SOIL PROFILE IDENTIFICATION AROUND NECATIBEY SUBWAY STATION (ANKARA, TURKEY), USING ELECTRICAL RESISTIVITY IMAGING (ERI)

Özgür Aktürk*[1] and Vedat Doyuran[2]

[1] Akdeniz University, Department of Geological Engineering, Dumlupınar Blvd., TR-07058, Campus - Antalya, Turkey

[2] Middle East Technical University, Department of Geological Engineering, Inonu Blvd., TR-06531, Ankara, Turkey

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Abstract

In this study, multi electrode resistivity method was applied in order to identify soil profile around Necatibey Subway Station of Kızılay-Çayyolu metro line, Ankara, Turkey. The Necatibey Metro Station is located within the alluvial deposits of Dikmen stream and the so-called Ankara clay. At the metro station a number of boreholes were drilled. However, due to the spacing of the boreholes the boundary between alluvium and Ankara clay deposits could not be separated precisely. Thus, electrical resistivity studies have been planned for the delineation of the boundaries of the two deposits.

For every measurement section, Schlumberger N6-Dipole Dipole N4, Dipole Dipole N6, Schlumberger N6 and Wenner Alpha arrays were used. Measured data were interpreted by using RES2DINV software and correlated with borehole logs. According to resistivity sections taken from the location of Necatibey Station, silty clay and gravelly sand units which belong to Dikmen stream channel deposits, as well as fill material overlying and clayey levels which belong to Ankara clay underlying these units were identified. Based on borehole logs and resistivity data 3-dimensional lithological subsurface model of the survey area is constructed. The resultant 3-dimensional diagrams may serve engineers as a practical tool while considering construction stages, groundwater-structure interactions within short and long term, and probable remedial measures.

Keywords: multi-electrode resistivity profile, two-dimensional resistivity survey, 3-dimensional subsurface model, Necatibey subway station

1. Introduction

It is common for major cities (e.g., the city of Ankara) to be founded on alluvial deposits of clays, silts and sands, usually classified as soft ground. Ground movements in response to the groundwater drainage and excavation of the tunnel will be transmitted to the surface. In order to estimate those movements (deformations) numerically, one has to construct soil profile precisely. Identifying critical soil profile at the working area is the basis of any numerical modeling. The Necatibey Metro Station is located within the alluvial deposits of Dikmen stream and the so-called Ankara clay. At the metro station a number of boreholes were drilled. However, due to the spacing of the boreholes the boundary between alluvium and Ankara clay deposits could not be separated precisely. Thus, in this study, Electrical Resistivity Imaging (ERI) was utilized to distinguish soil types at the study area. By correlating these geophysical test results with the boring logs, 3-dimensional soil profile was revealed at the study area to build up a basis for numerical models.

2. Location of the Study Area

The study area is the Ankara Subway System Kızılay-Çayyolu Line Necatibey Station located among the buildings of Turkish General Stuff, Turkish Air Force and General Directorate of Highways (Figure 1).

Figure 1. Study area and resistivity profile locations shown by solid lines [6].

Necatibey Station is about 140 m long. It has two horse-shoe shape main tunnels each 9 meters high and 11 meters wide. There are also four connection tunnels between them. Above the tunnel floor there will be a pedestrian floor and a shopping center. Three escalators were also planned for the pedestrians.

Since the project is located among residential, governmental and military buildings, the construction stage is undergoing major challenges. The project works have to be performed under extreme care in order not to damage any of the surrounding structures above ground or service infrastructure founded below the ground as well as not to interfere with daily lives of the population within the vicinity of the neighborhood. Passing by many important residential and governmental areas the project would have a major effect on the city of Ankara. Although the project is designed to make this a positive one, a minor mistake in the engineering applications can cause a mess in this critical area.

The reason which makes this project special and construction works difficult is that the extension of the Necatibey Station passes through the alluvium of the Dikmen Creek almost perpendicular. Dikmen Creek watershed starts from the south ridge of Dikmen and extends towards Sıhhiye (Figure 2). Its catchment area is about 13.5 km^2. Çaldağ Hill at the North of Oran Site is the highest peak in the catchment area and the elevation around the Eskişehir road is about 890 meters. Average slope of the valley is about 8 degrees. The intersection area of Eskişehir road and Dikmen Valley is just west of the Turkish Air Force and between Turkish General Stuff and Necatibey Street. Since the topography is getting flat in this part Dikmen Valley spreads out laterally and continues towards Sıhhiye roughly.

3. Boring Logs

In order to reveal the geology along the Necatibey Station a number of boreholes were planned. A total of 11 boreholes were drilled [12] to figure out the type, thickness, contact relationships, geological and geotechnical properties of lithological units present along the Necatibey Station. Details regarding these boreholes are given.

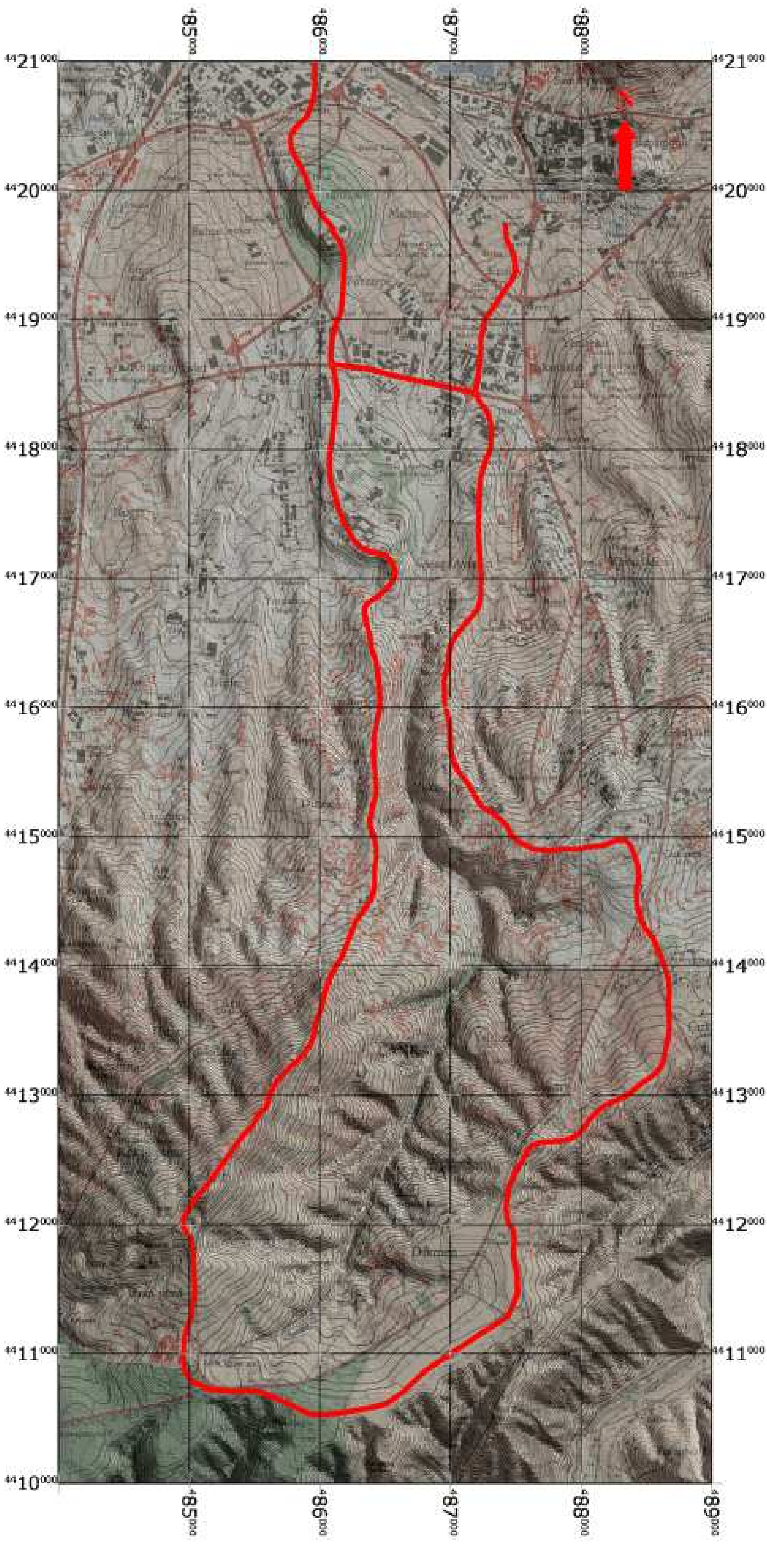


Figure 2. Dikmen Creek catchment area (scale: 1/50000).

By considering soil groups (according to Unified Soil Classification System), color index and SPT values the units belonging to alluvium and Ankara clay (Gölbaşı formation) were separated. Boring logs were reinterpreted and illustrated in Figure 3 through Figure 7 by considering their level and coordinates and by constituting cross-sections.

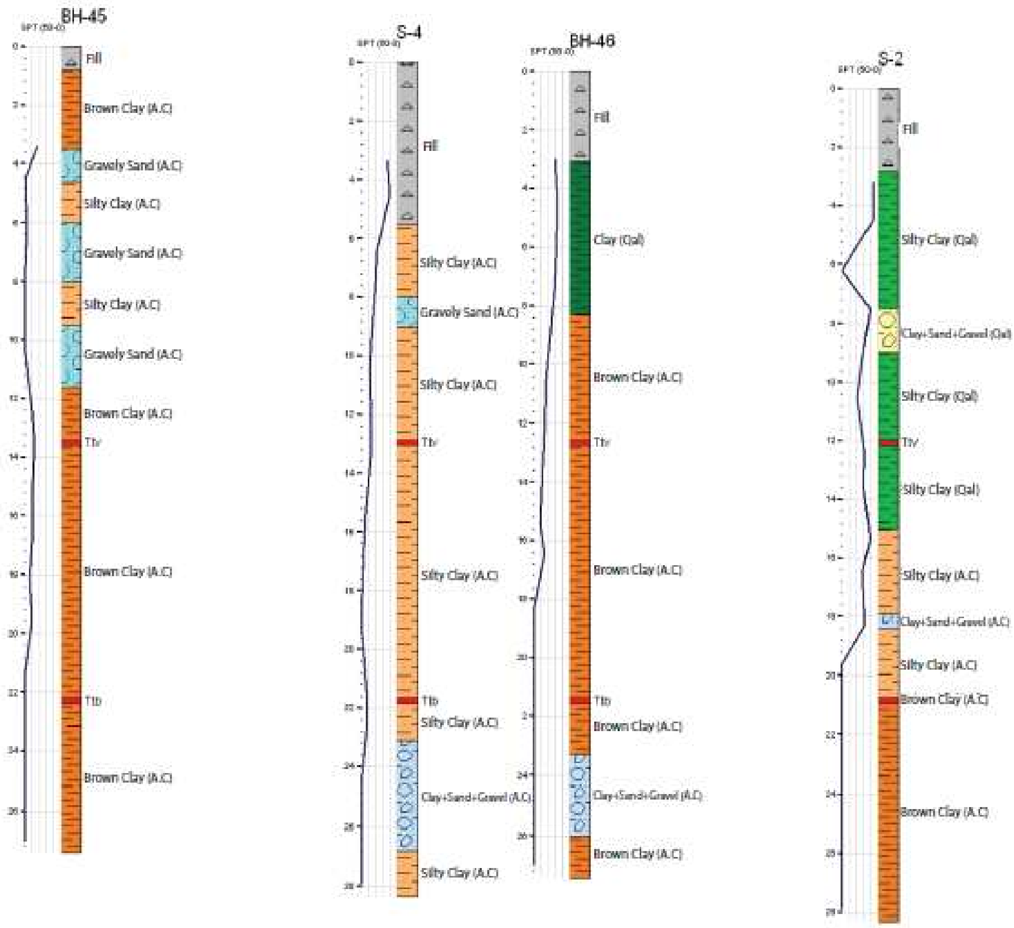


Figure 3. Line 1 boring logs.

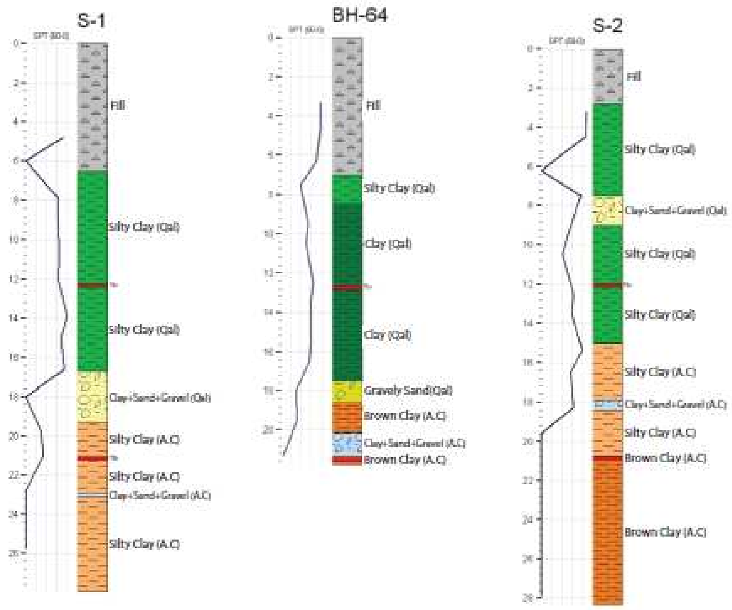


Figure 4. Boring logs between Line1 and Line 2.

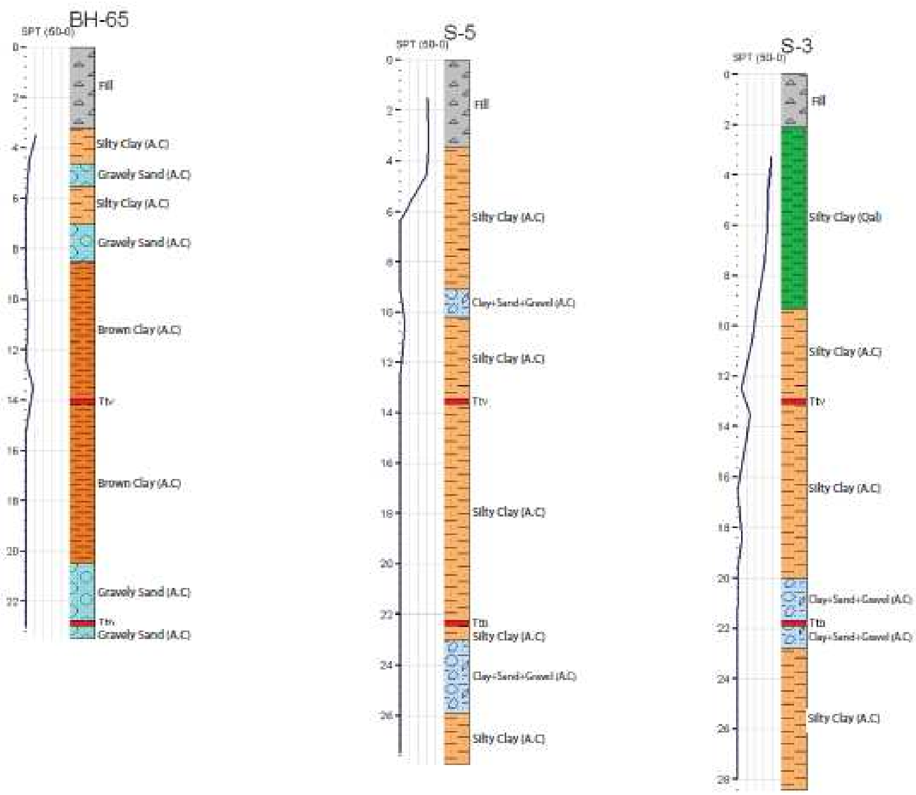


Figure 5. Line 2 boring logs.

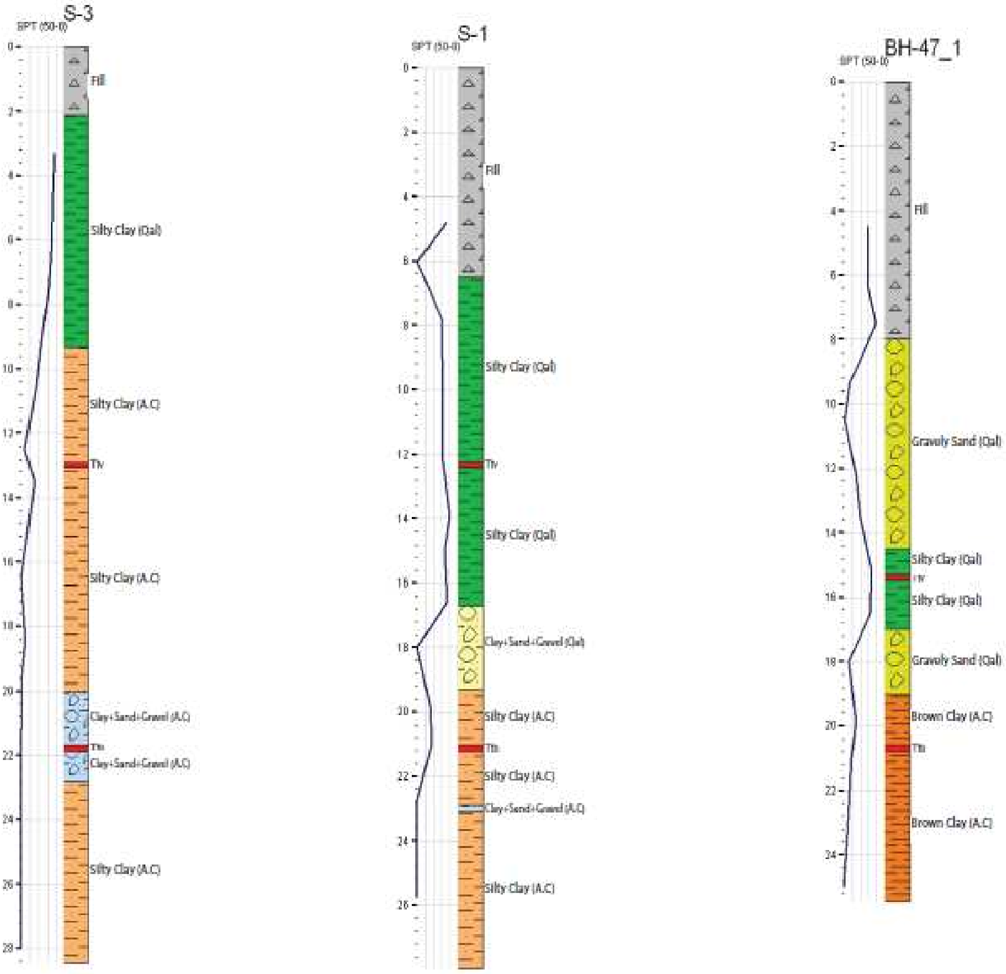


Figure 6. Line 2 boring logs (cont'd).

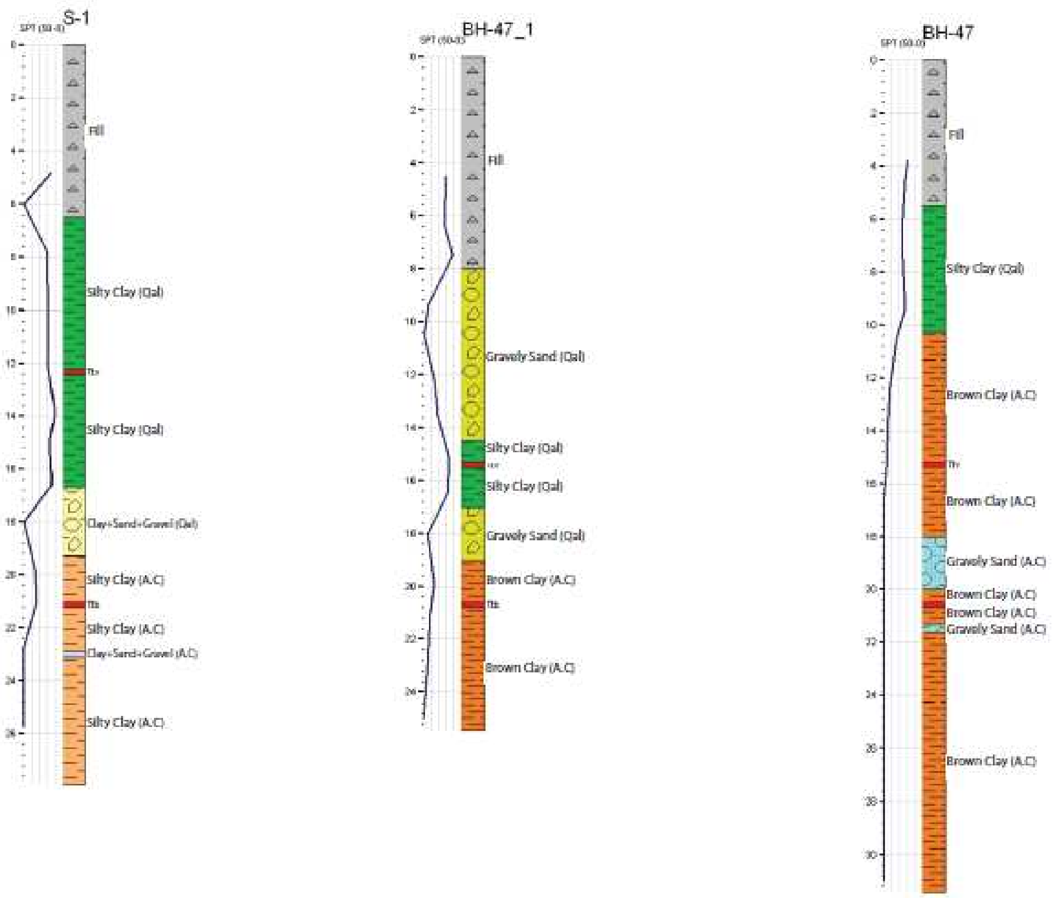


Figure 7. Line 2 boring logs (cont'd).

Boring logs indicate that clayey, silty and sandy gravelly levels belong to Dikmen Creek alluvium and are observed at BH-46, BH-64, S-1, S-2, S-3, BH-47-1 and BH-47. Boring logs BH-46, BH-47 and S-3 penetrate thru clay and silty clay levels of the Dikmen Creek alluvium. Sandy gravelly levels are encountered within boring S-1 (16.70-19.30 m), S-2 (above tunnel roof, 7.50-9.00 m), BH-64 (17.50-18.60 m), BH-47-1 (8.00-14.50 m and 17.00-19.00 m). The thickest channel fill (gravelly sand, 6.50 m) of the Dikmen Valley is observed in BH-47-1. At 2.50 m. below this channel fill there is another gravelly sand unit (2.00 meters thick) representing probably an old river bed.

The alluvium of the Dikmen Valley cuts Necatibey Station almost perpendicularly and it is composed of clay, silty clay and gravelly sand units. Aforementioned alluvium aquifer is the only reason for high rate (8 l/sec) and continuous groundwater flow during construction of main tunnels [11]. The Ankara clay is dominantly composed of silty and/or sandy clays with occasional sand and gravel lenses. Even though fine-grained deposits are dominant, the sand and gravel lenses are also encountered. The Ankara clay is of Pliocene age [12]. It is basically silty clay and gravelly, sandy clay that is red, brown and beige, fissured, contains carbonate concretions, partly has layers of sand and gravel, either low or high in plasticity, very stiff and over-consolidated.

4. Electrical Resistivity Imaging (ERI) studies

Electrical Resistivity (ER), also called DC Resistivity, is one of the oldest and most popular geophysical techniques in the field of near surface geophysics. During the last two decades the technique has been revolutionized in terms of data acquisition systems, i.e. the development of multi-electrode and capacitively-coupled resistivity systems and processing software. After these developments, the method has been more frequently referred to as Electrical Resistivity Imaging (ERI) or Electrical Resistivity Tomography (ERT).

Electrical Resistivity Imaging (ERI) is based on injecting electrical current into the subsurface using a pair of electrode (current electrodes) and measuring the potential gradient between another pair of electrode (potential electrodes). The measured resistance is then converted into apparent resistivity by multiplying the resistance by an appropriate geometric factor, which depends on the type of acquisition array being used. The apparent resistivity is then inverted in order to come up with the true subsurface resistivity and to reveal the thickness and depth of individual resistivity layers within the subsurface. Inversion is a fundamental step in all modern resistivity imaging surveys. It is, basically, a mathematical procedure by which the subsurface physical parameter distribution is estimated based on a set of field measurements ([1], [2]).

4.1. Data Acquisition and Processing

In a typical survey, most of the fieldwork is in laying out the cable and electrodes. After that, the measurements are taken automatically and stored in the computer. Most of the survey time is spent waiting for the resistivity meter to complete the set of measurements. To obtain a good 2-D picture of the subsurface, the coverage of the measurements must be 2-D as well. As an example, Figure 8 shows a possible sequence of measurements for the Wenner electrode array for a system with 20 electrodes. In this example, the spacing between adjacent electrodes is “a”. The first step is to make all the possible measurements with the Wenner array with electrode spacing of “1a”. For the first measurement, electrodes number 1, 2, 3 and 4 are used. Notice that electrode 1 is used as the first current electrode C1, electrode 2 as the first potential electrode P1, electrode 3 as the second potential electrode P2 and electrode 4 as the second current electrode C2. For the second measurement, electrodes number 2, 3, 4 and 5 are used for C1, P1, P2 and C2 respectively. This is repeated down the line of electrodes until electrodes 17, 18, 19 and 20 are used for the last measurement with “1a” spacing. For a system with 20 electrodes, note that there are 17 (20-3) possible measurements with “1a” spacing for the Wenner array [3].

After completing the sequence of measurements with “1a” spacing, the next sequence of measurements with “2a” electrode spacing is made. First electrodes 1, 3, 5 and 7 are used for the first measurement. The electrodes are chosen so that the spacing between adjacent electrodes is “2a”. For the second measurement, electrodes 2, 4, 6 and 8 are used. This process is repeated down the line until electrodes 14, 16, 18 and 20 are used for the last measurement with spacing “2a”. For a system with 20 electrodes, note that there are 14 (20 - 2x3) possible measurements with “2a” spacing.

The same process is repeated for measurements with “3a”, “4a”, “5a” and “6a” spacing. To get the best results, the measurements in a field survey should be carried out in a systematic manner so that, as far as possible, all the possible measurements are made. This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements [4].

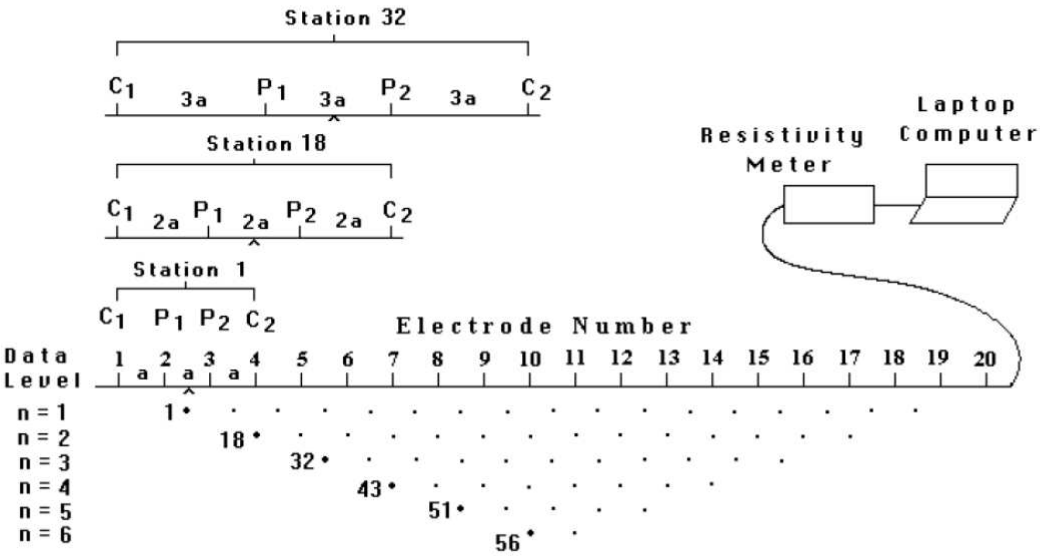


Figure 8. The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudosection [3].

4.2. Considerations and Limitations

There are different factors that affect the movement of current in the subsurface and therefore the performance of the ERI: water content, temperature, ions (their concentration and mobility), metal content, porosity, permeability, clay content and skin depth. Like any other geophysical method, there must be a sufficient contrast in the subsurface physical properties (resistivity) in order for the method to be successful in imaging the subsurface and detecting the target. Furthermore a given material can have a large range of resistivity and therefore overlapping values could pose a problem when interpreting the resistivity data.

One of the difficulties associated with ERI is finding sufficient accessible space, especially with the pole-pole and pole-dipole arrays. Another challenge is that highly conductive surface materials will confine the current follow in the top layer and therefore limit the amount of information coming from deeper layers. The method is also susceptible to interference from nearby grounded metal fences, buried pipes, cables, etc.

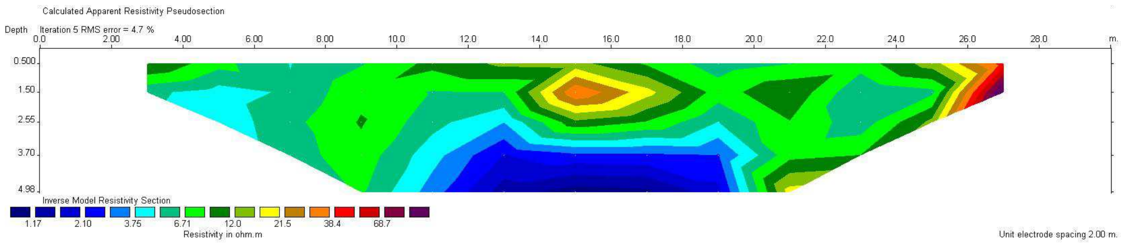
It is always important to keep in mind the resolution capability of the technique and the used acquisition parameters when inverting the resistivity measurements. The resistivity phenomenon is based on the diffusion equations, so its resolution is inherently poorer than the seismic or GPR methods at depths greater than one wavelength [5].

4.3. Field Application: Data Acquisition, Processing and Interpretation

The exact locations of resistivity profiles were superimposed using solid red lines and illustrated in Figure 1. As it can be seen from the Figure 1, the study area is located among the buildings of Turkish General Stuff, Turkish Air Force and General Directorate of Highways. Due to the highly settled area there was a lack of place for intelligent cables to extend. The profile lengths were 30 m with 2 m electrode spacing for profile 1, 52.5 m with 3.5 m electrode spacing for profile 2 and 75 m with 5 m electrode spacing for profile 3.

For every profile four different electrode arrays were utilized. These were namely a) Schlumberger N6 Dipole Dipole N4, b) Dipole Dipole N6 S1, c) Schlumberger N6, and d) Wenner Alpha. The measured resistivity data were then need to be inverted to get true

resistivity values of the subsurface. In order to invert measured resistivity values RES2DINV [7] inversion software was used. RES2DINV is a computer program that will automatically determine a two-dimensional (2D) resistivity model for the subsurface for the data obtained from electrical imaging surveys [8].
A forward modeling subroutine is used to calculate the apparent resistivity values, and a non-linear least-square optimization technique is used for the inversion routine [9]. The software supports both the finite difference and finite element forward modeling techniques. This software can be used for surveys using the Wenner, pole pole, dipole dipole, pole dipole, Wenner Schlumberger and equatorial dipole dipole arrays. In addition to these common arrays, the program even supports non-conventional arrays with an almost unlimited number of possible electrode configurations.
After inversion process, resultant 2D resistivity images were illustrated in Figure 9 through Figure 11 to interpret subsurface profile and results were correlated with boring logs. As mentioned before, four different array configuration were used for every profile and the letters a, b, c and d indicate these different electrode configurations.



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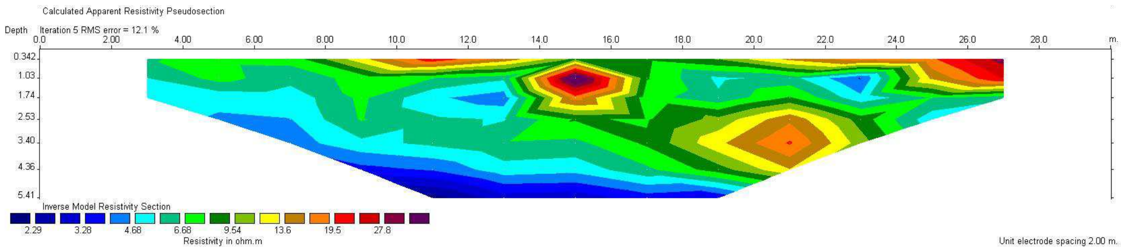

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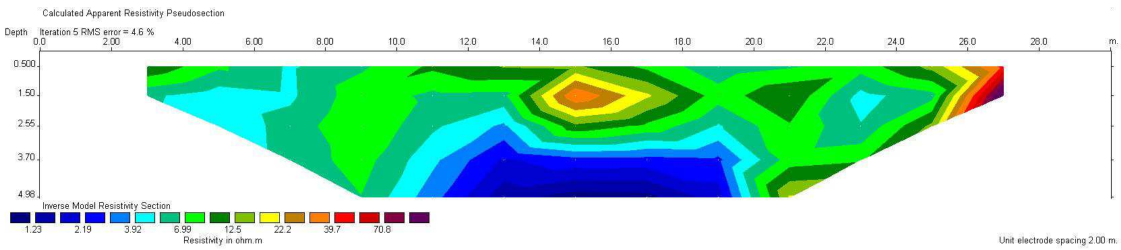

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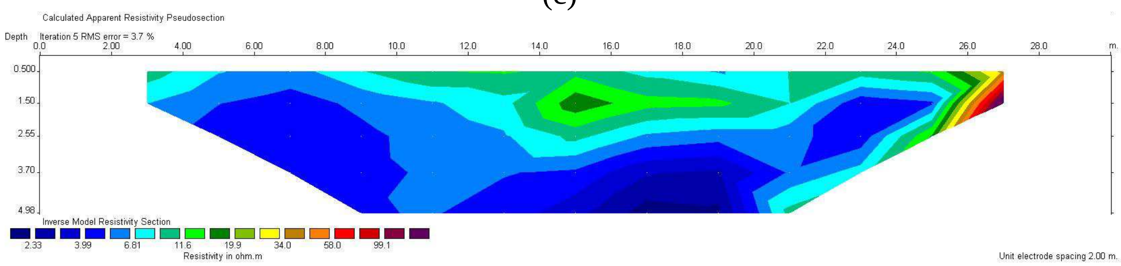
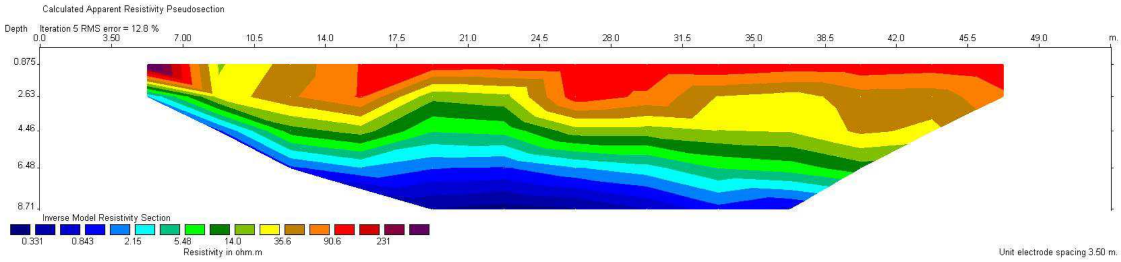


(d)

Figure 9. Interpretation of a) Schlumberger N6 Dipole Dipole N4, b) Dipole Dipole N6S1, c) Schlumberger N6, d) Wenner Alpha electrode configurations for profile 1 [10].

The length of profile 1 was 30 m with 2 m electrode spacing as illustrated in Figure 9.a, b, c and d. Since penetration depth is directly proportional to profile length and electrode spacing, the penetration depth for profile 1 was limited and it was about 5 m. First 1 to 1.5 m was interpreted as “fill” due to the resistivity values between 9 to 15 Ωm. After 1.5 m depth, “clayey soil” took place up to deepest point of the section (5 m) with 2-3 Ωm resistivity values. The closest boring log to the profile 1 is BH 45 and the lithology constructed by interpreting profile 1 resistivity values is reasonably in agreement with the BH 45 log for the uppermost 5 m.



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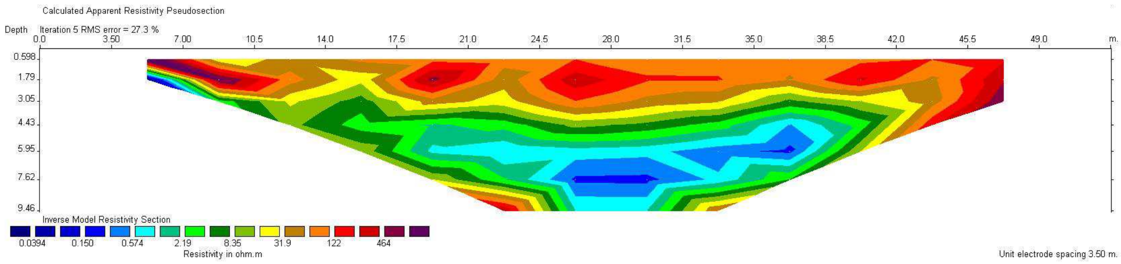

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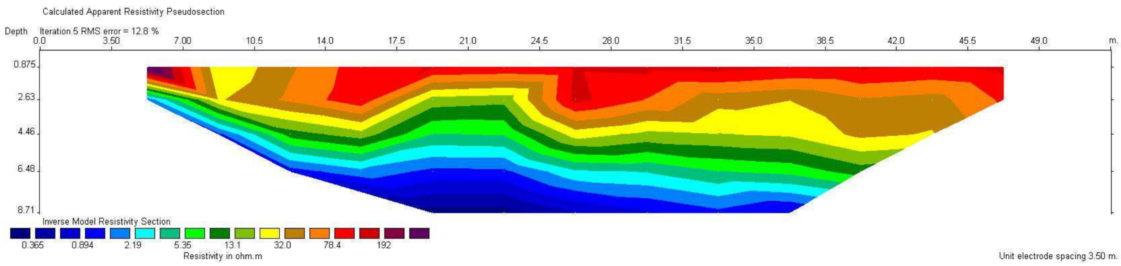

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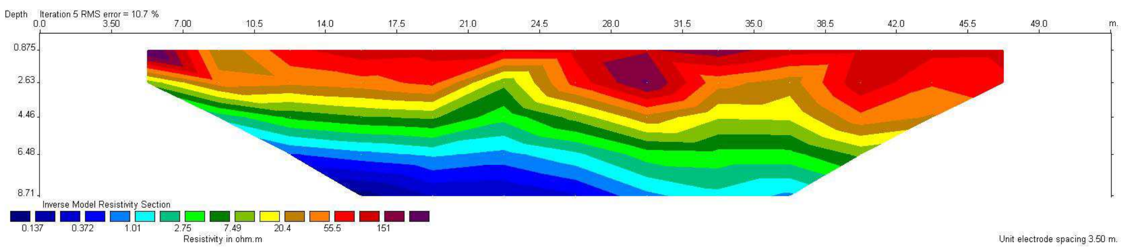
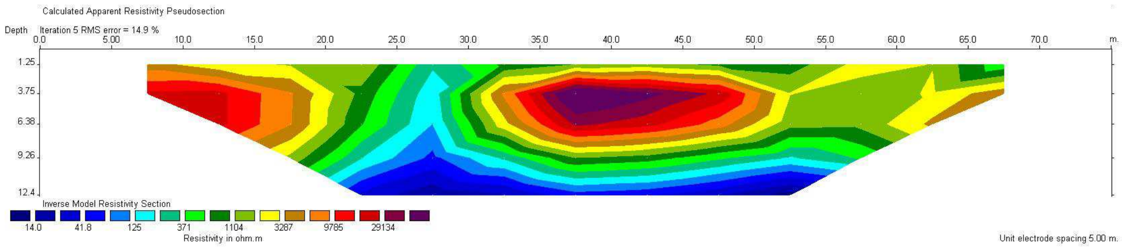


(d)

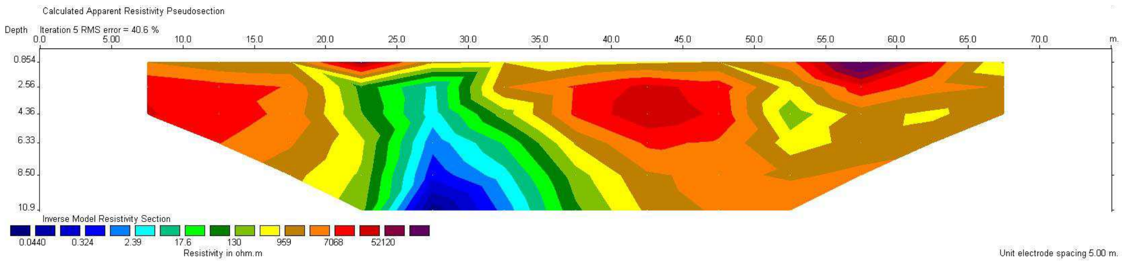
Figure 10. Interpretation of a) Schlumberger N6 Dipole Dipole N4, b) Dipole Dipole N6S1, c) Schlumberger N6, d) Wenner Alpha electrode configurations for profile 2 [10].

Figure 10.a, b, c and d illustrate 2D resistivity image for profile 2. As seen, profile length was 52.5 m and reachable depth was about 9 m. First 3-4 m depth was occupied by “fill material”

with 5-13 Ωm resistivity values. This part (3-4 m) was underlain by “wet clayey soil” with low resistivity values. The closest borehole logs (S3 and S5) are in a good agreement with interpretation of profile 2 resistivity values.



(a)



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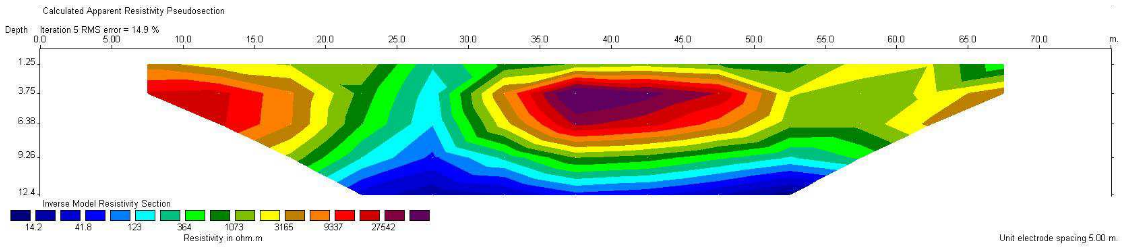

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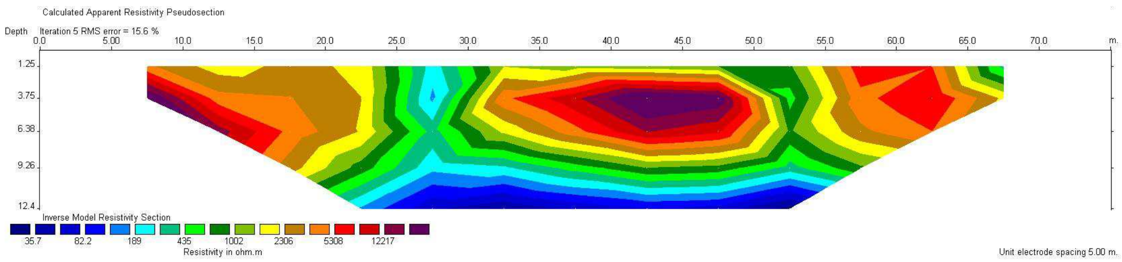


(d)

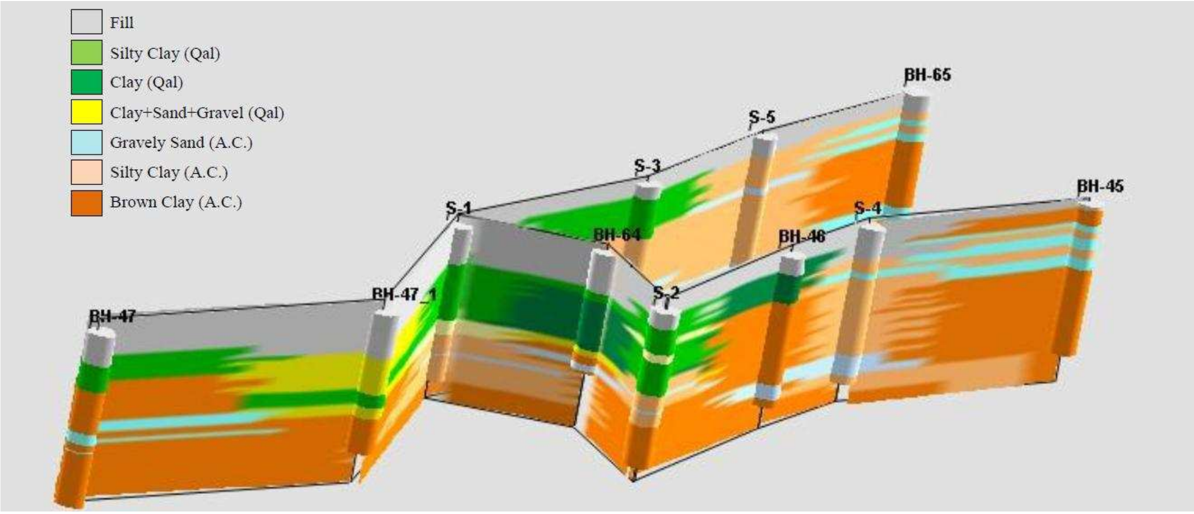
Figure 11. Interpretation of a) Schlumberger N6 Dipole Dipole N4, b) Dipole Dipole N6S1, c) Schlumberger N6, d) Wenner Alpha electrode configurations for profile 3 [10].

Profile 3 was the longest section and its 2D images were illustrated in Figure 11.a, b, c and d. The length of the profile is 75 m and 12.5 m depth was displayed. It was thought that first 7-8 m occupied by “fill material” and after that depth “silty clayey alluvium” took place. The abrupt increase in resistivity values at 4-5 m depth may indicate a concrete structure. BH 64 log that is the closest borehole to the profile is in accordance with the interpretations.

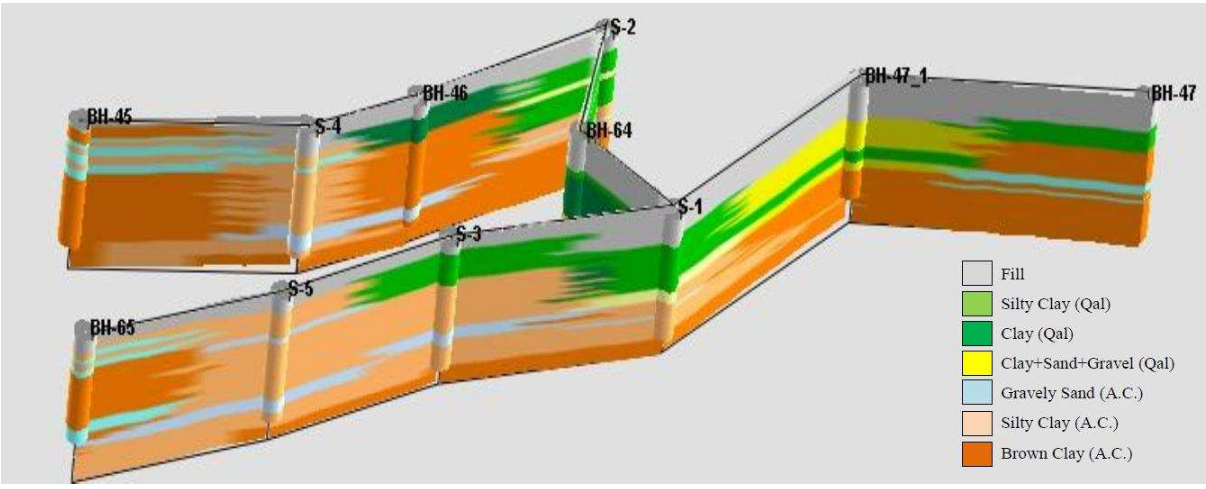
5. CONCLUSION

The Necatibey Station of the Ankara Subway System is located within the alluvial deposits of Dikmen Creek and the so-called Ankara clay. At the subway station a number of boreholes were drilled. However, due to the spacing of the boreholes the boundary between alluvium and Ankara clay deposits could not be separated precisely. Thus, ERI studies have been planned for the delineation of the boundaries of the two deposits.

With the interpretation of 2D electrical resistivity images and borehole logs together, the regional 3D subsurface panel diagrams were constructed and presented in Figure 12.a) looking North to South and b) looking South to North.



(a)



(b)

Figure 12. Regional 3D subsurface panel diagram created by interpreting 2D electrical resistivity images and borehole logs together a) North to South, b) South to North [10].

By examining these 3-dimensional subsurface panel diagrams a critical soil profile was chosen in order to construct a basis for the numerical models that utilized to estimate the ground deformations taking place at the Necatibey Station site of the Ankara Subway System and its close vicinity in response to tunnel excavations and groundwater drainage.

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