Evaluation of Semanggol Formation (Permian Facies) Using Electrical Resistivity Tomography and Seismic Refraction Tomography Parameter

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Abstract. Outcrop studies are a fascinating part of geology as it evidently shows the aftermath of how the earth forming processes billion years ago. Outcrops do not cover majority of the Earth’s land surface as it is covered by soils or vegetation thus cannot be seen clearly. In Kedah, Malaysia, there are many outcrops exposed in the state. The aim of this research studies was to correlate the parameters of geophysical survey with the properties of the Permian facies of Semanggol Formation in Kedah. The Permian facies consists of bedded chert and claystone. Two geophysical technique, electrical resistivity tomography (ERT) and seismic refraction tomography (SRT) were applied at the same line on top of the outcrop at Bukit Kukus beside Kulim – Baling (Kedah) road. The arrays used for ERT are Pole–dipole and Wenner–Schlumberger. The spacing between electrodes for ERT is 1.5 m while the geophone spacing for SRT is 2 m. Both ERT and SRT line is 60 m and 46 m respectively. Based on the results of both geophysical techniques, relating the porosity and permeability (poroperm) with geophysical parameters, it can be concluded that the bedded chert of low poroperm having seismic velocity and resistivity values at range of 1500 m/s – 2500 m/s and 1400 Ωm – 45000 Ωm. Whereas for claystone, it is very soft and laminated, concluding having high poroperm with seismic velocity between 600 m/s – 1200 m/s and resistivity values between 400 Ωm – 1000 Ωm.

1. Introduction
Outcrop can be defined as a visible exposure of bedrock or ancient superficial deposits on the surface of the earth. Due to frequent tectonic uplift or erosion processes, some locations of outcrops may be exposed such as on steep hillside, mountain ridges and riverbanks.

In Kedah, Malaysia, there are many outcrops and geological formations which having a certain number of rock strata that have a comparable lithology or other similar properties. The main focus of the outcrop studies is the Permian facies of Semanggol Formation located in Kedah. To understand the petrophysics of the Permian facies, thin section of the chert sample has been made by the petrography department at Mineralogy and Geosciences Department, Ipoh (JMG). From the thin section, the texture characteristics of the chert can be observed under the polarized microscope. Two types of geophysical survey are conducted on top of the outcrop; Electrical Resistivity Tomography (ERT) and
Seismic Refraction Tomography (SRT). In supporting the results of ERT and SRT, the petrophysics of chert specifically the porosity and permeability (poroperm) are analyzed. These methods are applied on top of the outcrops simultaneously. Both ERT and SRT gave parameters that can be related to the porosity and permeability of rocks.

2. Geological Setting of the Study Area
The study area is specified at the chert unit of Kulim – Baling area. In Kuala Ketil area as shown in Figure 1, isolated hills locally called Bukit Kukus has been excavated and exposed a part of the Semanggol Formation. The orientation of the section is almost north – south direction [1]. The northern part of the section is cut and leveled into one terrace contrarily to the southern part of the section which consists of two terraces. Generally, both sections exposed moderate to highly weathered mudstone, sandstone, tuffaceous sandstone, tuff, paraconglomerate, siliceous shale and chert that illustrate the chert unit of the Semanggol Formation [2].

There are four lithofacies recognized in the Permian part of the Semanggol Formation at Bukit Kukus. In an ascending sequence, these facies are laminated black mudstone, interbedded mudstone and sandstone, volcanogenic sediments and thinly bedded chert. The bedded chert is a pelagic facies which formed in the deep marine environment. [3].

![Kulim-Baling](image)

**Figure 1.** Google Earth map of the study area in Kuala Ketil.

3. Methodology
The layout of the survey line is conducted exactly on top of the 6.5 m height Permian facies outcrop of the Semanggol Formation as show in Figure 2. The electrode spacing for ERT is 1.5 m whereas for SRT, the geophone spacing is 2 m. Both ERT and SRT line is 60 m and 46 m respectively. For ERT, two arrays are applied on the field, Pole – dipole and Wenner – Schlumberger array. The Pole – dipole array has good horizontal coverage. Different from other common array, this array is an asymmetrical array thus over symmetrical subsurface structures the apparent resistivity anomalies in the pseudosection are asymmetrical. The Wenner – Schlumberger array is a combination form of the classical Schlumberger array and is averagely sensitive to both vertical and horizontal structures [4].
While for SRT, the shot points are between geophone 1 and 2, 6 and 7, 12 and 13, 18 and 19, 23 and 24. The offset is at -10 m and 30 m. Hammer is used as the source. The equipment used for ERT and SRT are ABEM Terrameter SAS4000 and ABEM Terraloc MK8 respectively.

After data acquisitions, ERT data is processed using Res2Dinv software while for SRT, it is processed using SeisOpt2D software. The tomography produced for both is then correlated with the outcrops. In correlating the geophysical tomography with the rock properties, rock sample is taken from the site for laboratory test. The rock sample of chert unit is send to the laboratory for porosity test measured by water immersion under vacuum. To get the intrinsic permeability, the rock sample is tested using nitrogen gas permeability test. From the result of porosity permeability, it is then correlated with the results of the geophysical tomography.

Figure 2. Permian facies outcrop of Semanggol Formation at Bukit Kukus.

4. Results and Discussion
Generally, the results of both ERT and SRT shows a good characterization of the outcrops. Since there are two types of facies presents at the study area: chert and claystone, therefore two distinct ranges of resistivity values and seismic velocities can be categorized. As shown in Figure 3, the Pole – dipole array clearly shows the similarity between the outcrops and the tomography result. There are two distinguishable low and high resistivity values. The resistivity values for claystone is between 400 Ωm to 1000 Ωm, whereas for chert, it has high resistivity values which is between 1400 Ωm to 45000 Ωm. The layout of the survey line is conducted exactly on top of the 6.5 m height chert unit outcrop of the Semanggol Formation as show in Figure 2.

Figure 3. Inversion model of 2-D resistivity of Pole-dipole array at Bukit Kukus.
Figure 4 shows the inversion model for Wenner – Schlumberger array with a result of shallower depth compared to pole – dipole array, the values of the resistivity is the same as Pole – dipole array. The claystone resistivity is between 400 Ωm to 1000 Ωm. The resistivity of chert is from 1400 Ωm to 45000 Ωm. Therefore, tomography results also show good correlation with the outcrop.

Figure 4. Inversion model of 2-D resistivity of Wenner-Schlumberger array at Bukit Kukus.

Based on the thin section of chert, the reason why the resistivity value is high is because of the radiolarian and sponge spicules is filled with quartz minerals as shown in Figure 5. Quartz minerals have high resistivity value from $4 \times 10^{10}$ Ωm up to $2 \times 10^{14}$ Ωm [5]. The thin section of claystone could not be made because of its soft characteristic. It is believed that there are many spaces between the laminated claystone that caused its soft properties thus lowering the resistivity value.

Figure 5. Thin section of chert.

Figure 6 shows an example of overlaying the inversion model of pole-dipole array on the outcrops to show that ERT results have good correlation to characterize the outcrop.
The tomography of seismic refraction survey shows a good correlation with the ERT results as shown in Figure 7. Seismic refraction results illustrate that chert has higher velocity values compared to the claystone due to its hard and brittle properties. The seismic velocity of claystone is between 600 m/s to 1200 m/s, whereby for chert the velocity is >1500 m/s. The in-filled radiolarian and sponge spicules with quartz has promotes the efficiency of sound waves to travel through the chert, compared to the laminated claystone having many air spaces between the layers.

To correlate the results of both ERT and SRT with the properties of rocks specifically in terms of porosity and permeability, two types of separated test is performed. Firstly, by conducting nitrogen permeability gas test to get the value of intrinsic permeability. Secondly, the porosity of rock samples is measured by water immersion under vacuum. In this study, only chert is tested due to its dense, formed by diagenetic concentration of silica within the purest biogenic calcareous – diatomaceous sediments that accumulated with only little dilution by terrigenous material [6] thus can be handle by the instruments. Claystone could not be done due to its soft properties thus consider having high porosity and permeability. The porosity result of the chert is 3% whereas permeability value is $1.98 \times 10^{-4}$ µd.

5. Conclusion
In this geophysical survey, both ERT and SRT gave good correlation with the outcrop physically. The characterization of the outcrop referring to the results of both geophysical tomography is nearly the same. This study contributes the application of geophysical method (ERT and SRT) in describing the
properties of rock specifically in terms of porosity and permeability. Table 1 summarise the Permian facies of Semanggol Formation (SF) with its geophysical parameters and rock properties.

Table 1. Table of Permian facies of SF with its geophysical parameters and rock properties.

| Permian Facies | \( \rho \) (\( \Omega \text{m} \)) | \( v \) (m/s) | Porosity (%) | Permeability (\( \mu \text{d} \)) |
|---------------|-----------------|-----------|-------------|-----------------|
| Claystone     | 400 – 1000      | 600 – 1200 | High        | High            |
| Chert         | 1400 – 45000    | >1500     | 3           | 1.98 x 10^{-4}  |

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