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Application of 2-D Resistivity Imaging and Seismic Refraction Method in Identifying the Structural Geological Contact of Sedimentary Lithologies

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Abstract. The interest of this study was to prove the existence of geological contact to field models with presences of outcrops as references. The physical relief of the outcrops can be determined by geological events of faulting, fracture, and folding. Geological contact plays important roles in environmental studies. 2-D resistivity imaging is the best method used for identifying the geological structures of study area located in Guar Jentik, Perlis and Bukit Kukus, Kedah. Besides that, seismic refraction method also applied at the study area. Results from both methods were integrated to get data correlation. There is good correlation produced which have successfully proved the existence of the faults and contact zones in study areas. Resistivity result shows that first study area has two main zones, red mudstone with resistivity value of 1 Ωm – 100 Ωm, sandstone with resistivity value of 2000 Ωm – 9000 Ωm, and Seismic refraction has provided the result on velocity of each zone, mudstone zone is 200 m/s - 1800 m/s and sandstone zone is >2000 m/s. The geological contact of fault is determined between the red mudstone zone and sandstone zone. In the second study area, the fracture was found within chert zone and contact zone is located between the chert zone and mudstone zone. In addition, the fold is found to form in the chert zone. Mudstone zone has resistivity value of 1 Ωm – 1500 m/s and chert zone has resistivity value of 2600 Ωm – 35000 Ωm. The first layer of the seismic section is consisting of mudstone with a velocity of <800 m/s and the velocity obtained for the second layer was generally >1200 m/s is interpreted as chert zones.

1. Introduction

Structural geology features are central to any study of past and present about the rock or sediment which has deformed relative to their original orientations or positions. The deformations may occur due to deformational conditions either stress and strain [1]. Fault and fold are very common structural features. Plate tectonic is the large-scale process that is the ultimate cause of the most deformation of the rocks and could lead to a mountain formation which can change the structure of the subsurface. As a conclusion, the type and direction of the plate tectonic of geologic structure could be determined by the observation of faulting, folding and layering present today. 2-D resistivity and seismic refraction

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are the best utilized to study subsurface characterization. 2-D resistivity methods were successfully used for detection in the shallow subsurface for maintaining the geo-environment and could get detail with deeper penetration for shallow subsurface study [2]. Geophysical exploration should not use as a stand-alone solution to problems. It will become a more effective component of site investigation if it was combined with another method such as seismic refraction. Near-surface seismic waves refraction can provide useful information about the near-surface for investigation of engineering and environmental purpose [3]. Besides that, this method will measure both depth and quality of hard rock regarding seismic velocity which could give more information about each of layer existence inside the subsurface. Thus, 2-D resistivity imaging and seismic refraction surveying were carried out to relocate the structural geology features such as fault and fold. This study was about the application of both methods to field models at selected area in Peninsular Malaysia with sedimentary outcrops.

1.1. 2-D Resistivity Imaging
Electrical resistivity is a bulk property of a material to inhibit the flow of electrical injection current. The current between a pair of surface electrodes (A and B) was inserted into the ground, and next pair of an electrode (M and N) used to measure the resulting potential on other electrodes by using current (I). The potential value was measured in unit voltage (V). An equation was produced from this relationship as in equation 1.

$$\rho \mathrm{a} = \mathrm{k}\frac{v}{I} \tag{1}$$

Thus, resistivity was interpreted as the ability of rock, soil or ground water to resist the flow of an electrical current. The increase in electrode spacing will cause the penetration deeper. Resistivity contrast could occur in the subsurface between different layers such as dry and water-bearing sediments or different lithology and different weathering layers. Electrical resistivity used to map subsurface variability in electrical properties caused by the change in lithology, structure, alteration, and contamination due to human activities. The electrical imaging system is being carried out by using multi-electrode resistivity meter system. The resistivity meter used was an ABEM SAS4000 with a pole-dipole array, and the instrument uses an automatic data longer which had allowed the data to be recorded as the survey progresses for later downloading to a computer for processing and presentation.

1.2. Seismic refraction method.
The seismic wave will travel across the boundaries by reflected their energy to the surface when there are two different rock types, and the remainder continues on its way at a different angle or being refracted [4]. Seismic refraction is the best tools in the study of earth structure to identify the characteristic and lithology. This method is depending on the ray path produce from discontinuities of wave velocity. Elastic moduli and densities of rock are considered to determine the seismic wave velocity.

2. General Geology
Perlis and Kedah were occupied with sedimentary lithology which was bounded in the Western Belt of Peninsular Malaysia.

2.1. Guar Jentik, Perlis
Hill B is an outcrop section that cut in a south-north direction. The stratigraphic of Hill B is well exposed where it does show transitional sequence from carbonate to clastic deposition [5]. There are two types
of formation in this area which is known as Jentik Formation and Kubang Pasu Formation. Hill B is divided into three informal units including unit 4 which is well bedded of dark limestone, unit 5 with the present of black mudstone interbedded with chert with slump structures, and unit 6 is proposed to

have thick beds of brownish-red mudstone interbedded with sandstone. From the excavation in this area, several types of marine fossil have been found to prove the existences of deep marine [6]. The electrical techniques used in this study area are 2-D Resistivity to study the structure of fault in the sedimentary outcrop and result obtained is supervised with Seismic Refraction method.

2.2. Bukit Kukus, Kedah
This small hill is proposed to have stratigraphic of chert unit which comprised black laminated mudstone, interbedded sandstone, mudstone, interbedded tuffaceous sandstone, tuff with a paraconglomerate bed, interbedded tuffaceous sandstone, siliceous shale, chert, bedded cert, tuffaceous mudstone and interbedded chert and siliceous mudstone [7]. Chert found at the site is observed and had been proposed to contain radiolarians which strongly indicated of late Early Permian to Middle Triassic of age by [8]. Bukit Kukus is mapped in Semanggol formation in Kuala Ketil Kedah and has being divided into the Siliceous and clastic rock into three members of the unit.

3. Study Area
The study was carried out at two different locations with the features of fracture, contact, and fold which is mainly focused on shallow subsurface investigations. The study area is located at Hill B, Guar Jentik in Perlis and Bukit Kukus in Kedah. Both study area is located in Peninsular Malaysia.

3.1. Guar Jentik, Perlis
The hilly ridge of the study area chooses is known as Hill B are located in the vicinity of Guar Sanai, Kampung Guar Jentik, Beseri District in Northwest Perlis, Malaysia such as shown in figure 1.

3.2. Bukit Kukus, Kedah
Bukit Kukus located in the small town of Kuala Ketil, Kedah is mainly exposed to sedimentary rocks from Semanggol Formation. 2-D Resistivity method and Seismic Refraction is adopted to map and characterize the structure of fault in this shallow subsurface of sedimentary outcrop such as shown in figure 2.

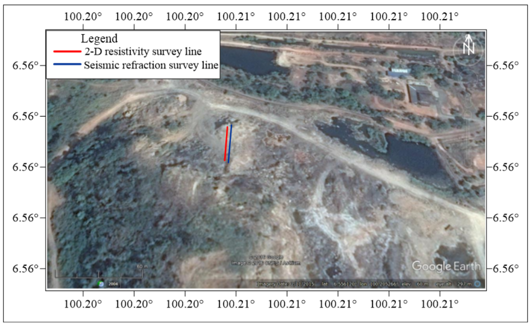

Figure 1. 2-D resistivity imaging and seismic refraction survey line at Guar Jentik, Perlis.

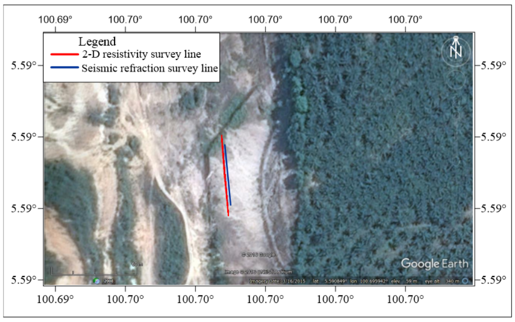

Figure 2. 2-D resistivity imaging and seismic refraction survey line at Kuala Ketil, Kedah.

4. Methodology
The 2-D resistivity imaging used the pole-dipole array with different electrode spacing on each area depends on accessibility on site. The space between electrodes is 1 m at Guar Jentik, Perlis and 1.5 m at Bukit Kukus, Perlis. Hence, the total length of the survey line at Guar Jentik was about 40 m and the total length of survey line at Bukit Kukus was about 60 m. This survey was conducted using ABEM SAS4000 Terrameter with smart cables and resistivity data was modeled using the Res2Dinv software. While for Seismic refraction method, the seismic wave produced by sledgehammer refracted from

different reflector boundary and detected by geophones (receiver). The total distance of survey line for seismic refraction is 46 m for both locations with geophone spacing of 2 m.

5. Result and discussion

The result from 2-D resistivity method is supervised by using the result from seismic refraction method. Resistivity pseudosection is produced from inverted data processing has displayed the resistivity data of earth materials. While seismic cross-sections can provide the earth profile used to interpret depth and dip direction of geological contact in each layer of the subsurface.

5.1. Guar Jentik, Perlis

Figure 3 shows the contouring model resistivity at Hill B which had successfully classified the structural geology of contact zone and the type of soils. The study area was divided into two main zones, red mudstone with resistivity value of 1 – 100 Ωm and sandstone with resistivity value of 2000 Ωm – 9000 Ωm. Figure 4 shows the countering model from the seismic refraction survey. Even though the depth of penetration does not enough as compared to resistivity model, the result from seismic refraction is able to characterize the geological structure at the study area and match with the resistivity survey.

Figure 5 shows the result of resistivity survey. There is contact between sandstone and red mudstone. The contrast value of the resistivity contouring was suggested to be the present of the contact zone between sandstone and red mudstone. The result from inversion model was chosen to overlap with the outcrop to supervise this study. There is high contrast at distance of 23 m which indicated the location of contact zone at Hill B. Figure 6 shows the results of the seismic cross sections of the Hill B which consists of two layers.

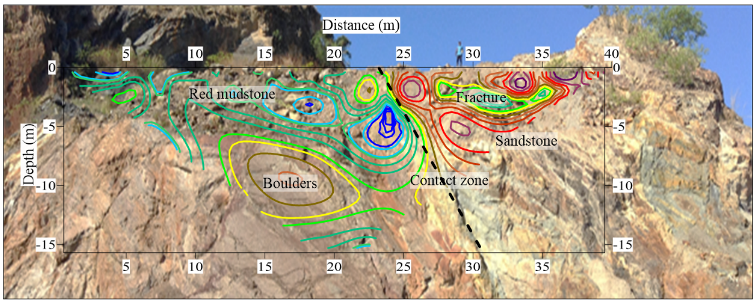

Figure 3. Contouring model of resistivity at Hill B, Perlis.

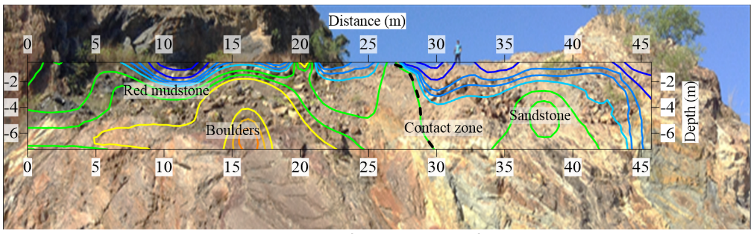

Figure 4. Contouring model of seismic refraction at Hill B, Perlis.

The distance scale of digitized value on these graphs are relative to the resistivity line respectively. Based on seismic refraction profile in figure 6, the seismic velocity of the mudstone zone is 200 m/s to 1800 m/s and the velocity of the sandstone zone is more than 2000 m/s. The result shows the first and second zone was abrupt by the velocity change as an outlined which was suggested the location of geological contact that presents between sandstone zone and red mudstone zone.

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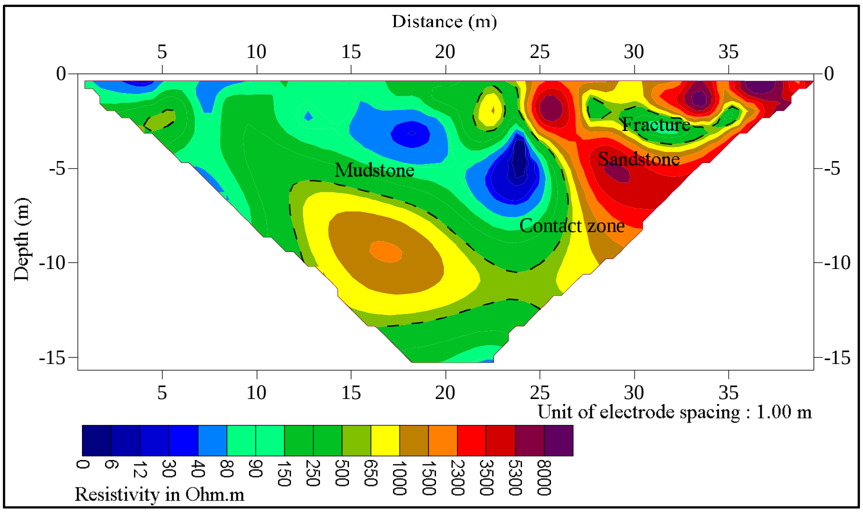

Figure 5. Inversion model resistivity at Hill B, Perlis

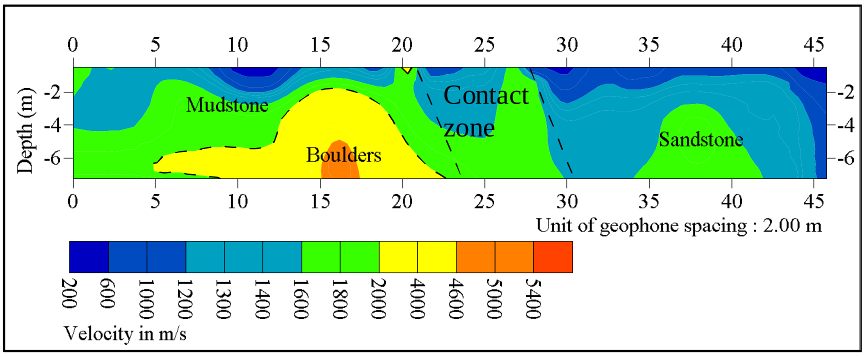

Figure 6. Seismic section at Hill B, Perlis

5.2. Bukit Kukus, Kedah

Figure 7-8 shows the contouring model resistivity and seismic refraction at Bukit Kukus. Based on figure 9, the resistivity results generally show the study area divided into two main zones, mudstone with resistivity value of 1 – 1500 Ωm and chert zone with resistivity value of 2600 – 35000 Ωm.

The contrast between low and high resistivity value indicates fault zone. Another contrast value shows the contact zone between mudstone and chert. Chert has higher resistivity due to its chemical properties which are rich in silica. This rock is mainly composed of microcrystalline silicon oxide (SiO_2).

The physical properties of chert are very hard and compact. Hence, electrical current could not easily penetrate within the rock and cause the resistivity be higher. Fold zone cause the resistivity value become too high because of folding of the rock has makes the rock to be more compact and electric current is flowing without having any impediment.

Resistivity result was strongly supported by the seismic cross section as shown in figure 10 conducted on the same line. The result shows the study area generally consisted of two main layers. The first layer is predominantly consisting of mudstone with a velocity of <800 m/s while the second layer with a velocity of >1200 m/s is interpreted as chert zones. The dashed lines indicate the fracture/fault and contact zone at the study area.

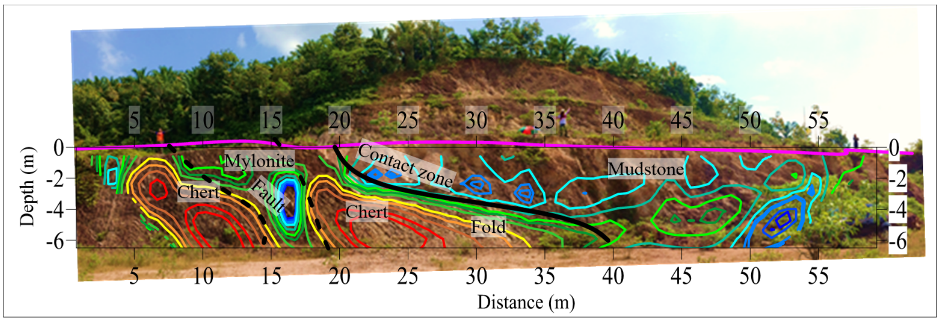

Figure 7. Contouring model of resistivity at Bukit Kukus, Kedah.

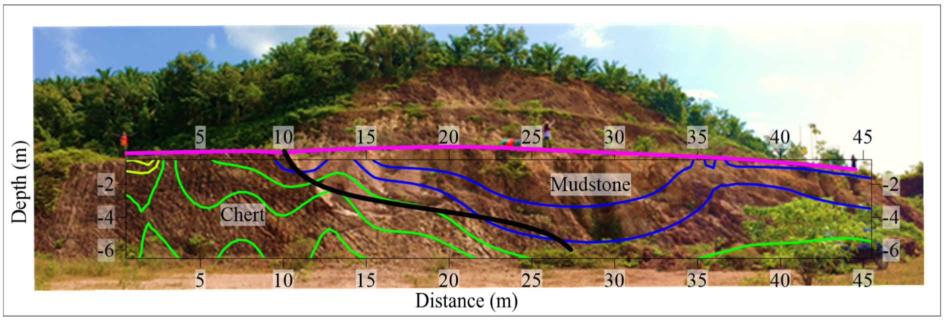

Figure 8. Contouring model of seismic refraction at Bukit Kukus, Kedah.

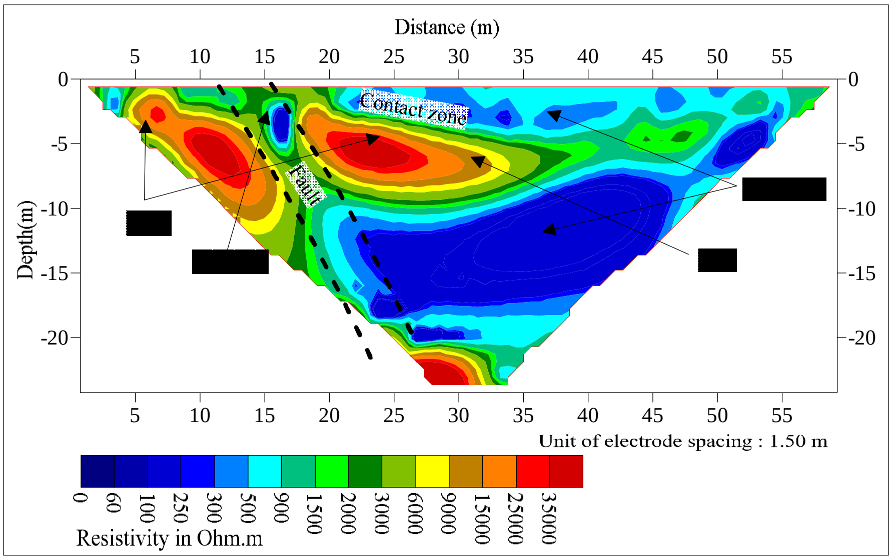

Figure 9. Inversion model resistivity at Bukit Kukus, Kedah.

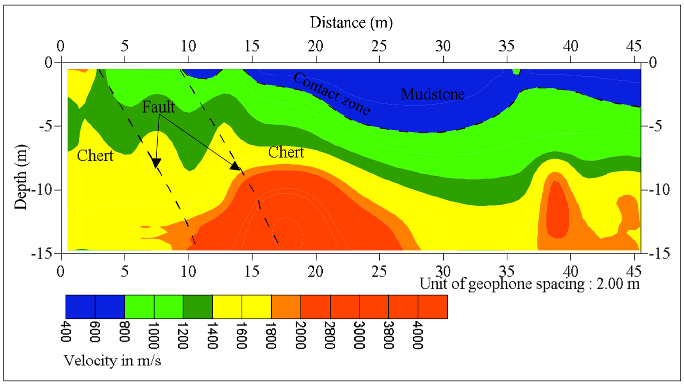

Figure 10. The seismic cross section at Bukit Kukus, Kedah.

6. Conclusion

In conclusion, the 2-D resistivity imaging and seismic refraction method have successfully proved the interpretation of shallow subsurface structural geology characterization of the study area in sedimentary lithology. The contrast between low and high resistivity value indicates the location of contact zone and fracture zone. The result obtains from both method in all study area might be different in their depth of penetration due to the different spacing number used for each survey line. The smaller the spacing, only small depth of penetration was obtaining but the better the resolution. Some of the survey lines have a different spacing was due to the limitation access at the study area which is making hard to plant the electrode/geophone. Both methods are good in identifying the geological structures of the subsurface.

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