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ORIGINAL PAPER

INTERCONNECTION OF ELECTRICAL RESISTIVITY TOMOGRAPHY AND BOREHOLE RECORDS FOR SUBSURFACE LITHOLOGIES AND GEOLOGICAL STRUCTURES STUDY

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ABSTRACT

Urbanization calls for constructions of infrastructures in accommodating the growing number of people as well as providing sufficient safety, waste management, transportation, and other services. Developing areas always require ground investigation to analyze both ground conditions and subsurface structures prior to any establishment to map the subsurface and identify any presence of geological formations that could hinder construction processes. Subsurface cavity is one of the most concerning geological formations in urban areas, making the key objective of this study is to also detect any presence of subsurface cavity. Electrical resistivity tomography (ERT) was utilized in the study, along with borehole record to verify the geophysical results with physical data. Pole-dipole array was employed in the investigation due to its benefit of deeper penetration as compared to other arrays without losing significant data resolution required in this study. From the ERT results and borehole records, the lithologies were categorized into two separate layers: overburden silt and fractured sandstone bedrock. The study area was inferred to require overburden layer reinforcement prior to construction processes to ensure the safety of workers and future infrastructures in the area.

1. INTRODUCTION

Near surface geophysical imaging requires thorough understanding of subsurface lithologies and structures (Jongmans and Garambois, 2007; Linford, 2006; Dahlin and Zhou, 2004), subsurface behaviours (Balarabe and Bery, 2021; Jongmans and Garambois, 2007) and hydrogeological conditions (Loke et al., 2003). Electrical resistivity tomography (ERT) is one of the numerous well-known geophysical methods used to study near surface geology stratification (Maślakowski et al., 2014).

Electrical resistivity tomography (ERT) is a geophysical approach that is often favoured by researchers and practitioners for subsurface lithologies investigation. Separations of rock and soil types can be delineated by the differences of their electrical resistivity (Loke et al., 2003), which varies depending on the mineral composition, porosity, moisture content and fluid saturation (Olayinka and Yaramanci, 2000). Therefore, ERT is an effective tool for mapping lithological boundaries, identifying weathered zones, and characterizing subsurface stratigraphy.

Furthermore, ERT is also commonly utilized prior to construction work to investigate boulders, buried pipelines, and voids that poses safety and technological issues during construction work (Konaté et al., 2023; Economou et al., 2022; Ungureanu et al., 2017). In order to reduce these issues, it is crucial to map the exact location of the anomalies on the study area. This method is also practical to determine the thickness of overburden layer (Ha et al., 2020; Gao et al., 2018) that benefits pre-construction work by influencing a more effective planning that reduces cost and time.

Although borehole drilling is capable of producing the lithologies of an area, it is both expensive and time consuming (Martinez-Santos et al., 2017). Additionally, a borehole can only provide a vertical data, leading to spending more time and money to extend the subsurface investigation in a broad study area. Therefore, the exploitation of ERT as a supplementary data is well-known throughout the globe with the objective to reduce the cost and time of drilling multiple boreholes, while generating 2-dimensional data of the study area (Ishak et al., 2022).

Interconnection of ERT data to borehole records are often implemented as an approach to achieve a wide coverage of reliable data (Abd Malik et al., 2023; Cardarelli and Filippo, 2009). In a previous

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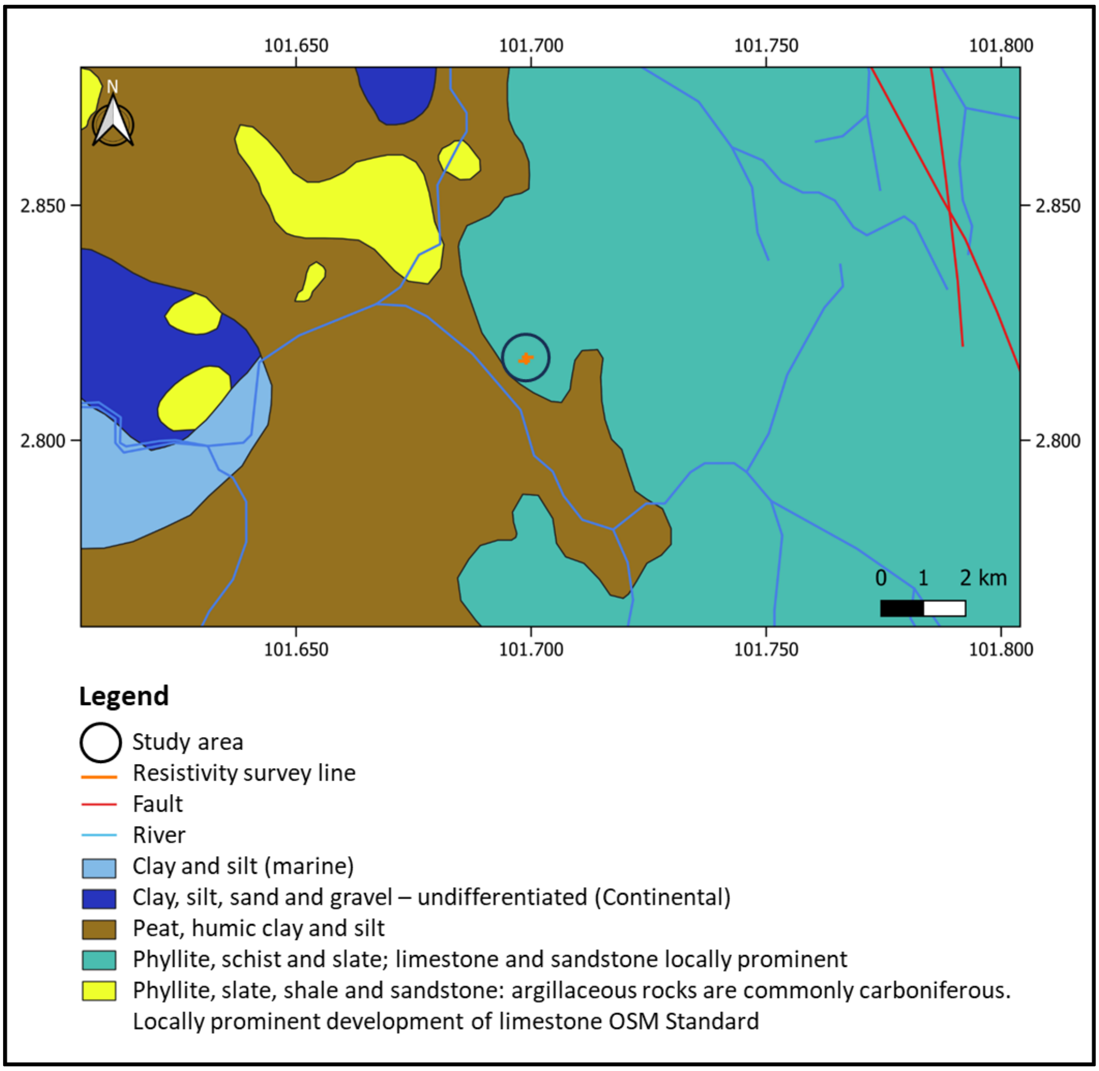


Fig. 1 The geological map of the study area in Sepang, Selangor (Mineral and Geoscience Department Malaysia, 1985).

study conducted by Zaini et al. (2020), similar approach of validating ERT data by utilizing borehole records was taken. The results from both data have successfully mapped the subsurface lithologies, which are overburden soil, fractured granite and fresh granite. Another take from this study is that the delineation of fractured granite from fresh granite from the different resistivity values measured, indicating that the conditions of similar type of rocks or soils affect its corresponding resistivity values.

On top of determining the subsurface lithologies, ERT can also infer geological structures within the subsurface layers (Skun et al., 2024). Mapping of faults are viable through this geophysical approach and was successfully demonstrated in a literature by Nabi et al. (2020). From their work, it is concluded that the determination of faults is visualized by the discontinuity and truncation of resistivity contours, indicating changes in subsurface materials, such as lithologies, water content, porosity or clay content, caused by a lateral shift or abrupt break.

Ground study is a crucial requirement prior to any construction works in order to map subsurface lithologies and determine the presence of geological structures, such as faults, fractures, cavities and boulders that could hinder construction processes. Therefore, the objective of this study is to map the subsurface lithologies alongside geological structures that might be present underneath the surface prior to initiation of construction process by utilizing the ERT method. The results obtained from this geophysical method will be verified with the available borehole records of the study area.

2. GEOLOGICAL SETTINGS

Figure 1 portrays the geology of Sepang, Selangor that was chosen for this research. The study area is situated close to the border of two geological formations: metamorphic rocks of phyllite, schist and shale, and sedimentary rocks of sandstone and limestone (Mineral and Geoscience Department Malaysia, 1985).

The study area is considered to be in a low seismicity region. According to the live update earthquake reports posted by United States Geological Survey (USGS), the maximum magnitude of

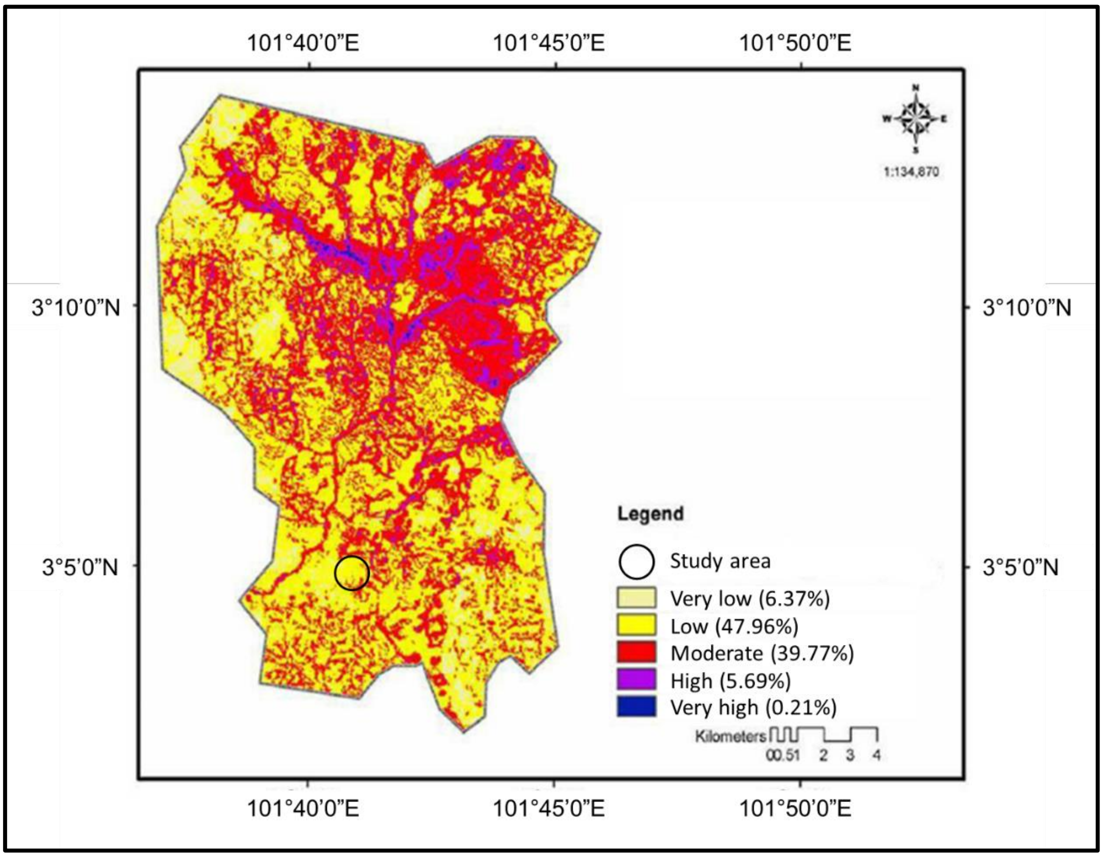


Fig. 2 Landslide susceptibility map of Kuala Lumpur (modified from Mahmud et al., 2013).

earthquake to be recorded in Selangor since January 2024 is at M5.4. However, Sepang was observed to have a low shear wave velocity, which was measured at a range of 101.22 m/s to 151.87m/s (Ismail et al., 2016). From this study conducted by Ismail et al. in 2016, the soils were classified as Class E, indicating the characteristics of soft soils as referred to Uniform Building Code (UBC).

According to the Malaysian Meteorological Department (MET), the rainfall distribution in Peninsula Malaysia is in between 1800 – 3500 mm. Rainfall intensity is one of the major variables causing landslides in Malaysia. Figure 2 portrays the landslide susceptibility map of Selangor. Landslide-prone areas with very high susceptibility were identified where the thematic layers of factors overlap, specifically in areas with slopes greater than 52° (very steep), rainfall rates of 139 mm or more, and dense lineament/fault zones. (Mahmud et al., 2013). Referring to the landslide susceptibility map in Figure 2, the study area in Sepang is located in a region of low landslide susceptibility.

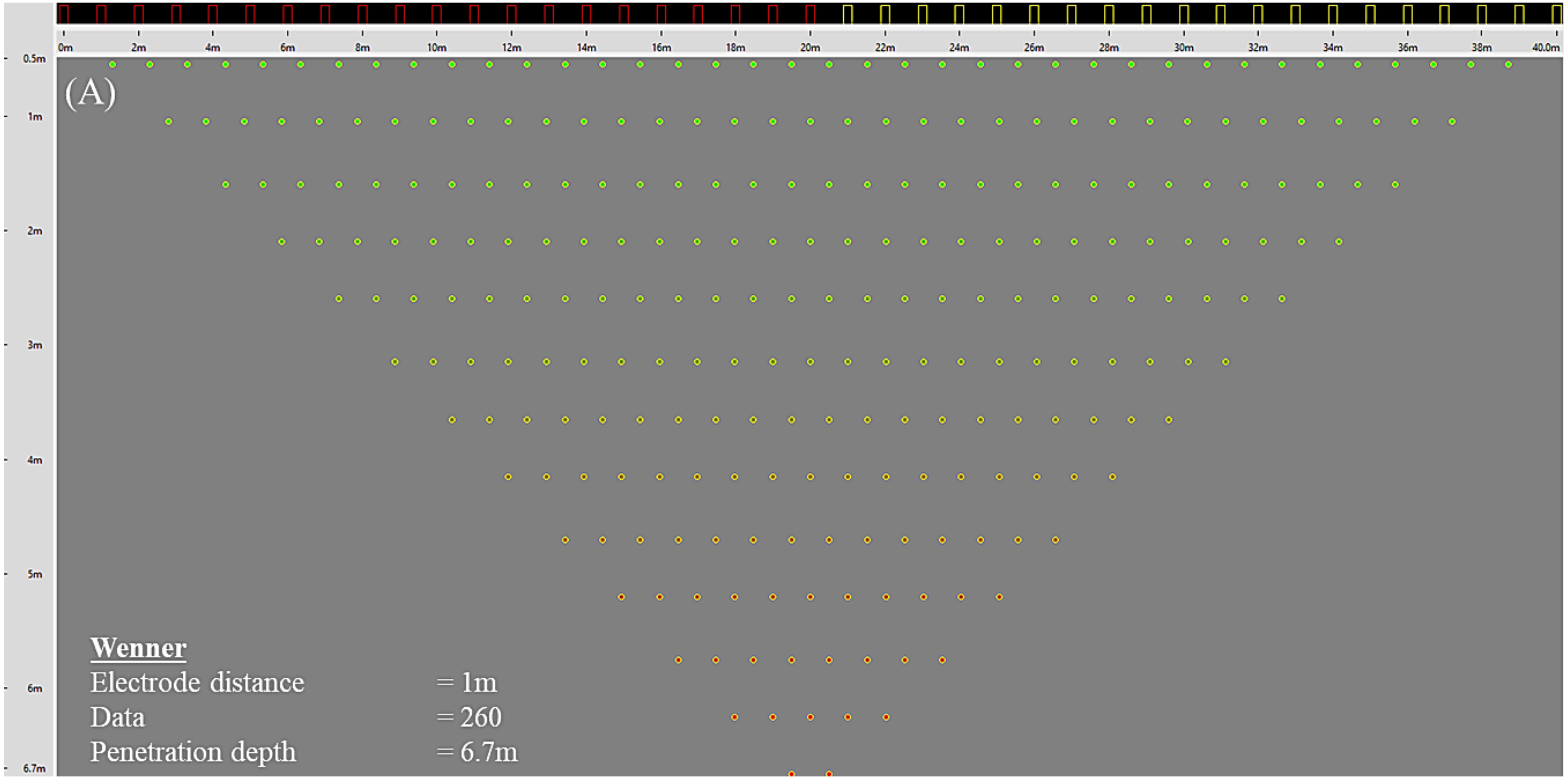
3. MATERIAL AND METHODS

The geophysical methods utilized in this study was electrical resistivity tomography ABEM Electrode Selector ES10-64C to arrange survey lines of two (2) resistivity cables with 21 electrode takeouts on each cable (2x21).

The pole-dipole array was used for data acquisition due to its ability to achieve greater depth of investigation and provide higher data resolution compared to most other available arrays (Okpoli, 2013; Dalin and Zhou, 2004). This asymmetrical array also more sensitive to non-uniformity subsurface and has good horizontal coverage, resulting as a reliable array to delineate subsurface features such as faults, voids or contaminant plumes from the surrounding medium (Shanshal et al., 2023; Prakash et al., 2022; Prikryl et al., 2007).

A comparison between four of the most commonly used arrays – Wenner, Schlumberger, dipole-dipole, and pole-dipole – can be observed in Figure 3 (Al-Zubedi and Abdulrazzaq, 2025). Wenner array offers a simple low data resolution of 260 datum points, and penetrates a shallow depth of 6.7 m for a configuration of 1m electrode distance. However, with the same electrode distance, a Schlumberger and dipole-dipole array provide better data resolution, recording 704 and 696 datum points respectively, and penetrate deeper into the subsurface layers at 7.6 m and 9.8 m. On the other hand, the pole-dipole array produces high data resolution with a total of 1607 datum points up to the depth of 10.3 m.

Each of these arrays are efficient depending on the specific objective of the study conducted. Even though the pole-dipole array measures the highest data count out of all four arrays, the time consumption for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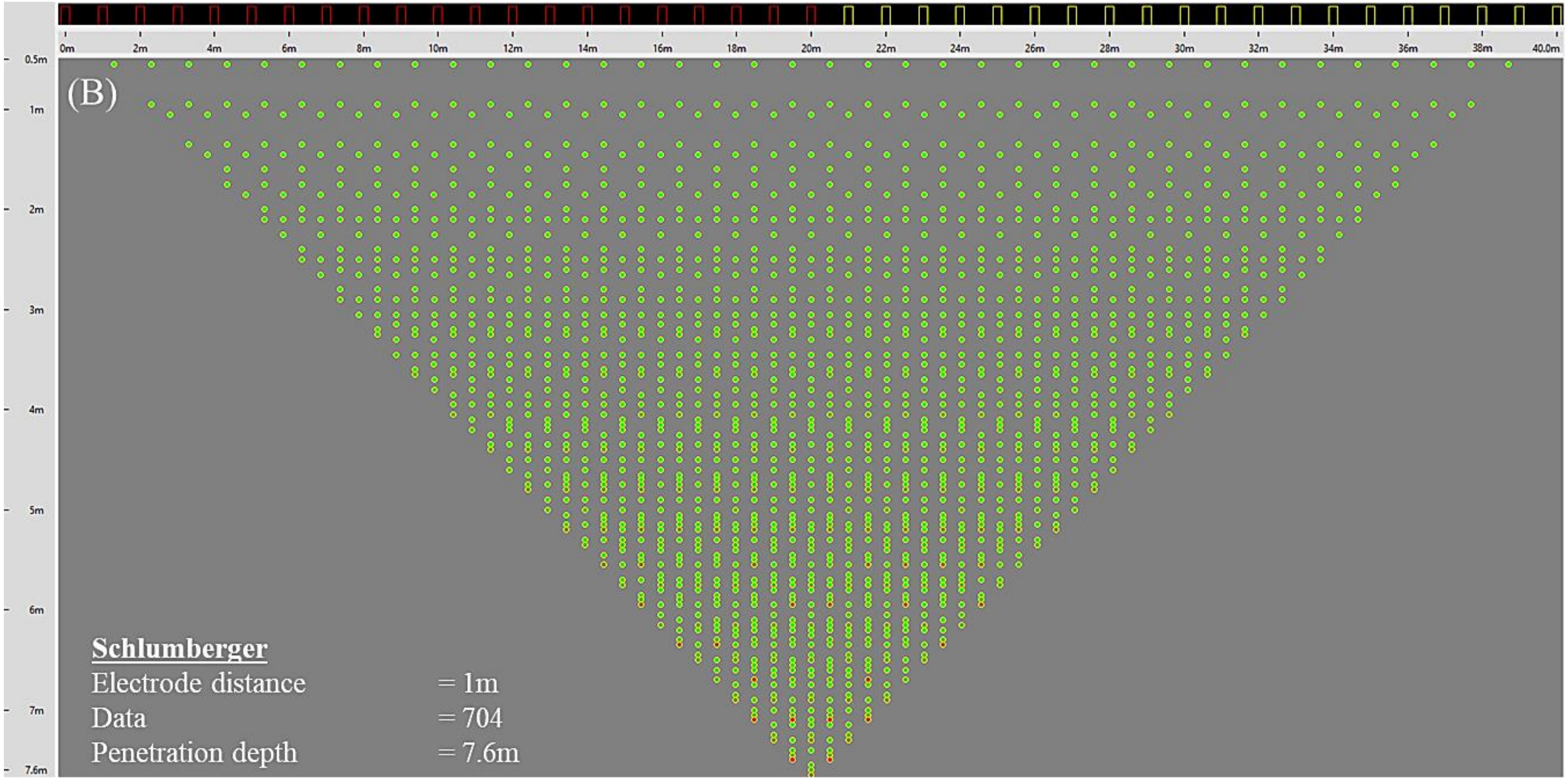
(A)
Wenner
Electrode distance = 1m
Data = 260
Penetration depth = 6.7m



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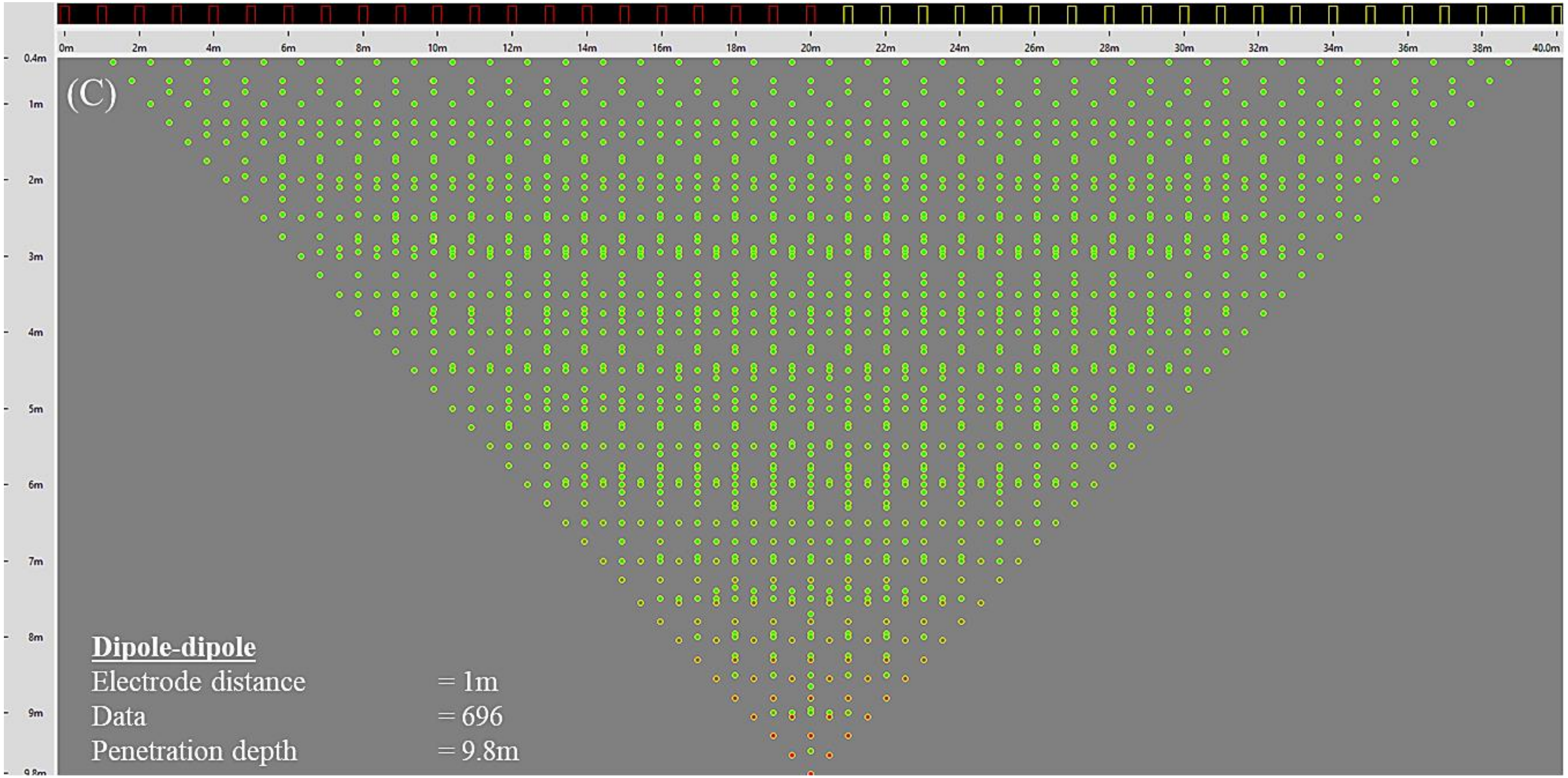
(B)
Schlumberger
Electrode distance = 1m
Data = 704
Penetration depth = 7.6m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38m
40.0m
0.4m
1m
2m
3m
4m
5m
6m
7m
8m
9m
9.8m
(C)
Dipole-dipole
Electrode distance = 1m
Data = 696
Penetration depth = 9.8m

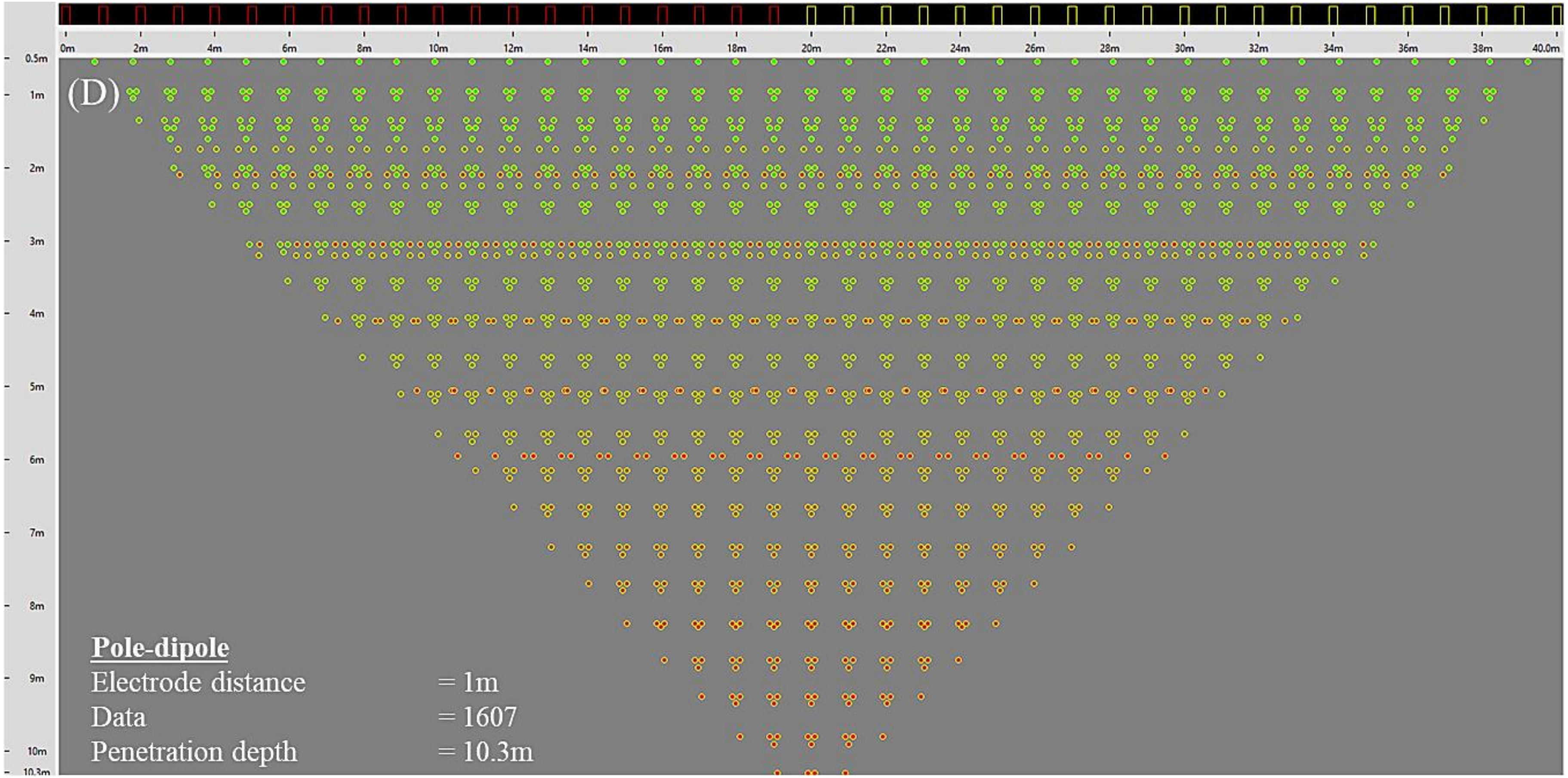

Fig. 3 Data resolution and penetration depth of commonly used ERT arrays: (A) Wenner, (B) Schlumberger, (C) Dipole-dipole and (D) Pole-dipole.

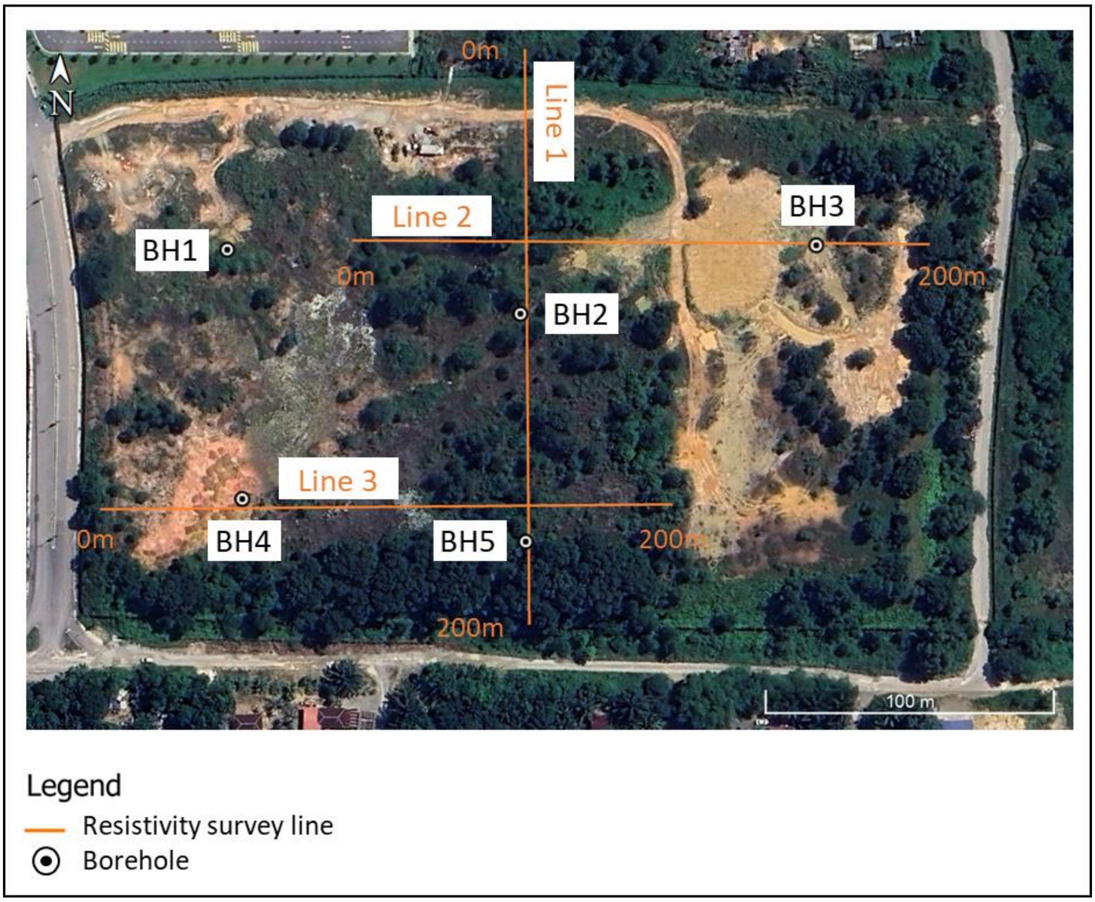

Fig. 4 ERT survey line conducted in the study area.

data collection will also be longer. In Figure 3, it is observed that Wenner array provides moderate horizontal and vertical resolution, making it efficient for a general subsurface profiling. Schlumberger array produces a low horizontal resolution, but high vertical resolution, which is suitable for detection of vertical changes. In contrast, dipole-dipole array generates a high horizontal resolution, but low vertical resolution that fits the objective of delineating lateral variations. Pole-dipole array computes a high horizontal resolution and moderate vertical resolution, which is efficient for structural studies in complex terrain.

Figure 4 demonstrates a total of three (3) ERT survey lines conducted in the study area. Two (2) of the survey lines were designed parallel to each other, orienting east-west with a gap distanced at 90 m, while one (1) of the survey cut across them perpendicularly to cover the area as much as possible and to correlate the data on the intersection points. The minimum electrode spacing was set to 5 m, thus stretches each survey line up to a length of 200 m. The locations of boreholes were also plotted in Figure 4 labelled as BH.

The study was conducted on a relatively flat topographic area with growing trees and bushes occupying the land with the objective to build a school. During the data collection, most of the areas were still covered with vegetations.

The collected data were then processed by utilizing Res2DInv software to compute true resistivity tomography that reflects the actual subsurface lithologies of the area. Each tomography was exported to Surfer8 software to produce contour maps for better and clearer presentation of the subsurface lithologies. Then, a verification of inferred subsurface materials obtained from the ERT survey was made by correlating the results to the borehole record.

4. RESULTS

Data interpretation is crucial to precisely understand the subsurface conditions. Therefore, the ERT results were correlated with the results obtained from borehole drilling to give stronger confidence in the data interpretation.

Figure 5 – 7 illustrate the ERT results with the related bore log superimposed on each survey lines. By doing this, the rockhead levels were confidently drawn, separating the silt overburden layer to the bedrock layer on the ERT results. The true resistivity value that separates the overburden layer from the hard layer is 815 Ωm, where the silt layer is inferred to be ≤ 815 Ωm, while the sandstone layer is inferred to be > 815 Ωm.

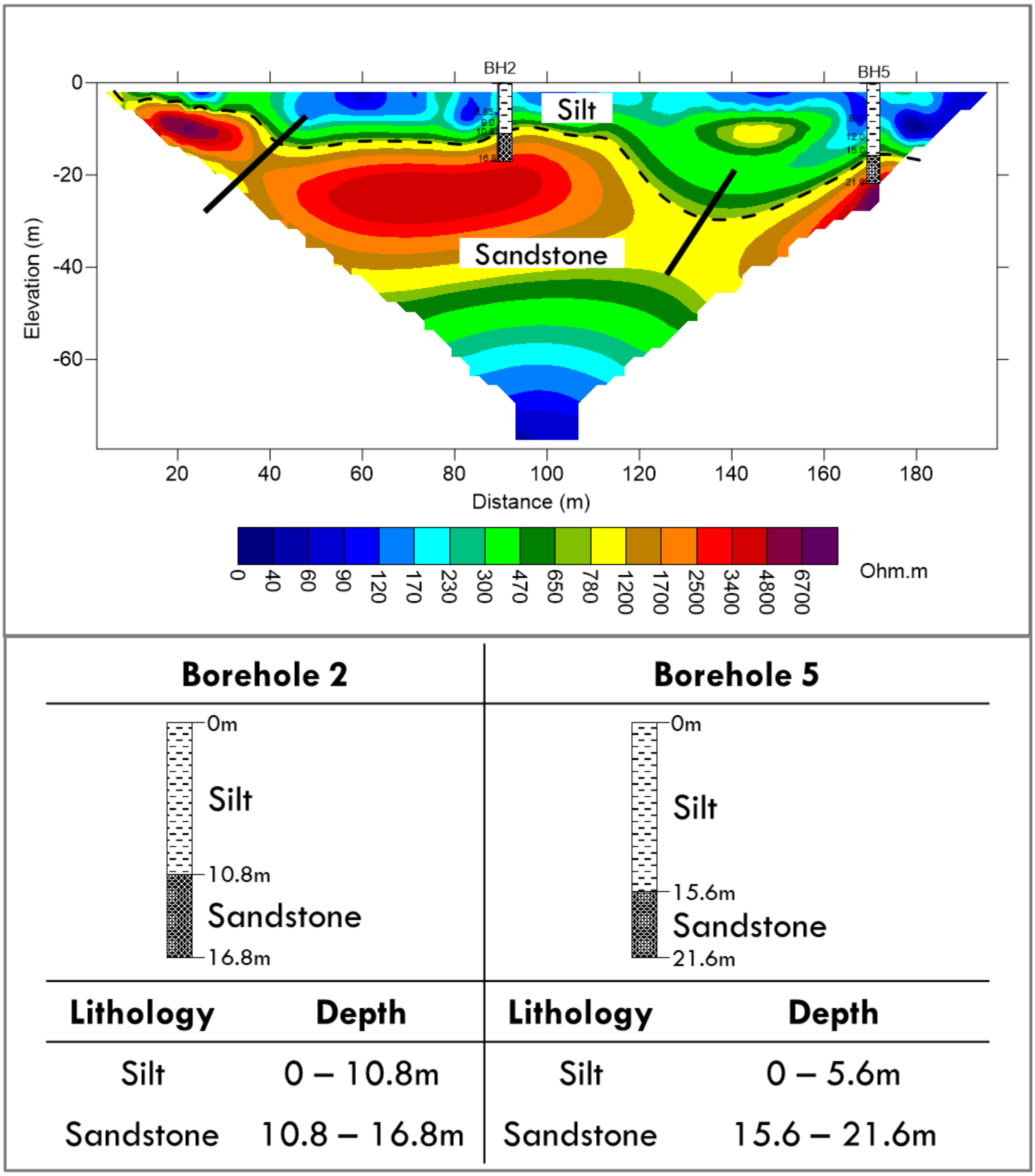

Fig. 5 ERT results generated from Line 1 with dashed line indicating the boundary between silt layer and sandstone layer.

In Malaysia, the general range of resistivity value for silt is recorded at 10 – 800 Ωm, while the resistivity values for sandstone varies from 500 Ωm to 5000 Ωm depending on the weathering rate of the lithology (Tan et al., 2018; Jinmin et al., 2013). With this reference, it is notable that silt has a lower resistivity value range as compared to sandstone. However, it can also be observed that the resistivity value range of 500–800 Ωm is applicable to both lithologies. Nonetheless, the borehole records on the resistivity survey lines of this study area coped well in distinguishing the resistivity boundary of these two lithologies, thus validating the boundary to be at 815 Ωm.

Furthermore, a few fractures are seen in the tomography displayed in Figures 5–7, indicated by the discontinuation of resistivity contours, that correlates to the changes of subsurface materials (Ezeh et al., 2022; Nabi et al., 2020). These fractures were drawn in Figures 5 – 7 with solid black lines. Based on the principle that, for a given material, a decrease in resistivity typically indicates an increase in water content – particularly when the infiltrating water is highly mineralized, as in this case (Huayllazo et al., 2023; Nabi et al., 2020). This approach has been utilized by numerous researchers to delineate fractures, especially for engineering construction

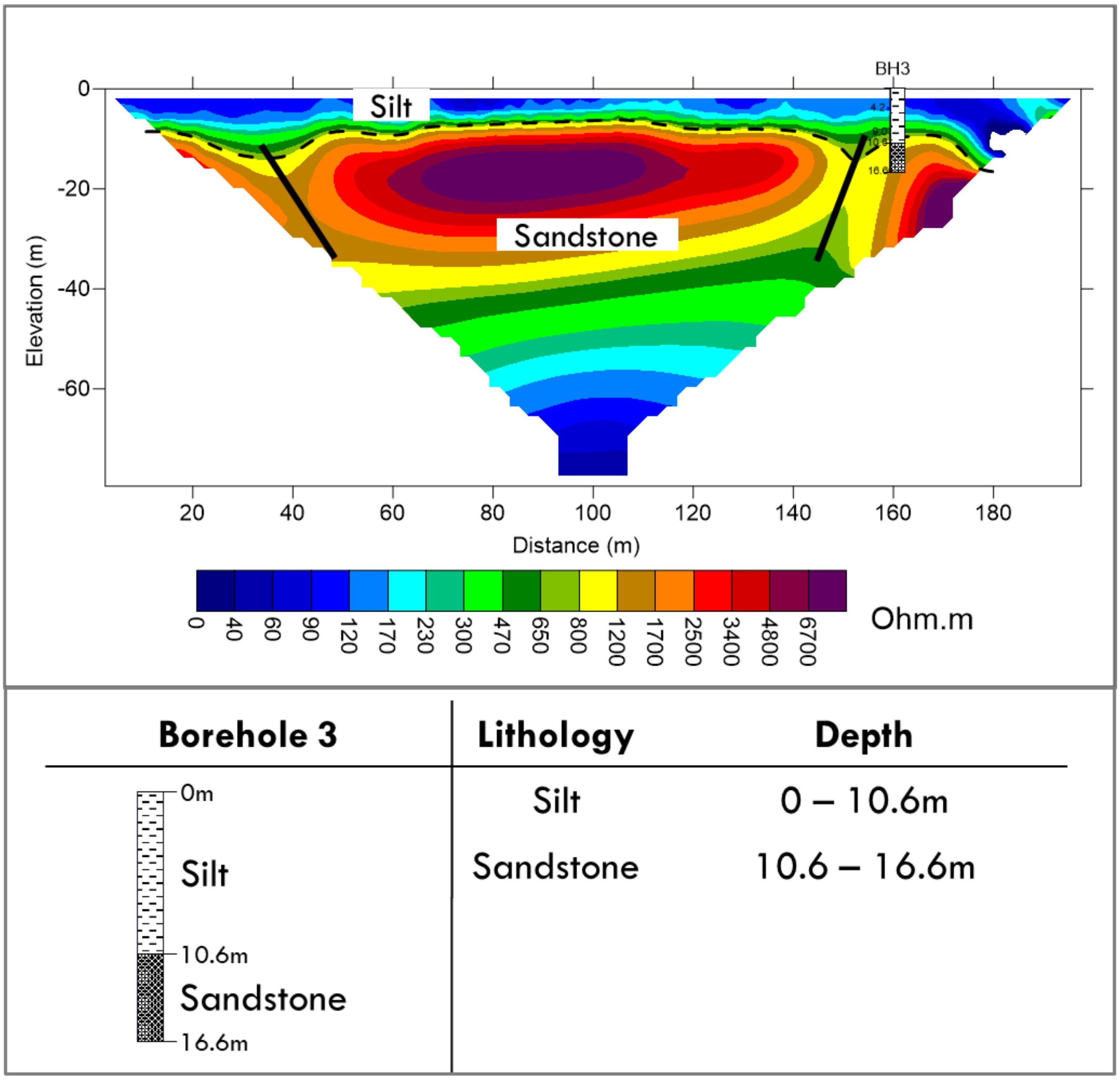

Fig. 6 ERT results generated from Line 2 with dashed line indicating the boundary between silt layer and sandstone layer at approximately -10 m in elevation.

works, groundwater development and waste disposal management (Riet et al., 2022).

According to literatures published by Das in 2015, silt overburden has low shear strength, thus is not suitable for bearing heavy loads unless the layer is sufficiently compacted and stabilized. To add on, silt overburden is highly compactible, making the layer prone to be compressed under load (Coduto et al., 2011). However, it was also mentioned that these challenges can easily be overcame, as the approaches to silt mitigation are wide and well-known.

Silt is a soft material, thus easily excavated whenever necessary to proceed with any construction (Coduto et al., 2011). Furthermore, the particle size of silt that is very fine will ease the excavation processes, thus facilitate for a quicker site preparation and grading (Hao et al., 2022). Excavated silts are also often reused for brickmaking, mud mortar and plaster, and plantation soil, which saves the cost of purchasing new raw materials (Hao et al., 2022).

Despite being easily excavated and widely reused, the retainment of silt layer is another approach taken in construction planning. A mixture of lime or cement or lime-cement into the silt overburden layer is often exploited to strengthen the shear strength of the silt (Jauberthie et al., 2010; Musta et al., 2010). In some cases, the use of geogrid layers is also implemented in the process of reinforcing the silt layer, as this improves the ductility of the overburden layer (Azadegan et al., 2013). Nevertheless, the use of piles, piers or rafts are also an alternative to reinforce the silt overburden layer (Ohja and Srivastava, 2023).

On the other hand, sandstone bedrock is readily suitable for future construction as it has high bearing capacity, low compressibility, and good drainage system (Bell, 2007). Some factors that should be taken

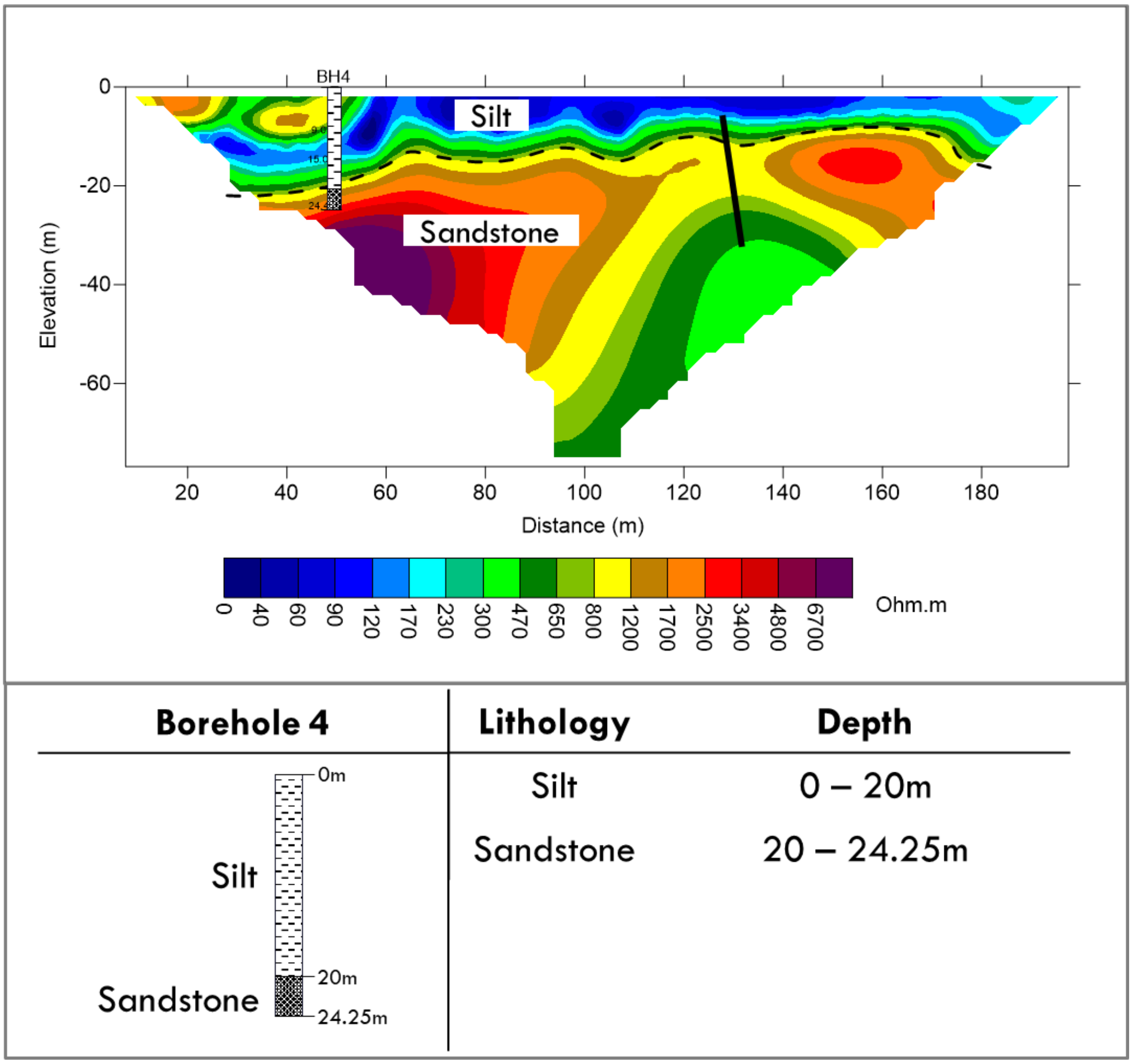

Fig. 7 ERT results generated from Line 3 with dashed line indicating the boundary between silt layer and sandstone layer at approximately 10–20 m in depth.

into consideration for sandstone bedrocks are the weathering grade that could reduce its strength (Bell, 2007; ISRM, 1981).

5. CONCLUSION

ERT surveys conducted in the study area successfully delineate the overburden layer of silts from the underlying bedrock of sandstone. The resistivity values that separate these two main layers are 815 Ωm, with silt layers recorded the resistivity values of ≤ 815 Ωm, and sandstone layers recorded the resistivity values of > 815 Ωm. This was validated by the borehole records obtained in the study area which quantified the same lithologies as seen in the ERT results. Additionally, fractures were also mapped on the ERT results shown by the discontinuity of lithology layer.

In conclusion, the overburden silt layer has to be reinforced prior to construction work to ensure the safety of workers and future infrastructures in the area, but the sandstone bedrock that has been mapped is inferred to be ready to bear the load of future infrastructures in the area. Therefore, this study area needs to strengthen or excavate the overburden silt layer before proceed with the school buildings construction work.

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