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Integrated geophysical approach for imaging sedimentary outcrop at Northwestern Peninsular Malaysia

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An outcrop is a visible exposure of bedrock or ancient superficial deposits on the surface of the Earth. In recent years, outcrop studies have become very important to understand the geology of the earth. The lack of studies on outcrops depends on the interpretations and observations at the surface of the earth only. Besides that, lack of specific physical value for the type of materials can cause misinterpretation of data. Therefore, 2-D resistivity and ground penetrating radar (GPR) were integrated to characterize the sedimentary outcrop. There are three study areas with the exposed outcrops located at Northwestern Peninsular Malaysia, which are Bukit Chondong, Guar Jentik and Bukit Kukus. The 2-D resistivity survey was performed using SAS4000 Terrameter with Pole-dipole array configuration while for GPR, the frequency of the antenna used is 250 MHz. The uppermost Kubang Pasu Formation at Bukit Chondong consists of repetitive facies of sandstone and mudstone. The mudstone and sandstone exhibit resistivity value of 20 to 130 and 100 to 400 Ωm, respectively whereas GPR shows contrast image in a reflection of the signal strength when the radar wave penetrates through different mediums of mudstone and sandstone. The resistivity value at Guar Jentik shows red mudstone with low resistivity value (10 - 150 Ωm) and sandstone gives higher resistivity (500 - 700 Ωm). The low contrast reflectivity in GPR is interpreted as red mudstone and the high contrast is sandstone. At Bukit Kukus, the chert facies give resistivity value of 1400 to 45000 Ωm while claystone gives 400 to 1000 Ωm, respectively. The chert area is low attenuation, thus permitting high contrast image in the radargram of the GPR and the low contrast is interpreted as claystone. The results show that 2-D resistivity and GPR methods well characterized the geological features of sedimentary outcrops. The inversion model of 2-D resistivity shows that the trend of contouring resistivity value is successfully matched with the outcrops' geological features. The radargram from the GPR showed compatibility to sedimentary structures in the outcrops. Therefore, both methods will give great potential for further studies on sedimentary outcrop.

Key words: 2-D resistivity, ground penetrating radar (GPR), features, Bukit Chondong, Guar Jentik, Bukit Kukus.

INTRODUCTION

Outcrop studies have become enormously prominent as the knowledge is highly related with the environmental

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and engineering implications. The importance of outcrop studies include understanding of the origins of geological structure, characterization of the aquifer properties, role of ecological function in maintaining soil fertility, productivity and biodiversity and the information gained can be helpful in reservoir mapping and exploration, in conjunction with characterizing the type of material that has potential to locate building structures. There are two main groups of expertise that is primarily related to the outcrop studies, which are in the view of geology and geotechnical application. In terms of geology approach, the factor that contributes to the uncertainty of the origin of outcrop stratigraphy is the lack of understanding about particular rock properties and location of the distribution. For example, geological map is composed and distributed by previous geologists to serve as guidance. Current tectonic activities that happen nowadays will affect the shape and structure of the subsurface details, thus necessitating some possible change in the geological profiles. Frequent inspection and survey need to be conducted to provide the latest update.

In terms of geotechnical approach, recent and various outcrop studies can be used to provide comparison within the type of materials that will further the understanding of the subsurface, which can be linked to several civil engineering works in Malaysia, such as in geotechnical engineering, rock mechanics and engineering geology, hydrology and environmental engineering, along with pavement engineering. The information obtained will help to implement the preferred alternative purposes related to geological and soil resources. For example, rock engineer needs general information about the elevations and type of structures to locate the materials with which to build them. For reservoir engineers, the value of rock permeability and porosity is one of the factors and significantly characterizes the type of subsurface materials that have potential to conduct oil and gas extraction activities.

Geophysics is a major discipline of earth sciences; it uses the concept of non-destructive methods of which the result is interpreted by looking at the interior of the earth from the surface. Atwa and Henish (2018) represented a sequential use of surface structural mapping and DC resistivity (DCR) method to obtain a sensible structural model in a cost effective way. Surface geophysical DCR sounding and 2-D resistivity methods were conducted to measure stratigraphic sections and establish structural characteristics of the rock units. Mitev and Yaneva (2012) demonstrates the potential of 2-D resistivity in recognizing and determining a specific sediment body among the sediment successions in areas with lack of outcrops, and the first attempt of this study is to delineate the diatomite deposits in South-West Bulgaria. Besides that, Omosanya et al. (2012) conducted combination of 2-D resistivity and geological mapping to study the geology and delineate geologic structures.

In this study, two different geophysical methods, which are 2-D resistivity and ground penetrating radar (GPR) methods are integrated to characterize the sedimentary outcrop.

Study area

In this study, 2-D resistivity and GPR survey were chosen to map sedimentary outcrop. The geophysical method was conducted on top of the outcrop. The exposed outcrop of Bukit Chondong, Beseri, Perlis is described as the Uppermost Kubang Pasu Formation (Figure 2), with the exposed outcrop clearly consisting of two different rocks comprised of mudstone interbedded with sandstone distributed in form of repetition layer (Hassan et al., 2013).

For the second study area, the latest research by Hassan (2013) indicates that the outcrop in Guar Jentik, Perlis is assigned as the Chepor Member of Kubang Pasu Formation. The outcrop is mainly composed of thick fossiliferous mudstone of various colors, interbedded with sandstone and bedded diamictite. During the observation, the outcrop features resembles the complex form shown in Figure 3. The obvious materials identified on the outcrop are the red mudstone and sandstone.

For the third study area, located at Bukit Kukus, Kedah the outcrop exposed black mudstone represents the lowermost part of the chert unit of the Semanggol Formation in this area. The lower terrace of the south section exhibits about 30 m wide of highly weathered mylonite separating the Late Permian bedded chert from tuffaceous mudstone (Figure 4) and interbedded in the Late Permian chert and siliceous shale. The upper terrace of the south section exposed an approximately 80 m wide thrust fault and bedded chert of the Middle Triassic.

Geology of the study area

The study area is located in Perlis, northwest Peninsular Malaysia as shown in Figure 1. The layout and structure of the Paleozoic rocks indicate the sedimentary basins in the general trend between northwesterly to northerly. The entire exposed outcrops at the study area have the same Paleozoic era, where the lithologies of the Paleozoic rocks are marine and cover almost 25% of Peninsular Malaysia (Foo, 1983).

There are two outcrops chosen in Perlis to conduct the research study, viz; Bukit Chondong and Guar Jentik. Both exposures of Bukit Chondong and Guar Jentik are in the Beseri District. The entire exposed outcrops at the study area have the same Paleozoic era with its own stratigraphy divisions and sedimentary succession where the oldest sediments are dated to be Late Cambrian and the youngest as Late Permian based on the Chronostratigraphic Chart, 2015 (Cohen et al., 2013). The last study area is the outcrop of Bukit Kukus located at Kuala Ketil, Kedah, Malaysia. The stratigraphy of this

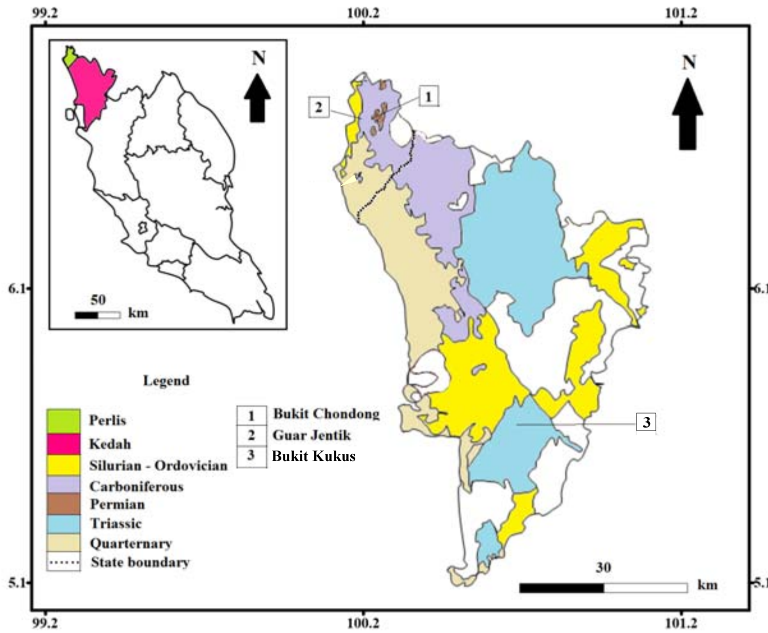

Figure 1. Geological areas in Northwest Peninsula Malaysia.

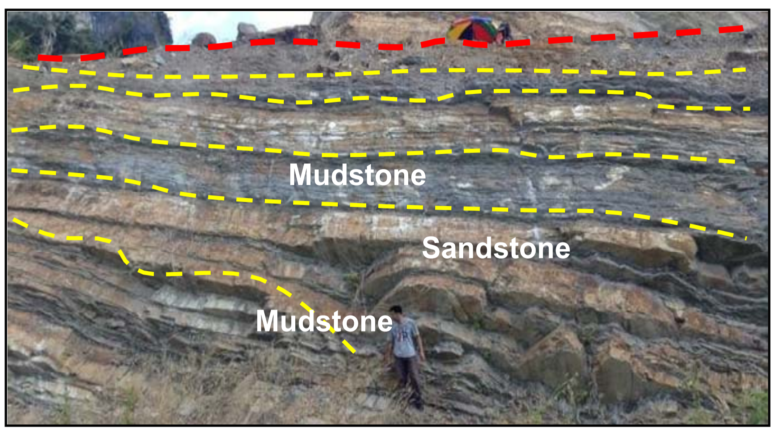

Figure 2. Outcrop of Bukit Chondong shows interbedded of mudstone and sandstone.

outcrop is known as the Semanggol Formation; one that was identified as Early Permian to Late Triassic.

METHODOLOGY

Two types of geophysical methods, viz; 2-D resistivity and GPR were applied in this study. The ground resistivity is a function of various geological parameters such as mineral fluid content, porosity and degree of water saturation in the rock. Variations in electrical resistivity may indicate changes in composition, layer or contaminant levels (Loke, 1994).

The parameter used for the GPR method is dielectric permittivity. Since the GPR method utilizes electromagnetic waves, the signal will be reflected to the surface when it encounters different subsurface materials that exhibit different dielectric permittivity (Reynolds, 1997). The GPR method is also influenced by the conductivity of the geological media. The depth of penetration is limited especially for the subsurface with conductive unconsolidated sediments like clay (Loke, 1999).

Data acquisition was conducted using Terrameter ABEM SAS4000 system and performed by Pole-dipole array configuration. A single 40 m survey line was proposed with a minimum of 1 m electrode spacing at Bukit Chondong and Guar Jentik while the Bukit Kukus survey line was proposed with 1.5 m minimum electrode spacing which makes the total length of survey line 60 m. The Pole-dipole array has relatively good horizontal coverage, more sensitive to vertical structures and the signal strength of this array is higher compared to the other array. The raw data will be converted and processed using RES2DINV software (Loke, 2004). For small electrode spacing, the apparent resistivity is close to the surface

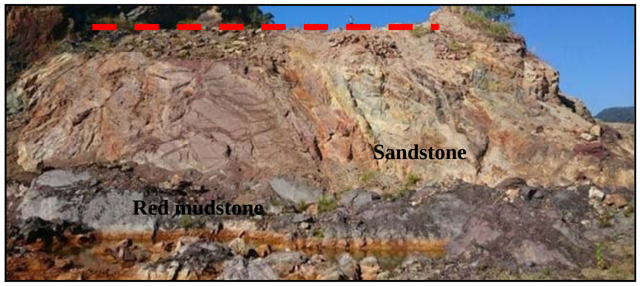

Figure 3. Outcrop of Guar Jentik shows features in complex form and obvious observation of red mudstone and sandstone materials.

Figure 4. Observation on the outcrop with contact of chert and mudstone marked with yellow dashes line at Bukit Kukus.

layer resistivity, whereas at larger electrode spacing, it gives deeper penetration. In this study, 1.5 m is chosen for detailed shallow penetration and cover along the hillslope area.

The computer program will automatically subdivide the subsurface, and then uses a least-square inversion scheme to convert the apparent resistivity values into the true resistivity and determine the appropriate resistivity value for geological interpretation (Loke, 1999). Later, the inversion results will be output into Surfer 10 software for gridding, contouring and mapping purposes. The 2-D resistivity results obtained from this survey will be correlated with the geological structures of the outcrop.

For the GPR method, the 250 MHz shielded antenna was used during this survey. At Bukit Chondong, the survey line for the GPR starts at 15 m of the resistivity line. The survey line for GPR at Guar Jentik starts from a distance of 12 m until 27 m of the resistivity line. The survey line for the GPR line at Bukit Kukus has the same distance with resistivity. Both the 2-D resistivity method and GPR method were conducted on the same line. The survey was carried out on top of the outcrop and the result was expected to be almost the same with the outcrop. The data processed using the Ramac GroundVision software will be in the form of radargram. This software basically functions to obtain more perceived images by using the common filters e.g. DC Removal, Time Varying Gain and Band Pass filter.

Background removal filter is applied by running average background subtraction to the data to remove the horizontal banding in profiles like the system noise, electromagnetic interferences and surface reflections. Time Varying Gain is chosen which is designed to have frequency response as flat as possible in passband. It is used to shape the frequency spectrum of a signal. Band Pass Filters can be used to isolate or filter out certain frequencies that lie within a particular band or range of frequencies. The application of the filtering helps to improve the signal to noise ratio and visual quality (Cassidy, 2009). The changes in amplitude of reflective will be interpreted as the geological signature.

RESULTS

The results from both of the geophysics method was analyzed by referring to the outcrop subsurface profile, where the inversion model of the resistivity is interpreted from the contouring image while the radargram image of the GPR method is interpreted based on the level of the reflective wave contrast of hyperbolic curves patterns for the materials at the outcrops.

Based on the observation of the outcrop, Figure 5 shows the interbedded of mudstone and sandstone mark with the yellow dashed line. As obtained from sedimentological studies, the uppermost succession of the Kubang Pasu Formation was identified at Bukit Chondong, Perlis. The Kubang Pasu Formation comprised of thick mudstone of various colors interbedded with sandstone (Hassan et al., 2013). The layer of mudstone and sandstone indicates tidal influence during sedimentation (Buatios and Mangano, 2003).

Based on observation of the outcrop, Figure 6 shows a complex structure of exposed sedimentary rocks. From

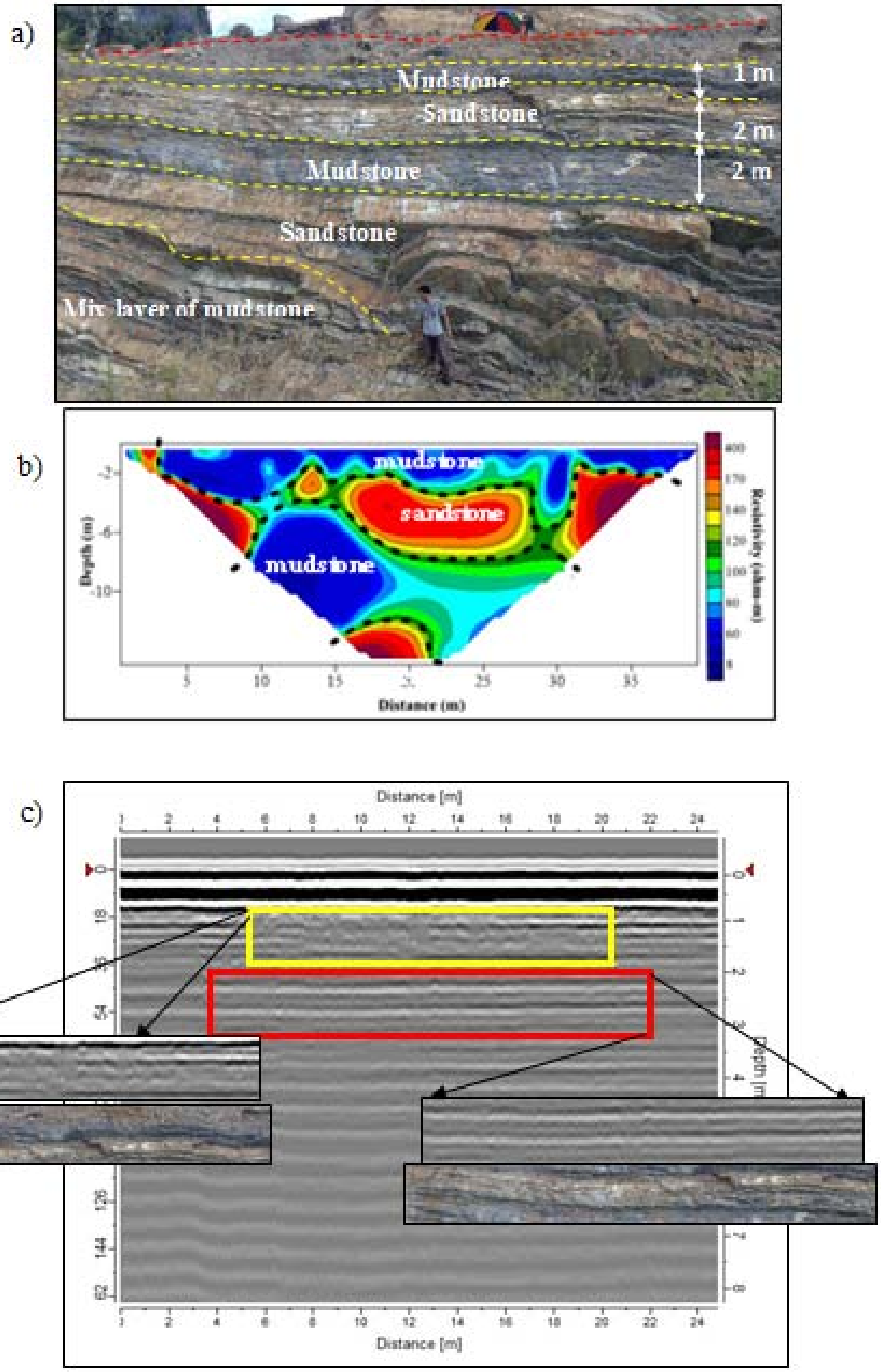

Figure 5. (a) Outcrop at Bukit Chondong, (b) Inversion model of 2-D resistivity method shows interbedded of mudstone and sandstone at Bukit Chondong, (c) Layering of mudstone (yellow box) and sandstone (red box) based from the reflective signal.

the sedimentological studies, the study area is tentatively assigned as Unit 6 of the Jentik Formation, which mainly consists of thick beds of brownish red mudstone, interbedded with sandstone (Hassan and Lee, 2002). The latest studies describe that the area is the Chepor Member of the Kubang Pasu Formation which is composed of thick fossiliferous mudstone of various colors, interbedded with thick beds of sandstone and bedded diamictites.

Based on the observation of the outcrop, Figure 7

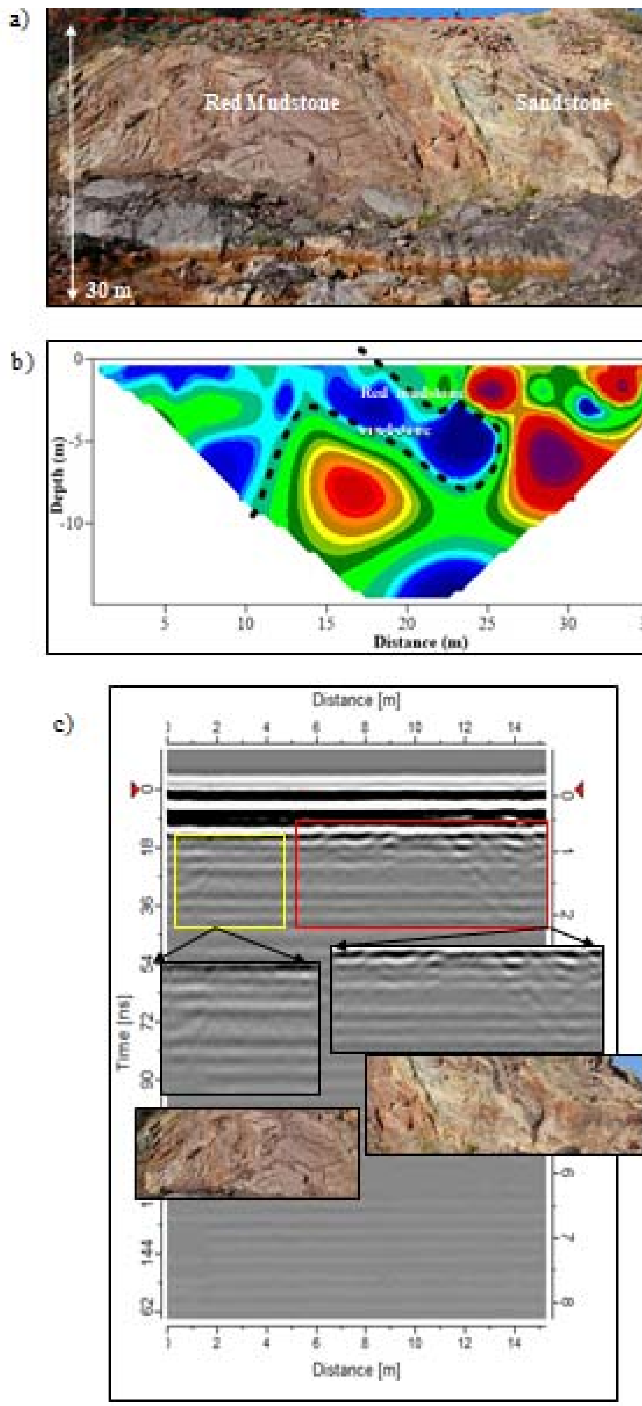

Figure 6. (a) Complex structure of sedimentary outcrop of Guar Jentik, (b) Inversion model of 2-D resistivity method at Guar Jentik, (c) Image of reflective signal for sedimentary rocks at Guar Jentik.

shows a contact of two different sedimentary rocks, which are chert and claystone that is marked with a yellow dashed line. From sedimentological studies, the late Permian age of the Semanggol Formation was identified at Bukit Kukus, Kuala Ketil, Kedah. The Semanggol Formation identified at the study area composed of claystone facies underlying the bedded chert facies. The abrupt increase in the detrital constituents from almost pure chert to almost pure terrigenous in this interval may indicate a period of relatively shallow depositional environment of this claystone interval while the pelagic chert facies is from the deep marine of deposition

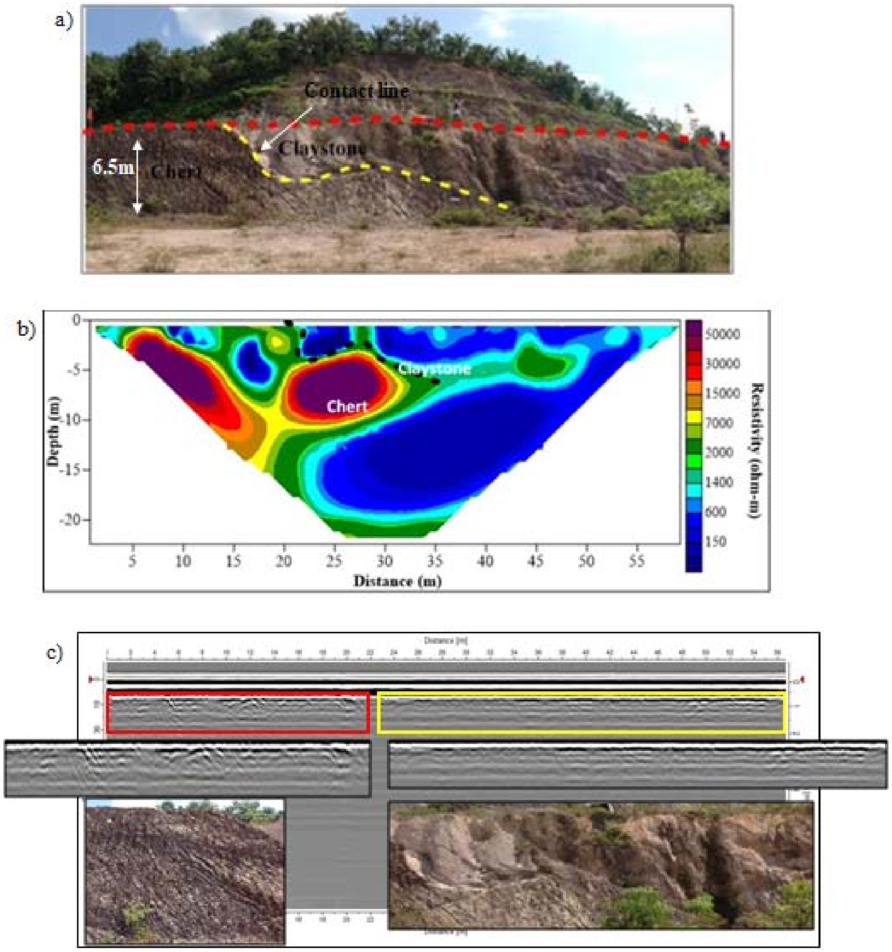

Figure 7. (a) Contact between chert and claystone marked with yellow dashes line, (b) Inversion model of 2-D resistivity at Bukit Kukus, (c) Verification of chert (red box) and claystone (yellow box) based from the reflective amplitude contrast.

environment (Baioumy and Ulfa, 2016). Based on the observation of the outcrop, both materials of chert and claystone are in contact with each other. The obvious geological features of contact between two different rock materials will be the reference for the geophysical results interpretation.

DISCUSSION

The materials identified within the outcrop features were determined by the resistivity values (ρ) and reflectivity amplitude from the GPR profile. The discussion is divided into three study areas which are Bukit Chondong, Guar Jentik and Bukit Kukus.

Bukit Chondong

The result of the inversion model for the outcrop of Bukit Chondong in Figure 5b shows that the interbedded mudstone and sandstone can be observed when comparing with the outcrop features. From the significant change in the contouring image of the inversion model, the interpretation of resistivity values indicate that mudstone is in the range of 20 to 130 Ωm, while sandstone is in the range of 100 to 400 Ωm (Loke, 1999).

The radargram profile in Bukit Chondong starts from the distance of 15 m of the resistivity survey line. In the radargram profile, Figure 5c shows the signal strength of amplitude reflectivity for mudstone and sandstone (Hänninen, 1997). The layering is labeled mudstone in the yellow box while the sandstone is in the red box. The depth of penetration in the radargram can only be observed until 8 m.

The determination of mudstone and sandstone is based on the obvious contrast display in the radargram in comparison with the actual materials of the outcrop features. The contrast image is a reflection of the signal strength when the radar wave penetrates through different mediums, which at this outcrop is the layering of mudstone and sandstone. The signal eventually decreases due to radar wave attenuation (Teoh et al., 2018). The low value of resistivity of mudstone from the previous inversion of 2-D resistivity will influence the radar wave penetration in giving high attenuation, thus permitting low contrast image in the radargram of the GPR and vice versa with the sandstone. For the interpretation, the low resistivity values from the depth of 1 to 2 m were interpreted as mudstone and the high resistivity value from the depth of 2 to 4 m were interpreted as sandstone.

Guar Jentik

For Guar Jentik, the inversion model of the outcrop in Figure 6b was interpreted as a complex structure and it was difficult to differentiate the arrangement of the type of sedimentary rocks based on the resistivity contrast. The complex structure might represent the geological features such as the symmetrical and asymmetrical ripple with cross lamination, cross bedding, parallel lamination, hummocky cross stratification and normal grading based on previous geologists' research. However, the obvious materials identified at the outcrop are the red mudstone and sandstone. From the significant change in the contouring image of the inversion model, the interpretation of resistivity values indicate that red mudstone is in the range of 10 to 150 Ωm, while sandstone is in the range of 500 to 7000 Ωm (Loke, 1999).

The radargram profile in Guar Jentik starts from the distance of 11 to 26 m of the resistivity line. In the radargram profile at Guar Jentik, Figure 6c shows the reflection of amplitude reflectivity of the subsurface materials. The depth of penetration in the radargram can only be observed until 8 m. The determination of red mudstone and sandstone is based on the obvious contrast display in the radargram and in comparison with the actual materials of the outcrop features. Radar wave attenuation is significant due to the materials having different dielectric materials (Sbartaï, 2016; Zajícová and Chuman, 2019). The red mudstone is labelled in the yellow box while the sandstone is in the red box. For the interpretation, the low contrast is interpreted as red mudstone and the high contrast is sandstone.

Bukit Kukus

Figure 7b shows the inversion model of 2-D resistivity at the outcrop of Bukit Kukus. Based on the inversion model of 2-D resistivity, the result shows that the image of contact between two different sedimentary rocks of chert and claystone marked with black dashes line are exactly the same with the outcrop features. The thickness of the outcrop is almost 6.5 m and the Pole-dipole array can penetrate up to 23 m. Based on the significant change in the contouring image of the inversion model, the interpretation of resistivity values indicate that claystone is in the range of 400 to 1000 Ωm (Loke, 1999) while chert is in the range of 1400 to 45000 Ωm.

The radargram profile in Bukit Kukus has the same distance of the resistivity line. In the radargram profile at Bukit Kukus, Figure 7c shows the signal strength of amplitude reflectivity of chert and claystone. The contrast image is a reflection of the signal strength between two different materials of chert and claystone, which will eventually decrease due to radar wave attenuation. The chert area is labelled in the red box while for claystone, it is in the yellow box. For the interpretation, the high contrast was interpreted as chert from the distance of 0 to 21 m and the low contrast was interpreted as claystone towards the distance of 60 m.

Conclusion

2-D resistivity and GPR methods were well utilized in the comparison of sedimentary outcrop. The outcrop geological features are well described based on the imaging result of the inversion model from 2-D resistivity and the radargram from GPR. The geophysical interpretations are based on the geological features observed from the outcrops. The outcrop at Bukit Chondong comprised of interbedded mudstone and sandstone. The mudstone and sandstone gives resistivity value of 20 to 130 Ωm and 100 to 400 Ωm, respectively while GPR shows contrast image in a reflection of the signal strength. The outcrop at Guar Jentik display complex geological features and the deposition of the materials observed was the red mudstone and sandstone. Red mudstone has low resistivity value (10 - 150 Ωm) while sandstone gives higher resistivity (500 - 700 Ωm). The low contrast reflectivity in GPR is interpreted as red mudstone while the high contrast is sandstone. For the outcrop at Bukit Kukus, the geological features are the contact line between chert and claystone which gives value of 1400 to 45000 Ωm (chert) with high contrast image in GPR radargram and 400 to 1000 Ωm (claystone) with low contrast image in GPR radargram. This study can characterize the subsurface geological features with the exposed geological outcrops. In the future, the geophysical techniques can provide useful data for shallow subsurface mapping applications without the outcrop especially with the 2-D resistivity method. GPR method solely depends on the radargram image thus the integration with other geophysical is needed to validate the results. This approach is important for decreasing the uncertainties of subsurface geological interpretations hence more reliable geological models can be introduced.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Atwa M, Henaish A (2018). Regional structural mapping using a combined geological and geophysical approach–A preliminary study at Cairo-Suez district, Egypt. Journal of African Earth Sciences, 144:104-121.

Baioumy HM, Ulfa Y (2016). Facies Analysis of the Semanggol Formation, South Kedah, Malaysia: A possible Permian-Triassic boundary section. Arabian Journal of Geosciences 9(8).

Buatios LA, Mangano MG (2003). Sedimentary Facies, depositional evolution of the Upper Cambrian-Lower Ordovician Santa Rosita Formation in northwest Argentina. Journal of South American Earth Sciences 16(5):343-363.

Cassidy NJ (2009). Chapter 5-Ground Penetrating Radar Data Processing, Modelling and Analaysis pp. 141-176.

Cohen KM, Finney SC, Gibbard PL, Fan JX (2013). The ICS International Chronostratigraphic Chart, Episodes 36:199-204.

Foo KY (1983). The Paleozoic Sedimentary Rocks of Peninsular Malaysia-Stratigraphy and Correlation, Workshop on Stratigraphic Correlation of Thailand and Malaysia (Haad Yai, Thailand).

Hänninen P (1997). Dielectric coefficient surveying for overburden classification. Geological Survey of Finland, Bulletin 396:1-72.

Hassan MHA (2013). Post-Conference Field Excursion to Northwest Peninsular Malaysia: Third International Conference on Paleontology of South East Asia: ICPSEA 3 10th - 13th October 2013

Hassan MHA, Yeow BS, Lee CP, Rahman AHA (2013). Facies Analysis of the Uppermost Kubang Pasu, Perlis: A Wave and Storm-influenced Coastal Depositional System. Sains Malaysiana, 42(8):1091-1100.

Hassan MHA, Lee CP (2002). Stratigraphy of the Jentik Formation, the transitional sequence from the Setul Limestone to the Kubang Pasu Formation at Guar Sanai, Kampung Guar Jentik, Beseri, Perlis-a preliminary study, Proceedings Geological Society of Malaysia Annual Geological Conference.

Loke MH (1994). Instruction manual for the 2D resistivity forward modeling program Res2Dmod pp. 1-11.

Loke MH (1999). Electrical Imaging Surveys for Environmental and Engineering Studies: A Practical Guide to 2-D and 3-D Surveys pp. 1-18.

Loke MH (2004). Tutorial: 2-D and 3-D electrical imaging surveys.

Reynolds JM (1997) An Introduction to Applied and Environmental Geophysics. England: John Wiley and Sons Ltd.

Mitev A, Yaneva M (2013). Application of 2D Resistivity Profiling for Delineation of Specific Lithological Bodies.

Omosanya KO, Mosuro GO, Azeez L (2012). Combination of geological mapping and geophysical surveys for surface-subsurface structures imaging in Mini-Campus and Methodist Ago-Iwoye NE Areas, Southwestern Nigeria. Journal of Geology and Mining Research 4(5):05-117.

Sbartaï ZM, Stéphane L, Jean PB, Gérard B, Ginette A (2016). Effect of Concrete Moisture on Radar Signal Amplitude. ACI Materials Journal 11(12).

Teoh YJ, Bruka MA, Idris NM, Ismail NA, Muztaza NM (2018). Introduction of a Ground Penetrating Radar System for Subsurface Investigation in Balik Pulau, Penang Island. Journal of Physics Conf. Ser, 995 012098.

Zajícová K, Chuman T (2019). Application of ground penetrating radar methods in soil studies: A review, Geoderma 343:116-129.