

# Study of Sedimentary Outcrop of Semanggol Formation with the Correlation of Geology, Geotechnical and Geophysics Technique

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**Abstract.** The study location was at Bukit Kukus, Kuala Ketil, Kedah, Malaysia where the geological outcrop of this Semanggol Formation comprises of chert, mudstone, and volcanic tuff. The study was conducted using two geophysical methods, which are 2-D Resistivity and Ground Penetrating Radar (GPR). The objectives of the study are to correlate both of the geophysical methods through the value of conductivity and to identify the physical properties of rocks through the value of porosity and permeability. The data acquisition for both methods was conducted on the same line. For 2-D Resistivity method, the length of the line is 60 m with 1.5 m electrode spacing and the array used was Wenner-Schlumberger. For GPR method, the survey line was on top of the resistivity line, and the frequency of the antenna used is 250 MHz. A good correlation exists between both of the GPR signature and contour maps for resistivity from the surfer 10 software with the outcrop feature. Conductivity value from both GPR and Resistivity method was compared and the range value of conductivity obtained from GPR method almost equivalent with Resistivity method based on derivation and calculation for the sedimentary rocks, which are 0.037 to 0.574 miliSiemens per metre (mS/m) for chert and 0.186 to 10.142 miliSiemens per metre (mS/m) for mudstone. Two types of rock samples were taken, and several geotechnical tests were conducted, but only the value of permeability,  $K$  and porosity,  $\phi$  of chert can be calculated, which are  $1.95\text{E-}22\text{ m}^2$  (original condition) and  $2.27\text{E-}22\text{ m}^2$  (dry condition) and 3 percent respectively as the sample of mudstone was damaged. The parameter of the 2-D resistivity method derived from Archie's law was used to calculate the porosity,  $\phi_f$  value using the Formation Factor equation. The range values of porosity,  $\phi_f$  for chert mostly in the range of 5 to 25 percent, which is 6.26 to 13.36 percent but slightly out of range for mudstone, which is 14.12 to 36.02 percent.

## 1. Introduction

Several studies on outcrop have been conducted for rocks corresponding in the subsurface that is rich in natural resources. Such continuous information on the outcrop and detailed information can be obtained, for example, petrology, facies, sedimentary structures, texture, grain types and diagenetic changes [1].

Mostly, the geotechnical event begins with a review of the task to define the required material properties. Then, site investigation of soil and rock properties was conducted at the area of interest to determine their engineering properties to proposed construction. Additional of site investigations are needed to gain an understanding of the area or which engineering will take place. It is a process



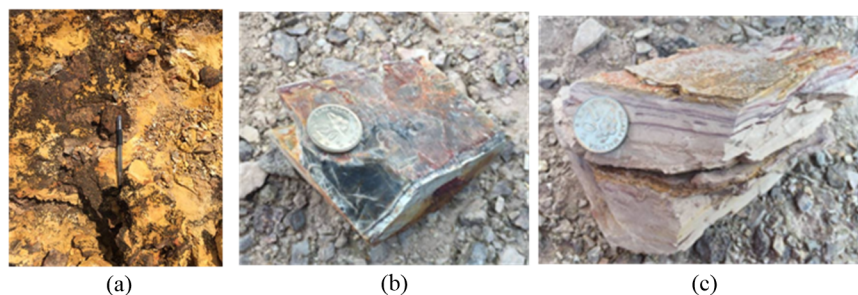
collecting information and uses principles of soil mechanics and rock mechanics to investigate subsurface conditions and materials, which to determine the relevant physical or mechanical and chemical properties of these materials [2].

The geophysical survey can act as an important role in defining the subsurface geology and the associated parameters which are calculated by application of a variety of invasive and noninvasive techniques. Analysis of data using geophysical methods usually helps produce a more cost effective program in locating the target. Basically, the methods of geophysics are utilized to retrieve analog data in the absence of outcrops or to enhance those with petrophysical data in comparable to the subsurface of interest. For example, ground-penetrating radar (GPR) has long been used to for static imaging [1]. Of all the physical properties of rocks and minerals, electrical resistivity shows the greatest variation.

Recently, a fieldwork has been carried out at Kuala Ketil, at the coordinate N: 05.59100° E: 100.69568° until N: 05.59046° E: 100.69573° which to determine the value of resistivity and conductivity of the sedimentary rocks from the outcrops features. Thus, the application of 2-D Resistivity and Ground Penetrating Radar (GPR) methods plays an important role to determine the resistivity and conductivity values of those sedimentary rocks.

## 2. Study Area

The study area that was conducted at Bukit Kukus, Kuala Ketil, Kedah, Malaysia with the coordinate of N 05.59100° E 100.69568° until N 05.59046° E 100.69573°. Survey line length of 60 m was proposed on top of the outcrop, which at one specific area that has high possibilities to become the target of interest and produce expected a visionary result. Based on the observation of the geological features, the outcrop shows a contact of two different sedimentary rocks, which are chert and mudstone. According to Jasin and Harun [3], there are seven lithofacies have been identified that may represent the chert unit in ascending order, laminated black mudstone, interbedded sandstone and mudstone, interbedded tuffaceous sandstone and tuff with a paraconglomerate bed, interbedded tuffaceous sandstone, siliceous shale and chert, bedded chert, tuffaceous mudstone and interbedded chert and siliceous mudstone. However, only the presence of volcanic tuff can be identified at the study area (Figure 1(a)). Figure 1(b) is the presence of chert with iron stains, and lastly, Figure 1(c) shows laminated mudstone that has been identified in the study area and based on observation, it was formed through the compaction process.



**Figure 1.** (a) Volcanic tuff, (b) chert and (c) laminated mudstone.

## 3. Methodology

Regarding geology, the outcrop at Bukit Kukus, Kuala Ketil, Kedah was observed, and the characteristics of the facies distribution with its geological features were identified. The rock samples from the outcrop were taken using the geology hammer. There are two different types of materials of the rock samples taken which are chert and mudstone.

Two different geophysical methods were utilized in this study. For 2-D Resistivity survey, the data acquisition was conducted using Terrameter ABEM SAS4000 system and performed by Wenner-

Schlumberger array. A single line was laid out with minimum 1.5 m spacing between electrodes which make the total distance of 60 m. The data processing and interpretations were managed using the RES2DINV software, and the data were then outputted into Surfer 10 software for gridding, contouring, and final presentation.

For Ground Penetrating Radar (GPR), the antenna frequency used is 250 MHz antenna and only one survey line conducted at the study location which exactly on top of the resistivity line. For GPR processing, the raw data need to filter such for instrument noise or any irregularities in the data using the Ramac GroundVision software. The knowledge of radar attenuation crossed by EM waves introduces significance absorptive losses or decreases the intensity of electromagnetic allow calculating the electrical conductivity [4].

Based on the Radargram interpretation, the distance in meter (m) and time of reflection in the nanosecond (ns) are important in finding the velocity,  $v$  in meter per second (m/s) of the medium travel. Equation (1) used to calculate the value of attenuation,  $\alpha$  based on the value of the velocity and the value of conductivity,  $\sigma$  obtain from the 2-D Resistivity method. The value of conductivity in Equation (2) is from the GPR method which was compared with the conductivity value from 2-D Resistivity method.

$$\alpha = 1.69 * \frac{\sigma}{\sqrt{k}} \quad (1)$$

$$\sigma = \omega \epsilon \sqrt{\left[ 2 \left( \frac{\alpha}{\omega \sqrt{\epsilon \mu}} \right)^2 + 1 \right]^2 - 1} \quad (2)$$

The resistivity of rock depends on number of factors such as the porosity and the water saturation [5]. Permeability and porosity test was conducted directly from the rock samples taken. Before the test begins, the rock samples undergo the coring process to form a cylindrical shape. Permeability test (Nitrogen Gas Permeability) was conducted in two conditions, which in original condition (after coring) and in dry condition. Flow rate,  $V$  in meter square per second ( $\text{m}^2/\text{s}$ ) and area,  $A$  in meter square ( $\text{m}^2$ ) was calculated through Equation (3) and (4) respectively, where  $D$  is the flowmeter diameter,  $H$  is the length head of flowmeter,  $T$  is average time,  $B$  is specimen diameter and  $L$  is the length of specimen. Intrinsic permeability,  $K$  in meter square ( $\text{m}^2$ ) value was obtained through calculation from the Equation (5).

$$V = \frac{\left( \frac{D^2}{4} \right) \pi H}{T} \quad (3)$$

$$A = \frac{\pi B^2}{4} \quad (4)$$

$$K = 2P^2 \frac{VL * 1.7 * 10^{-16}}{A(P_1^2 - P_2^2)} \quad (5)$$

Porosity test (Water Absorption and Porosity Measured by Water Immersion under Vacuum) was conducted later where the weight of the rock samples was measured in original condition ( $W_4$ ). Then the rock samples undergo vacuum pressure process where the samples were left in the vacuum saturation apparatus for three hours. After three hours, the samples were immersed completely in water together with the vacuum pressure for another three hours. Then samples were left only in the water for another an hour. The samples were taken out, and the weight of the rock samples was recorded in water ( $W_3$ ) and in air ( $W_2$ ). Porosity,  $\phi$  value was obtained in percentage, (%) through calculation from the Equation (6).

$$\phi = \frac{W_2 - W_4}{W_2 - W_3} \quad (6)$$

Archie's law link the electrical resistivity of a rock to its porosity, to the porosity of the water that saturates its pores and to the fractional saturation of the pore space with the water. Archie began by naming the ratio of the resistivity of the rock  $\rho_o$  to that of the pore water  $\rho_w$  the formation resistivity

factor,  $F$ . Formation resistivity factor is the ratio of the resistivity of 100% water saturated rock to the resistivity of the water with which it is saturated [6].

Equation (7) is the calculus for the formation resistivity factor, where  $\rho_f$  is the resistivity value for the unconsolidated layer. The value of  $\rho_f$  was assumed on top of the layer of the outcrop, which at where the data was acquired, while for  $\rho_w$  is fluid resistivity which was assumed as the lowest resistivity value and using the Wenner-Schlumberger array the value of  $\rho_w$  is 55.57 ohm-m. Once the value of  $F$  is obtained, porosity,  $\phi_f$  of each of the materials can be calculated using Equation (8), where the values of tortosity factor,  $a$  and cementation factor,  $m$  was referred from Archie's formula for different lithologies in Table 1. The value of  $a$  and  $m$  are fixed at 0.62 and 1.95 respectively as the outcrop is a sedimentary rock from the Paleozoic age.

$$F = \frac{\rho_f}{\rho_w} \quad (7)$$

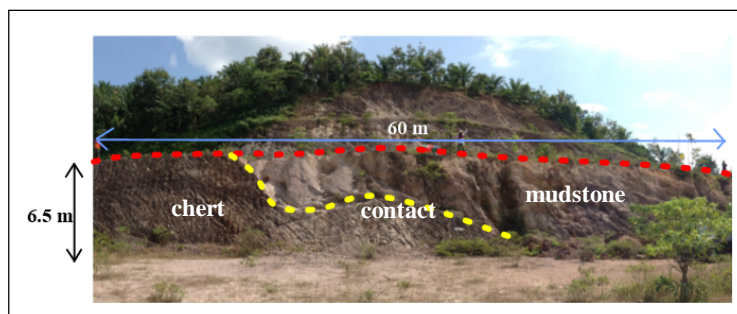
$$F = a * \phi^{-m} \quad (8)$$

**Table 1** Archie's formula for different lithologies (Keller, 1966)

Description of rock	$a$	$m$
weakly cemented detrital rocks, such as sand, sandstone and some limestones, with a porosity range from 25 to 45 % (Tertiary age)	0.88	1.37
moderately well cemented sedimentary rocks, including sandstones and limestones, with the porosity range from 18 to 35 % (Mesozoic age)	0.62	1.72
<b>Well-cemented sedimentary rocks with a porosity range from 5 to 25 % (Palaeozoic age)</b>	<b>0.62</b>	<b>1.95</b>
Highly porous volcanic rocks, such as tuff, aa and pahoehoe with porosity 20 to 80 %	3.5	1.44
Rocks with less than 4 % porosity, including dense igneous rocks and metamorphosed sedimentary rocks	1.4	1.58

#### 4. Results and Discussion

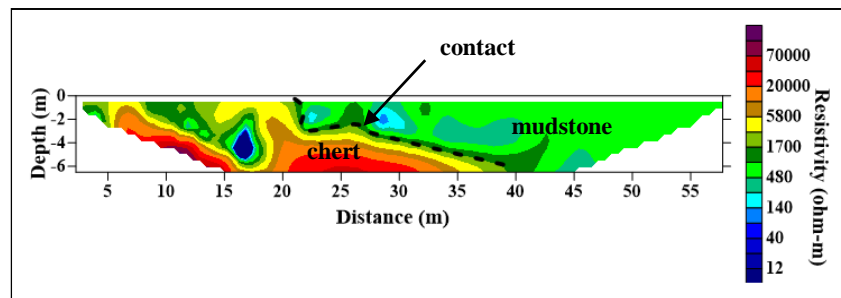
Figure 2 shows the outcrop features of the study area consist of contact of chert and mudstone mark with a yellow dotted line. This zone could indicate fracture presence due to high weathering process at the contact. The properties of the rock could be confirmed and identify through the value of geophysical method that was conducted on top of red dotted line and geotechnical tests.



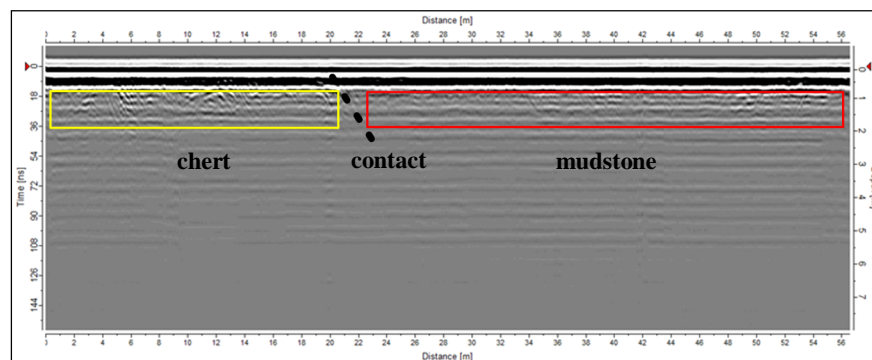
**Figure 2.** The outcrop with thickness of 6.5 m show contact of chert and mudstone.

In comparison with the outcrop in Figure 2, the result of the pseudosection for 2-D Resistivity method in Figure 3 for Wenner-Schlumberger array process from the Surfer 10 show a positive correlation. Based on the pseudosection map, the contact zone could dictate by the trend of the

resistivity contour, which reflects the vertical resistivity distribution within the depth of 6.5 m that have been cut to correlate with the outcrop thickness. The value of resistivity for mudstone is the lowest compared to chert. This is because the majority of chemical sedimentary rocks of mudstone come from minerals left behind by evaporated water. Mudstone has a resistivity value of 12-900 ohm-m, while the chert exhibited a resistivity of 1700-130000 ohm-m respectively. For GPR interpretation, Figure 4 displays the result of the Radargram after filtered to obtain more perceive image. The white and black stripes indicate amplitude values alternately. The obvious reflected signal was identified, where the contact of both chert and mudstone are nearly at the same distance.



**Figure 3.** Pseudosection map result in using Wenner-Schlumberger array with depth of 6.5m.



**Figure 4.** Amplitude contrast from the GPR Radargram results until depth of 7m.

At the different distance and depth give the different value of time in the Radargram, thus show the different velocity of materials. The knowledge of the radar energy attenuation is important to identify electrical properties of different materials in the ground, which in this case is to determine the value of conductivity for chert and mudstone at the study area. Generally, attenuation is the interruption of a radar beam by intense precipitation. Based on the calculation of average value, Table 2 shows attenuation value for chert and mudstone are in the range of 0-0.04 and 0.01-0.64 Neper per meter (Np/m) subsequently. Thus, conductivity value from GPR method could determine where for chert and mudstone are in the range of 0.037-0.574 and 0.186-10.142 miliSiemens per meter (mS/m) respectively. The conductivity value from both GPR and 2-D Resistivity method are almost equivalent. This implies that conductivity value of the outcrop can be obtained from GPR method and successfully correlated with the 2-D Resistivity method.

In general rock classification, permeability,  $K$  and porosity,  $\phi$  is included in the basic rock properties. The permeability of rock is the measure of resistance to the flow of fluid through a rock. While for the porosity of rock could be simplified as a measure of its ability to hold a fluid. Based on the test of the geotechnical event, both permeability and porosity of the rock samples could be determined, and the values are organized as in Table 2. For permeability test (Nitrogen Gas Permeability), only permeability value of chert could be calculated, while the other sample which is mudstone is not available as the sample was damaged directly from the coring process. Using the Equation (5), the average time for the original condition is longer because it takes a lot of pressure to



squeeze fluid through a rock compared to the dry condition which fluid passes through rock easily in shorter time. Thus, chert in original condition has the low permeability which is  $1.95\text{E-}22\text{ m}^2$ , but high permeability after dry condition which is  $2.27\text{E-}22\text{ m}^2$ . Water absorption,  $A$  for chert was measured by subtracted weight of the sample in original condition after dry in the oven, ( $W_4$ ) from the weight of the sample in the air after undergoes the porosity test procedure, ( $W_2$ ) and the product was divide with ( $W_4$ ). For porosity test (Water Absorption and Porosity Measured by Water Immersion under Vacuum), the water absorption,  $A$  for chert is 1.2. Thus, the porosity,  $\phi$  was calculated when the product of ( $W_2 - W_4$ ) is divided by the product of the weight of the sample in the water after undergoes the porosity test procedure, ( $W_3$ ) subtracted from ( $W_2$ ) as in Equation (6). As a result, the porosity for chert is 3 percent. More interpretation for the porosity value for both samples of chert and mudstone could be done using the value of Formation Factor,  $F$ . Porosity value for both chert and mudstone can be calculated through resistivity method using both Equation (7) and (8). The porosity obtained from the Formation Factor,  $\phi_f$  for chert is in the range of 5 to 25 percent referring to Table 1, however for mudstone, the porosity value,  $\phi_f$  is slightly out of range.

**Table 2** Permeability Test and Porosity Test

Sample	Attenuation, $\alpha$ (Np/m)	Conductivity, $\sigma$ (mS/m)		Conditions	Permeability, $K$ ( $\text{m}^2$ )	Porosity, (%)	
		Resistivity	GPR			$\phi$	$\phi_f$
<b>Chert</b>	0 - 0.04	0.036 - 0.556	0.037 - 0.574	Original Dry	$1.95\text{E-}22$ $2.27\text{E-}22$	3	6.26 - 13.36
<b>Mudstone</b>	0.01 - 0.64	0.18 - 9.813	0.186 - 10.142	Original Dry	Not available Not available	Not available	14.12 - 36.02

## 5. Conclusions

This study area consists of chert and mudstone. The conductivity value obtains from GPR method was identified and compared with resistivity method, which is (0.037 – 0.574 mS/m) for chert and (0.186 – 10.142 mS/m) for mudstone. For permeability and porosity test,  $1.95\text{E-}22\text{ m}^2$  (original condition) and  $2.27\text{E-}22\text{ m}^2$  (dry condition) and 3 % respectively for chert sample only. Using Formation Factor, the porosity,  $\phi_f$  obtain for chert is (6.26 – 13.36 %) and (14.12 – 36.02 %) for mudstone. The research on the porosity of clay rock should be improved to obtain a successful result and well correlation. The study on outcrop expands the interpretation and show good correlation in the view of Geology, Geophysics, and Geotechnical method.

## 6. Acknowledgements

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