hosted their Annual General Meeting for the 2023/2024 session at the Azman Hashim Gallery. This program was held with the intention of having an annual gathering where all Geology students and lecturers could formally meet and socialize after the formalities. In the meeting, the new line of GSM UMS – Geology Club Committee Members was introduced to students and lecturers during the duty handover ceremony. After the main event, there had also been a community service, namely GeoClean Shore which is a beach cleanup at the Outdoor Development Centre (ODEC), UMS followed by a casual bonding session for the students and lecturers.

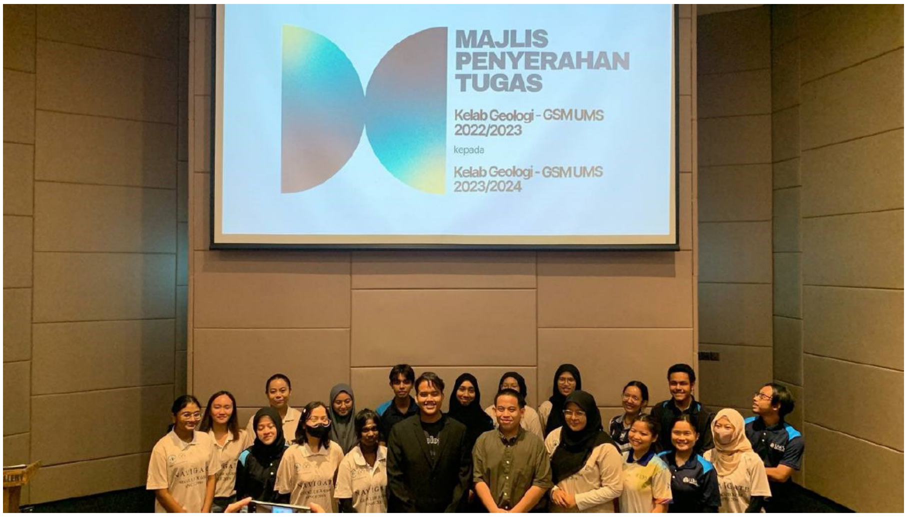


Figure 1: Committee members of GSM UMS – Geology Club 2023/2024.
Photo by: AGM Publicity Team

Figure 2: Committee members of GSM UMS – Geology Club 2022/2023.
Photo by: AGM Publicity Team

Figure 3: Question and Answer Session for the previous and new High Committee Members. Photo by: AGM Publicity Team

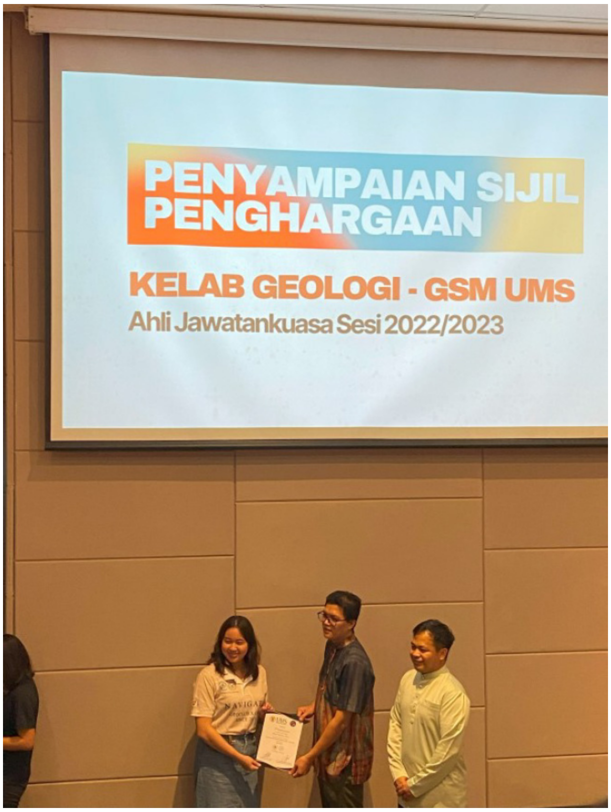


Figure 4: Presentation of appreciation certificates to the previous Geology Club committee members.
Photo by: AGM Publicity Team

Figure 5: GeoClean Shore at Outdoor Development Centre (ODEC).
Photo by: AGM Publicity Team

In addition to that, on December 12, 2023, the GSM UMS – Geology Club held GEOTALK PLUS: Geology Software & Career “The Future of Geology” at Seminar Room 1, Faculty of Science and Natural Resources. In the talk, the final year students who had finished their industrial training highlighted the skills required in using software that can be used for determining the subsurface based on resistivity, gamma rays and neutrons. Other than that, the talk also focused on the importance of soft skills and various experiences of the 4th year students during their industrial training.

Figure 6: Poster of ‘GEOTALK PLUS: Geology, Software & Career’ Programme.
Photo by: GEOTALK PLUS Publicity Team

Figure 7: One of the Final Year students.
Photo by: GEOTALK PLUS Publicity Team

Prepared by,
Nur Najwa binti Mohd Zuhid
Secretary, GSM-Universiti Malaysia Sabah Geology Club
23rd January 2024

NEWS

Marine Geoscience Program UMT leads the way: Establishment of International Association of Geomorphologists (IAG) National Scientific Member in Malaysia

In a significant stride towards advancing the field of geomorphology in Malaysia, Universiti Malaysia Terengganu (UMT), through its Marine Geoscience Program, Faculty of Science and Marine Environment, has played a pivotal role in the establishment of the International Association of Geomorphologists (IAG) National Scientific Member (NSM) to represent Malaysia starting from 2023. The membership will help to solidify Malaysia's presence in the global geomorphological community, promote IAG activities and highlight UMT's commitment to academic excellence and research leadership.

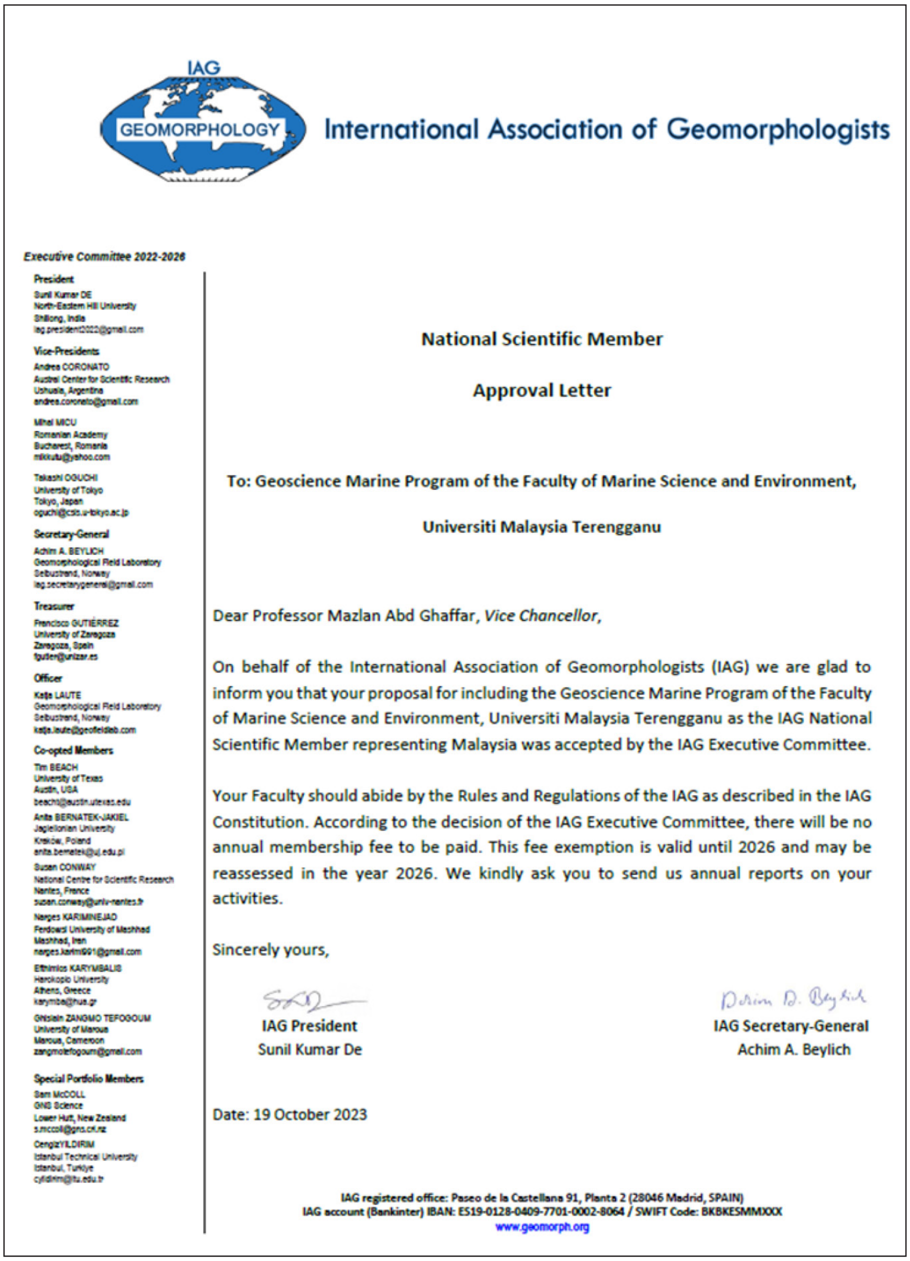
Geomorphology, the interdisciplinary and systematic study of landforms and the Earth surface processes that create and change them, holds crucial insights into understanding natural landscapes and environmental changes. Recognizing the importance of fostering collaboration and knowledge exchange in this field, the Marine Geoscience Program UMT took the initiative to propose the establishment of the IAG National Scientific Member in Malaysia to the current IAG Executive Committee during July to September 2023. The IAG Executive Committee officially accepted our proposal on 19 October 2023. The establishment of this national chapter is a testament to UMT's dedication to promoting scientific research and collaboration on both national and global scales.

As stated in its website (www. geomorph.org), IAG is a scientific, non-governmental, and non-profit organization, with the primary goal of the advancement and promotion of geomorphology as a science through global collaboration and the dissemination of geomorphological knowledge. The IAG was founded in 1989 during the Second International Conference on Geomorphology in Frankfurt/Main (Germany). In order to accomplish its goals, IAG establishes the working groups and task forces, organizes regional and international conferences, managing publications, and exchanging information. The IAG membership is typically by countries. Until now, 78 countries have been affiliated to the IAG through their respective National Scientific Members including the new member, Malaysia. Activities of the IAG are steered by its Executive Committee which is elected every four years.

One of the primary objectives of the IAG National Scientific Member in Malaysia is to facilitate collaboration and networking among geoscientists and geomorphologists in the country. This will enable researchers, academics, and professionals in the field to share expertise, exchange ideas, and collectively contribute to the advancement of geomorphological knowledge within the Malaysian context. Furthermore, the establishment of this national chapter opens doors for Malaysian researchers to engage with the international geomorphological community. Additionally, the establishment of the IAG National Scientific Member in Malaysia aligns with the country's broader initiatives to promote science, technology, engineering, and mathematics (STEM) fields. It reinforces Malaysia's commitment to fostering a culture of scientific inquiry, innovation, and research excellence. Through participation in IAG activities, such as regional and international conferences on geomorphology, international geomorphology week, workshop and seminar series, and other IAG events, Malaysian geoscientists/geomorphologists can stay abreast of the latest developments in the field and contribute their unique perspectives to global discussions. There are also a lot of training programs/events organized for young geoscientists/geomorphologists and students.

For any inquiries about the IAG and its National Scientific Member in Malaysia, you can contact Assoc. Prof. Dr. Edlic Sathiamurthy (edlic@umt.edu.my) or Dr. Dony Adryansyah Nazaruddin (dony@umt.edu.my) at the address of Marine Geoscience Program, Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.

Prepared by,
Dr. Dony Adryansyah Nazaruddin and A.P. Dr. Edlic Sathiamurthy
Universiti Malaysia Terengganu



IAG GEOMORPHOLOGY

International Association of Geomorphologists

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National Scientific Member

Approval Letter

To: Geoscience Marine Program of the Faculty of Marine Science and Environment, Universiti Malaysia Terengganu

Dear Professor Mazlan Abd Ghaffar, *Vice Chancellor*,

On behalf of the International Association of Geomorphologists (IAG) we are glad to inform you that your proposal for including the Geoscience Marine Program of the Faculty of Marine Science and Environment, Universiti Malaysia Terengganu as the IAG National Scientific Member representing Malaysia was accepted by the IAG Executive Committee.

Your Faculty should abide by the Rules and Regulations of the IAG as described in the IAG Constitution. According to the decision of the IAG Executive Committee, there will be no annual membership fee to be paid. This fee exemption is valid until 2026 and may be reassessed in the year 2026. We kindly ask you to send us annual reports on your activities.

Sincerely yours,

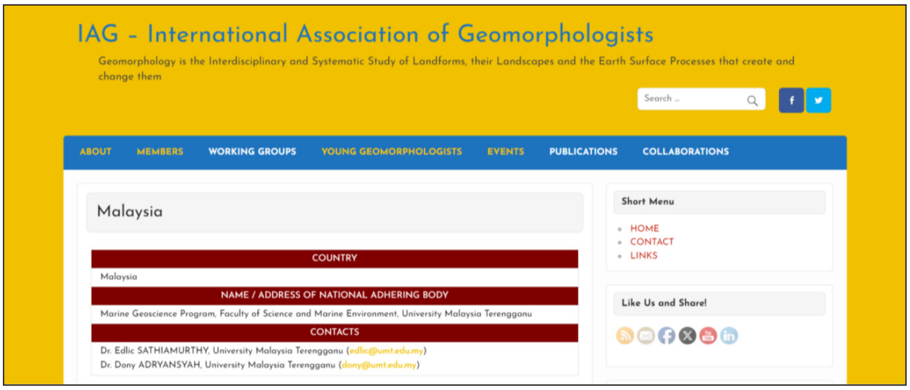
IAG President
Sunil Kumar De

IAG Secretary-General
Achim A. Beylich

Date: 19 October 2023

IAG registered office: Paseo de la Castellana 91, Planta 2 (28046 Madrid, SPAIN)
IAG account (Bankinter) IBAN: ES19-0128-0409-7701-0002-8064 / SWIFT Code: BKBKESMMXXX
www.geomorph.org

Approval letter of the establishment of the IAG National Scientific Member for Malaysia.



Address and contacts of the IAG National Scientific Member for Malaysia.

UPCOMING EVENTS

May 6-9, 2024: Offshore Technology Conference 2024; Houstan, Texas, USA. See details at https://2024.otcnet.org/.

May 9-10, 2024: CANADA 2024 - Geosciences Technology Workshop: Optimizing Exploration Workflows: Bridging Expertise between the Rockies and the Andes; Calgary, Canada. More details at https://www.aapg.org/career/training/in-person/workshops/workshop-details/articleid/66145#program.

May 22-23, 2024: Carbon Capture, Utilization and Storage (CCUS); Rie de Janeiro, Brazil. More details at https://ccusevent.org/latinamerica/2024/save-the-date.

May 28-29, 2024: AAPG Europe Regional Conference 2024; Krakow. More details at https://erc.aapg.org/2024.

June 10-13, 2024: 85th EAGE Annual Conference and Exhibition; Oslo, Norway. Visit the event website https://eageannual.org/welcome/ for further information.

June 17-19, 2024: Unconventional Resources Technology Conference (URTeC) 2024; Houstan, Texas, US. More details at https://urtec.org/2024/save-the-date.

August 25-31, 2024: 37th International Geological Congress (IGC 2024); Busan, Republic of Korea. Further information about the conference can be found at https://www.iugs.org/igc.

September 23-25, 2024: 2024 Annual Technical Conference & Exhibition (ATCE); New Orleans, Louisiana, USA. More details at https://www.atce.org/.

September 30 - October 2, 2024: AAPG International Conference and Exhibition (ICE); Muscat, Oman. Details at https://muscat2024.iceevent.org/.

October 21-24, 2024: AAPG/ EAGE/ SEG Digitalization in Geosciences Symposium; Khobar, Saudi Arabia. More details at https://www.aapg.org/global/middleeast/events/announcement/articleid/65046.

November 4-6, 2024: 4D Forum – Insight to Actions: A global forum on creating value, reducing cycle time and optimizing production and injection in a digital world; Galveston, Texas. More details at https://seg.org/calendar_events/4d-forum-insight-to-actions-creating-value-reducing-cycle-time-and-optimizing-production-and-injection-in-a-digital-world/.

November 7-9, 2024: 5th International Conference on Geology and Earth Sciences; Bali, Indonesia. Get in touch with Ms. Vera Lee (Conference Secretary of ICGES), Tel.: +86-18123342942 or email to icges_contact@academic.net for more information.

November 19-21, 2024: Latin America and Caribbean Energy Summit 2024: Security, Strategy and Transition; Punta Del Este, Uruguay. More details at https://www.aapg.org/global/latinamerica/events/announcement/articleid/66156.

November 20-21, 2024: Asia Petroleum Geoscience Conference & Exhibition (APGCE) 2024, Kuala Lumpur Convention Centre, Malaysia. For further enquiries, please contact : Intan Bhaizura, Tel: +6012 342 2979, Email: bhaizura@icep.com.my or Noor Diyana Atiqah, Tel: +6012 614 3063, Email: diyana@icep.com.my.

February 18-20, 2025: International Petroleum Technology Conference (IPTC); Kuala Lumpur, Malaysia. More details at https://www.iptcnet.org/2025.

NGC 2024

37th National Geoscience Conference

"Geoscience for a sustainable future"

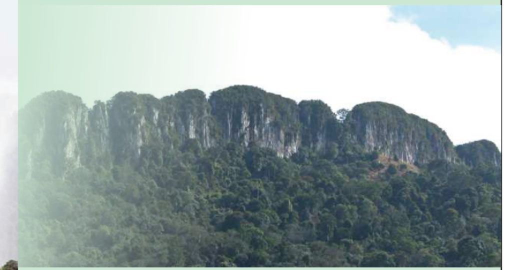
1st - 3rd October 2024

UNIVERSITI MALAYA

In conjunction with Faculty of Science 65th Sapphire Jubilee

Conference Dates have been changed from the First Circular

Second Circular



Venue:
Wyndham Grand Bangsar Kuala Lumpur

The Geological Society of Malaysia is pleased to announce that the 37th National Geoscience Conference (NGC) will be held in collaboration with the Department of Geology, Universiti Malaya from 1st-3rd October 2024. The NGC 2024 will continue the tradition as the premier geoscience event in the country; well attended by geologists from academia as well as the public and private sectors.

Call for Papers:

We invite abstracts for Oral and Poster presentations that will fit the theme or sub-themes of the conference. Abstracts can be submitted to the email: geologicalsociety@gmail.com

Abstract template is provided in the conference website.

Deadline: 01 August 2024

Full manuscripts may also be submitted for publication in the Bulletin of the Geological Society of Malaysia or Warta Geologi.

https://umevent.um.edu.my/NGC2024

Themes/Sub-themes:

- Disaster Risk Reduction, Climate Hazards and Engineering Geology
- Climate Change and Energy Mineral Resources
- Groundwater Resources
- Conservation Geology, Geotourism
- Quaternary, Coastal and Marine Geology
- Tectonics and Structural Geology
- Stratigraphy, Sedimentology and Paleontology
- Geochemistry
- Geophysics, Geospatial Applications and Geotechnology
- Policies, Ethics and Professional Practice

Registration Fees:

Early Bird Registration: (till 15 August 2024)

- RM 500* for GSM/IGM Members (with paper presentation)
- RM 600* for GSM/IGM Members (without paper presentation)
- RM 700* for non-GSM Members (inclusive of 1-year GSM membership)
- Student GSM Members - To be announced later

*RM 100 will be returned if full manuscript is accepted for publication

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- Post Conference Field trip
- Best Oral Presentation Award
- Best Poster Presentation Award
- BOG CPD Points

Exhibition Booth charges:

- Size: 3 x 3 metres
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Organising Chairman:

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Associate Professor,
Department of Geology, Universiti Malaya, Kuala Lumpur

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Title

The title must be informative and reflects the content of the paper. It should be concise (less than 20 words). Avoid using abbreviation in the title. Titles in Malay should include an English translation.

Author's Address

Affiliations, address, and email of all authors must be provided. The addresses should be sufficient for correspondence.

Abstract

Abstracts in Malay (optional for manuscripts in English) and English, each in one paragraph and should not exceed 300 words, is mandatory. It should clearly identify the subject matter, results obtained, interpretations discussed, conclusions reached and significance of the study. The abstract should not contain any undefined abbreviations or references.

Keywords

Four to eight keywords (including in the Malay language for manuscripts in Malay) that is relevant to the content of the paper is mandatory.

Acknowledgements

Acknowledgement to reviewers and institutions or agencies must be included at the end of the text. All funding sources must be mentioned in this section and acknowledged accordingly.

Authors Contributions

A statement of the roles played by each author, e.g. data analysis, experimental design is required.

Declaration of Competing Interest

A declaration of any conflict of interest must be communicated in a statement in the published paper.

References

In the text, references should be cited by author and year and listed chronologically (e.g. Smith, 1964; Jones *et al*., 1998; Smith & Tan, 2000). For both Malay and English paper, all references must be listed in English. Title of non-English manuscripts should be translated to English. Where available, include Digital Object Identifier (DOI) and URLs for the references that have been provided. Self-citations should be limited to less than 10% of the total citations in the paper.

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Book:
Hutchison, C.S., 1989. Geological Evolution of South-east Asia. Clarendon Press, Oxford. 368 p.

Chapter of book and Symposium volume:
Hosking, K.F.G., 1973. Primary mineral deposits. In: Gobbett, D.J. & Hutchison, C.S. (Eds.), Geology of the Malay Peninsular (West Malaysia and Singapore). Wiley-Interscience, New York, 335-390.

Article in Malay:
Lim, C.H. & Mohd. Shafeea Leman, 1994. The occurrence of Lambir Formation in Ulu Bok Syncline, North Sarawak. Bulletin of the Geological Society of Malaysia, 35, 1-5. (in Malay with English abstract).

Online document:
Smith, J., 2019. Minerals and rocks are valuable natural resources. Minerals Web Society. http://minerals.org/articles/12/32/index. Accessed 20 July 2020.

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Use the table function in Word to insert tables. Tables are limited to a maximum of five (5) and these should be cited in the text and numbered consecutively. Do not submit tables as images. Tables should have a title and a legend explaining any abbreviation or symbol used. Insert the caption at the top of each table. The captions should begin with the term Table followed by the number and a colon, all in bold. The text after the colon should be in regular font. Avoid excessive tabulation of data. Tabulated data may be included as an Appendix or Supplementary Data.

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All illustrations must be useful, necessary and of good quality. A maximum of ten illustrations (photographs, graphs and diagrams) are allowed and these should be cited in the text and numbered consecutively as Figures. The scales for maps and photomicrographs should be drawn on the figure and not given as a magnification. Illustrations should be drawn to fit and be legible at a maximum one full page of A4 size. High resolution illustrations, photographs, drawings, figures, and images shall be requested upon acceptance for publication. Each figure should have a caption describing the figure accurately and concisely. Insert the caption after each figure. The captions begin with the term Figure followed by the number and a colon, all in bold. The text after the colon should be in regular font.

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All illustrations, figures, and tables are placed within the text at the appropriate points, rather than at the end.

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