FRACTURED GROUNDWATER INVESTIGATION

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Abstract

Integrated geoelectrical resistivity and seismic refraction survey have been used to investigate groundwater accumulation in the fractured zone of the granite bedrock. Three seismic refraction and twenty geoelectrical resistivity surveys with Wenner configuration were conducted on the relatively flat area. Lineament interpretation has been done prior to geoelectrical resistivity survey. The resistivity profiles show that the sediment thickness vary from 5 m to about 40 m with resistivity value of less than 200 ohm.m. The same indication of un-compacted material thickness is also shown by relatively low seismic velocity of less than 1800 m/s. In the several sites, fractured zone indication where the possibility of accumulated groundwater is well observed.

Keywords: Geolectrical resistivity, Seismic refraction, Fractured, Groundwater

Introduction

Groundwater is most important of natural resources. The searching of groundwater reserve is more difficult when the sediment is relatively thin due to the bedrock is not enable to contain water. However, some impermeable bedrock undergo to the permeable due to occurance of the fracture in their body. The fractured bedrock is one of important groundwater resources in the area where the bedrock occur at the shallow depth and cause the unconsolidated sediment just occupied at the relatively thin.

Geoelectrical resistivity methods have been used widely to investigate the near subsurface. One of pamous application is to study the groundwater system. The ability of this method to distinguish the different resistivity zone, is the key in the subsurface investigation. Islami et al. 2012 used geoelectrical resistivity to investigate groundwater system in the shallow aquifer. Seismic refraction is very useful in interpretation of geoelectrical resistivity profiling. Seismic refraction survey will support the geoelectrical resistivity as it ability to distinguish compacted and uncompacted material.

Generally, the investigation is to identify and delineate the subsoil for possibility of groundwater and fracture prospect. The combination of two methods, geoelectrical resistivity and seismic refraction is very useful in helping to identify and to search the suitable prospect well for unfracturedss and fractured groundwater. The location of this survey is given in Figure 1. The survey was conducted on October 2012, with the total of 20 survey lines for geoelectrical resistivity and 3 survey lines for seismic refraction.

Figure 1. The investigation area

Methodology

A. 2-D Geolectrical Resistivity Imaging Method

2D geoelectrical resistivity imaging surveys were performed using the ABEM Terrameter SAS4000 resistivity meter which carried out with a multi-electrode resistivity meter system (Figure 2). The Wenner arrays were employed due to among the other configurations, the Wenner array shows a good signal-noise ratio. The signal strength is inversely proportional to the geometric factor used to calculate the apparent resistivity value for the configuration. The Wenner geometric factor is smaller than the geometric factor of other configurations (Telford et al., 1990).

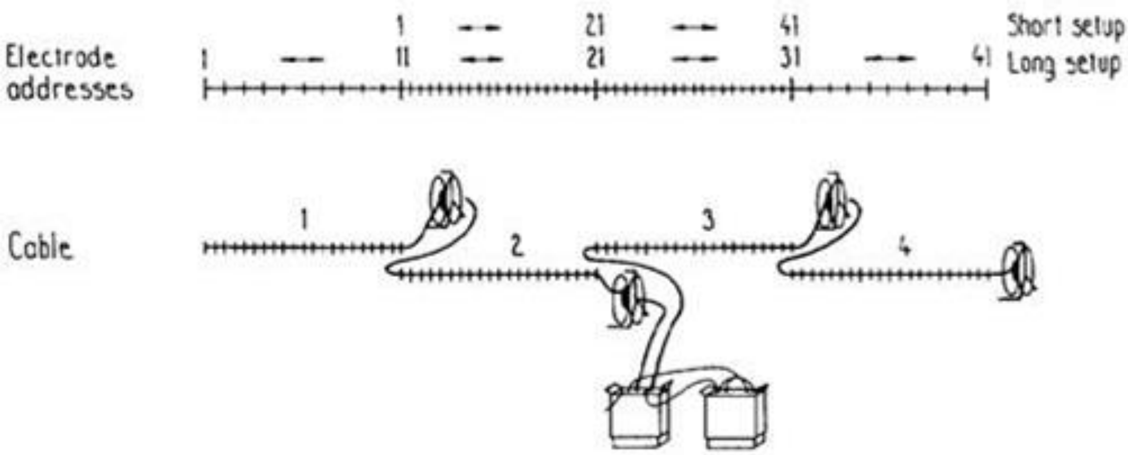


Figure 2. Sketch system layout using four electrode cables with 5 meter intervals (400 m total length) (Abem, 2007)

The geoelectrical resistivity method basically measures the resistivity distribution of the subsurface materials. The resistivity value of some of the earth materials and water is given in Table 1. Igneous and metamorphic rocks typically have high resistivity values due to the electrical current relatively difficult to flow within this material. The resistivity of these rocks is mainly dependent on the degree of fracturing. In the subsurface, the fractures of igneous and metamorphic rock are commonly filled with ground water due to the water table in Malaysia is generally shallow. The greater the fracturing, the lower is the resistivity value of the rock. As an example, the resistivity of granite varies from 2000 ohm-m in wet condition to 10,000 ohm-m when it is dry. When these rocks are saturated with ground water, the resistivity values are decreased to a around hundred ohm -m. Soils above the water table is drier and has a higher resistivity value of several hundred to several thousand ohm-m, while soils below the water table generally have resistivity values of around 200 ohm-m and less.

Table 1. Resistivity of some common rocks and soil (Keller and Frischknecht 1996)

Material	Resistivity (ohm-m)
Alluvium	10 to 800
Sand	60 to1000
Clay	1 to 100
Groundwater (fresh)	10 to 100
Sandstone	$8 - 4 \times 10^3$
Shale	$20 - 2 \times 10^3$
Limestone	$50 - 4 \times 10^3$
Granite	5000 to 1,000,000

Due to the area is bounded by the sea at the south part, the groundwater is vulnerable contaminated by seawater. Table 2 shows resistivity value for different medium saturated with different seawater content. Increasing seawater content causes the resistivity value decreases drastically. The total anion content of water in the soil pores has a significant effect on resistivity. It is quite remarkable that the resistivity appears to be extremely sensitive to small changes in the total anions. The environment of the soil and the percentage of clay content in the soil also influence the resistivity value. The area of investigation is mainly in the palm oil plantation area which the chemical fertilizer is used for plantation. Islami, et al., (2012b) reported that in the area such as in palm oil plantation, shallow groundwater tends to be contaminated by nitrate and chloride. These conditions will also effecting in decreasing the medium resistivity.

Table 2. Resistivity of some sediment with different depositional environment saturated by different seawater content (Islami, 2012a)

Seawater (%)	Marin (ohm.m)	Sand bar (ohm.m)	Flooded Zone (ohm.m)
0	12 to 15	40 to 45	100 to 180
5	4 to 7	9 to 11	21 to 23
10	3 to 5	5 to 7	10 to 13
25	~ 3	~ 5	~ 9
50	~ 1	~ 2	~ 4
100	~ 0.2	~ 0.7	~ 1.5

B. Seismic Refraction Method

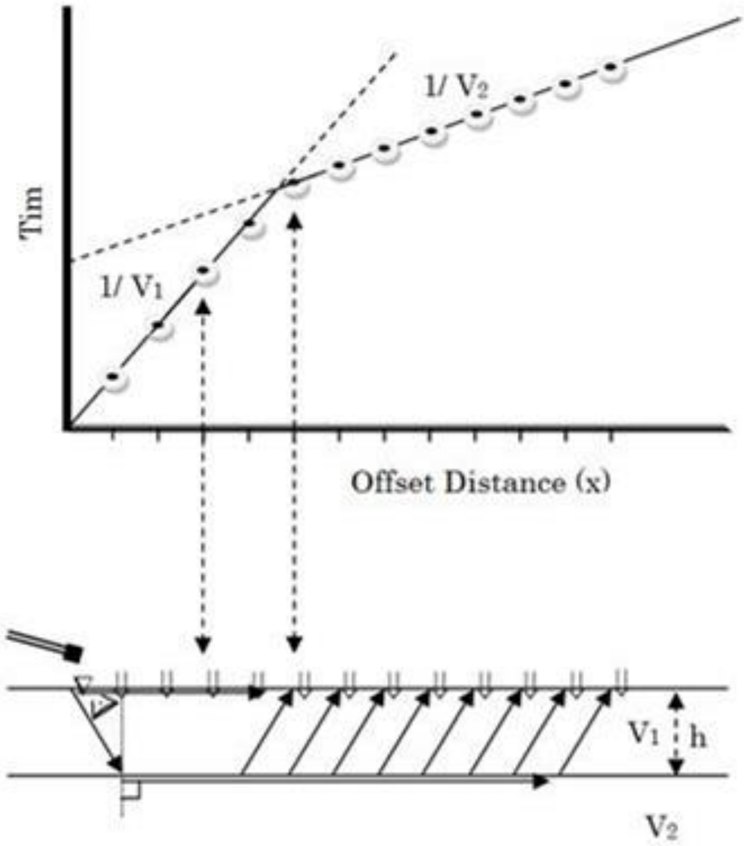
Seismic refraction method is basically to measure the medium velocity in the subsurface. Table 3 shows the velocity of earth material. Besides the type of the material, bulk density of material is the main factor that affecting P and S wave velocity. For example, velocity of the soil filled by air will be less than when it is filled by water. This is due to bulk density of soil filled by water more than filled by air. Another example, velocity of weathered granite will be less than velocity of fresh granite. In this investigation, ABEM Terraloc MK8 was used to perform seismic refraction survey with 24 geophones. Each geophone is spread with maximum of 7 m long, that means the total survey length is 168 m. Hammer was used as a source for P wave seismic energy.

Table 3. Velocity of the material (Robinson, 1988).

Material	P wave (m/s)	S wave (m/s)
Air	332	~0
Water	1500	~0
Petroleum	1300	~0
Steel	6100	3500
Granite	5500-5900	2800-3000
Basalt	6400	3200
Sandstone	1400-4300	700-2800
Limestone	5900-6100	2800-3000

The simplify concept of seismic refraction method is given in Figure 4. In seismic refraction surveys, only the first pulse on each trace is used in the analysis. This pulse is called the first arrival, because it indicates the first of several waves that reach the receiver. The time of first arrival is needed to plot versus offset of the geophone. This data plot (time versus distance) allow to calculate wave velocity and subsequently to obtain the thickness of the layer of the subsurface.

Observe Figure.4, that a straight line can be drawn through these points that also passes through the origin of the graph. This fact indicates that the first arrivals to reach these receivers must be the direct waves that have travelled straight along the surface from the source. The straight alignment shows that the additional time required for the wave to travel to a farther receiver is directly proportional to the additional distance to the receiver.



Fgure. 4. Direct and critically refracted raypaths and the time-distance diagram showing the first and the secondary breaks from the raypaths (after Robinson, 1988)

C. Lineament interpretation

The geophysical survey was done based on interpreted lineament derived from DEM map. The interpreted lineament map is given in Figure 5. The lineament interpretation is inportand prior to the survey data in the field. This is due to the possibility of crack or fracture can occur along the lineament. In the Figure 5, the lineament is observed from the northern part to the seaward. In the study area, minor lineament is mainly observed and distributed in the whole study area. Generally, lineament orientation is Northwest to the Southeast. Based on the lineament direction, the survey in the field is expected perpendicular along to the lineament. However, some limitation has been found in the field due to lacking of space for the survey.

Figure 5. Map of interpreted lineament using DEM data.

D. The survey

There is a total of 19 geoelectrical resistivity survey lines initially were carried out within the area and 1 survey at the outside (Figure 6). The length of each survey line is 400 meters except at P8, P15, P19 and P20 where the space was not avelaible. For the seismic refraction, three survey lines were conducted at P3, P5 and P6.

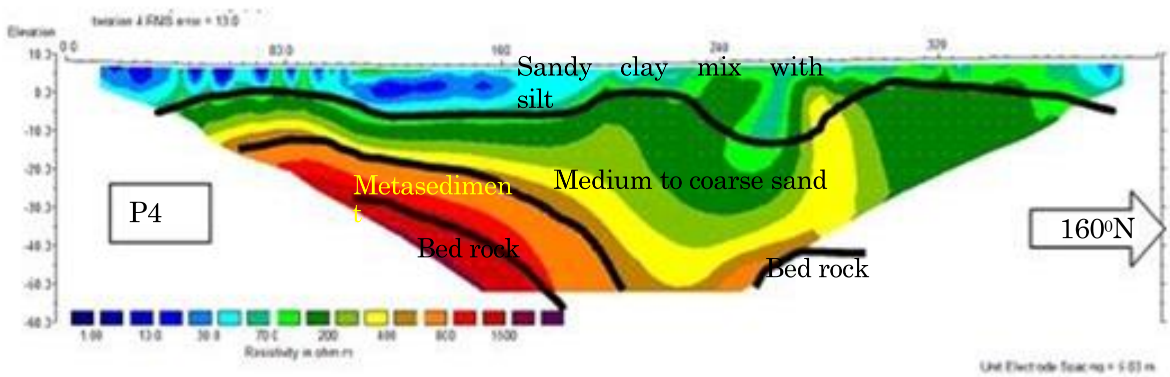
Figure 6: Survey lines within the area captured by Google.

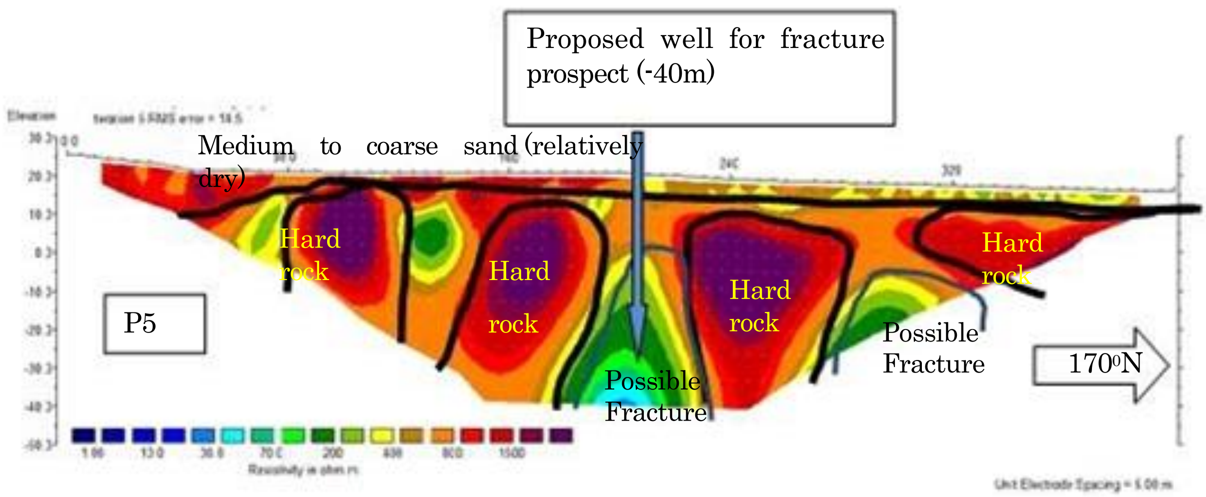
Result

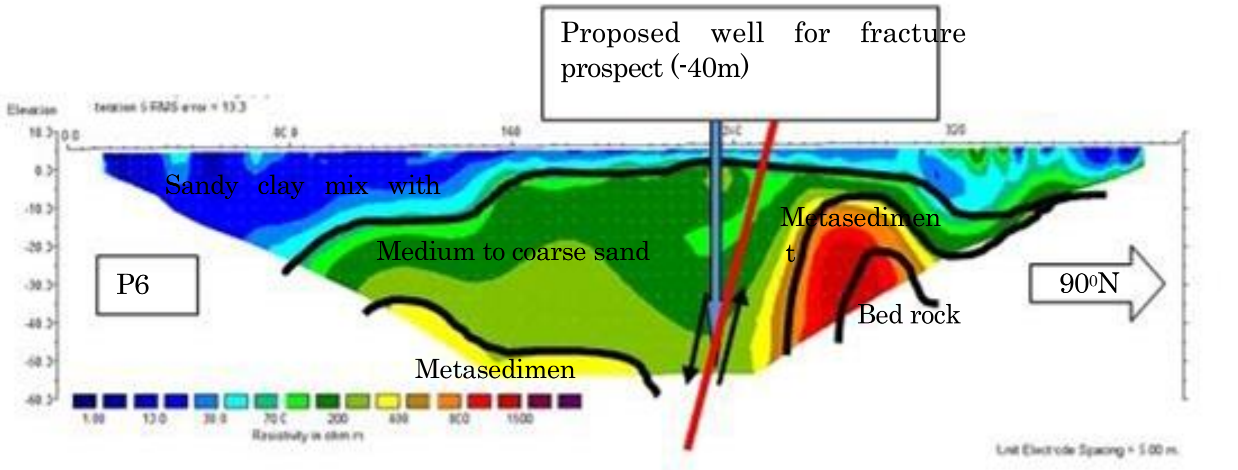
A. Geoelectrical Resistivity Result.

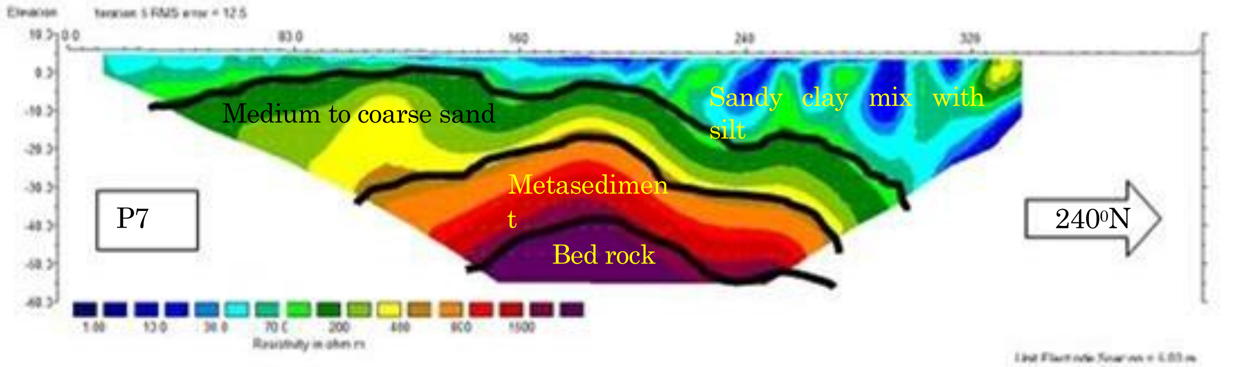
The selected geoelectrical resistivity models are given in Figure 7. The result shows that resistivity profiles consist of three major zones. The first zone is the resistivity value with less than 80 Ωm which is correlating to sandy clay mix with silt. The second zone is resistivity with value around 100-300 Ωm that corresponds from medium to coarse sand. The third zone is resistivity value of more than 700 Ωm corresponding to the bedrock (metasediment and granite). In the several lines, the possibility of bedrock fracture is observed at the depth of more than -20 m. These zones are possible for fracture groundwater prospect.

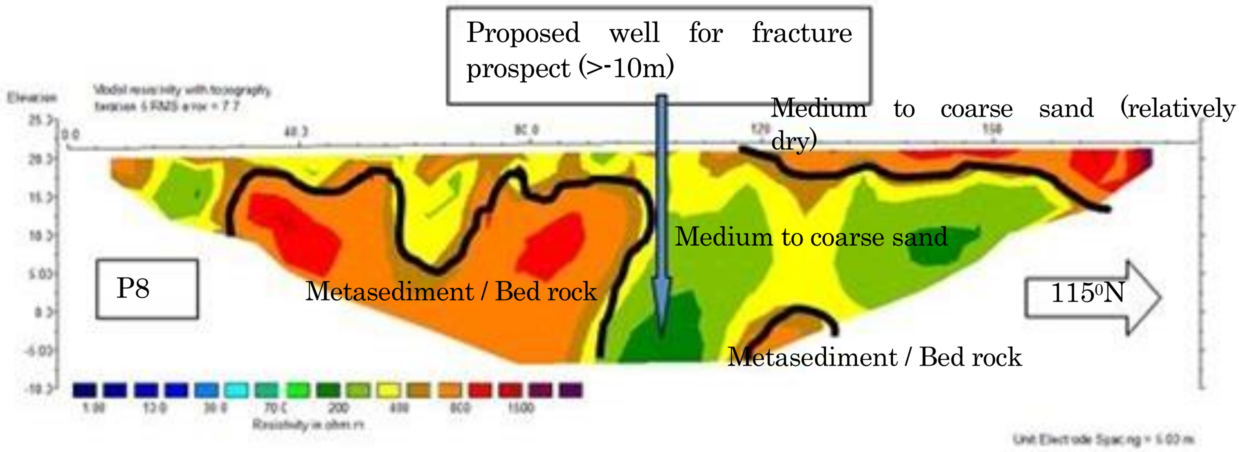
Generally, fracture can be found in the middle of phase I to the northeastern. Meanwhile in the west, there is no fracture can be found. However, the basement depth is relatively deeper in the west (> 40 m depth). As a recommendation, location and depth of propose well are given in the resistivity model.






Proposed well for fracture prospect (-40m)
Sandy clay mix with
Medium to coarse sand
Metasedimen t
Bed rock
Metasedimen
P6
90ºN
Resistivity in ohm.m


Medium to coarse sand
Sandy clay mix with silt
Metasedimen t
Bed rock
P7
240ºN
Resistivity in ohm.m


Proposed well for fracture prospect (>-10m)
Medium to coarse sand (relatively dry)
Medium to coarse sand
Metasediment / Bed rock
Metasediment / Bed rock
P8
115ºN
Resistivity in ohm.m

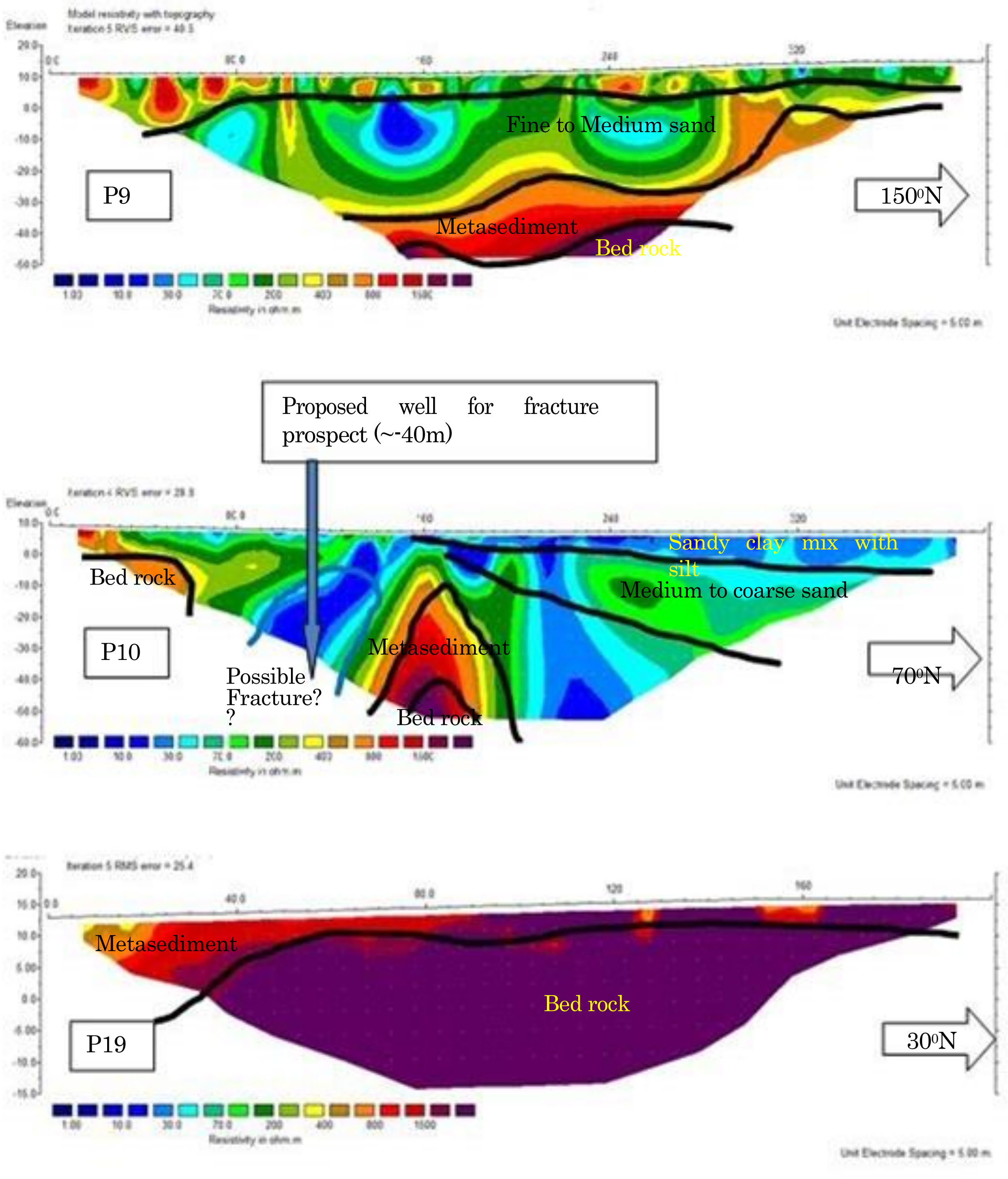


Figure 7. 2D geoelectrical resistivity model

B. Seismic Refraction Result.

Seismic refraction measures medium velocity in the subsurface. In this investigation, seismic refraction survey just detects two or three difference layers (Figure 8 and 9). This is due to: a) in the west and north part, the low velocity zone (peat and soft clay fully saturated) is relatively thicker. This condition causes the seismic energy cannot travel away from the source. The energy has been absorbed by low velocity medium. b) The contrast velocity just caused by basement which the first arrival of travel time from refracted seismic has been covered by direct wave from near surface.

Survey at the P5

The first layer: Velocity = 900-1400 m/s corresponding to the unconsolidated soil (sandy clay filled by air and water). The second layer: Velocity 2777 m/s corresponding to the weathered bedrock filled by water.

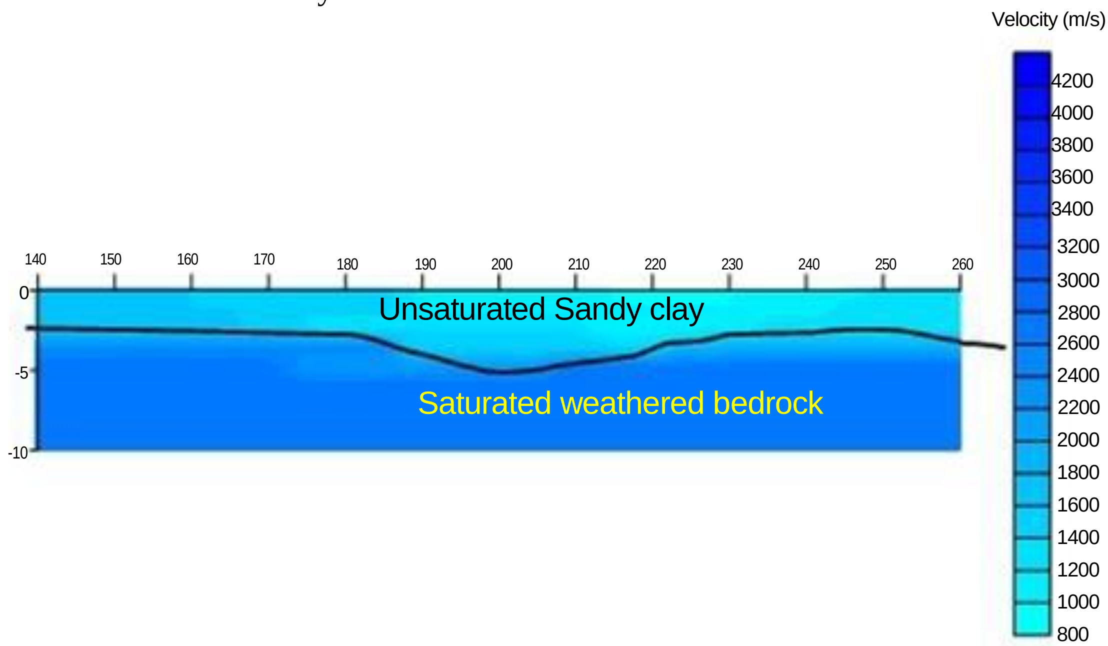


Figure 8. Subsurface velocity for L5

Survey at the P3

The first layer: Velocity = 800-1800 m/s corresponding to the unconsolidated soil (sandy clay filled by air and water). The second layer: Velocity 2000-2200 m/s corresponding to the saturated sandy clay.

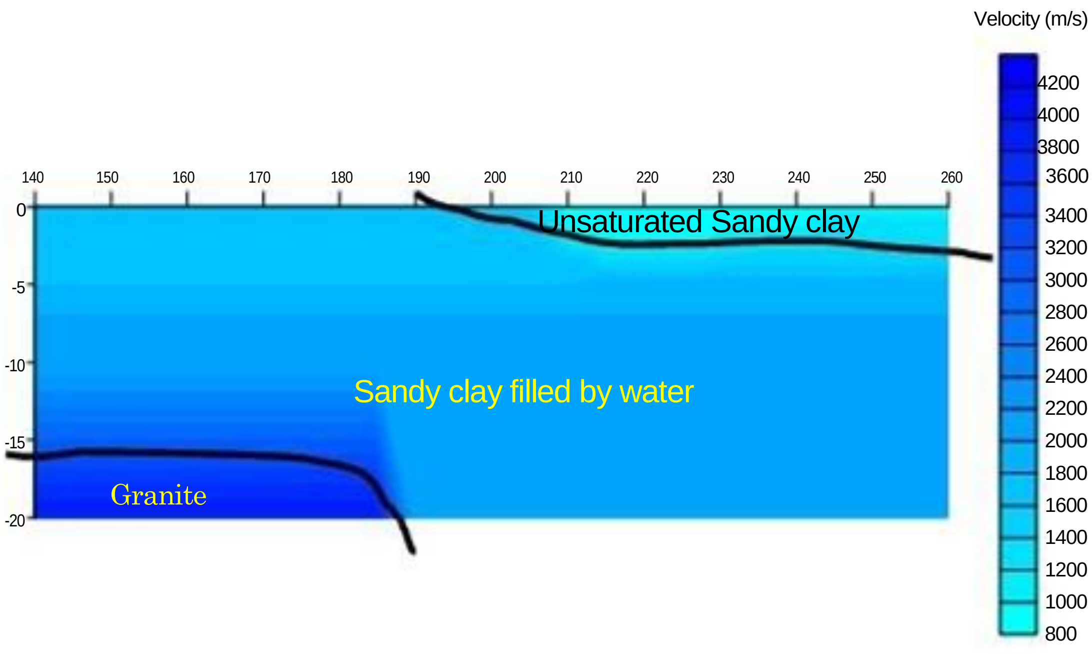
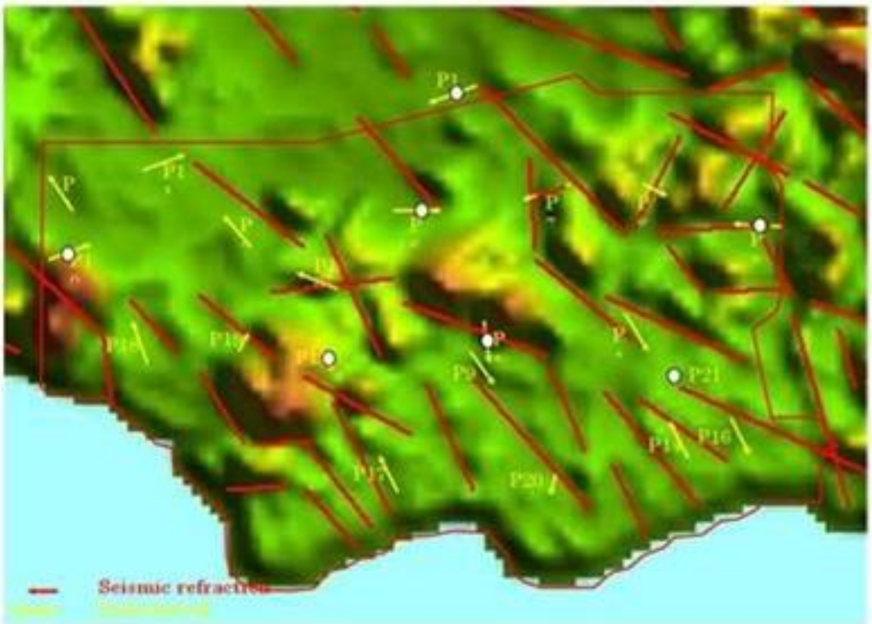


Figure 8. Subsurface velocity for L3

C. Recommendation for well location

Figure 9. shows the recommendation well for the fractured and un-fractured groundwater.



P5, P6, P10, P13, P15 = prospect for fractured groundwater (~ -50 m depth)
P3 = prospect for deeper fractured groundwater (> -50 m depth)

Figure 9. Recommendation for well location.

Conclusion

Geoelectrical resistivity has been successfully to locate the fracture zone of the granite bedrock. The un-compacted material is indicated by relatively lower resistivity value. This is also supported by seismic refraction survey which this zone has relatively low velocity. In several site, fractured zone is clearly imaged in the resistivity profiling. Finally, the possibility to locate well for groundwater resources from fractured zone can be predicted.

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