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Shear joints and its relations with subsurface structures in Batu Melintang, Jeli, Kelantan, Malaysia

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Abstract

Shear joint is the common rock deformation structures formed in Batu Melintang, Jeli due to its location within Bentong-Raub Suture zone. The structural analysis of shear joint can give information about the direction of maximum and minimum stress exerted on a rock while undergoing deformation as the effect of stress fields in the study area. The subsurface structural analysis is done by using the geophysical resistivity method. It displays the subsurface structure in the area for confirmation of the structure found on the surface whether it is highly fractured, moderately fractured or low fractured. The research area was divided into six grids for systematic field measurement. The shear joints orientation were taken while conducting geological mapping and recorded using rose diagram analysis; while the geophysical resistivity method was carried out with a varied length of survey lines set at 200/100m and 1.25/2.5/5m electrode spacing. The subsurface depth of penetration for each survey line is varied, ranging from 0m to 50m. The data is processed in RES2DINV software to obtain the pseudosection profile of the subsurface. The study area principal stress was identified; the maximum stress force σ_1 was directed in NW-SE in direction of S107°E and N287°W, while minimum stress σ_3 was directed in NE-SW in direction of N17°E and S197°W. The pseudosection subsurface image also displayed a correlation between surface shear joint structures and subsurface structures. The subsurface investigation; according to the pseudosection found that the study area consists of highly fractured structure displayed as several weak zones and fractures of bedrock.

1. INTRODUCTION

Rock deformation occurs within most of the Earth rocks. A variety of brittle structures is formed at the upper crust from microcrack to continent scale. The most abundant structures formed are joints and fractures as an indicator of brittle rock deformation. These structures are formed when the rocks were being subjected to forces (Engelder, 1987). Joints are divided into several types; including shear joint. Shear joint is formed due to shearing stresses involved in folding and faulting of rocks. The characteristic of shear joint is commonly clear-cut and tightly closed, occur in two sets and intersect at a high angle to form a conjugate joint system. According to Segall and Pollard (1983), if the origin of the joint is understood, we can accurately interpret the deformation occurred in the area. Hence, the analysis of shear joint is important to determine the principal stress of an area for a better understanding of the local geology and its stress fields.

The geophysical technique especially electrical resistivity imaging (ERI) method is commonly conducted to assess the subsurface structure. This method is also proven to provide a more detailed subsurface structure as reported by Muchingami *et al*. (2012). The researched found that 2D electrical resistivity surveys (ERI) provide a more detailed subsurface structure as it provides a more detailed interpretation compared to 1D electrical sounding (VES). In Malaysia, several previous researched conducted the application of resistivity method for subsurface structure investigation especially geohazard assessment such as landslide and sinkhole, e.g., (Bakhshipour *et al*., 2013, Abidin *et al*., 2017, Rauff *et al*., 2020). The assessment of detailed subsurface structure helps to avoid the dangerous geological hazards in the future as the accuracy assessment at 95% confidence level (Arisona *et al.,* 2020). Thus, the geophysical method is a suitable method to conduct a subsurface investigation. Thus, the objective of this study is to determine the principal stress of the study area and its correlation with the subsurface structure according to the shear joint analysis.

1.1. The study area

Batu Melintang is located at the northern part of Jeli, Kelantan. The study area is part of Mangga Formation which consists of metamorphic sequences (Figure 2) of arenaceous, argillaceous, pyroclastic, and calcareous and also schistose rocks found in the eastern part of the Belum

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area (The Malaysian and Thai Working Groups, 2006). Batu Melintang is chosen for this research due to its location which part of Bentong-Raub Suture Zone and Central Gold Belt with complex metamorphic rock structure. In the study area, several types of metamorphic rocks are experiences rock deformation. The deformation structures were found in the field such as joints, shearing, folds and faults. However, this study was focused on the shear joint due to numerous measurement of joint orientation were found in the field. The study area was divided into six grids for systematic data measurement and analysis (Figure 1). The map of study area and the location of survey lines in the grid are shown in Figure 1.

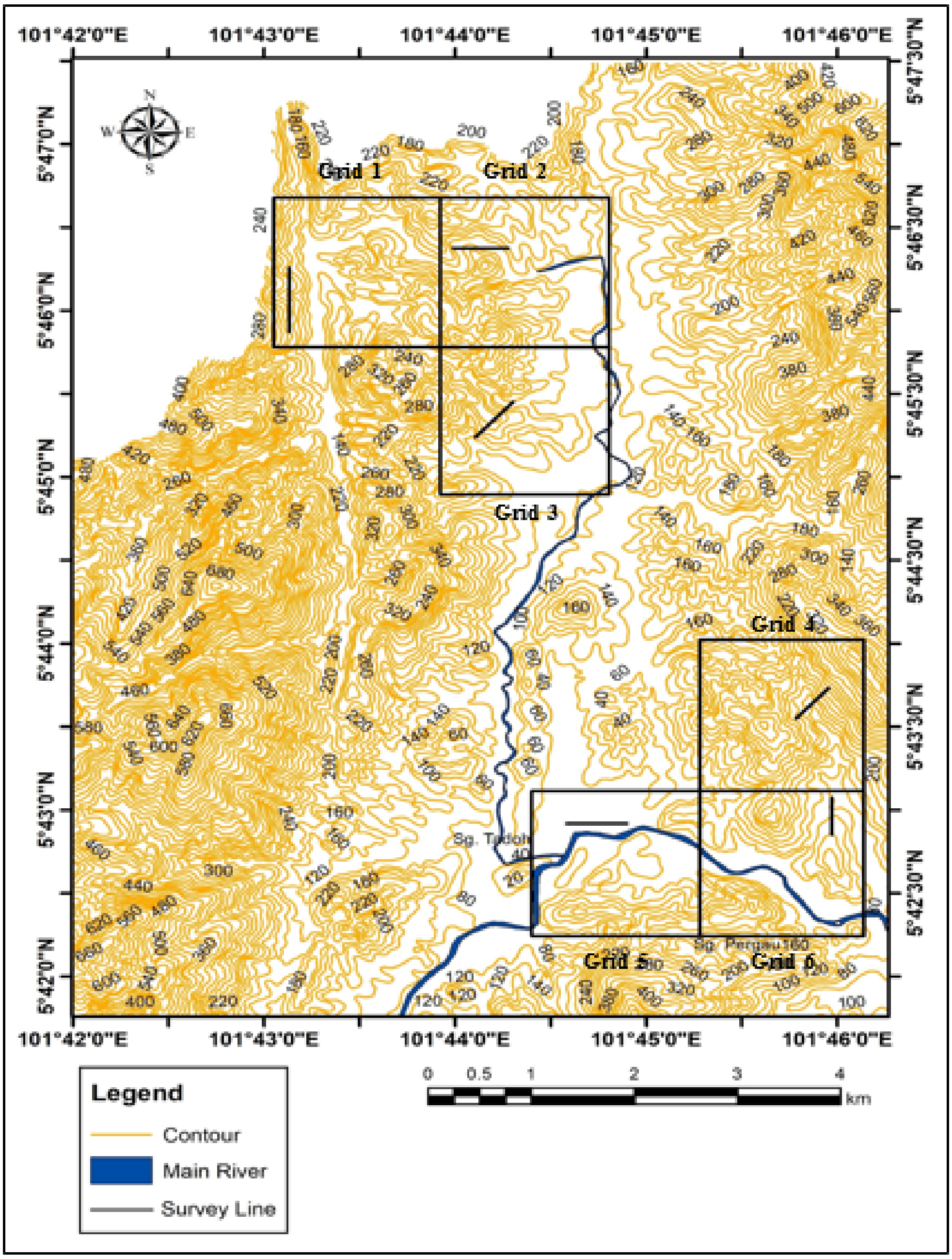

Figure 1: Map of study area and the location of ERI survey lines.

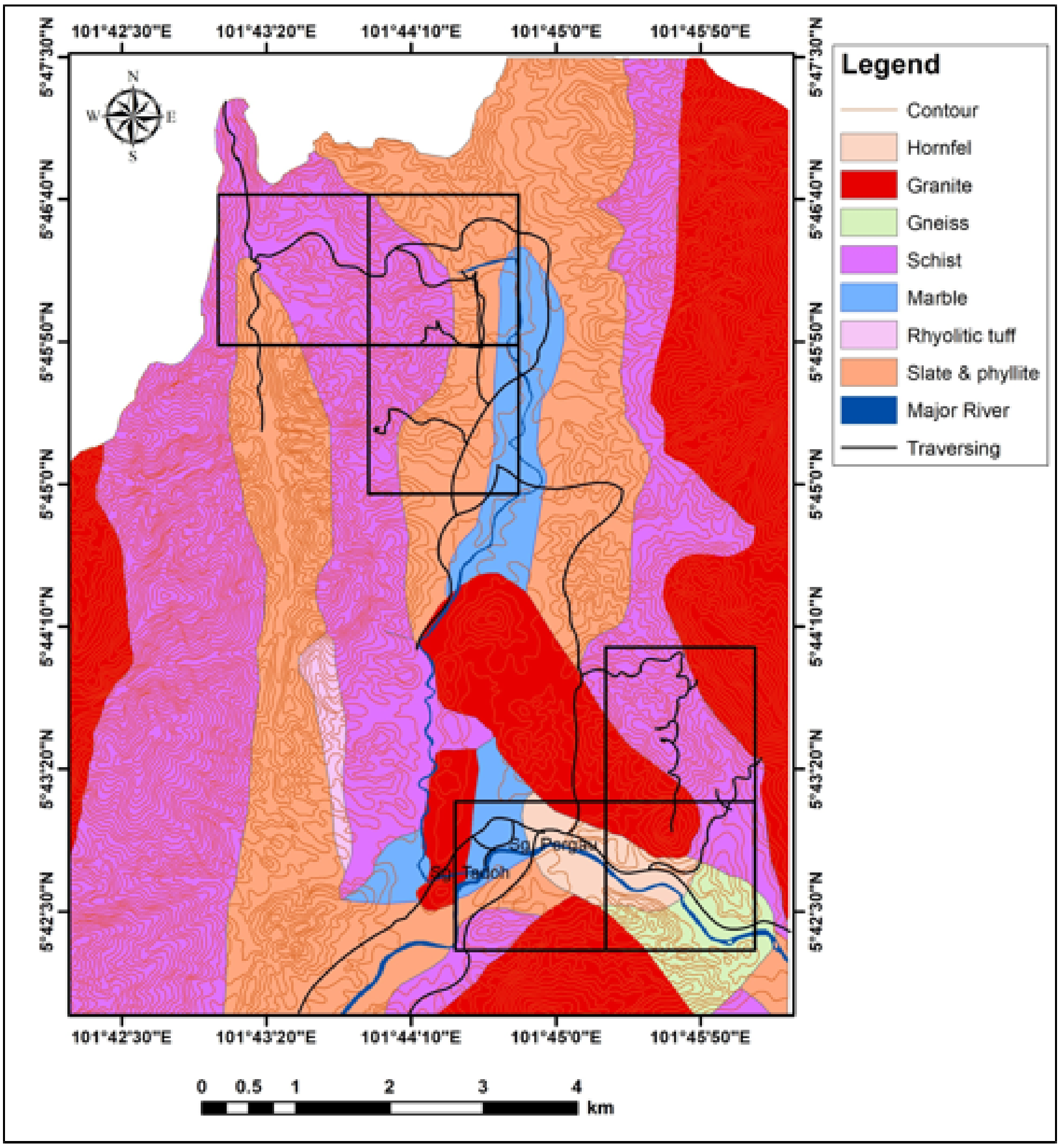

Figure 2: Geological map of study area with traversing.

2. MATERIALS AND METHODS

2.1 Traversing

Traverse was done to observe and record all the geological data found in the study area. Traversing is shown in Figure 2, by following the river traverse and following off-road traverse. This study aimed to determine the shear joint pattern and behaviour based on joint orientation. Hence, the measurement of joint orientation was taken during traversing in the field. The total number of measurement taken for joint orientation is 723 (n=723). This task was mostly carried out at fresh or key outcrops where the structures are better exposed (Figure 3). Geological compass was used for joint orientation measurement and GPS was used to mark the location of joint reading taken. The recorded data was processed in GeoRose software to produce a rose diagram according to the grid on the base map. The rose diagram able to show the trend of the orientation data which provide the direction of shear joint principle stress.

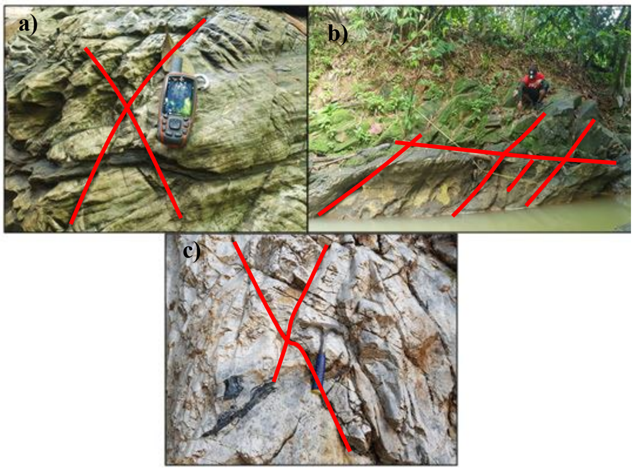

Figure 3: a), b) Example of conjugate shear joint exposed on the outcrop and c) similar shear joint orientation found in the field.

2.2 Resistivity Method

The resistivity method can provide information about geology and subsurface structures underlain in the area (Loke, 1999). This method consisted of several types of electrode configuration used for data acquisition such as Wenner, Schlumberger and Pole-Dipole. These types of configuration array have better depth penetration and better resolution of a subsurface image. The obtained results from geophysical resistivity method are used for comparison and correlation between surface data and subsurface data. In this study, this method is used to compare and correlate the intensity and orientation of shear joint data on the surface with the intensity of joint/fractured in the structure for better understanding of local geology.

Six survey lines were carried out in the study area. Wenner, Schlumberger and Pole-Dipole electrode configuration was used in this study. The different configuration is used at a particular area depending on the suitability of the location. The total length of lines conducted for this survey is 200/100m with 1.25/2.5/5m electrode spacing. Figure 4 shows the equipment used for resistivity survey including ABEM Terrameter LS, battery, Lund imaging cable, electrode clip, cable connector, steel electrode, 200m multiconductor cable, GPS and hammer. The raw survey data obtained at the field was processed by using RES2DINV software to obtain the pseudosection profile which displayed the subsurface resistivity values and subsurface structure. Interpretation of pseudosection was made and further discussed to make confirmation of the surface structure. The location of survey lines conducted is shown in Figure 1.

Figure 4: Equipment used for resistivity survey.

3. RESULTS AND DISCUSSION

3.1 Structural analysis of Shear Joint

The shear joint orientation measurements were taken within each of the grid as shown in the base map. The obtained data from each grid was plotted in GeoRose software to display the rose diagram which shows the frequencies of orientation data. Results of the overall shear joint structural analysis were presented in Figure 5(b) while the results of structural analysis for each grid were displayed in Figure 6. The rose diagram in Figure 5(b) showed the trends of shear joints orientation in the study area were striking at 70°-75° and 140°-145°. The two shear fractures trends thus interpreted to be conjugate shear set in this study area; following the norm pattern of shear fractures.

In the orientation of principal stress for shear joint (Figure 5(a)), a shear fracture is inclined to the maximum stress (σ_1) and minimum principal stress (σ_3) axes, while the intermediate stress (σ_2) axis lies in the shear fracture plane (Borradaile, 2014). Hence, the direction of maximum stress force σ_1 was determined based on the angle θ between shear fracture plane and maximum stress (σ_1) that obey the $25° < \theta < 45°$ norm (Borradaile, 2014). The direction of strain field for the study area was identified through analyzed the overall shear joint rose diagram in Figure 5(b). Two conjugate shear joints sets in Figure 5(b) cross at 75° angle. The θ angle displayed in the rose diagram was 37° which comply the $25° < \theta < 45°$ rule for determination of the maximum stress σ_1 direction. Comparing to the orientation of shear joint in the field, the applied maximum stress force σ_1 was directed in NW-SE in direction of S107°E and N287°W. As the direction minimum stress σ_3 is perpendicular to the direction of maximum stress σ_1, it was determined that the applied minimum stress force σ_3 was directed in NE-SW in direction of N17°E and S197°W.

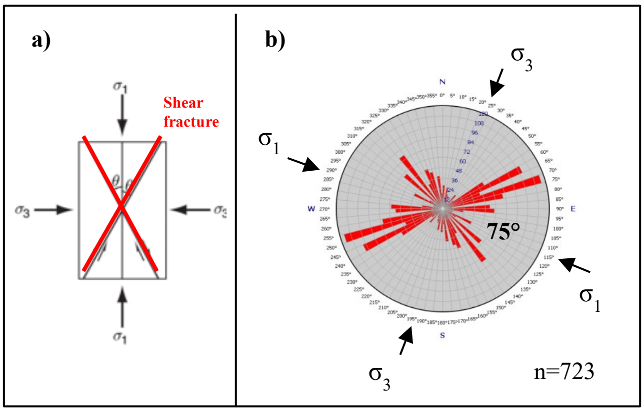

Figure 5: a) The principle orientation of shear fracture and b) Rose diagram of overall shear joint orientation.

The rose diagram for each grid contained almost the same trends with the overall shear joint orientations. As discussed before, the stress field was identified. Following the shear joint orientation in Figure 5(b), the rose diagram of Grid 2, 5 and 6 had the nearest trend with the overall rose diagram. This indicated that most of the rock deformation; dense shear joints happened in Grid 2,5 and 6 as the maximum stress might highly be exerted in these areas compared to other areas. Simply, the rock in that particular area of Grid 2, 5 and 6 experienced high deformation due to the high maximum stress, σ_1 applied which causing highly fractured structures to form. By observing the frequency of the joint orientation in Figure 6, it showed almost all grids consisted of highly fractured

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outcrop except for Grid 3 that had a moderately fractured outcrop. Grid 3 had the lowest total number of joint orientation measurement taken in the area compared to another grid area. Further confirmation of shear joint orientation and its connectivity with subsurface structure was made through subsurface structural analysis.

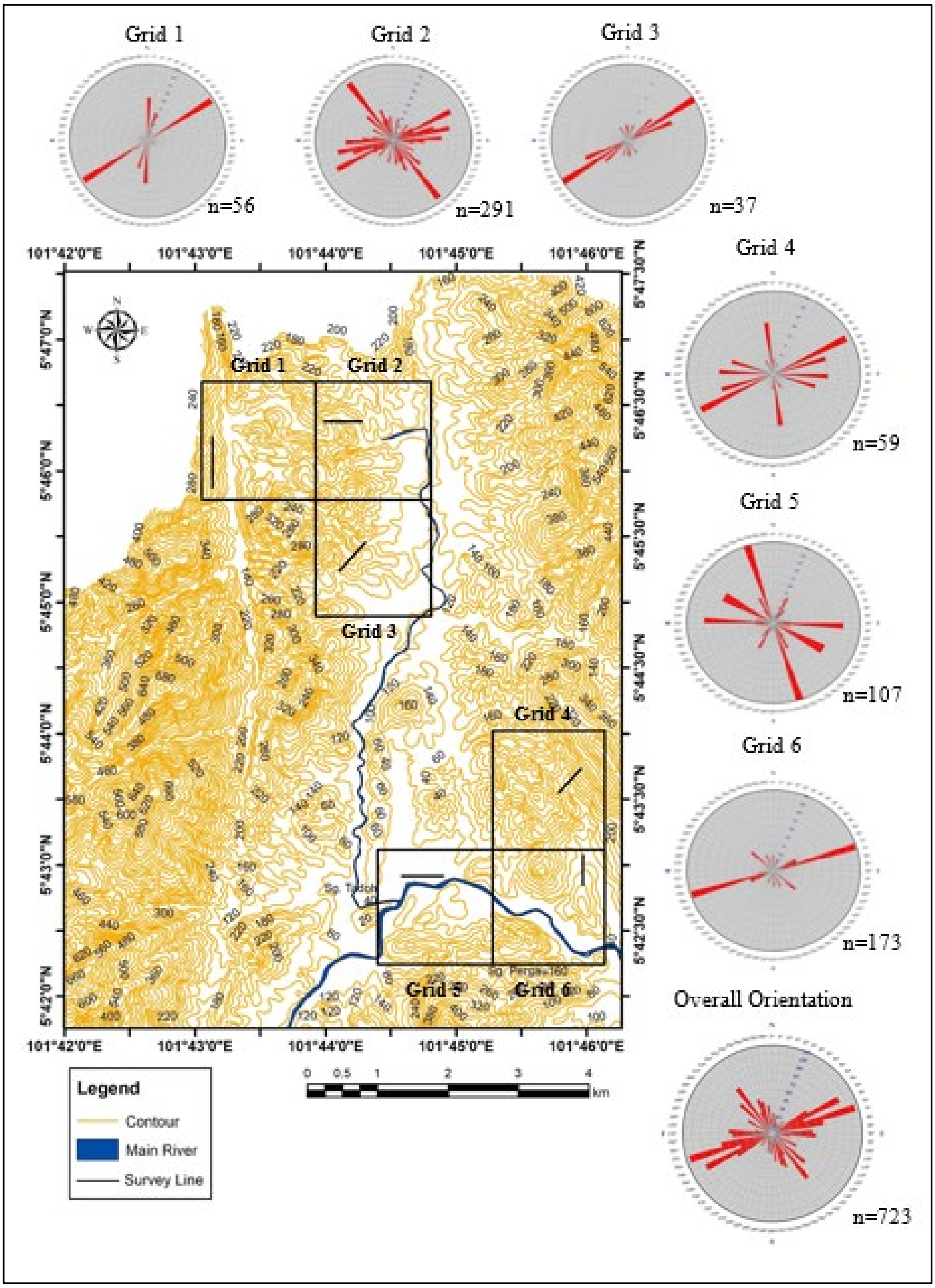

Figure 6: Rose diagram of shear joint orientation for each grid.

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3.2 Analysis of Subsurface Structure

Analysis of subsurface structure was done by using the resistivity method. This method was able to produce an image of the subsurface structure through the measured resistivity value of subsurface materials. Classifications of shear/weak zone and bedrock position were done through interpreting the resistivity value. The area with low resistivity value was classified as shear/weak zone; while the area high resistivity value was classified as bedrock. Six survey lines were carried out in the study area; one survey line in each grid. The results of the pseudosection profile for each survey line (Figure 7) was displayed the subsurface image a depth ranging from 0m to 50m.

The resistivity profile of Grid 1 in Figure 7(a) displayed a shear zone that extended along the survey line. The shear zone/ weak zone has low resistivity value less than 400Ωm. The largest shear zone was located in the left part of the pseudosection as an indication of highly rock deformation occurred at this area. The effect of shearing in the right part of the survey line indicates a combination of several smaller shear zones that make the zones highly fractured. The bedrock identified to have shaped like a dome consists of high resistivity value more than 400Ωm and located at 10m to 30m depth.

Based on the resistivity profile of Grid 2 in Figure 7(b), the area with low resistivity value less than 1500Ωm was classified as shear/weak zone. The shear zone showed fracturing occurred on the right side of pseudosection. The area with resistivity value more than 1500Ωm was classified as bedrock; fractured bedrock. Two large bedrocks were identified in this area. The two bedrocks were experienced high deformation which caused it to be highly fractured.

The resistivity profile of Grid 3 in Figure 7(c) showed two shear zones detected in the area (resistivity values <567Ωm). These two shear zones indicated the presence of fractured line which caused fracturing occurred on the bedrock in this area. Three fractured lines were displayed in the pseudosection according to the shape of both shear zone formed subsurface. While the fractured bedrock (resistivity values >567Ωm), experienced shearing from both shear zone, affecting it to moderately fractured due to the size of shear zone in this area was slightly small compared to others.

By referring to the resistivity profile of Grid 4 in Figure 7(d), there was a shear zone (resistivity values <400Ωm) extended along the survey line with 0m to 25m depth. The largest shear zone was located in the middle of the pseudosection. Besides, there was also bedrock present in the area with resistivity value higher than 400Ωm. The bedrock was located at the centre of a survey line with 15m to 30m depth. The shear zone in this grid had a low angle shear plane that might be caused by the effect of a thrust fault.

Based on the resistivity profile of Grid 5 in Figure 7(e), an uplifted structure was exposed in the pseudosection. The high resistivity value (>400Ωm) area was classified as an uplifted limestone block that correlated to the Gunung Reng formation. The shear zone with low resistivity value (<400Ωm) was extended along the survey line and divided at the centre due to the uplifted limestone block. The present of shear zone indicated shearing occurred in the area which caused highly fractured limestone block formed.

The resistivity profile of Grid 6 in Figure 7(f), the shear/weak zone was also identified. The large shear zone present in the area affected the nearby bedrocks. The bedrocks undergo shearing which caused it to be highly fractured. As showed in the pseudosection, the two bedrocks (resistivity value >400Ωm) located at depth of 0m to 30m was the evidence of fractured bedrock present subsurface.

Through analysed all the pseudosection profile of the study area, it is found that each of the surface structural data is correlated and similar with the subsurface structural data in term of the intensity of shear joint exposed in the particular area. The high frequency of shear joint surface data indicated a highly fractured subsurface zone and vice versa. These data is very helpful for further investigating gold mineralization in the study area as it is part of the Central Gold Belt.

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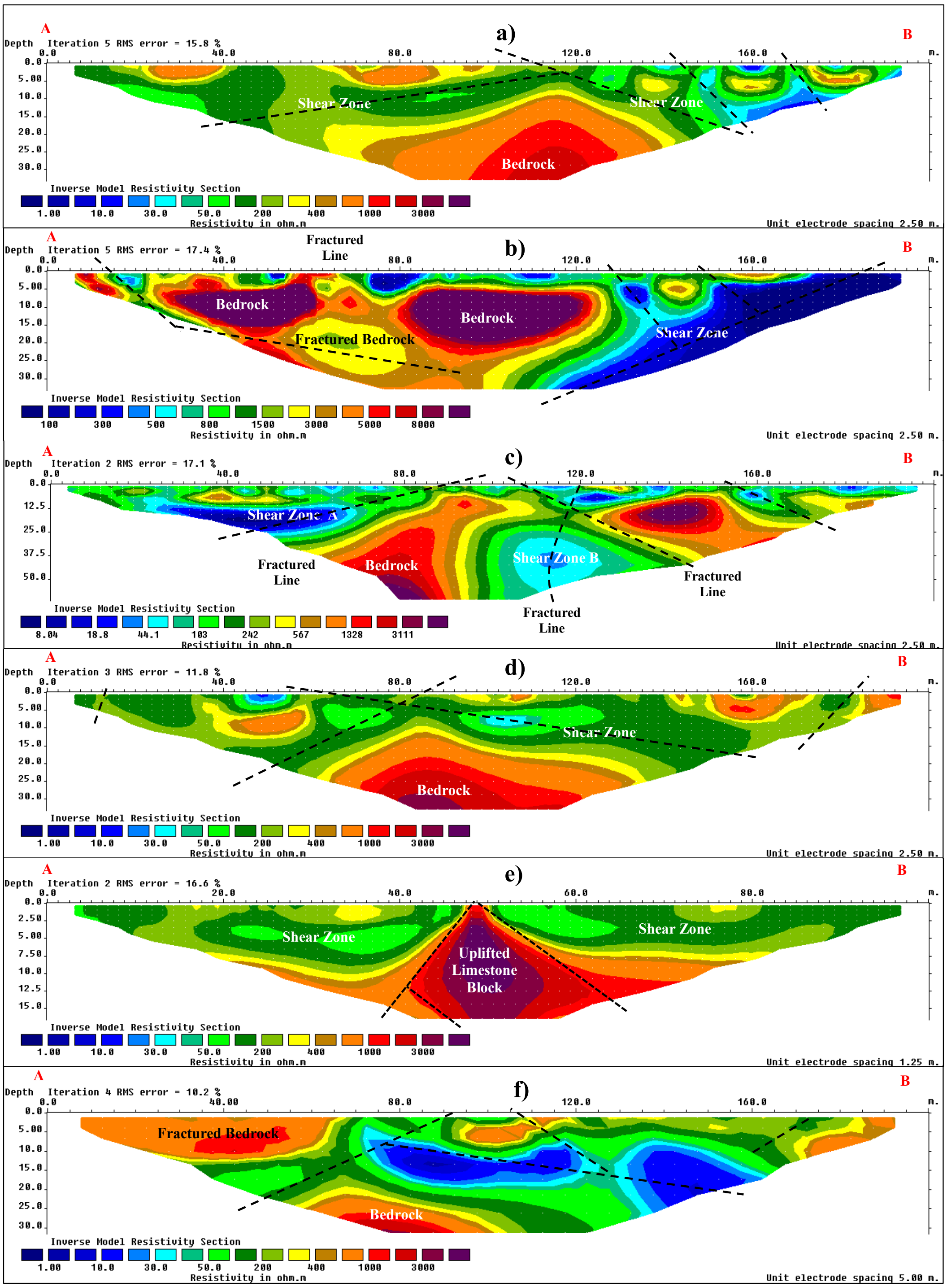

Figure 7: Subsurface resistivity profile of a) grid 1, b) grid 2, c) grid 3, d) grid 4, e) grid 5 and f) grid 6.

4. CONCLUSION

Analysis of shear joint showed the stress field for the local area; maximum stress force σ_1 was directed in NW-SE and minimum stress force σ_3 was directed in NE-SW. The results showed that the stress field of the study area is complying with the structural stress of Bentong-Raub Suture Zone. The comparison of surface data and subsurface image presented a correlation between both surfaces shear joint and subsurface structural analysis. The surface data of shear joint was proven to be valid and correlated for comparative used with the subsurface data.

Based on the pseudosection of the subsurface, the study area consists of highly fractured structure displayed as several weak zones and fractures of bedrock. The subsurface structure present in the pseudosection was the strong confirmation of the shear joint formed at the surface.

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