Identification of Sungai Batu Sediment using 2-D Resistivity Imaging and Seismic Refraction Methods for Ancient River Mapping at Kedah, Malaysia

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Abstract. Sungai Batu is an earliest civilization in Southeast Asia with evidenced by the discovery of riverside jetty, iron smelting, and ritual monuments. The evidences can lead to prediction of buried river caused by geological and sedimentation process. This study was conducted to study sediment deposit characteristic and to map thickness of the sediments using 2-D resistivity imaging and seismic refraction for ancient river mapping. A total of thirty, 2-D resistivity and nine seismic survey lines were conducted at the study area. Four of the lines R1-R4 and S1-S4 were correlated and validated with existing on site boreholes BH1-BH4 to identify sediment type and thickness. The validated values applied to the remaining survey lines which no borehole record to map the subsurface of the study area. Based on the results, Sungai Batu area consist of clay with resistivity value of 6.6-25.9 Ω.m and velocity value of 716.9-1606.9 m/s; sandy clay with resistivity value of 6-265.1 Ω.m and velocity value of 1003.6-1901.4 m/s; while shale was identified with resistivity value of >686.6 Ω.m and velocity value of >2051.7 m/s. Boundary between clay/sandy clay with shale was identified with resistivity value of 314 Ω.m and velocity value of 1822 m/s. The integration of the 2-D resistivity and seismic refraction identified that the thickness of Sungai Batu sediment is 0-150 m and Sungai Batu ancient river was successfully map based on thickness of sediment which is >45 m.

1. Introduction

Since 1840, Sungai Batu, Kedah had become a very attractive location by researchers to study archeology case [1]. The human civilization evidence or remaining found in the Sungai Batu such as temples, building materials, religious sculptures, inscriptions and many artifacts such as pottery, trade, ceramic, glass, metals and also various types of beads from Proto-historic period [2]. The evidence of ancient structure shows that Sungai Batu was a basis of economic region with Sungai Batu river used as an international enter port [3].

During 1st and 2nd century, the mid-south of Kedah was a famous as a port which recorded area as marine. Due to increasing sea level in the year 1400 was changed of geomorphology in the Sungai Batu area had changed to landed area [4]. Theoretically, sedimentation of rocks, soil, and mineral from weathering process was transported from a higher area to the lower area, and also influenced by the regional geology. Based on the historical and geological evidence, the sea level fluctuations are about
2-3 m in 200 years or less [5]. In the peninsular Malaysia West and East coasts, the sea level decreased about 0.7 and 0.5 mm/year respectively [6]. Sedimentation process of Sungai Batu area controlled by depositional process two rivers which is from the Sungai Merbok river, Sungai Batu river and Malacca Strait. Therefore, sediments from Gunung Jerai was transported from the Sungai Merbok river and Sungai Batu river to lower region with high turbidity current until it settled down due to gravity factor [7]. Hydrogenous sediments of Malacca Strait play an important role in the deposition process in the Sungai Batu area [8]. The sediments from Malacca Strait are transported due to longshore drift from tidal current to formed range of landforms.

A Sedimentation process in Sungai Batu happened due to the conversion by soil and geomorphology change. The resistivity value of sediment deposition origin from the Sungai Batu was identifying 3 soil types (loose and dry alluvium with resistivity value >100 Ω.m indicated the first layer, saturated alluvium with resistivity value 10-50 Ω.m indicated as the second layer and moist condition with resistivity value <100 Ω.m indicated as the third layer) and resistivity value more 300 Ω.m which is indicated as river bed [5]. In this study, 2D resistivity imaging was conducted at the study area to map of ancient Sungai Batu, Kedah.

2. General Geology and Study Area

The study area conducted at Sungai Batu area which is in between Merbok and Sungai Petani. The area located in Lembah Bujang district. Generally, the geology of the study area consists of two formation types; Jerai Formation and Petani Formation (Figure 1). Jerai Formation consists of few rock types; granite, sandstone, shale and minor conglomerate. Petani Formation consists of shale, siltstone, sandstone, orthoquartzite and homologous. Soil types of the study area are clay and sandy clay. Generally, the study area is flat, which dominated by secondary jungle and oil palm plantations. Gunung Jerai located at the northern part of the study area and Merbok River located at the southern part and Malacca Strait at the western part.

![Figure 1. Geological map of the study area [9].](image-url)
3. Methodology

Figure 2 shows the current flow and potential distribution. The resistivity measurements are made by injecting current into the ground through two current electrodes (C1 and C2) and measuring resulting voltage difference at two potential electrodes (P1 and P2). The potential difference is then given by Equation 1.

\[
\Delta V = \frac{\rho I}{2\pi} \left( \frac{1}{r_{C1P1}} - \frac{1}{r_{C2P1}} - \frac{1}{r_{C1P2}} + \frac{1}{r_{C2P2}} \right) \tag{1}
\]

From the current (I) and potential different (\(\Delta V\)) values, an apparent resistivity (\(\rho_a\)) value is calculated using Equation 2 [11].

\[
\rho_a = k \frac{\Delta V}{I} \tag{2}
\]

Field measurements used Pole-dipole array with 4 multi-electrode cables consist of 21 takeout in each cable for electrode connection. Cable are lied in a straight line with cables 1 and 2 (3 and 4) are connected by cable joints, and a station placed between cable 2 and cable 3 consist of an electrode selector, a resistivity meter and remote cable for connecting current electrode, C2 (Figure 3).
When seismic waves propagate in a homogeneous subsurface, wave will travel with constant velocity and the geophones record the ground movement. With the information of geophone spacing, distance from shot point to the first geophone (shot offset) and arrival time of the waves to each geophone, a time-distance graph can be produce. Due to the waves is traveling with constant velocity and the geophones were planted at equally spaced, the time-distance graph produces a straight line (Figure 4) [13].

From the time-distance graph, the arrival time, \( t \) of direct wave is given by Equation 3.

\[
t = \frac{x}{V_1}
\]  

where;
\( x \) = Distance from shot point to receiver
\( V_1 \) = Velocity of first layer (m/s)

Taking the first derivative of the equation with respect to \( x \), the velocity is obtained (Equation 4 and 5)

\[
\frac{dt}{dx} = \frac{1}{V_1}
\]

where;
\( dt \) = Interval time (sec)
\( dx \) = Interval distance (m)

Therefore;

\[
V_1 = \frac{1}{\text{slope}}
\]
The study consists of 30, 2-D resistivity survey lines (R1-R30), 9 seismic refraction survey lines (S1-S9) and 4 boreholes (BH1-BH4), scattered in the area. Line R1 and S1 are located on the same survey line which borehole BH1 is located. The same arrangement are design for R2-R4 and S2-S4 with borehole BH2-BH4 are located respectively. The correlation and validation of the three methods (R1-R4, S1-S4 and BH1-BH4) are conducted to identify the sediment characteristic. Line R5-R30 and S5-S9 are planned in such away to cover study area and the validation result of 2-D resistivity imaging and seismic refraction are used to map the sedimentation pattern and Sungai Batu ancient river.

The 2-D resistivity data was processed using Res2Dinv and Surfer8 software. Seismic refraction data was processed using FIRSTPIX v4.21 software to pick first arrival time and SeisOpt@2D v3.5 software was used to produce a tomography result. The data were then transfer into Surfer8 software for correlation, validation and final presentation.

The 2-D resistivity imaging, seismic refraction tomography results and borehole record were correlated and validated to identify the relation between resistivity, seismic velocity and N-values. The validated values applied to others 2-D resistivity, seismic refraction survey lines without borehole for interpretation to achieve research objective.

4. Results and Discussions

From the correlation and validation of the 2-D resistivity imaging, seismic refraction and borehole results, a relationship between resistivity and velocity values for Sungai Batu soil type was identified (Table 1).

| Soil type  | Resistivity value (Ω.m) | Velocity value (m/s) | N-Value |
|------------|-------------------------|----------------------|---------|
| Clay       | 6.6-25.9                | 716.9-1606.9         | 7-20    |
| Sandy clay | 6-265.1                 | 1003.6-1901.4        | 6-35    |
| Shale      | 4.7-668.6               | 1747.1-2051.7        | 50-70   |

The resistivity and velocity values identified from the analysis of R1-R4, S1-S4 and BH1-BH4 were used for the rest of the 2-D resistivity imaging and seismic refraction lines which they do not have any borehole record to identify the soil type for each survey lines. From the results, the boundary between clay/sandy clay and shale identified with resistivity value of 314 Ω.m and velocity of 1822 m/s. This value are digitize every 5 m spacing to produce shale contour map surface topography. The final results of all the survey lines (2-D resistivity imaging and seismic refraction) are used to map the sediment thickness and identify Sungai Batu ancient river.

Figure 5 shows shale topography contour map generated from 2-D resistivity imaging and seismic refraction results. Based on the topography contour map, it was identified that thickness of Sungai Batu sediment was increasing from North-East towards South-West. The thickness parts of the sediment >45 m with ravine shape identified flowing from North-West to South-West and East. This indicate that this part is Sungai Batu ancient river.
5. Conclusions

2-D resistivity imaging were conducted in Sungai Batu area with two objectives which are to study sediment deposit characteristic and to map the ancient river. The study identified two types of sediment deposit covering the study area which is clay with resistivity value of 6.6-25.9 Ω.m and velocity value of 716.9-1606.9 m/s, sandy clay with resistivity value of 6-265.1 Ω.m and velocity value of 1003.6-1901.4 m/s. The thickness of the sediment deposit identified in the study area is from 0 to 150 m. The clay and sandy clay layers are laid on the top of hard layer of shale with resistivity value of 4.7-668.6 Ω.m. The boundary between the sediment deposits and the hard layer (shale) is identified from correlation between 2-D resistivity, seismic refraction and borehole results which indicated by resistivity values of 314 Ω.m and 1822 m/s respectively.

Sungai Batu ancient river has been successfully mapped using 2-D resistivity imaging, where the sediment deposits are characterized by low resistivity and velocity values (<314 Ω.m and <1822 m/s) while shale is characterized by high resistivity and velocity values (>314 Ω.m and >1822 m/s). The contrast values indicate the Sungai Batu ancient river flowing from North-West and East.
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