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Shallow subsurface modelling of Sungkai using ERT and potential fields methods

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ABSTRACT

Development of hot spring sites in Malaysia has been targeted by authorities to enhance its touristic and recreational assets. Previous experiences showed that some hot springs were damaged, and the flow of water had stopped, or the water temperature had decreased. To solve this problem, the knowledge of the subsurface structural model may be needed. The modelling should be carried out using non-invasive methods according to the present land-use conditions. Hence, the geophysical methods are adopted as they have two advantages; first, they are non-invasive; second, they are cost effective. The present work was conducted to aide in both modelling the subsurface structures and guiding the development plans of the recreation complex. Besides, the study focusses on the shallow part of the geothermal system that pave the way for more deeper study to weigh the potential of establishing a geothermal power plant near the site. Geophysical methods used in this study are the 2D ERT and potential fields (magnetic and gravity). Pseudo 3-D ERT block was created from the 2-D profiles to compare with the of the potential fields. The final model of the area deduced that the area is affected by a shear zone. The present-day hot spring is located near the boundary of the shear zones. The model also shows that there are several sites in the complex with stable subsurface that can be used for development without affecting the hot spring system.

1. Introduction

Southeast Asia is characterized by numerous hot springs that are used for power generation and recreational

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activity. Wagner et al. [1] pointed out that almost seventy hot springs were identified in Peninsular Malaysia region. All the hot springs there are being used for medical and recreational purposes. As the number of visitors to these recreation complexes increase, the plan for extensions increased too. Some previous experiences delineated that unsupervised development may lead to damages to the hot spring. It is likely due to affecting the near surface structures that controls the hot water flow through the hot spring. Henceforth, authorities are looking for supervised development through the modelling of near surface structures.

The near surface structures may be modelled by several techniques. However, the suitable ones should be non-invasive and cost effective. As a result, the geophysical methods came under the focus as a suitable candidate as pointed out by several studies (e.g. [2-9]). Several geophysical techniques may possess a suitable candidate to tackle the problem. For the present study, two techniques were adopted; namely, ERT (Electrical Resistivity Tomography) and the potential field methods (gravity and magnetic).

Potential field methods are sometimes defined as the structural methods. This is because these techniques are sensitive to the lateral change in either density or magnetic susceptibility. The methods can hence define structures such as faults and folds that tends to bring rock volumes of different physical properties laterally together. ERT, on the other hand, is an imaging technique that map the subsurface bodies based on the electrical resistivity. Rock resistivity is generally high. However, when the rock or mass is either saturated or partially saturated with water, the resistivity is decreasing significantly. Hence, ERT is not only sensitive to change in lithology but also water saturation as well. This is adding value that can define where the groundwater is located.

2. Study area and Geologic setting

The present investigations were conducted at the FELDA residence complex that is located at Sungkai, Perak (Figure 1). The site is used for recreation based on the presence of hot water from hot spring there. The total area of the residence is 0.22 km^2 with relatively flat topography. Not far from the complex the Sungkai river is flowing in an NE-SW direction. The water of the Sungkai river is used in the facility to cool down the hot water for recreational purposes The flow of the Sungkai river follow a fault that cuts through the granitic batholith.

The hot spring at Sungkai belongs to the N-S trending hot springs. It is actually in the heart of this trend with reported high surface temperature. About 20 km to the south, the highest surface temperature hot spring of Kampung Ulu slim is located. Both hot springs of Sungkai and Kampung Ulu Slim have hot water close to the boiling temperature that are sometimes used for boiling eggs for visitors.

Geology of Peninsular Malaysia has been studied by several researchers (e.g. [10-16]). The location of the hot spring under consideration is located close to the granitic ridge that trend NNW-SSE (Figure 2 and 3). Baioumy et al., [17] pointed out that most hot springs in this zone is located at low altitude sites. The surface rock units for sites close to the granitic batholith are many Phyllite metamorphic rocks. In addition, Sum et al. [18] pointed out that hot springs are located along a fault zones that runs in the NNW-SSE trend parallel to the main tectonic of the Malay Peninsula. The site at Sungkai is characterized by a rather flat surface with elevation at about 65 m above the sea level. Towards the northern part of Felda residence, the ground elevated gradually to reach about 90m.

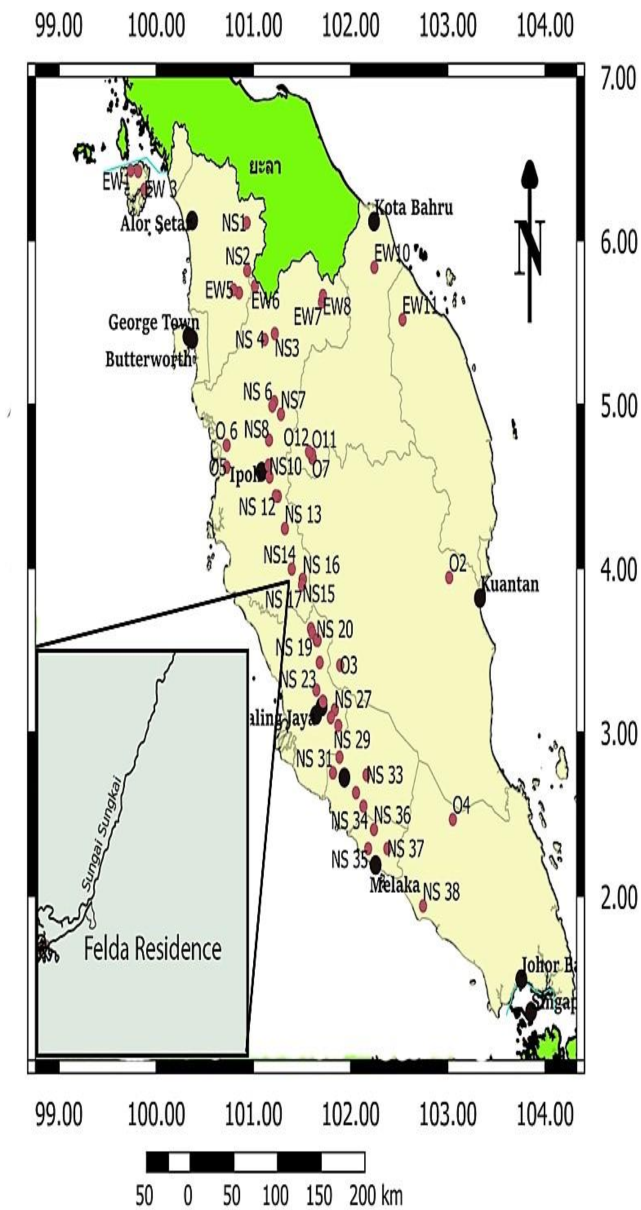

Figure 1. Location Map of the study area at FELDA residence, Sungkai, Perak. The map also shows the hot springs in Peninsula Malaysia (modified after [1]).

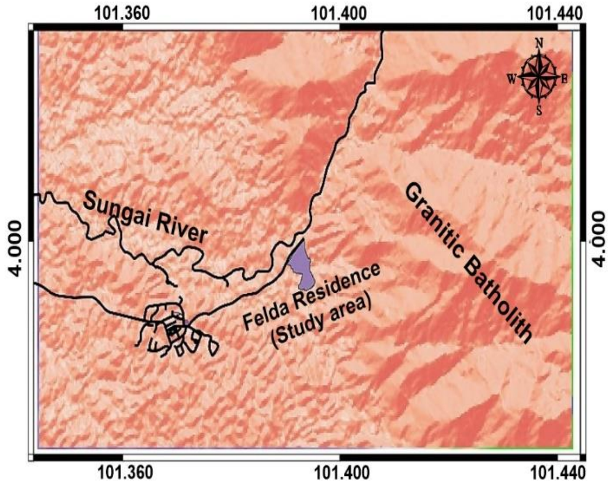

Figure 2. Topographic map of the study area.

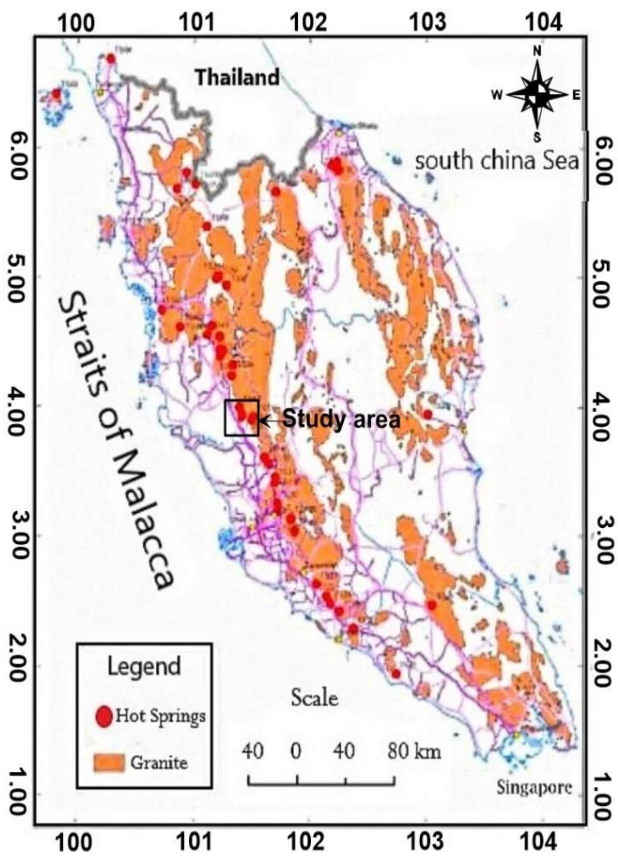

Figure 3. Geologic setting of Peninsular Malaysia with the geographic locations of hot springs that are located at or near the granitic batholith.

2. Materials and Methods

Three geophysical methods are used in the present work to study the near surface structure at Sungkai, Perak. The methods adopted are the Electrical Resistivity Tomography (ERT), Gravity and land magnetic. The methods are used in an integrated strategy so that they validate each other.

2.1 Electrical Resistivity Tomography

ERT method belongs to the electrical method that is generally sensitive to the overall electrical conductance or resistance of rocks. Most of rocks show high electrical resistance, however, when the pores or cracks of the rock is saturated with water, their electrical resistivity is reduced significantly. For this reason, electrical resistivity techniques are powerful for groundwater exploration. However, some rocks such as clays show low resistivity that sometimes cause confusion when groundwater exploration is conducted. This confusion can be resolved by the help of other geophysical tools such the induced potential (IP) technique. The geology information about the study area pointed out that Phyllite is present in the study area. Phyllite is a metamorphic rock that possess low electrical resistivity.

The 2-D resistivity surveys were conducted along 5 profiles at Sungkai Klah area (Fig. 4). Profile No. 1 was oriented along East to West (E-W) across the study area with a length of 800 m and the resistivity and IP measurements were conducted in this profile using pole-dipole array to reach as deeper depth as possible. The other profiles almost oriented North to South (N-S) with a length ranged from 200 m to 300 m and the resistivity measurements were conducted using Wenner-Schlumberger array. The resistivity measurements were collected using ABEM SAS 4000 with Lund imaging system. The electrodes spacing for the acquired 2-D resistivity profiles was 10 m at the first profile and 5 m in the others.

The processing of the obtained data was carried out using Res2Dinvx64 [19], which uses finite elements to solve the inverse modelling and produce an image of the electrical resistivity distribution in the subsurface based on the smoothness-constrained least-squares optimization method ([20]). The subsurface model generally consists of several rectangular cells with fixed positions and sizes, but the resistivity value is allowed to change. The (L1–norm) robust constraint inversion was selected to enhance the sharp changes in the resistivity values that linked to the shear zones and an initial damping factor of 0.15 and minimum damping factor of 0.02 were used in the inversion process. The width of model cells was set at the same of the unit electrode spacing.

2.2 Gravity and magnetic

Gravity and magnetic methods adopted are classified as potential field method. Both methods utilized land surveying using Scintrex autograv CG-5 and Proton magnetometer for gravity and magnetic survey respectively. The original plan for the survey utilized a uniform grid of 25 m separation. However, because of the terrain and land use at the site, the grid is modified to random grids at those obstacles. The total number of measured stations are 264 and 251 for gravity and magnetic respectively. From the distribution shown in Figure 4, the measurements are well distributed in the surface occurrences of the hot springs. The effect of the non-uniform is concentrated at the areas to the east. However, because this non-uniform distribution in measurements could result in aliasing for the gridded data, the produced grids are low-pass filtered to suppress the possible effect of aliasing

The reduction of the gravity and magnetic data are applied following the standard techniques. For gravity data, the latitude, free air, bouguer and terrain corrections were applied using information about the latitude, elevation above the geoid and terrain. For geomagnetic data, the corrections are applied for diurnal variation using measurement of fixed base station at the site. Moreover, because the study area is located near the equator, reduction to the equator (RTE) filter was applied to the data. The outputs from both surveys after applying all the necessary corrections are like to a great extent. The corrected gridded gravity and magnetic data are shown in Figures 5 and 6.

For analysis and modeling of gravity and magnetic data various filters were applied. As mentioned earlier the non-uniform distribution for the measuring stations may result in aliasing of short wavelength shallow structures. This could be misleading in the interpretation of the final model obtained. To overcome the aliasing a low filter was applied to both gravity and magnetic data. Low-pass filtering in the present study was applied by the upward continuation filter for an elevation of 70 m (Figure 7). The filtered grids are then used for the subsequent modeling techniques. The modeling techniques adopted in the present study is tilt angle filter.

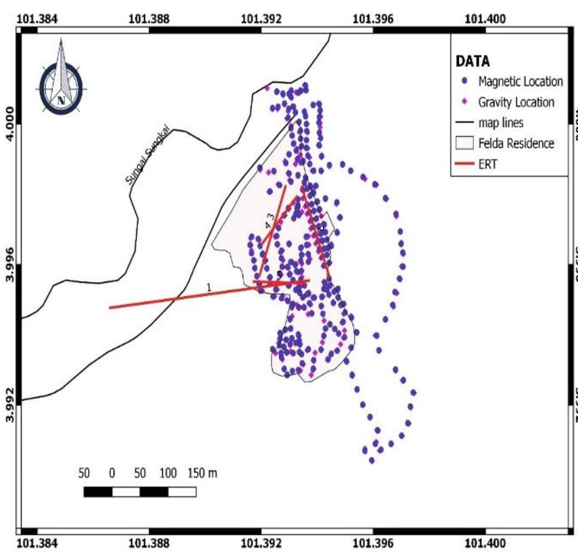

Figure 4. Survey layout at the study area. The center of the area surrounds the surface occurrences of the hot springs.

Tilt angle filter is used for detecting the boundaries of the anomalous body in the present work. The method is introduced long time ago and have been applied and modified by several researchers ([21-29]). The method is sometimes names tilt derivative because the filter itself if the ratio between the first vertical derivative and the horizontal gradient of the potential field. The zero contour of the applied tilt angle is believed to delineate the boundary of the anomalous body

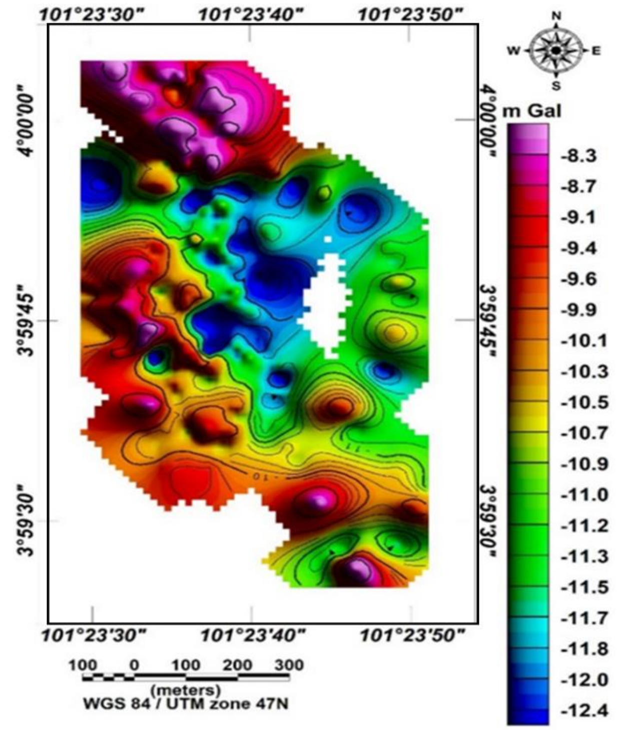

Figure 5. Bouguer gravity map for study area at Felda residence at Sungkai, Perak.

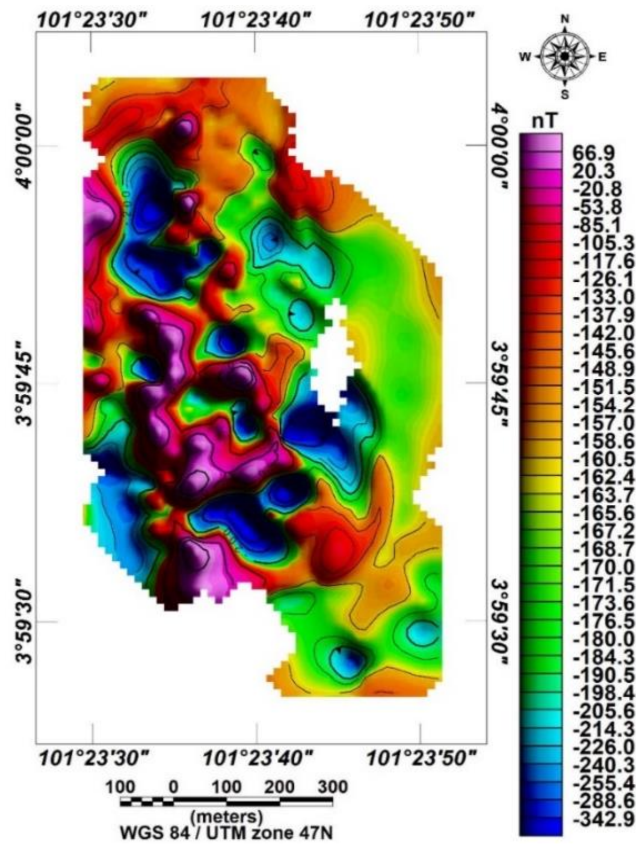

Figure 6. Total magnetic field of the study are at Sungkai, Perak

4. Results and Discussion

The resistivity method primarily used to determine the anomalous zones that mostly related to shear zone activity that are useful targets associated with geothermal activities and to define the resistivity distribution at different depths beneath the survey area.

The models of all profiles show the relatively similar structures with resistivity values less than 600 Ohm-m in all profiles (Figs 8 to 12). These resistivity values in the study area are mainly related to the existence of Phyllite rocks (i.e. metamorphic rock which was originally formed of shale or mudstone, composed mainly of clay minerals and characterized in general with resistivity values less than 500 Ohm-m) in the study area. The environmental condition for the formation of Phyllite is characterized by low level of heat, pressure and chemical activity that might be a consequence the geothermal activities in the study area.

There is a main anomalous zone, a shear zone formed by resistivity value of less than 80 ohm-m. This zone is extended from more than 300 m depth and reach to the surface point at hot spring location (Fig 8) which may indicate a shear zone that is associated with the geothermal activity in the study area. This feature prevails in all profiles that are trending in near E-W direction.

In profile 1 (Fig 8), the middle region beneath the centre of resistivity profile, the rapid changes of resistivity from high to low resistivity values which could indicate a fracture or a fault zone. The features of this zone probably show a high degree of alteration. This is also confirmed with low chargeability value IP modelling (Figure 8a). Moreover, the low resistivity zone (less than 10 ohm-m) in profile 1, is probably the geothermal circulation zone which extended from 100 m to deeper levels of about 300 m.

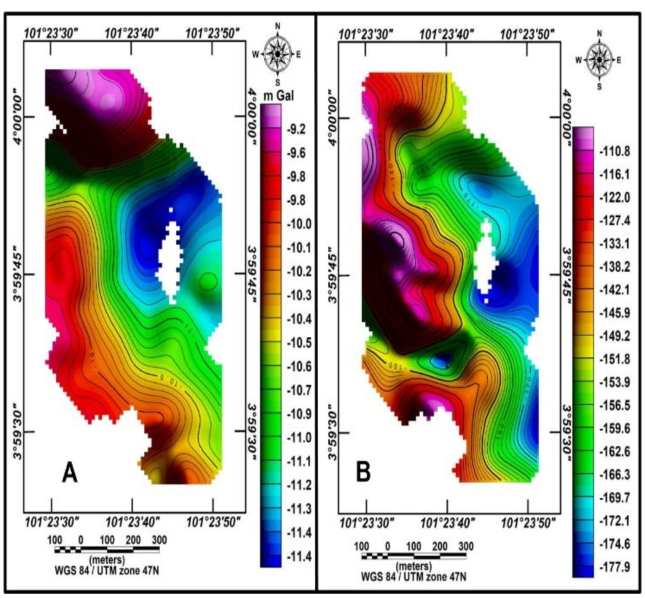

Figure 7. Low-pass filter of a) bouguer gravity and b) reduced to the equator total magnetic field at Sungkai, Perak.

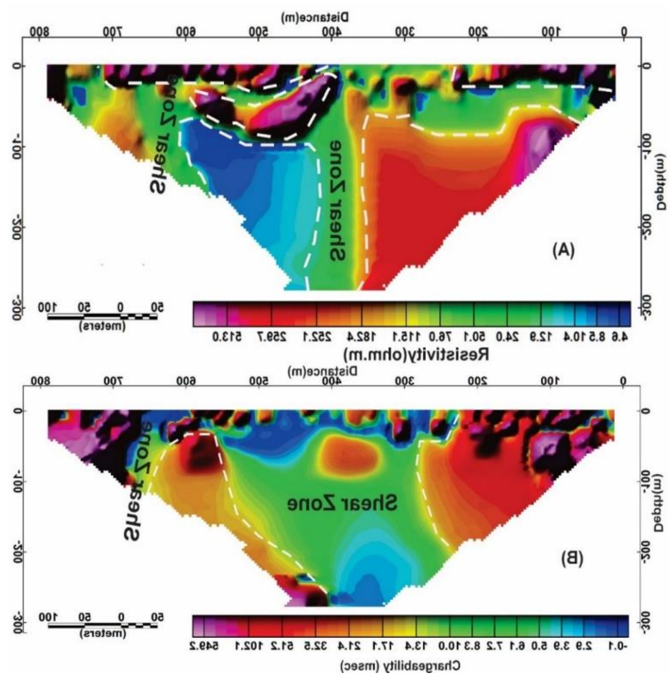

Figure 8. 2D resistivity (above) and chargeability (below) inversion models of the ERT/IP profile showing the position of the shear zone that associated with geothermal activity in the study area.

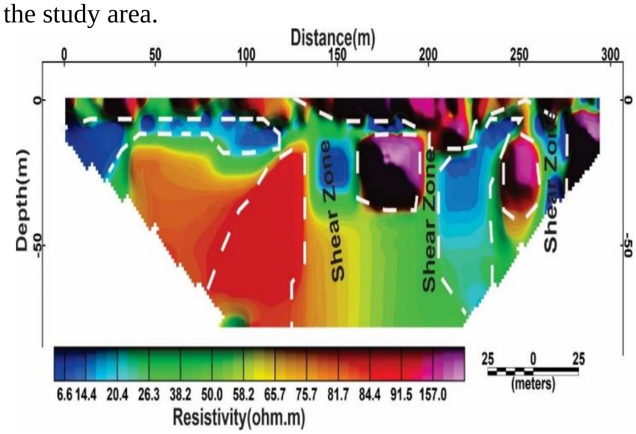

Figure 9. 2D resistivity image inverted from the profile 2 data set and showing the shear zone associated with geothermal activity in the study area.

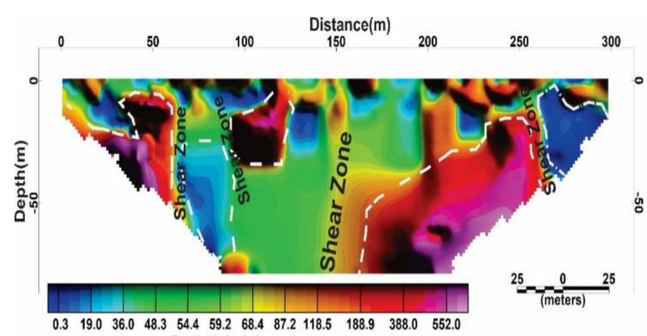

Figure 10. 2D resistivity image inverted from the profile 3data set and showing the shear zone associated with geothermal activity in the study area.

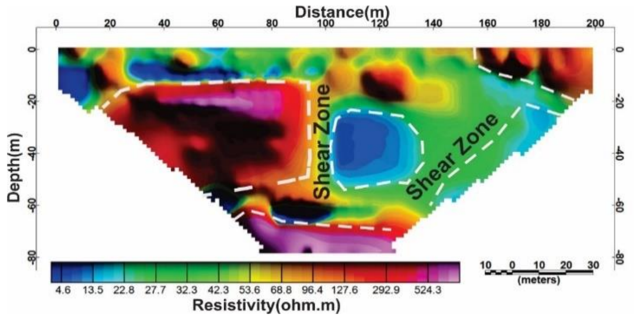

Figure 11. 2D resistivity image inverted from the profile 4 data set and showing the shear zone associated with geothermal activity in the study area.

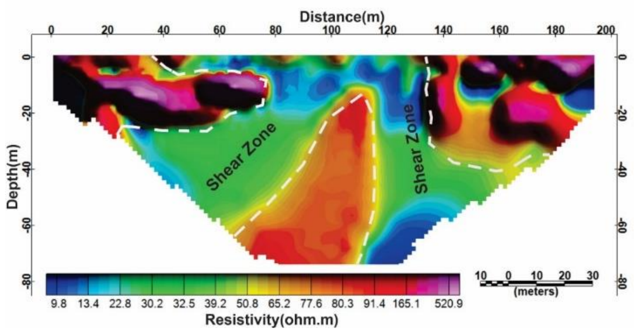

Figure 12. 2D resistivity image inverted from the profile 5 data set and showing the shear zone associated with geothermal activity in the study area.

The tilt angle filter was applied to the gravity anomaly and RTE magnetic anomaly. The result of the filter is shown in Figure 13. The tilt angles show some similarity showing a possible shear zone that is trending NW-SE. The possible shear zone interpreted from the tilt angle filter may be the structures that controls the flow of the hot water up to the surface. In figure 2, it can be observed that Sungkai river is flowing from NE to the SW. The direction of the shear zone here seems like a conjugate to the fault trends that controls the flow of Sungkai river.

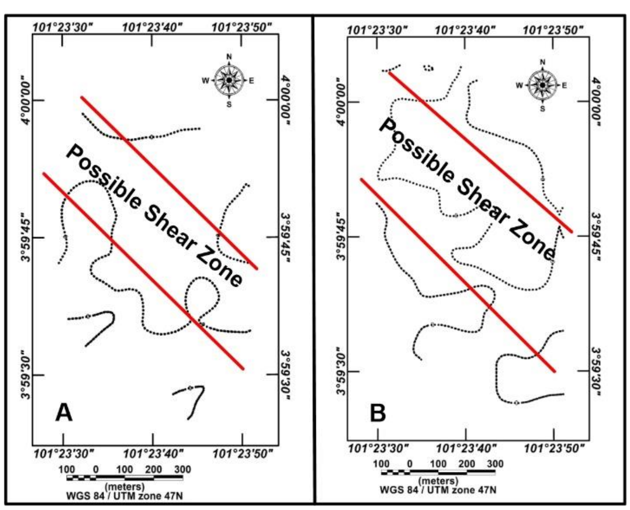

Figure 13. Tilt angle model for a) gravity anomaly and b) RTE magnetic anomaly.

To collect the pieces together, a pseudo 3D ERT composite plot is generated (Figure 14). It can be observed from the plot that the shear zone is close to vertical. Also, it can be observed also that the part of the shear zone represented in the plot is also trending in the NW-SE direction. This supports the interpretation made from the tilt angle filter. Moreover, it is observable that the resistivity near the surface at both sides of the shear zone is relatively reaching a magnitude of about 1100 ohm-m. Whereas at the shear zone, both the resistivity and the chargeability have low values. This may indicate that there is a localized heat effect near the shear zone area that causes alteration that leads to reduction in the resistivity values.

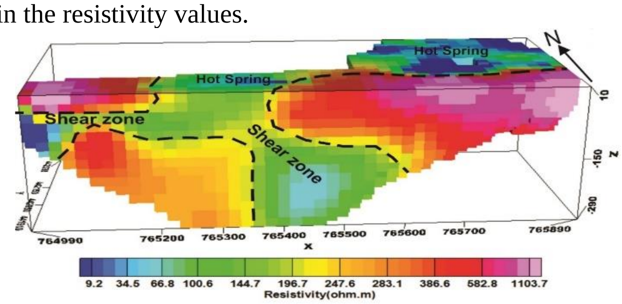

Figure 14. Composite pseudo 3D ERT based on the 2D cross sections. The surface occurrence of hot springs is marked on the plot.

Conclusions

The focus of the present research is to delineate the main components of the geothermal system at Felda residence at Sungkai, Perak. The geothermal system comprises the heat sources, the hot water aquifer, the geologic structures that controls the flow of the water up to the surface and the cap rock. The heat source is usually the deepest part of the geothermal system with depths that can deep down to few kilometers. The heat source at Peninsular Malaysia is believed to be of non-volcanic origin, this believe is supported by the geochemical analysis of water samples from several hot springs. The reasonable assumption for the hot source at the study area is the magma cooling or radioactive disintegration of granitic batholith at depth. Other components of the geothermal system are shallower with depths of hundreds of meters. The study was conducted to help the sustainability and development plans at the area. Another possibility is to check the possibility of exploiting the geothermal system there to produce electric power. Unfortunately, the maximum depth of investigation was not sufficient to study the heat source. However, the rest of the components are delineated to an acceptable level. The analysis shows that hot water aquifer (or at least the shallow part of it) is located under the middle part down to depth of about 300 m as obtained from the ERT profile 1 (figure 8). The shear zone represents both the aquifer and the controlling structure that guides the water flow at certain parts. Phyllite is believed to represent the cap rock of the geothermal system. Based on the results obtained here, any future development plans for the area should avoid the central part of the area where the flow of hot water take place. This will ensure that the structures controlling the hot water flow will not be affected. In addition, it is believed that the heat source may not to be deep with possible depth of less than 1 km. This is supported by the presence of mineral alteration at shallow depths and the results from geothermometers.

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