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Subsurface Characterization using Electrical Resistivity Method at Jelutong Dump Site, Georgetown, Northeast District, Penang

25th April 2021

Prepared by:
Assoc. Prof. Ir. Dr. Mohd Ashraf Mohamad Ismail

For:

HTC-Geoengineering Sdn. Bhd.
1, Lorong Talang 1, Taman Perai Utama, 13600 Perai, Pulau Pinang

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1 INTRODUCTION

1.1 General

USAINS Holding S.D.N. BHD. is contracted by H.T.C. Geoengineering Sdn. Bhd. to carry out subsurface characterization using electrical resistivity method at Jelutong Dump Site, Georgetown, Northeast District, Penang.

1.2 Objectives of the Study

This electrical resistivity survey aims to map and describe near surface and subsurface conditions at the site. The geophysical method using an electrical resistivity survey is used to acquire 2D electrical resistivity profiles of the site's subsurface condition concerning engineering geology/geotechnical application studies to achieve this objective.

1.3 Scope of Work

The scope of work for both the 2-D electrical resistivity survey comprises the following:

5 Survey alignments using Schlumberger with max 400 m in length. Each survey's length is based on the maximum allowable area to lay out the cable at site.

1.3.1 2-D Electrical Resistivity Survey

Electrical resistivity survey is often carried out to infer the subsurface condition from the electrical resistivity anomaly obtained from the electrical resistivity measurement. Electrical resistivity methods measured the earth materials' resistivity to infer the kind of material beneath the surface. The differences in the earth materials' resistivity will be used to identify and infer the different lithology and the hydrogeological condition. In general, huge areas can be covered by using this method. The electrical resistivity equipment is shown in Figure 1. Meanwhile, the proposed electrical resistivity survey layout is shown in Figure 2. An example of the electrical resistivity result is shown in Figure 3.

2 SUMMARY OF EVENTS

The work is planned to be conducted in 3 working day as detailed out below:

Date	Time	Task
21 April 2021	7.00 am. 9.00 am. 9.30 am. 10.00 am. 3.00 pm.	- Mobilization from U.S.M. Eng., Campus. - Arrive at site. - Site Recognition study for all survey lines - Data acquisition - Demobilization
22 April 2021	7.00 am. 9.00 am. 9.30 am. 10.00 am. 3.00 pm.	- Mobilization from U.S.M. Eng., Campus. - Arrive at site. - Site Recognition study for all survey lines - Data acquisition - Demobilization
26 April 2021	7.00 am. 9.00 am. 9.30 am. 10.00 am. 3.00 pm.	- Mobilization from U.S.M. Eng., Campus. - Arrive at site. - Site Recognition study for all survey lines - Data acquisition - Demobilization

3 PERSONNEL AND EQUIPMENT

3.1 Personal

3.1.1 U.S.M. Geophysical Survey Team

The following geophysical survey team from U.S.M. has been provided on-site for the electrical resistivity survey operation.

NO.	NAME	FUNCTION
1.	Assoc. Prof. Ir. Dr. Mohd Ashraf Mohamad Ismail	Geophysicist and Geotechnical engineer
2.	Ahmad Halmi Ghazali	Senior Assistant Engineer
3.	Rais Yusoh	Geophysicist
4.	Muhammad Khairi bin A. Wahab	Geophysicist
5.	Khairul Nizam Kamarrol	Geophysicist

3.2 LIST OF EQUIPMENT

3.2.1 Electrical Resistivity Equipment's

The following equipment was used for the electrical resistivity survey, as shown in Table 1 and Figure 1.

Table 1: Electrical resistivity survey equipment

NO.	ITEM	QUANTITY
1.	Terrameter LS	1
2.	100 m and 200 m cables sets (4 unit)	2
3.	Multi-purpose Cable 100m	2
4.	Jumpers	42
5.	Non-Polarized electrode	41
6	Cable Adapter (to laptop)	1
7.	Connection Cable (ES 10-64)	1
8.	Battery Cable	1
9.	12-volt Battery	4
9.	2 lb Hammer	4
10.	Laptop	1
11.	Remote cable	2
12.	GPS	2

Figure 1: ABEM Terrameter LS system.

4 FIELD PROCEDURE

4.1 Electrical Resistivity Survey

The resistivity origin is based on the four electrodes that are currents, c_1 and c_2, and potentials, p_1 and p_2, due to a study by the Schlumberger brothers in 1920. Reynolds (2011) mentioned that quantitative interpretations and conventional sounding surveys were generally used for the next 60 years after the Schlumberger brothers' work. In this method, the center point of the electrode arrays remains fixed, but the electrode spacing increases to gain detailed information about the subsurface. There are some ordinary arrays used in resistivity survey, and their geometric factors are based on the change of spacing between electrodes as shown in Figure 2.

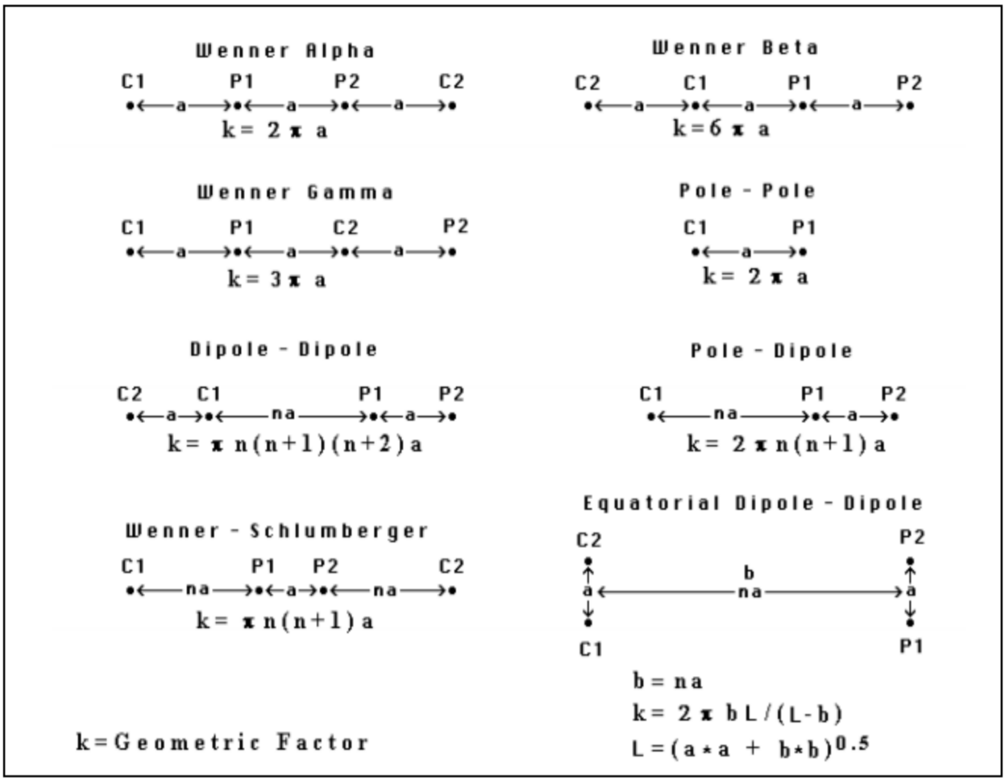


Figure 2: Common arrays used in resistivity survey and their geometric factors (Loke, 1994)

The electrical imaging system is now mainly carried out with a multi-electrode resistivity meter system. Such surveys use a number (usually 25 to 100) of electrodes laid out in a straight line with a constant spacing. A computer-controlled system is then used to automatically select the active electrodes for each measure (Griffith and Barker, 1993). Throughout the survey conducted in the proposed site, the pole-dipole protocol has been used with the ABEM SAS4000 system. Figure 3 shows the arrangement of a resistivity survey line. The data collected in the survey can be interpreted using an inexpensive microcomputer.

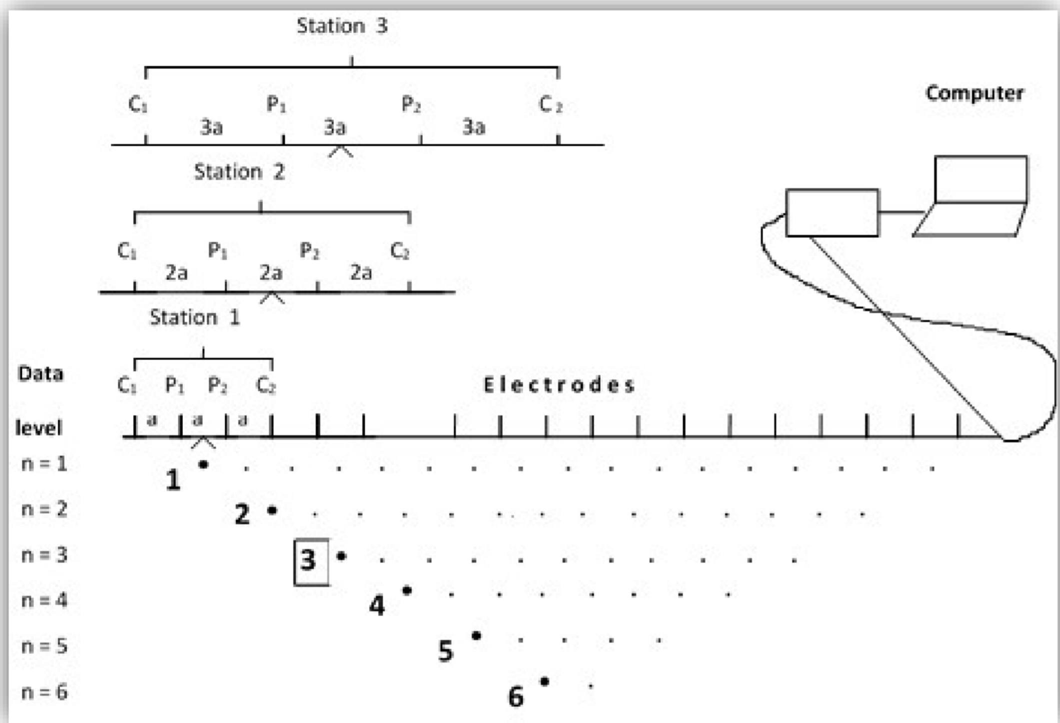


Figure 3: The electrodes' arrangement for a 2-D electrical survey and the sequence of measurements used to build up a resistivity section.

The resistivity method measures the resistivity distribution of the subsurface material. Tables 2 and 3 show the resistivity value of some of the typical rocks, soil materials, and water (Keller and Frischknecht 1966). Igneous and metamorphic rocks typically have high resistivity values. The resistivity of these rocks is mainly dependent on the degree of fracturing. Since the water table in Malaysia is generally shallow, the fractures are commonly filled with groundwater. The greater the fracturing, the lower is the resistivity value of the rock. For example, granite's resistivity varies from 5000 ohm-m in wet conditions to 10,000 ohm-m when it is dry. When these rocks are saturated with groundwater, the resistivity values are low to moderate, from a few ohm-m to less than a hundred ohm-m. Soils above the water table are drier and have a higher resistivity value of several hundred to several thousand ohm-m, while soils below the water table generally have resistivity values of less than 100 ohm-m. Also, clay has a significantly lower resistivity than sand.

Table 2: Resistivity of some common rocks and soil materials in the survey area (Keller and Frischknecht 1966)

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

Table 3: Electrical resistivity of some types of waters (Keller and Frischknecht 1966)

Type of water	Resistivity (ohm-m)
Precipitation	30 - 1000
Surface water, in areas of igneous rock	30 – 500
Surface water, in areas of sedimentary rock	10 - 100
Groundwater, in areas of igneous rock	30 - 150
Groundwater, in areas of sedimentary rock	> 1
Seawater	≈ 0.2
Drinking water (max. salt content 0.25%)	> 1.8
Water for irrigation and stock watering (max. salt content 0.25%)	> 0.65

4.1.1 Interpretation Technique

RES2DINV program is used to process converted raw data in the extension of. D.A.T. format. After the field survey, the resistance measurements are reduced to apparent resistivity values by the inversion process. RES2DINV used a least-squares inversion scheme to determine the appropriate resistivity value so that the calculated apparent resistivity values agree with the measured values. The inversion process is carried out to obtain three types of resistivity section, which comprise apparent resistivity, measured apparent resistivity, and inverse model resistivity (Figure 4). The misfit between measured and calculated apparent resistivity produces root mean square (R.M.S.) values. The R.M.S. error may be due to random error and systematic error. The random error may cause by the effect of telluric current that influences the whole resistivity readings while systemic error may cause by infirm contact between the electrode and the earth. The resistivity contour value is adjusted based on geological information that fits the resistivity range with different colors.

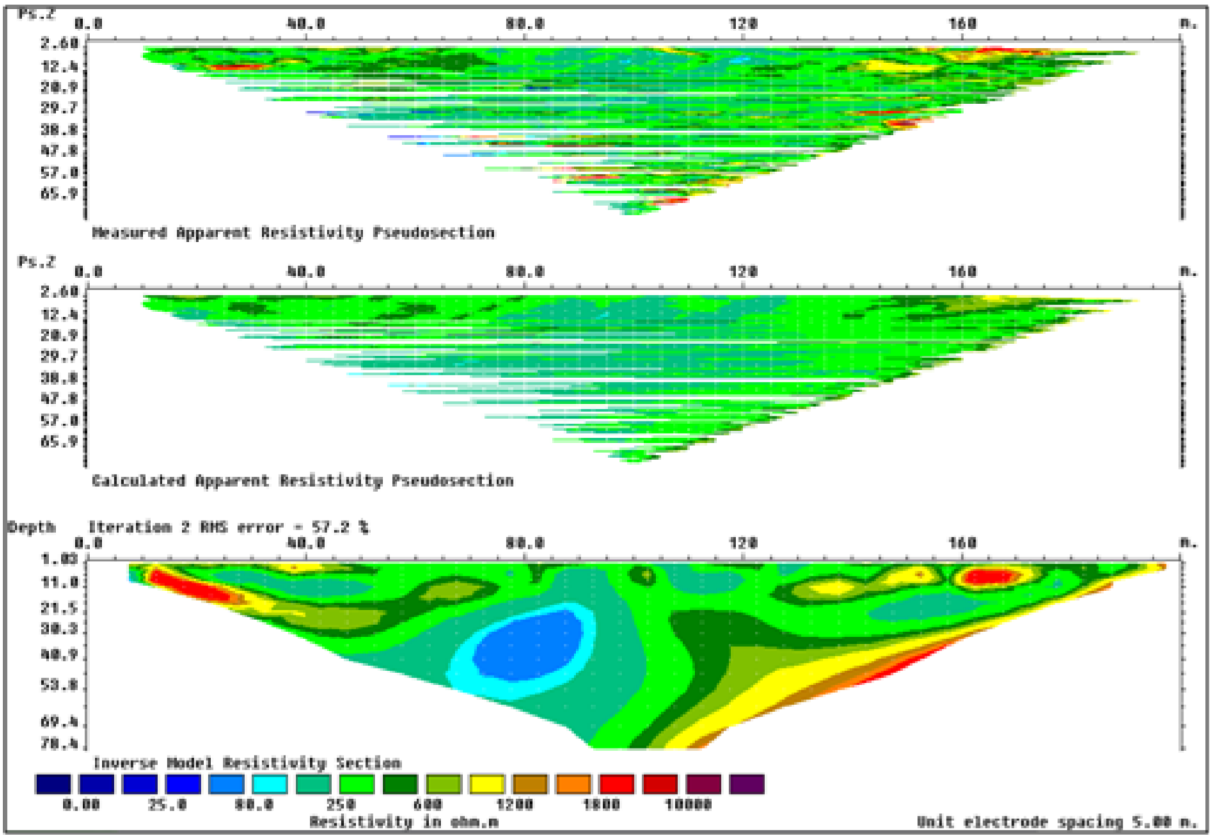


Figure 4: Example of the produced resistivity section by RES2DINV.

5 Result and Discussion

5.1 Study area and activities

This section presents the interpretation of electrical resistivity results and a related description of the investigation area's subsurface conditions. The location and geological condition of the study area are located on the reclaim area of Gula Formation. Suntharalingam and Teoh (1985) introduced the Gula Formation for a sequence of mainly grey to green-grey marine to estuarine clay. The formation varies in thickness from a few metres in the east to about 20m in the west and can be separated in two distinct members which is Matang Gelugor Member and Port Weld Member. According to Bosch (1986), Gula Formation consist of clay, silt, and sand with minor of gravel, shell and coral deposited in a marine environment after the most recent major low sea level. Kamaludin (1990) defined the Matang Gelugor

Member as comprising sand, gravel and sandy clay deposited in littoral and marine environments. While Port Weld Member consist of mainly silt and clay deposited in a mangrove environment with locally minor sand and gravel. All members in Gula Formation are deposited during Holocene (Figure 5 and 6).

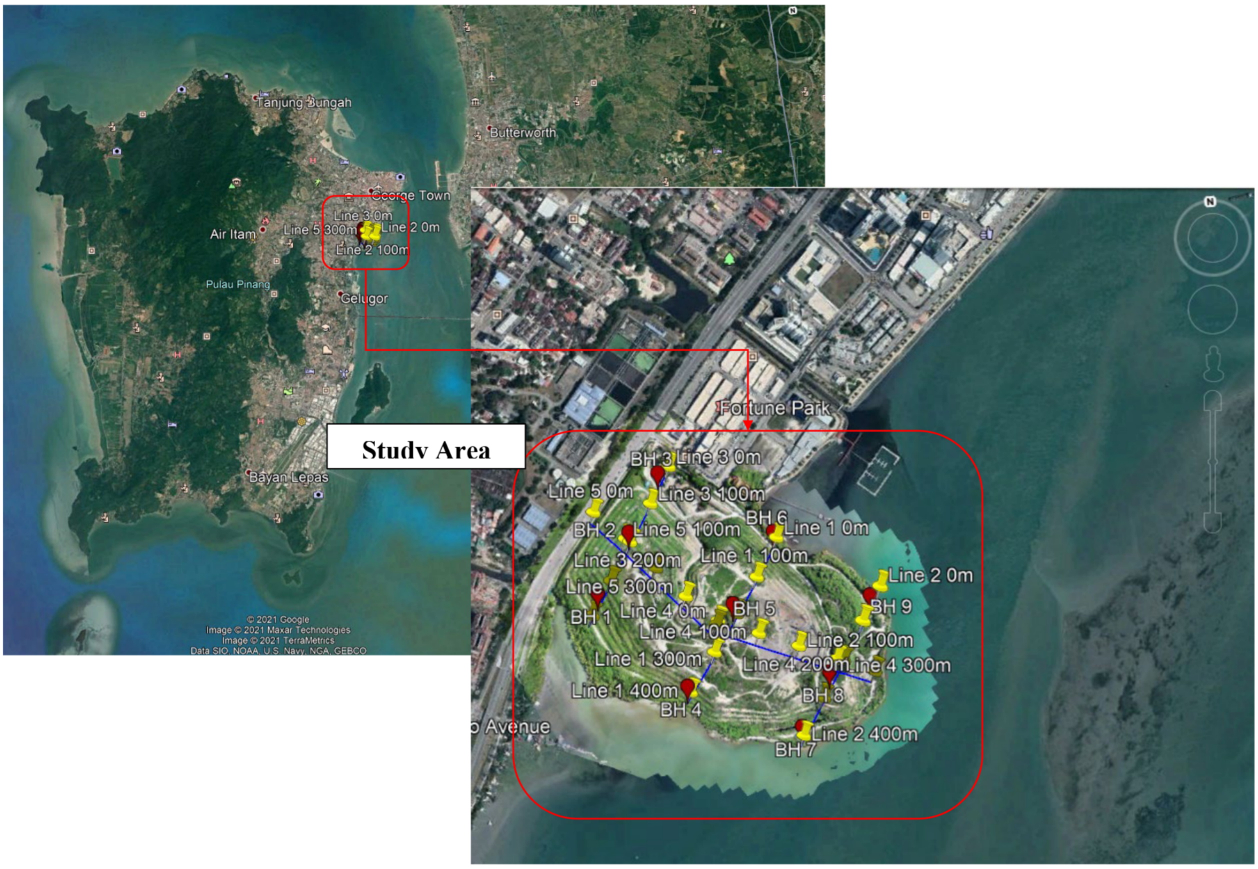


Figure 5: Location of the study area at Jelutong Dump Site, Georgetown, Northeast District, Penang.

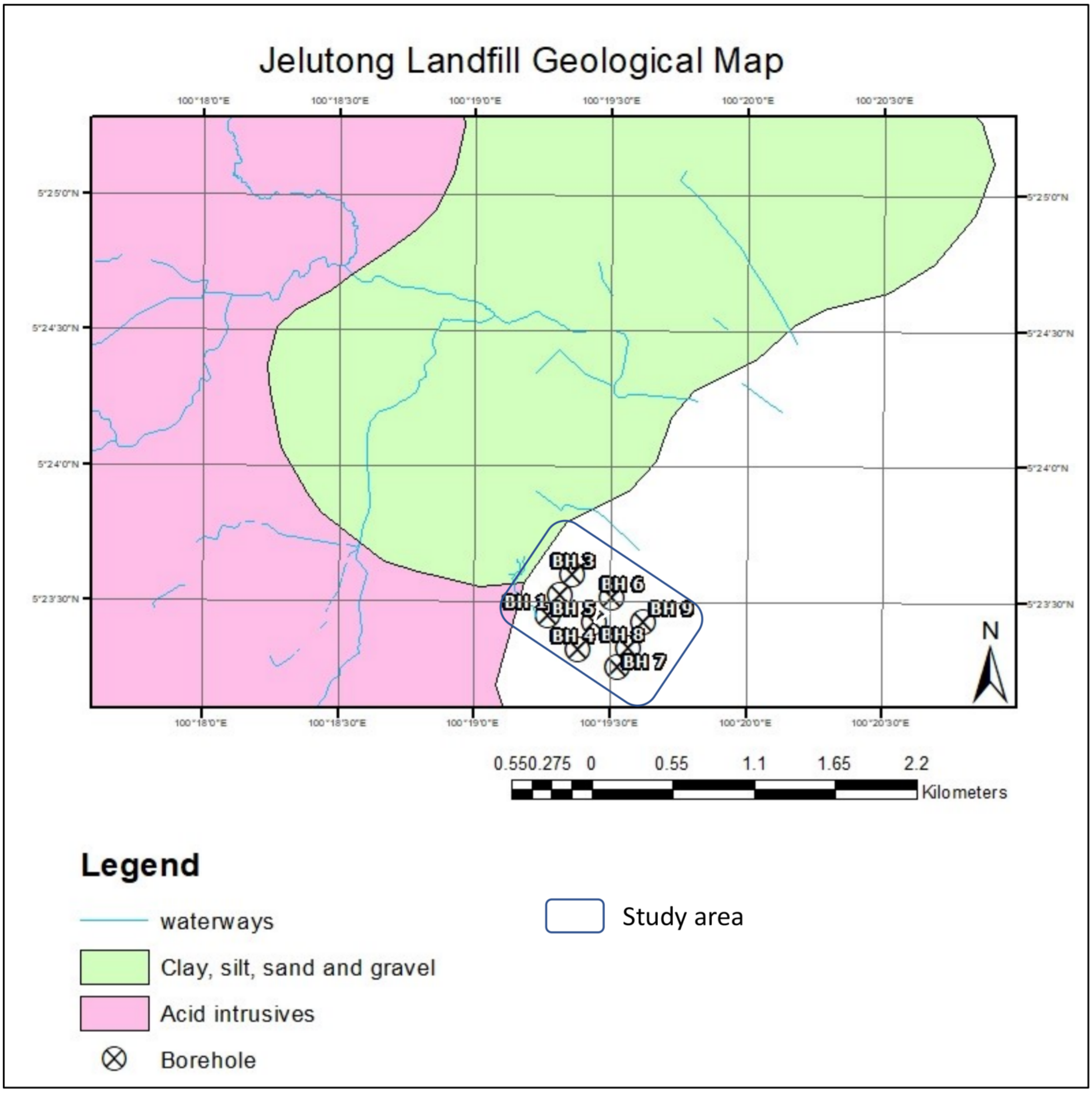


Figure 6: Geological condition of the study area at Jelutong Dump Site, Georgetown, Northeast District, Penang.

The overall survey alignments are shown in Figure 7 with the coordinates of the survey lines tabulated in Table 4. Meanwhile, the survey activities and the survey line are given in Figure 8 to 14.

Figure 7: Plan view of the 2D ground resistivity investigation area with the survey alignment at Jelutong Dump Site, Georgetown, Northeast District, Penang.

Table 4: Electrical Resistivity Survey Alignment Point

Line	POI	Latitude	Longitude
L1	L1_0m	5°23'30.79"N	100°19'30.42"E
	L1_400m	5°23'19.20"N	100°19'22.93"E
L2	L2_0m	5°23'26.36"N	100°19'30.42"E
	L2_400m	5°23'15.23"N	100°19'31.55"E
L3	L3_0m	5°23'36.86"N	100°19'22.39"E
	L3_400m	5°23'25.68"N	100°19'15.67"E
L4	L4_0m	5°23'19.90"N	100°19'37.41"E
	L4_400m	5°23'24.61"N	100°19'25.30"E
L5	L5_0m	5°23'33.70"N	100°19'16.30"E
	L5_400m	5°23'24.30"N	100°19'25.15"E

Figure 8: Resistivity survey line 1 at Jelutong Dump Site, Georgetown, Northeast District, Penang.

Figure 9: Resistivity survey line 2 at Jelutong Dump Site, Georgetown, Northeast District, Penang.

Figure 10: Resistivity survey line 3 at Jelutong Dump Site, Georgetown, Northeast District, Penang.

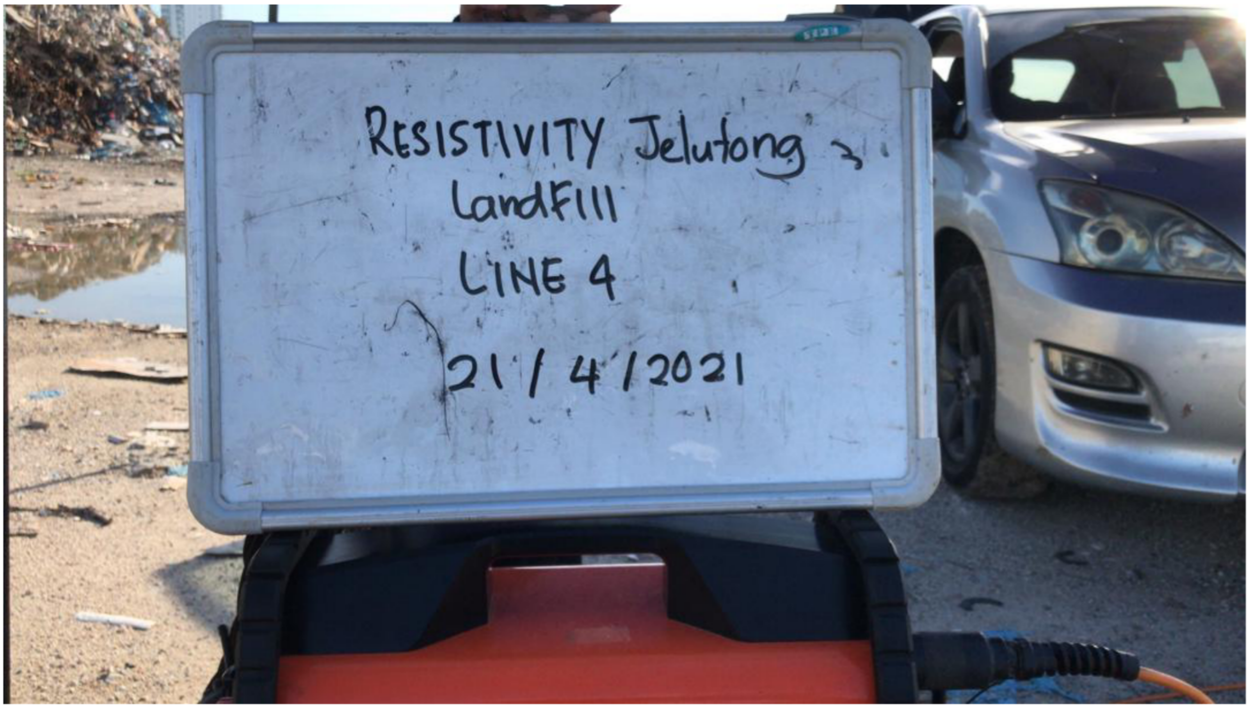


Figure 11: Resistivity survey line 4 at Jelutong Dump Site, Georgetown, Northeast District, Penang.

Figure 12: Resistivity survey line 5 at Jelutong Dump Site, Georgetown, Northeast District, Penang.

Figure 13: Resistivity survey activities at Jelutong Dump Site, Georgetown, Northeast District, Penang.

Figure 14: Resistivity survey activities at Jelutong Dump Site, Georgetown, Northeast District, Penang.

5.2 Resistivity results interpretation

This study's next step is to interpret the 2D resistivity models to characterize the subsurface of the dumping site area. Figure 15 to 19 shows the 2-D electrical resistivity image for survey Line 1 to 5. Based on the resistivity surveys carried out in the study area, the followings interpretation has been suggested based on the resistivity values to earth materials as given in Tables 5, 6, 7, and 8:

The earth materials resistivity values mainly depend on the materials porosity, moisture content, and liquid resistivity. In general, lower resistivity values are typical of saline water (seawater), brackish water, leachate, and clay. Intermediate resistivity values are associated with intermediate to fresh groundwater, partially saturated sandy soil, and the dumping materials. Meanwhile, high resistivity values are related to dry earth materials and dumping materials such as construction waste. In the interpretation of the electrical resistivity profiles, it is found that the small contrast in resistivity values between the leachate, saturated clay and saline seawater will not be adequate to map the differences or delineate the boundaries each of the different materials mentioned. For example, a very low to low resistivity values anomaly can be generated by an increase in ion content of the leachate plume or saline seawater in areas of sandy soil or clayey soils. The above problem is normally can be resolved by using the integration between electrical resistivity and Induce Polarization (I.P.) methods to distinguish between clay or sand bearing saline seawater or with leachate, which both are generally showing a similar low resistivity value.

A sizeable waste deposit was inferred to occupies most of the upper part of the resistivity profiles (line 1 to 5) from the surface to the depth of approximately 30-50 m in depth. A significant fraction of the uppermost layer is partially saturated to saturated without any significant leachate or saline to brackish water presence. However, the localize very low resistivity values present in this layer need to be further investigated to confirm if any leachate plume could represent together with the fill materials in this layer. This layer is also characterized by low to intermediate resistivity values (> 45 ohm.m to > 500 ohm.m) which implies that this layer is within the zone of groundwater fluctuation and highly affected by the infiltration of rainwater precipitation. The localized intermediate to high resistivity values (more than 200 ohm.m) presence in the upper layer indicate the presence of significant bulk materials of construction waste materials. The electrical resistivity values in this zone are also influenced by the seasonal variation of monsoon.

The subsequent layer for all the electrical resistivity profiles is interpreted as the boundary between the fill materials to the original soil. The low to very low resistivity values can be interpreted as an uncontaminated saturated clay layer or an original soil (Clayey/Silty Sand) with leachate/saline seawater/brackish water. In general, this layer can be delineated into three different zones. The first zone is characterized by very low resistivity values ranging from less than 0.5 ohm.m to 4.5 ohm.m. This zone might consist of vary saline to saline seawater with T.D.S. values of more than 10,000 mg/l and possible mix up with leachate plume. The lithology for this zone is consist of saturated clay to very porous sandy soil or silty to clayey sand. The second zone is characterized by salty brackish water with a potential mix up with leachate plume with T.D.S. value more than 1,500 mg/l. The lithology of this zone is quite like the first zone. The third zone is characterized by similar lithology of zone 1 and 2 but with poor to intermediate quality of groundwater.

The influence of seawater intrusion into this dumping site together with the present of leachate plume can be confirmed through the borehole drilling where several details chemical testing on the soil and the water sampling need to be carried out to confirm the findings from this electrical resistivity imaging. It is also strongly advice t o integrate the electrical resistivity with induced polarization (IP) methods to clearly differentiate the dumping waste, saline seawater, leachate plume, clay to sand materials and to confirm the zone of the mixture between the seawater, leachate, clay, and sand materials.

Table 5: Resistivity correlation (Liu and Evett, 2005)

Ohm-ft	2π Ohm . cm	Types of Materials
5 – 10	1000 – 2000	Wet to moist clayey soils
10 – 50	3000 – 15,000	Wet to moist silty clay and silty sols
50 – 500	15,000 – 75,000	Moist to dry silty and sandy soils
500 – 1000	30,000 – 100,000	Well-fractured to slightly fractured bedrock with moist-soil-filled cracks
1000	100,000	Sand and gravel with silt
1000 – 8000	100,000 – 300,000	Slightly fractured bedrock with dry-soil-filled cracks; sand and gravel with layers of silts
8000 (plus)	300,000 (plus)	Massive bedded and hard bedrock; coarse, dry sand and gravel deposits

[1]**Courtesy of Soiltest Inc.**

Table 6: Typical Resistivity Values of Earth Materials (Lee, 2002)

Material	Resistivity (ohm-cm)
Clay and saturated silt	0 – 10,000
Sandy clay and wet silty sand	10,000 – 25,000
Clayey sand and wet silty sand	25,000 – 50,000
Sand	50,000 – 150,000
Gravel	150,000 – 500,000
Weathered rock	100,000- 200,000
Sound rock	150,000 – 4,000,000

***Source*: Peck et al. (1974)**

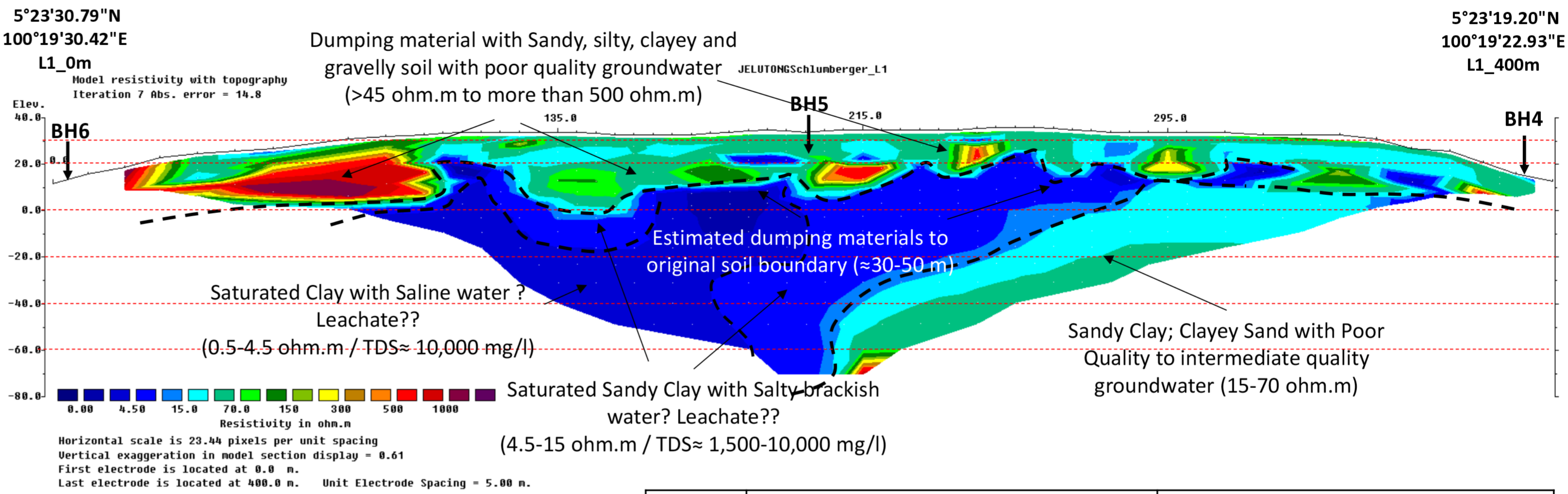
Lee. T., S. 2002. Slope Stability and Stabilization Methods: Geologic Site Investigation in chapter 4. 2nd. Ed. John Wiley & Sons, Inc. New York. pp, 228.

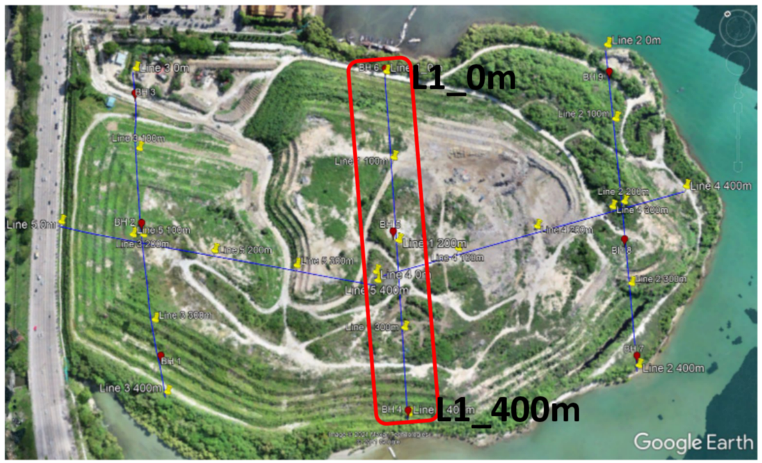
Table 7: Resistivity's of some of water and sediments (modified from Zohdy et al., 1993)

Resistivity, Ω m	Sediments	Interpretation
0.5–2.0	Very porous sand, or saturated clay	Seawater; very saline water; TDS: about 20 000 mg/l
2.0–4.5	Porous sand, or saturated clay	Saline water; TDS: about 10 000 mg/l
4.5–10.0	Sandy saturated, or sandy clay	Salty Brackish water; TDS: 10 000–1500 mg/l
10.0–15.0	Sandy clay, sandy gravel	Brackish water; TDS: 5000–1500 mg/l
15.0–30.0	Sand, gravel, some clay	Poor quality fresh water TDS: 1500–700 mg/l
30.0–70.0	Sand, gravel, minor clay	Intermediate quality Fresh water; TDS ~ 100 mg/l
70.0–100.0	Sand, gravel, no clay	Good quality fresh water; TDS small
More than 100.0	Coarse sand, gravel, no clay	Very good quality fresh water; TDS very small

Table 8: Resistivity's of some common rocks, minerals, and chemicals (Keller and Frishcknecht 1966, Daniels and Alberty 1996 and Loke 1999)

Material	Resistivity (Ωm)	Conductivity (Siemen/m)
Igneous and Metamorphic rocks		
Granite	5×10^3-10^6	10^{-6}-2×10^{-4}
Basalt	10^3-10^6	10^{-6}-10^{-3}
Slate	6×10^2-4×10^7	2.5×10^{-8}-1.7×10^{-3}
Marble	10^2-2.5×10^8	4×10^{-9}-10^{-2}
Quarzite	10^2-2×10^8	5×10^{-9}-10^{-2}
Schist	50-10^4	2×10^{-2}-10^{-4}
Hornfels	8×10^3-6×10^7	1.7×10^{-8}-1.3×10^{-4}
Sedimentary rocks		
Sandstone	8-4×10^3	2.5×10^{-4}-0.125
Shale	20-2×10^3	5×10^{-4}-0.05
Limestone	50-4×10^2	2.5×10^{-3}-0.02
Soils and water		
Clay	1-100	0.01-1
Alluvium	10-800	1.25×10^{-3}-0.1
Groundwater (Fresh)	10-100	0.01-0.1
Seawater	0.2	5
Chemicals		
Ferum	9.074×10^{-8}	1.102×10^7
0.01 M Potassium Chloride	0.708	1.413
0.01 M Sodium Chloride	0.843	1.185
0.01 M acetic acid	6.13	0.163
Xylene	6.998×10^{16}	1.429×10^{-17}

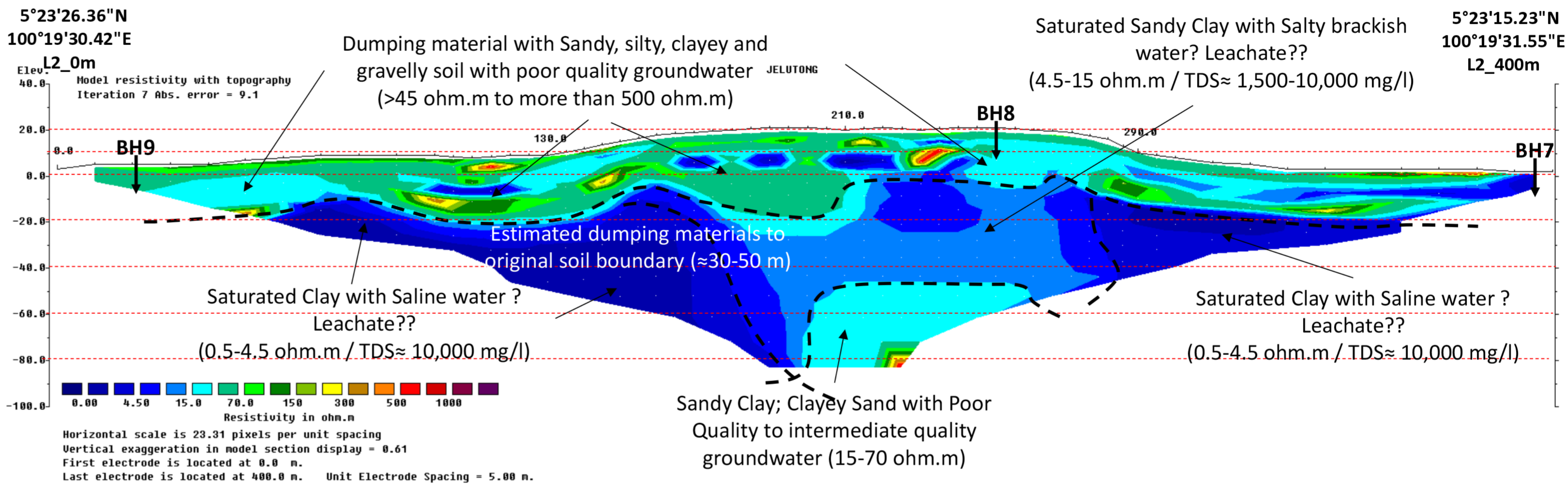


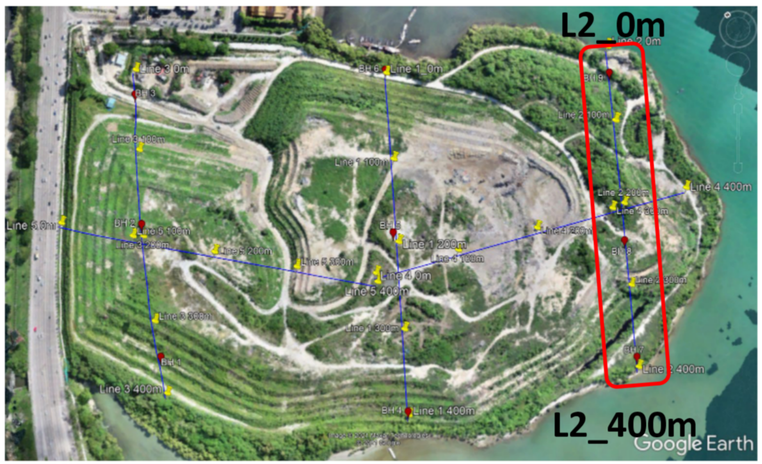


Resistivity Value (ohm.m)	Description (Liquid)	Description (Lithology/Material)
0.5-4.5	Very saline water to saline water (TDS > 10,000 mg/l) Leachate +++	Saturated clay, very porous sandy soil
4.5-15	Salty brackish water (TDS > 1,500 mg/l) Leachate ++	Saturated clay, silt with sand (Sandy clay, sandy silt)
15-70	Poor to Intermediate Quality groundwater	Sandy clay; Silty Clay or Clayey sand
45->500	Saturated to partially saturated earth materials (influence by precipitation; infiltration)	Dumping materials consist of wood, concrete, plastic etc.; Sandy, silty, clayey and gravelly soil

Electrical Resistivity Survey Line 1	**Subsurface Characterization using Electrical Resistivity Method at Jelutong Dump Site, Georgetown, Northeast District, Penang**

Figure 15: 2D ground resistivity result for Line 1 using Res2DINV software.

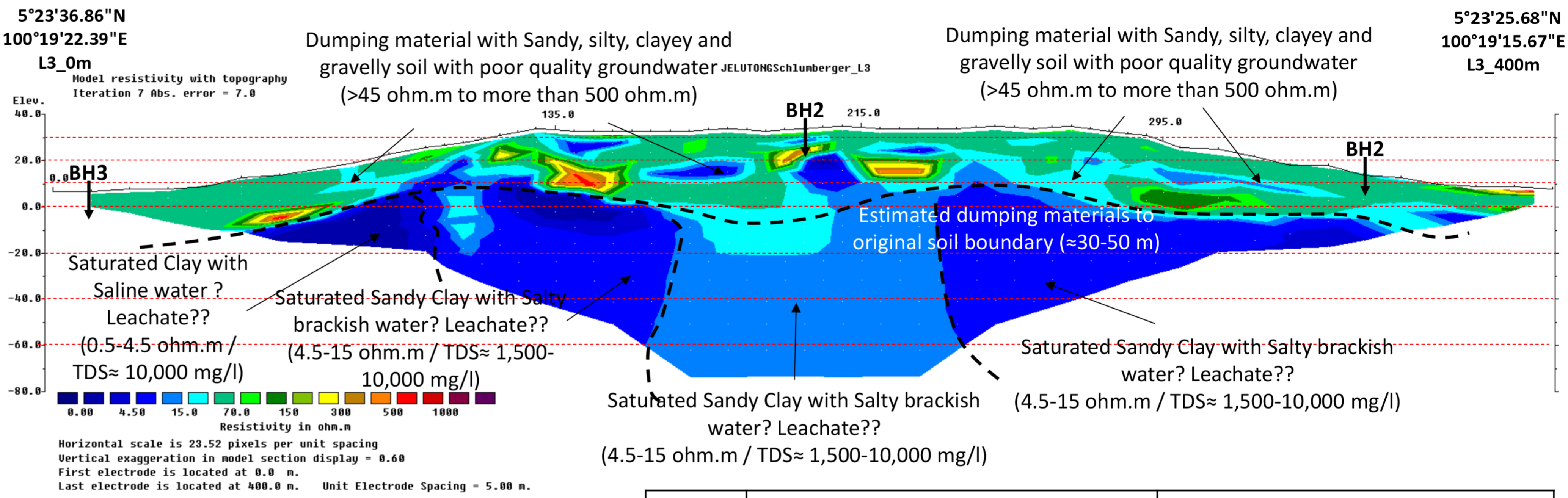


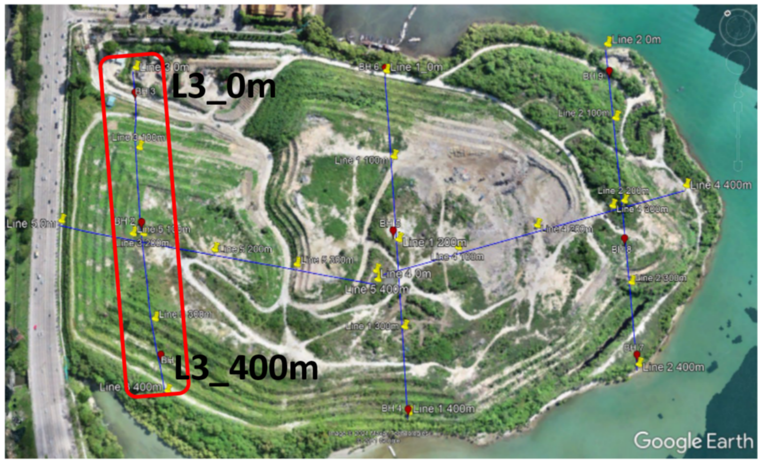


Resistivity Value (ohm.m)	Description (Liquid)	Description (Lithology/Material)
0.5-4.5	Very saline water to saline water (TDS > 10,000 mg/l) Leachate +++	Saturated clay, very porous sandy soil
4.5-15	Salty brackish water (TDS > 1,500 mg/l) Leachate ++	Saturated clay, silt with sand (Sandy clay, sandy silt)
15-70	Poor to Intermediate Quality groundwater	Sandy clay; Silty Clay or Clayey sand
45->500	Saturated to partially saturated earth materials (influence by precipitation; infiltration)	Dumping materials consist of wood, concrete, plastic etc.; Sandy, silty, clayey and gravelly soil

Electrical Resistivity Survey Line 2	**Subsurface Characterization using Electrical Resistivity Method at Jelutong Dump Site, Georgetown, Northeast District, Penang**

Figure 16: 2D ground resistivity result for Line 2 using Res2DINV software.

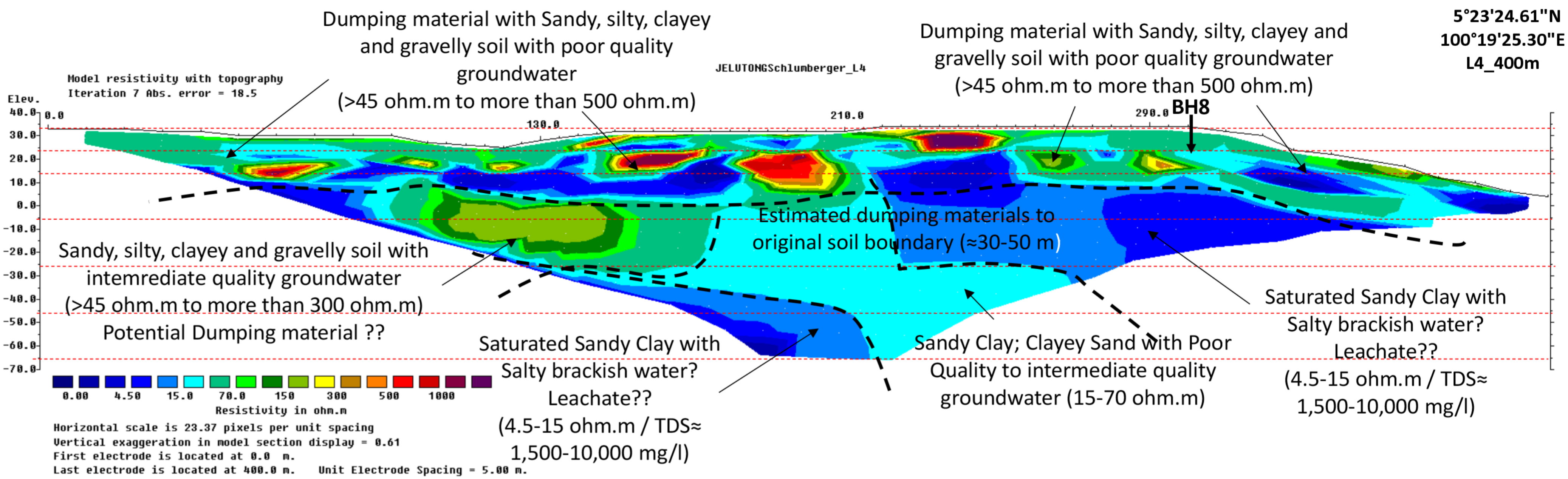




Resistivity Value (ohm.m)	Description (Liquid)	Description (Lithology/Material)
0.5-4.5	Very saline water to saline water (TDS > 10,000 mg/l) Leachate +++	Saturated clay, very porous sandy soil
4.5-15	Salty brackish water (TDS > 1,500 mg/l) Leachate ++	Saturated clay, silt with sand (Sandy clay, sandy silt)
15-70	Poor to Intermediate Quality groundwater	Sandy clay; Silty Clay or Clayey sand
45->500	Saturated to partially saturated earth materials (influence by precipitation; infiltration)	Dumping materials consist of wood, concrete, plastic etc.; Sandy, silty, clayey and gravelly soil

Electrical Resistivity Survey Line 3	**Subsurface Characterization using Electrical Resistivity Method at Jelutong Dump Site, Georgetown, Northeast District, Penang**

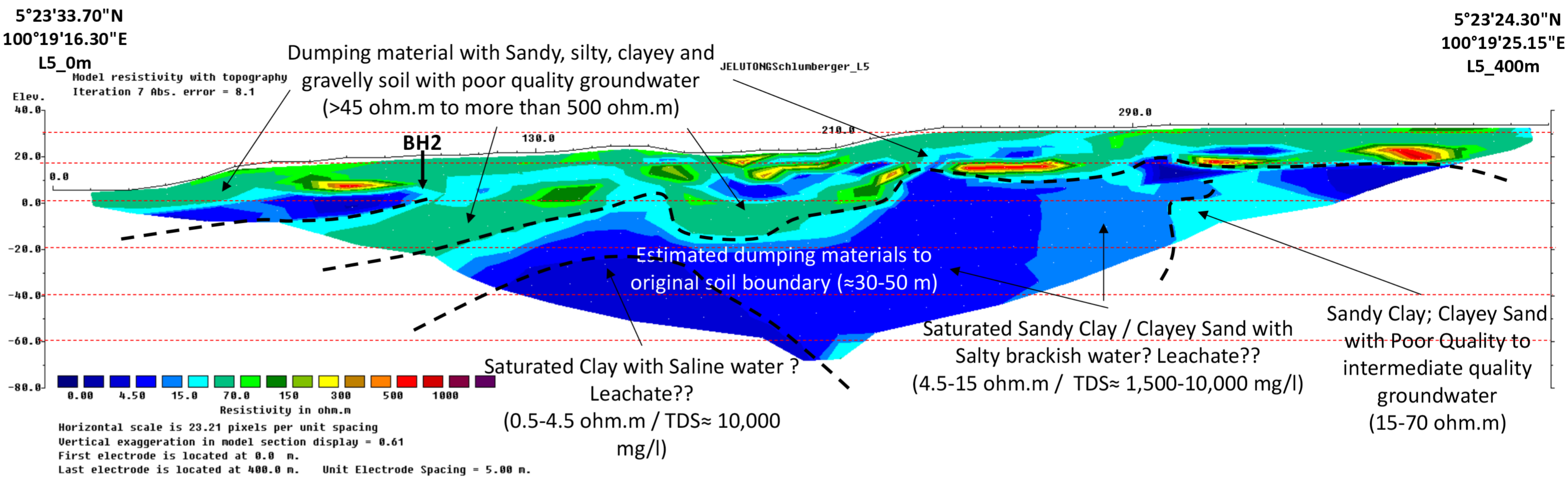
Figure 17: 2D ground resistivity result for Line 3 using Res2DINV software.



Resistivity Value (ohm.m)	Description (Liquid)	Description (Lithology/Material)
0.5-4.5	Very saline water to saline water (TDS > 10,000 mg/l) Leachate +++	Saturated clay, very porous sandy soil
4.5-15	Salty brackish water (TDS > 1,500 mg/l) Leachate ++	Saturated clay, silt with sand (Sandy clay, sandy silt)
15-70	Poor to Intermediate Quality groundwater	Sandy clay; Silty Clay or Clayey sand
45->500	Saturated to partially saturated earth materials (influence by precipitation; infiltration)	Dumping materials consist of wood, concrete, plastic etc.; Sandy, silty, clayey and gravelly soil

Electrical Resistivity Survey Line 4	**Subsurface Characterization using Electrical Resistivity Method at Jelutong Dump Site, Georgetown, Northeast District, Penang**

Figure 18: 2D ground resistivity result for Line 4 using Res2DINV software.



Resistivity Value (ohm.m)	Description (Liquid)	Description (Lithology/Material)
0.5-4.5	Very saline water to saline water (TDS > 10,000 mg/l) Leachate +++	Saturated clay, very porous sandy soil
4.5-15	Salty brackish water (TDS > 1,500 mg/l) Leachate ++	Saturated clay, silt with sand (Sandy clay, sandy silt)
15-70	Poor to Intermediate Quality groundwater	Sandy clay; Silty Clay or Clayey sand
45->500	Saturated to partially saturated earth materials (influence by precipitation; infiltration)	Dumping materials consist of wood, concrete, plastic etc.; Sandy, silty, clayey and gravelly soil

Electrical Resistivity Survey Line 5	Subsurface Characterization using Electrical Resistivity Method at Jelutong Dump Site, Georgetown, Northeast District, Penang

Figure 19: 2D ground resistivity result for Line 5 using Res2DINV software.

6 CONCLUSION

A geophysical investigation using electrical resistivity method was conducted at the dumping site located at Jelutong, Georgetown, Northeast District, Penang. The main objective of the electrical survey is to delineate the different lithologic layers, to estimate the boundary between the dumping materials to the original soil and to evaluate the contamination of groundwater through the seawater intrusion and the leachate plume. From the results, the dumping site can be categorized into 2 distinctive layers. The first layer is characterized as the fill layer with the dumping waste materials with the thickness of this layer varies from 30-50 m in depths. The electrical resistivity of this layers is generally ranging from 45 ohm.m to more than 500 ohm.m with localize very low resistivity values of less than 30 ohm.m. The electrical resistivity values of this zone are strongly influence by the seasonal variation of the monsoon, where the groundwater level fluctuation is affected by the infiltration from precipitation. The subsequent layer consists of original soil mainly clayey/silty sand or sandy/silty clay with mix of saline seawater and leachate. This finding should be confirmed with borehole drilling with soil chemical/groundwater analysis. As a conclusion, the electrical resistivity results alone without the integration with induced polarization (IP) methods cannot clearly differentiate/delineate the boundaries or the mix zones between saline sweater intrusion, leachate plume and clay to sand soil.

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