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Characteristics of 2-D Electrical Resistivity Imaging Survey for Soil

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ABSTRACT

The present work is aimed to show the efficiency of 2-D Electrical Resistivity Imaging (ERI) in probing the subsurface soil for site investigation, in addition to highlight some capabilities and characteristics of the sections acquired by 2D-ERI survey. In the field survey, where the University of Technology site is chosen for such investigation, ERI technique has been used implementing three common arrangements (Wenner, Wenner-Sclumberger and dipole-dipole). Different resolving powers have been obtained for the used arrays. Wenner-Schlumberger array gives moderate number of possible measurements and has a median depth of investigation of about 10% larger than that for the Wenner array. It is moderately sensitive to both horizontal and vertical structures, thus it might be a good compromise between the Wenner and the dipole-dipole arrays. Good agreements have been obtained between the stratigraphic columns of the site with the inversion models using the different arrays. The distribution of resistivity of the inversion models for the study site reflects the highly inhomogeneous subsurface soil with a wide variation of soil resistivity at different depths.

Keywords: Nondestructive Test; Electrical Resistivity Imaging (ERI); 2-D; Site Investigation.

خصائصية المسح التصويري ثنائي الأبعاد للمقاومة النوعية الكهربائية للتربة

الخلاصة

يهدف العمل الحالي إلى إظهار كفاءة تقنية المقاومة النوعية الكهربائية التصويرية ثنائية الأبعاد (2D-ERI) في فحص التربة تحت السطحية للتحري الموقعي، بالإضافة إلى تسليط الضوء على بعض قدرات وخصائص المقاطع التصويرية التي تم الحصول عليها بواسطة المسح الكهربائي ثنائي الأبعاد (2D-ERI). في المسح الحقلي, حيث أختير موقع الجامعة التكنولوجية لهذا التحري, حيث استخدمت تقنية (ERI) بتنفيذ ثلاثة ترتيبات شائعة (فنر و فنر-شلمبرجر وثنائي القطب-ثنائي القطب). تم الحصول على قوى تحليلية مختلفة باستخدام هذه الترتيبات.أعطى ترتيب فنر-

شلمبرجر عدد معتدل من القياسات الممكنة وبمعدل عمق للتحري أكبر بحوالي 10٪ مما هو لترتيب فينر. كما انه حساس بدرجة متوسطة للتراكيب الأفقية والعمودية, وبالتالي قد يكون حلا وسطا جيدا بين ترتيبي فينر و ثنائي القطب- ثنائي القطب. تم الحصول على اتفاقات جيدة بين العمود الطباقي للموقع مع نماذج الانعكاس باستخدام الترتيبات المختلفة. عكس توزيع المقاومة من نماذج الانعكاس لموقع الدراسة التربة تحت السطحية غير المتجانسة للغاية مع تباين واسع للمقاومة النوعية للتربة في الأعماق المختلفة.

INTRODUCTION

Electrical resistivity survey is non-destructive, very sensitive, quick and economical of geophysical method. It offers a very attractive tool for describing the subsurface properties without digging. It has been used for many decades in geological, geotechnical, hydro geological and mining investigations. More recently, it has been used for environmental surveys. It has been already applied in various contexts like: groundwater exploration, landfill and solute transfer delineation, agronomical management by identifying areas of excessive compaction or soil horizon thickness and bedrock depth, and at least assessing the soil hydrological properties [1, 2].

The ground resistivity is related to various geological parameters such as the minerals and fluids content, porosity and degree of water saturation in soils/rocks. The purpose of electrical surveys is to determine the subsurface resistivity distribution of the sounding soil volume by making measurements on the ground surface. Artificially generated electric currents are supplied to the soil and the resulting potential differences are measured. Potential difference patterns provide information on the form of subsurface heterogeneities and of their electrical properties. The greater the electrical contrast between the soil matrix and heterogeneity, the easier is the detection. From these measurements, the true resistivity of the subsurface can be estimated [3].

The surveys, depending on the areas heterogeneities can be performed in one-, two- or three-dimensions and also at different scales resolution from the centimetric scale to the regional scale. The use of 2D and 3D resistivity surveys has enabled us to map complex geological structures that were not previously possible with conventional 1D resistivity surveys. With the newly introduced technical developments, equipments, automatic inversion techniques and computer hardware such surveys can now be routinely carried out by small firms [3, 4].

Also it has been discovered that 2-D ERI method is cost effective, efficient and less time consuming in geotechnical investigation than most geotechnical tests [5]. Another important advantage of ERI is that it produces continuous information of the subsurface and probes into several meters below the surface whereas, engineering soil test is a point investigation and does not go beyond a few meters below the surface [6, 7].

The present work is aimed to show the efficiency of 2-D Electrical Resistivity Imaging (ERI) in probing the subsurface soil for site investigation, in addition to highlight some capabilities and characteristics of the sections acquired by 2D-ERI survey.

SITE INVESTIGATION AND FIELD WORK

2D and 3D Electrical resistivity imaging or tomography (ERI or ERT) techniques are increasingly used for a wide range of engineering geophysics, geotechnical and environmental problems. Because of simplicity in field implementation, two dimensional resistivity surveys are still used in most investigations; however, they can lead to distorted and misleading results in heterogeneous areas. The most commonly used arrays in the 2D electrical imaging surveys are conventional arrays such as the Wenner, Schlumberger or dipole-dipole arrays Figure (1).

The site under investigation is located in the University of Technology. The soil profile distinguishes three major subsoil stratifications for the site as indicated by the borehole of 15 m in depth [8] Figure (2). The subsoil profile can be summarized as follows: the top layer (from ground surface to about 4.5 m in depth) consists of gravelly sandy to silty clay with water table <1m; the second layer (4.5-10.5 m) consists of silty clay with fine sand, at about 5.5 m within this layer a pearched unclean water exists; while the third layer (10.5- E.O.B 15 m.) consists of clean sandy layer with amounts of silt and fine gravel. Clean water exits at about 12 m.

The method adopted in the field investigation is the 2-D electrical resistivity imaging technique. The ERI investigations were carried out along a profile lane in one site located in the University of Technology using Wenner, dipole-dipole and Wenner-Schlumberger arrays.

ELECTRICAL RESISTIVITY IMAGING (ERI)

Electrical Resistivity Imaging survey data were acquired using ABEM SAS 4000 Lund Imaging System. Other components are: electrode selector (ES464); Lund imaging cable; steel electrodes connected to a multi-core cable; external battery; cable connectors; multi function cable; and jumpers with a robust waterproof design for reliable operation in harsh environment as shown in Figure 3a. The multi-core cable is attached to an electronic switching unit which is connected to a laptop computer. In a typical survey, most of the fieldwork is in laying out the cable and electrode and most of the survey time is spent waiting for the resistivity meter to complete the set of measurements. Most of the fieldwork is involved in laying out the cable and electrodes. With this equipment, consecutive readings were taken automatically and the results averaged continuously. After reading the control file, the system selects the appropriate array and electrodes spacing for each measurement. These measurements are taken automatically and stored in the computer.

SAS results are more reliable than those obtained using manually operated single-shot systems [9], because the latest equipment is an automated machine connected with a laptop with an electronic switching unit that automatically selects the relevant four electrodes for each measurement [10, 11]. The ABEM was very effective in the area and generally did not encounter a lot of problems during field data collection.

The most commonly used arrays in the 2D electrical imaging surveys such as Wenner, dipole-dipole and Wenner-Schlumberger arrays have been chosen for this survey for their high resolution and depth of penetration [11] Figure (1). The total length of the surveyed profile was 40 m at an inter-electrode spacing of 1 m

Figure (3b). The data was processed and inverted using RES2DINV software. The program generates the inverted resistivity-depth image for each profile line. The instruments used the surveyed profile lane, and the layout of a possible sequence of measurements for the Wenner electrode array for a system with 20 electrodes are shown in Figure (3a, b and c) respectively.

RESULTS AND INTERPRETATION

Characteristics of 2D Electrical: Resistivity Imaging Sections

The sensitivity function basically refers to the degree to which a change in the resistivity of a section of the subsurface will influence the potential measured by the array. The higher the value of the sensitivity function, the greater is the influence of the subsurface region on the measurement [7, 11, and 12].

The best way to reduce such ambiguity is to use additional data/ information from other sources [5], such as drilling boreholes. In addition, the root mean square (RMS) is an important factor which may lead to fictitious subsurface picture. RMS values after 3 iterations are about 20 and 27% using Wenner and Wenner-Schlumberger arrays respectively and around 60% using dipole-dipole array as illustrated in the inverted resistivity sections for the three arrays shown in Figure (4a to c).

The difference in the contour pattern in the sensitivity function plot helps to explain the response of the different arrays to different types of structures by using the different arrays to map the same region which gives rise to some different contour shapes in the pseudo section plots Figure (4). The sensitivity pattern for the Schlumberger array Figure (4c) is slightly different from the Wenner array Figure (4a) with a slight increase in resistivity values (vertical curvature) below the centre of the array, and slightly lower sensitivity values in the regions between the C1 and P1 (and also C2 and P2) electrodes.

Generally, the distribution of subsurface soil resistivity in the inversion models of the study site Figure (4) shows a wide variation in soil resistivity and at different depths along the profile line for each array, starting from low values of <1ohm.m to higher values of >2000 ohm.m. The resistivity values for Wenner array are ranging from <1 to >50 ohm.m; for dipole-dipole are <1 to >2000 ohm.m; and for Wenner-Schlumberger ranges from <1 to about 10 ohm.m.

The top layer of the surveyed profile is characterized by its relatively low resistivity with thickness of about 5 m in the left half to < 4 m in its right half. This layer represents the clayey soil which consists of pockets of lower or higher resistivity values so it is highly inhomogeneous. The subsurface heterogeneity comes from the presence of clay and silt with amounts of sand and sometime gravel in addition to organic materials (e.g. the roots of the adjacent date palms along the profile appeared in Figure (3a) and indicated in Figure (5a). The presence of such roots could probably cause some anomalies with low or high resistivity depending whether in dry or wet conditions. Very low resistivity (<1 ohm.m) is identified near water well located along the profile lane (appeared in Figure 3a and indicated in Figure (5a). While the presence of high to very high resistivity materials near the surface in the end of the profile might be a result of concrete boulder materials which could be now buried in the sediment Figure (5a). At the intermediate depth (2.5-5m), three elongated anomalies with high resistivity are appeared which represent the in homogeneity of the site and could refer to the amounts of sand and sometime gravel. At greater depth below the top soil (> 5m), in both arrays Wenner and Wenner-Schlumberger (on the contrary, dipole-dipole gives the reverse for its high RMS as indicated in Figure (b), the sharp decrease in resistivity (<1ohm.m) indicates the presence of saturated soil interpreted as an pearched aquifer which is confirmed by water well in the site. All other areas are marked by relatively low resistivity (<1 ohm.m- blue color) indicating the presence of fine soil material and increase in the percentage of clay in soil matrix.

In addition, the distribution of subsurface soil resistivity may be clarified by correlating the inverted sections for the three arrays Figures(4 and 5) with the conductivity sections (inverse of resistivity sections) shown in Figure (6) and with the minimum and maximum resistivity sections shown in Figure (7).

Inversion Process Parameters Affecting Field Data

This section describes very brief outlines of some of the parameters that one can modify to fine-tune the inversion process. Thus, some of the inversion parameters that affect the field data will be outlined.

An important factor affects data is the calculation of the root mean square to show the average error in inversion sections. This is achieved by fitting the field with the computed one by means of attempting several iterations (for example; 3, 5 and 10 iterations shown in Figure (8). Results show that the RMS values are about 20% obtained in the Wenner and Wenner-Schlumberger arrays using 5 iterations remaining with this value till 10 iterations. Whereas, around 57% RMS is obtained for dipole-dipole array using 10 iterations showing increasing value with more 10 iterations. For the three arrays, this indicates that the data are fitted with the computed response and the average error is less than 20 and 57% in all the data respectively.

Another important factor is the quality of the field data. Good quality data usually show a smooth variation of apparent resistivity values in the pseudosection. To get a good model, the data must be of equally good quality. If the data is of poorer quality, with unusually high or low apparent resistivity values, there are several things that could be done. The first step is to look at the apparent resistivity pseudosection. If there are spots with relatively low or high values, they are likely to be bad data points. With the RES2DINV program, one can also plot the data in profile form that helps to highlight the bad datum points, and remove them from the data set manually Figures(9 and 10).

If the bad datum points are more widespread and random in nature, there are two program inversion parameters that one can modify. Firstly, increase the damping factors. A larger damping factor would tend to produce smoother models with less structure, and thus poorer resolution, but it would less sensitive to noisy data Figure (11). The second setting is the robust data constrain option. The inversion subroutine normally tries to reduce the square of the difference between the measured and calculated apparent resistivity values. Data points with a larger difference between the measured and calculated apparent resistivity values are given a greater weight. This normally gives acceptable results if the noise is random in nature. However, in some cases, a few bad data points with unusually low or high apparent resistivity values (outliers) could distort the results. To reduce the effect of such bad datum points, the robust data constrain causes the program to reduce the absolute difference between measured and calculated apparent resistivity values. The bad data points are given the same weight as the other data points, and thus their effect on the inversion results is considerably reduced Figure (12).

Another factor that can be controlled is the size and distribution of the rectangular blocks used by the inversion model Figure (13). By default, the program uses a heuristic algorithm partly based on the position of the data points to generate the size and position of the model blocks. The depth to the deepest layer in the model is set to be about the same as the largest depth of investigation of the datum points, and the number of model blocks does not exceed the number of datum points (i.e no. of model blocks equals no. of datum points). In general, this produces a model where the thickness of the layers increase with depth, and with thicker blocks at the sides and in the deeper layers as shown in Figure 13a for Wenner array. For most cases, this gives an acceptable compromise. The distribution of the datum points in the pseudosection is used as a rough guide in allocating the model blocks, but the model section does not rigidly follow the pseudosection. To produce a model with more uniform widths, one can select a model where the number of model blocks can exceed the number of datum points Figure (13 b). As the number of model blocks increase, the computer time needed to carry out the inversion also increases. Figure (14 a, b and c) illustrates the size and distribution of the rectangular blocks for dipole-dipole and Wenner-Schlumberger arrays with their inversion models.

Figure (15) shows the block distribution generated by a more quantitative approach based the sensitivity values of the model blocks for Wenner array as an example. This technique takes into account the information contained in the data set concerning the resistivity of the subsurface for a homogeneous earth model. It tries to ensure that the data sensitivity of any block does not become too small (in which case the data set does not have much information about the resistivity of the block). Also, one can use different algorithms for subdividing the subsurface into rectangular blocks to interpret the data from a 2-D imaging survey Figure (15).

Models can be obtained with the default algorithm, by allowing the number of model blocks to exceed the number of datum points, a model which extends to the edges of the survey line and using the sensitivity values for a homogeneous earth model, an example for Wenner array is shown in Figure (16).

The thickness of the layers can also be modified; this can be used to extend the maximum depth of the model section beyond the depth of investigation of the data set. This is useful in cases where a significant structure lies just below the maximum depth of investigation of the data set Figures (17 and 18).

CONCLUSIONS

The present study highlights some conclusion remarks as follows:

1. The different 2-D resistivity imaging arrays implemented to map the same region give rise to some different contour shapes in the pseudosection plot which is due the difference in the sensitivity function and the response of the different arrays to different types of structures.
2. Different resolving powers have been obtained for the used arrays. Wenner-Schlumberger gives moderate number of possible measurements and has a median depth of investigation of about 10% larger than that for the Wenner array. It is moderately sensitive to both horizontal and vertical structures, thus it might be a good compromise between the Wenner and the dipole-dipole array.

3. Good agreements have been obtained between the stratigraphic column of the site with the inversion models using the different arrays. The distribution of resistivity of the inversion models for the study site shows the highly inhomogeneous subsurface soil with a wide variation of soil resistivity at different depths.
4. The top soil layer consists pockets of lower and higher resistivity values, so it is highly inhomogeneous. This layer shows that the subsurface consists of clay and silt with amounts of sand and sometime gravel. In addition the existence of organic materials.
5. In addition, the present study outlines some of the inversion parameters that affect the field data and some capabilities and specifications characterizing the inversion sections of 2D Electrical Resistivity Imaging Survey.

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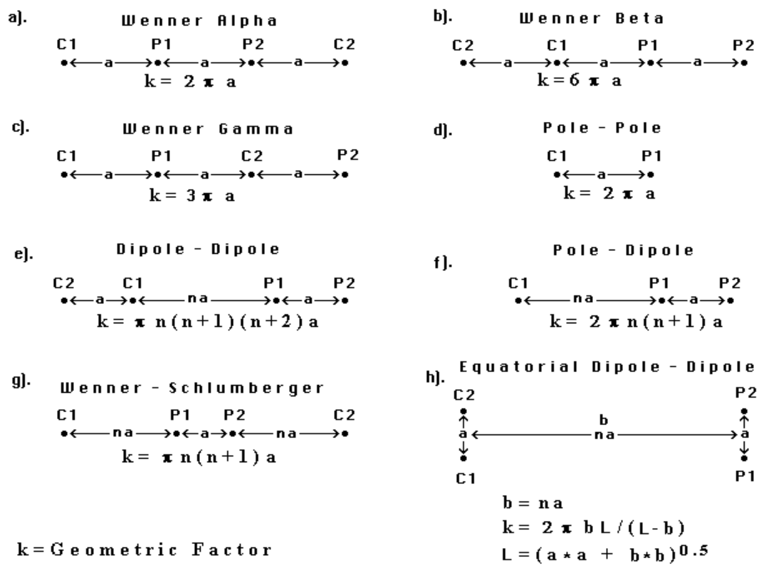


Figure (1) Common arrays used in resistivity surveys and Their geometric factors.

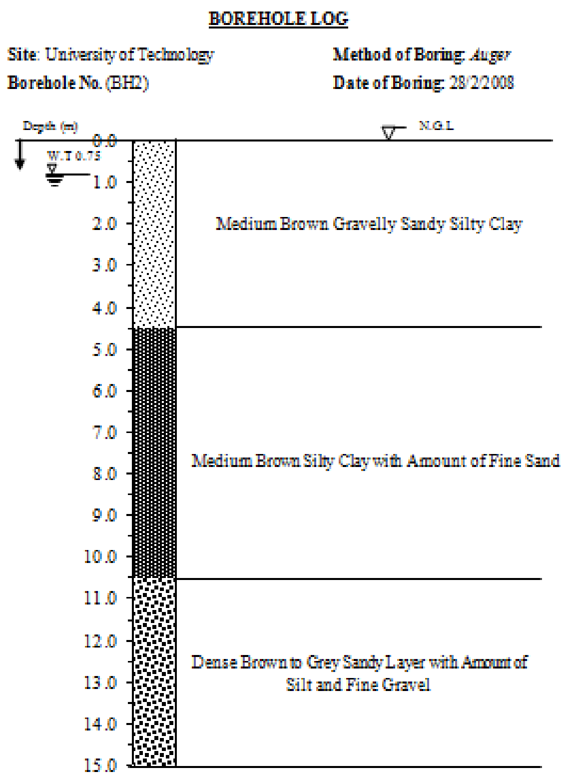
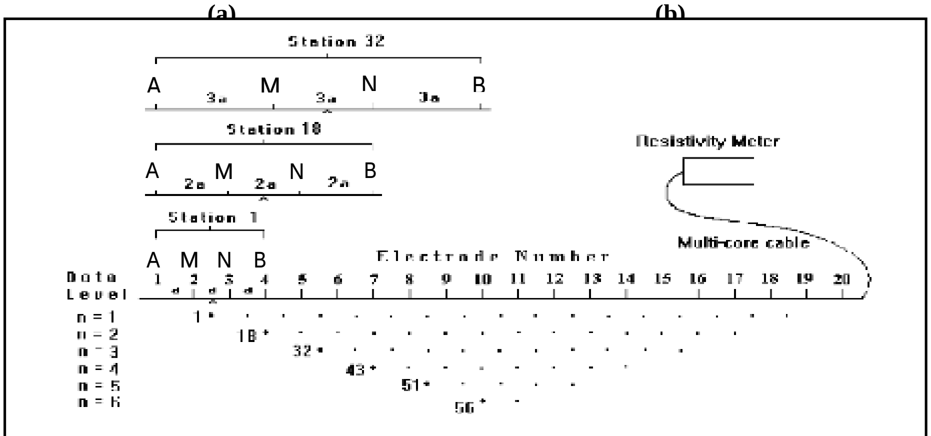


Figure (2) Stratigraphic column for the existed Borehole Within the site [8].

(a)

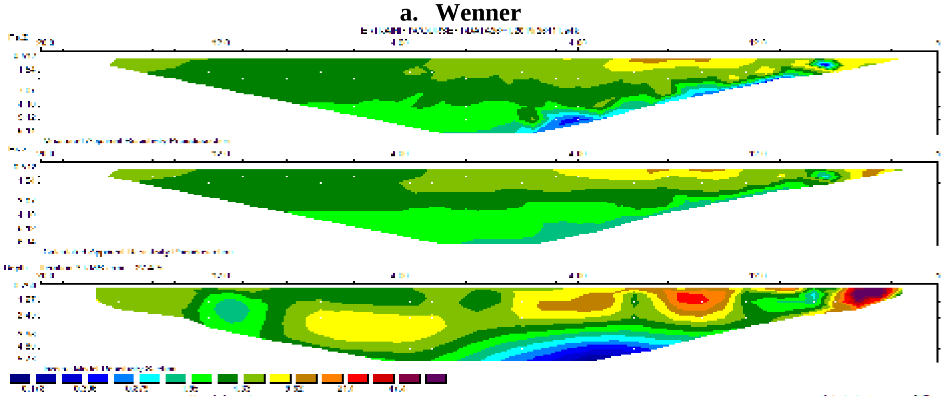
(b)



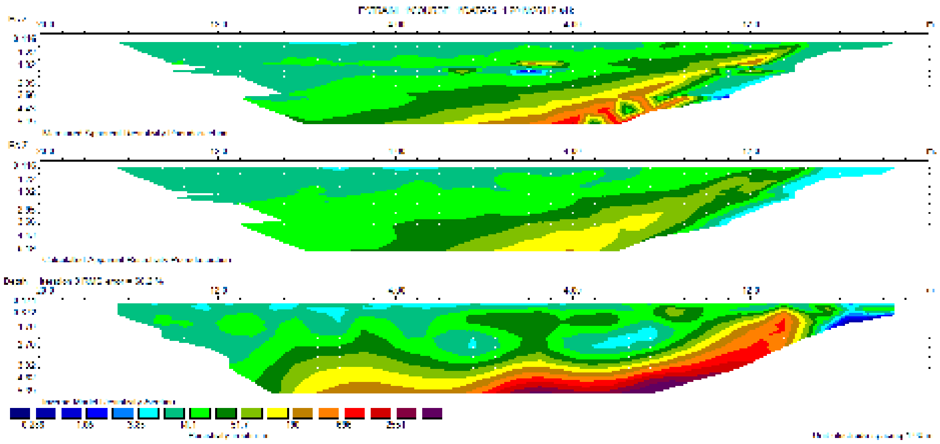
(c)

Figure (3a). ABEM SAS system; (b). The surveyed profile lane; and (c). Survey procedure for Wenner.

a. Wenner



b. Dipole-Dipole



c. Wenner-Schlumberger

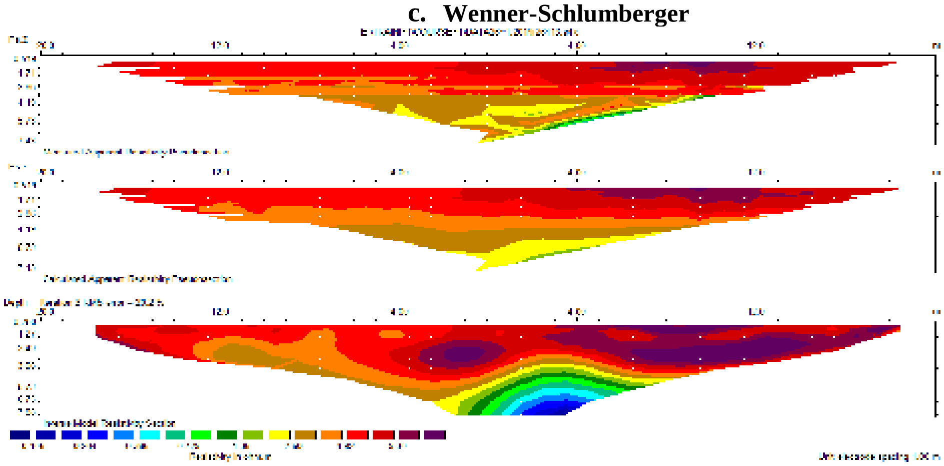
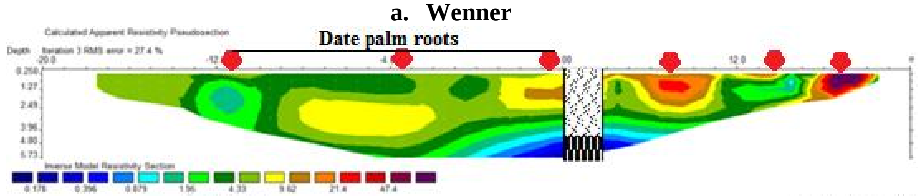
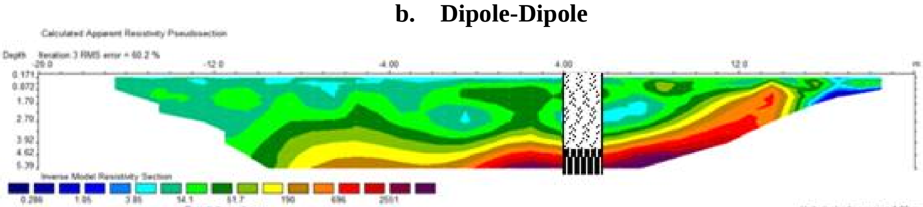


Figure (4) Inversion sections using Wenner, dipole-dipole and Wenner-Schlumberger arrays.

a. Wenner



b. Dipole-Dipole



c. Wenner-Schlumberger

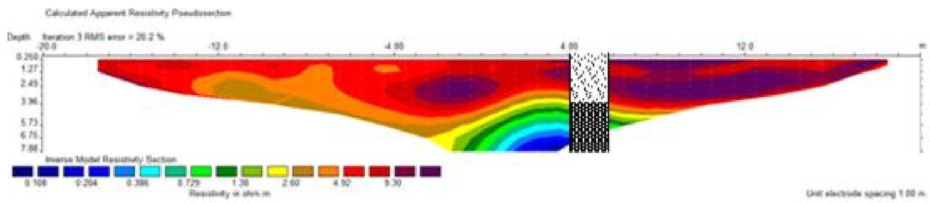
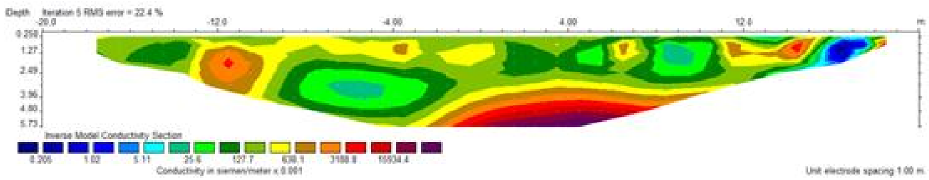
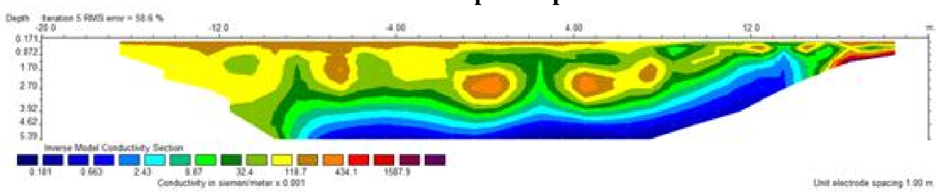


Figure (5) Correlation of inversion sections for the three arrays with the existed borehole and other features.

a. Wenner



b. Dipole-Dipole



c. Wenner-Schlumberger

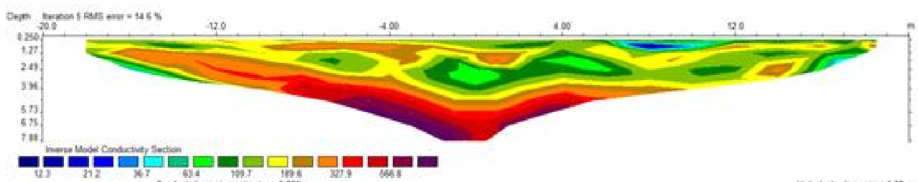
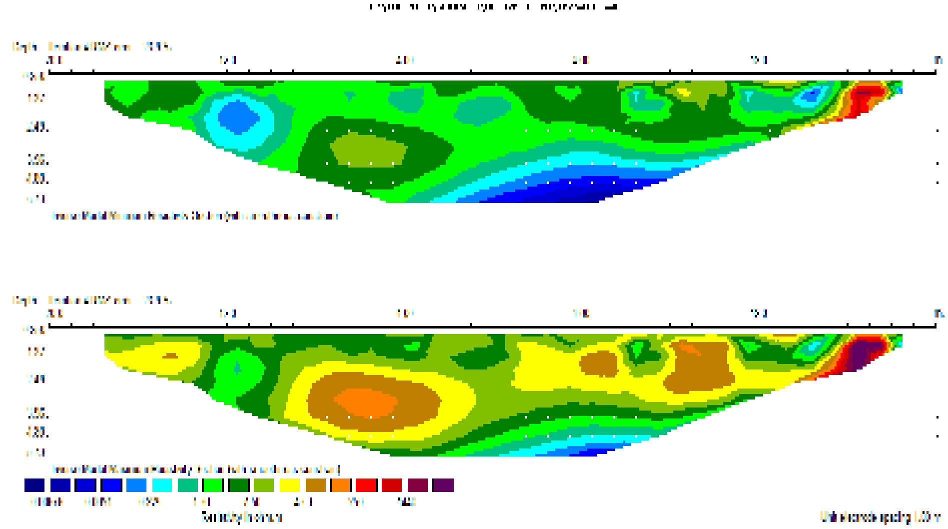
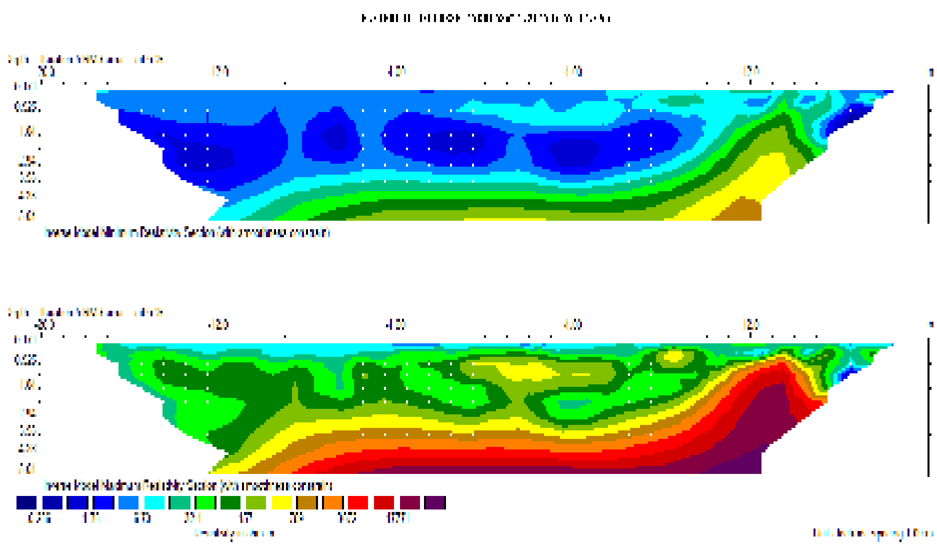


Figure (6) Conductivity sections for the three arrays.

a. **Wenner**



b. Dipole-Dipole



c. Wenner-Schlumberger

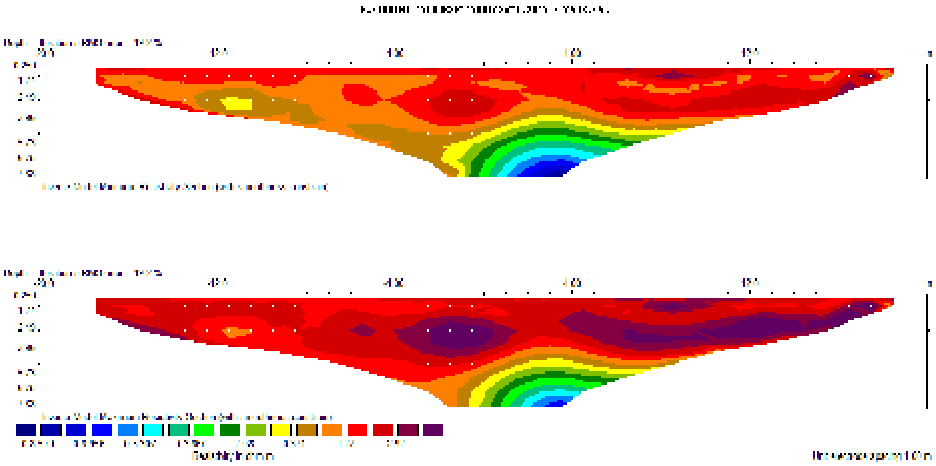
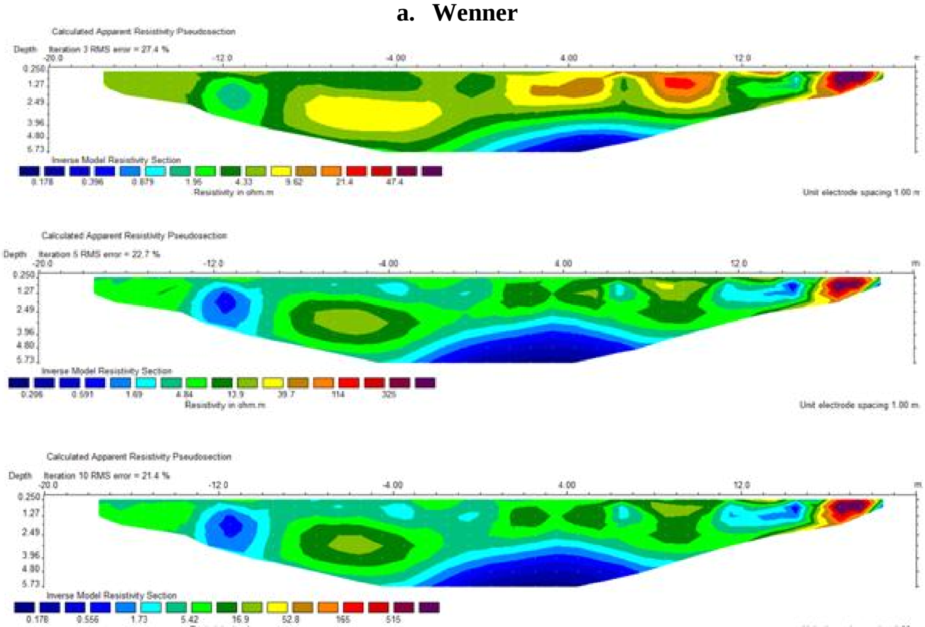
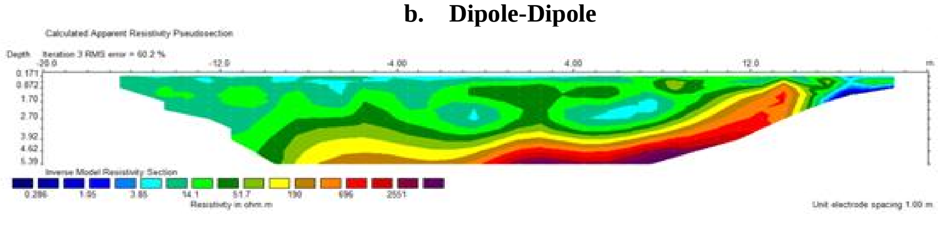


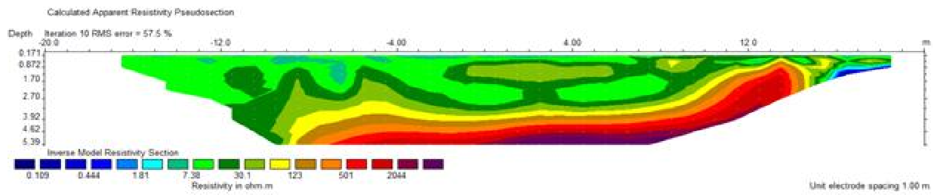
Figure (7) Minimum and maximum resistivity sections for the three arrays.

a. Wenner



b. Dipole-Dipole





c. Wenner-Schlumberger

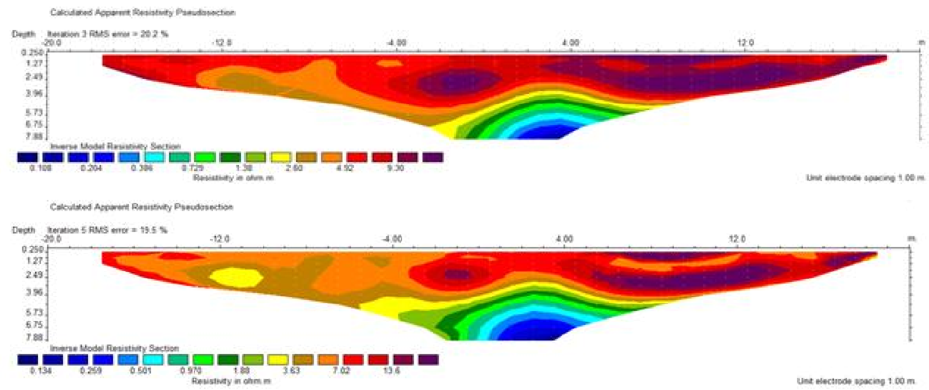
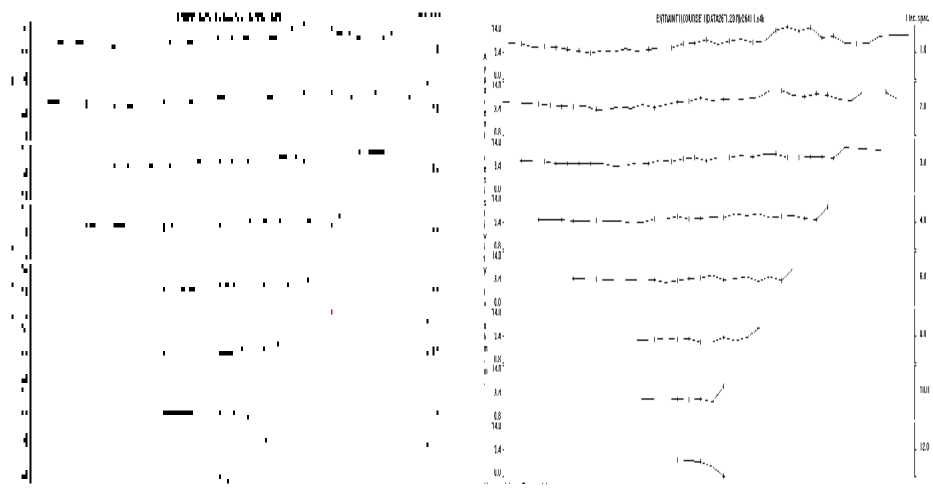


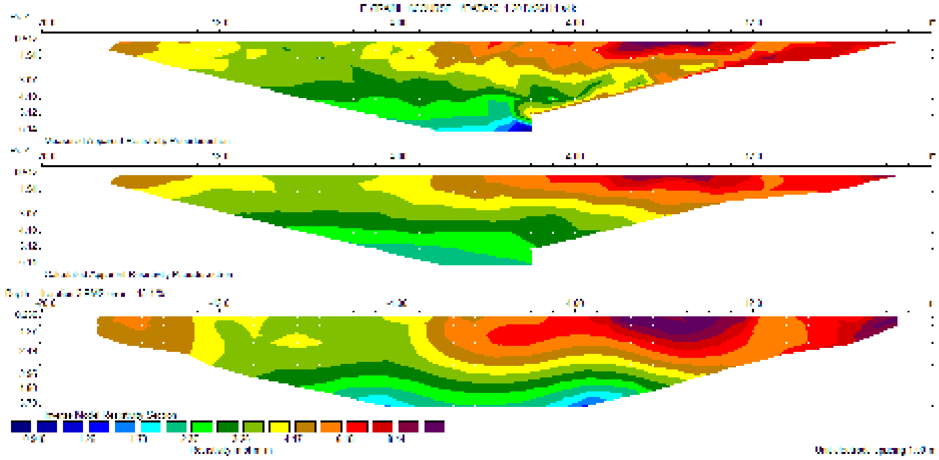
Figure (8) Inversion sections for the three arrays with different iterations.



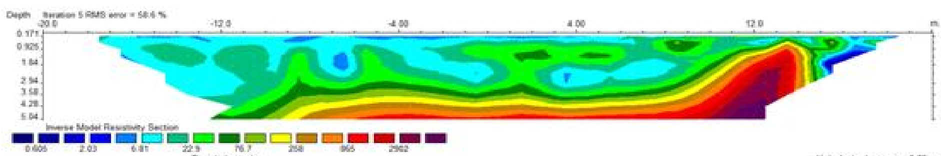
(a) **(b)**

Figure (9) (a). Wenner original datum points with the proposed bad datum points. (b). Extermination bad datum points.

a. Wenner



a. Dipole-Dipole



b. Wenner-Schlumberger

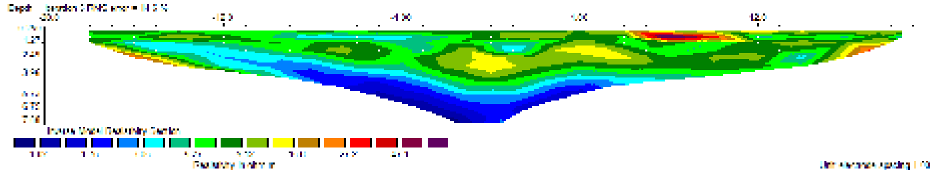
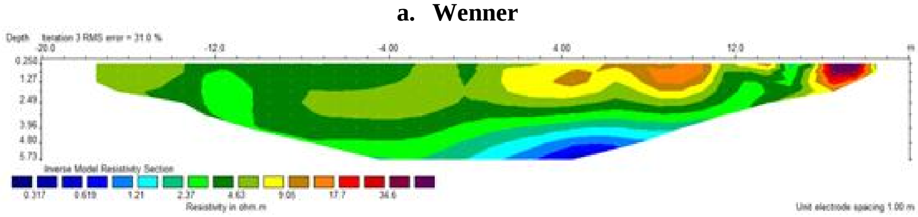
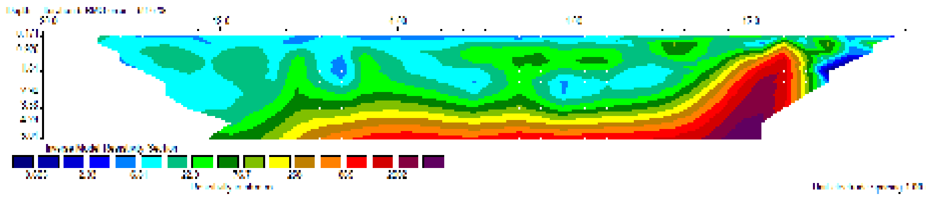


Figure (10) Resistivity section after extermination bad datum points.

a. Wenner



b. Dipole-Dipole



c. Wenner-Schlumberger

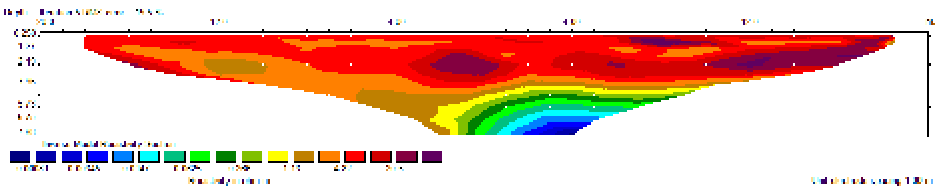
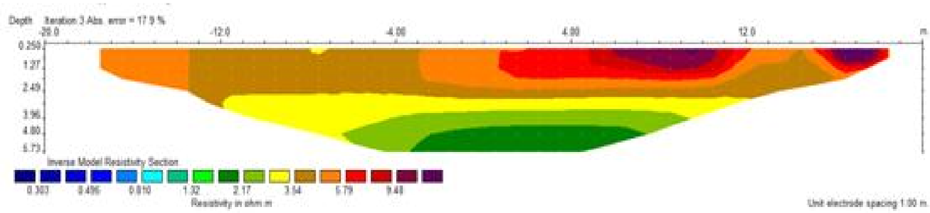
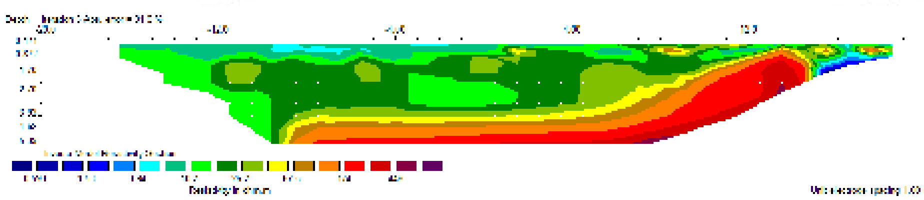


Figure (11) Effect of damping factor.

a. Wenner





b. Wenner-Sclumberger

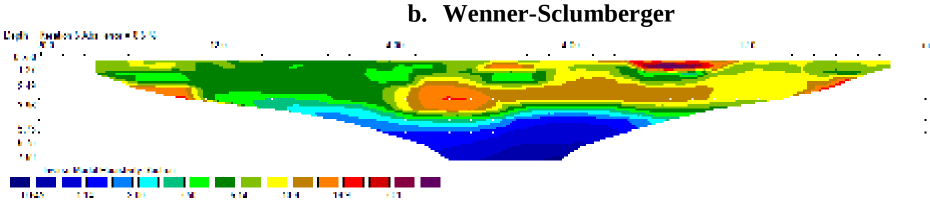
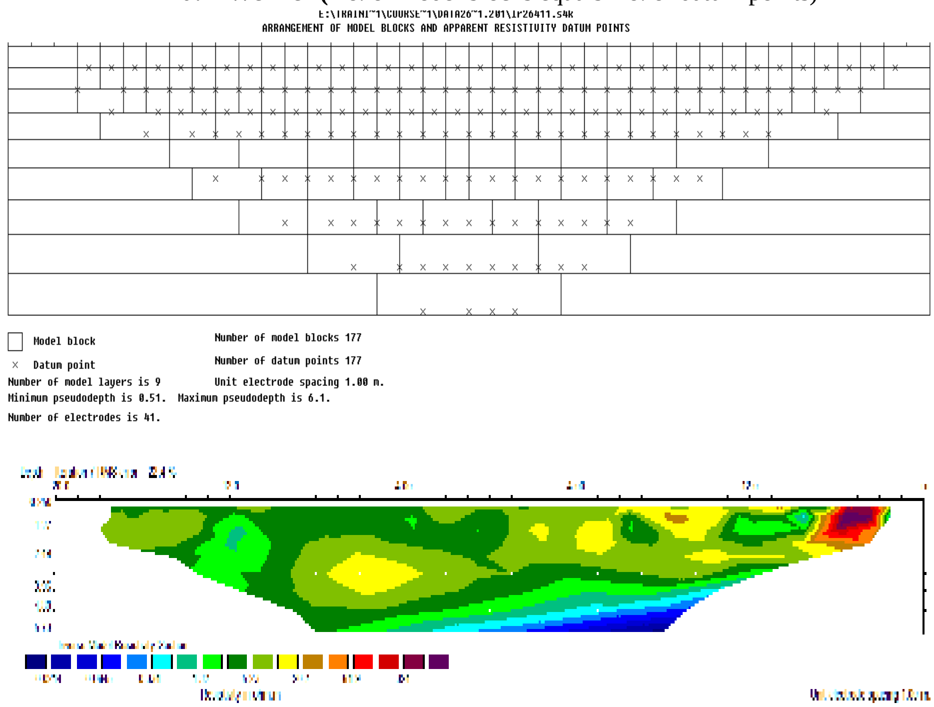


Figure (12) Effect of robust data constrain option.

a. Wenner (No. of model blocks equals No. of datum points)



b. Wenner (No. of model blocks exceed No. of datum points)

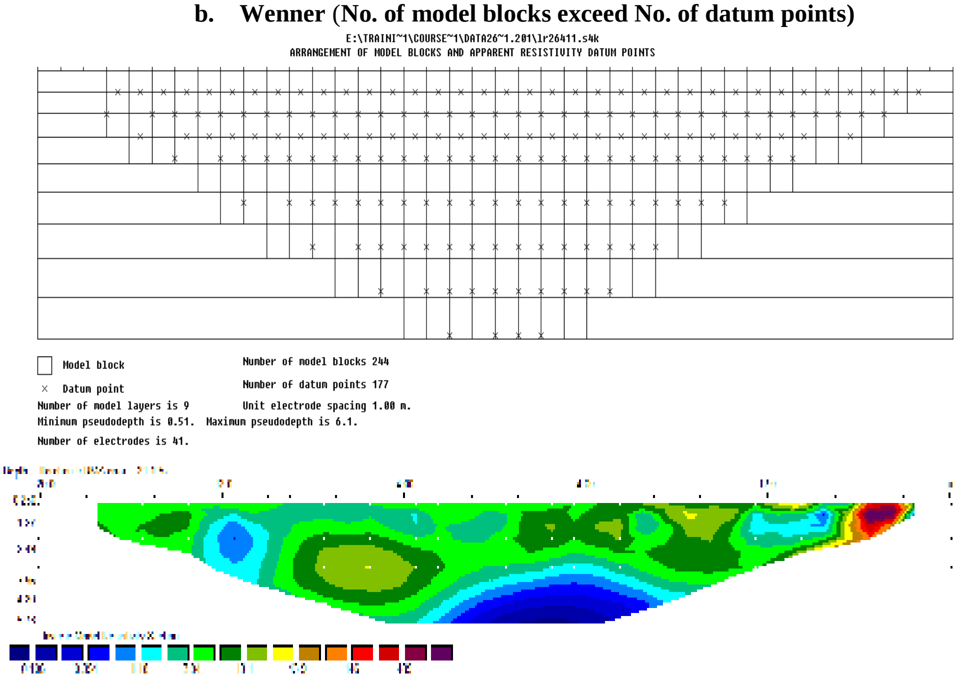
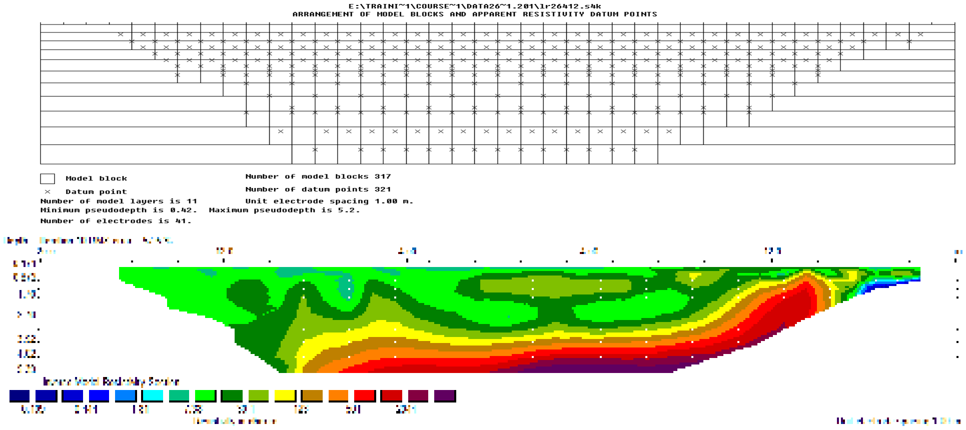
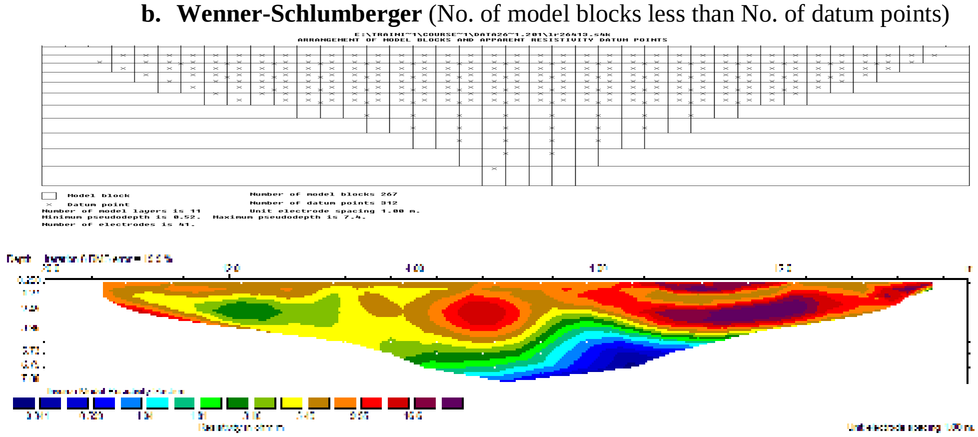


Figure (13) the size and distribution of the rectangular blocks for the applied Arrays with their inversion models.

a. Dipole-Dipole (No. of model blocks less than No. of datum points)



b. Wenner-Schlumberger (No. of model blocks less than No. of datum points)



c. Wenner-Schlumberger (No. of model blocks exceed No. of datum points)

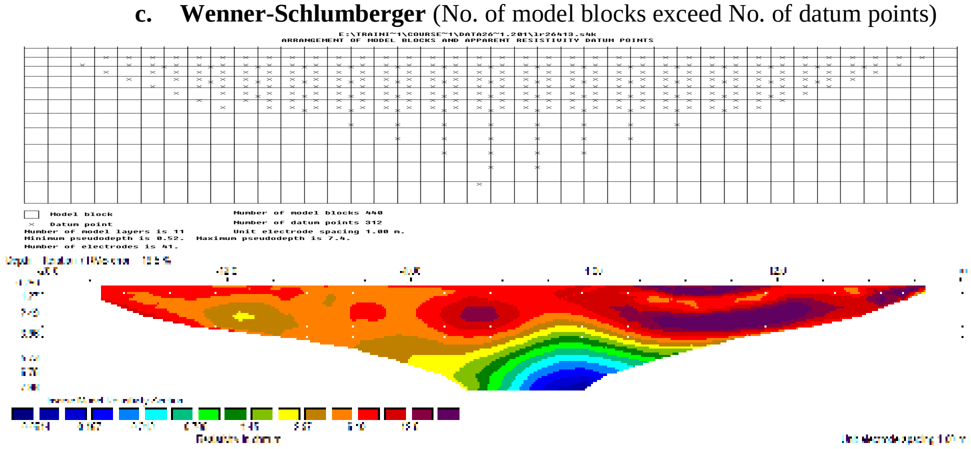


Figure (14) the size and distribution of the rectangular blocks for the applied arrays with their inversion models.

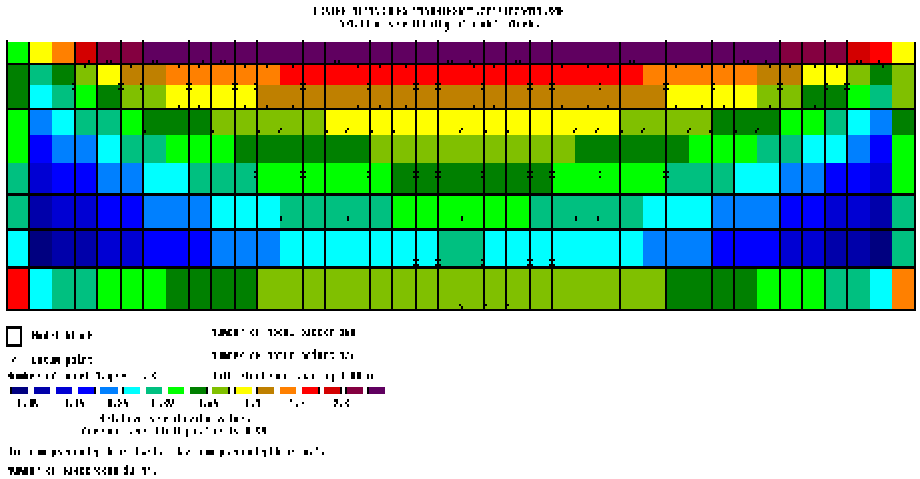


Figure (15) Block distribution generated by the sensitivity values of the model blocks for Wenner array.

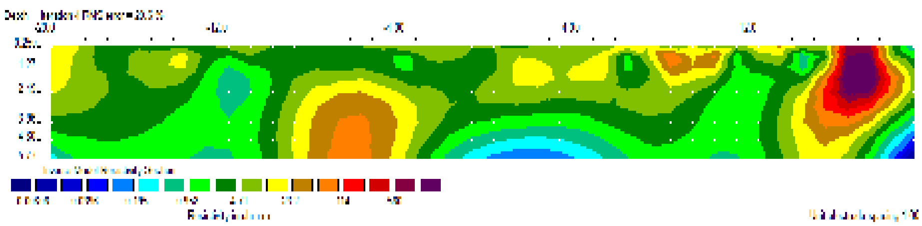
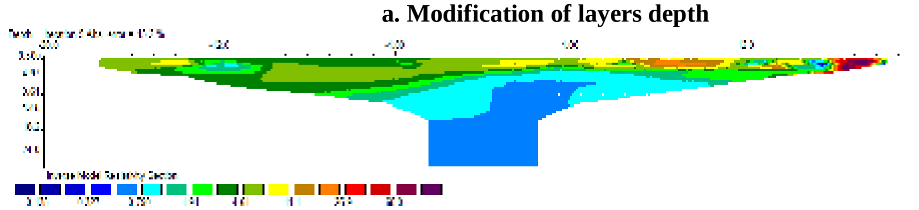


Figure (16) Eextended model for Wenner array.

a. Modification of layers depth



b. Extended model

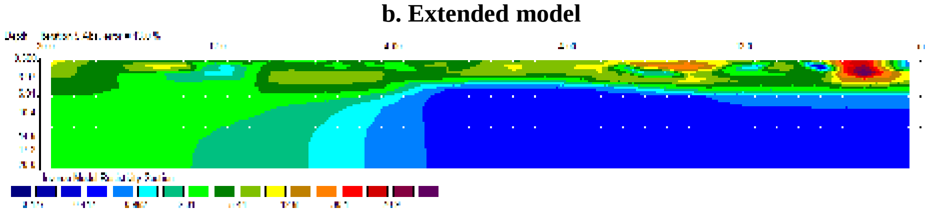


Figure (17) Modification of layers depth (a) with extended model (b) using Wenner array.

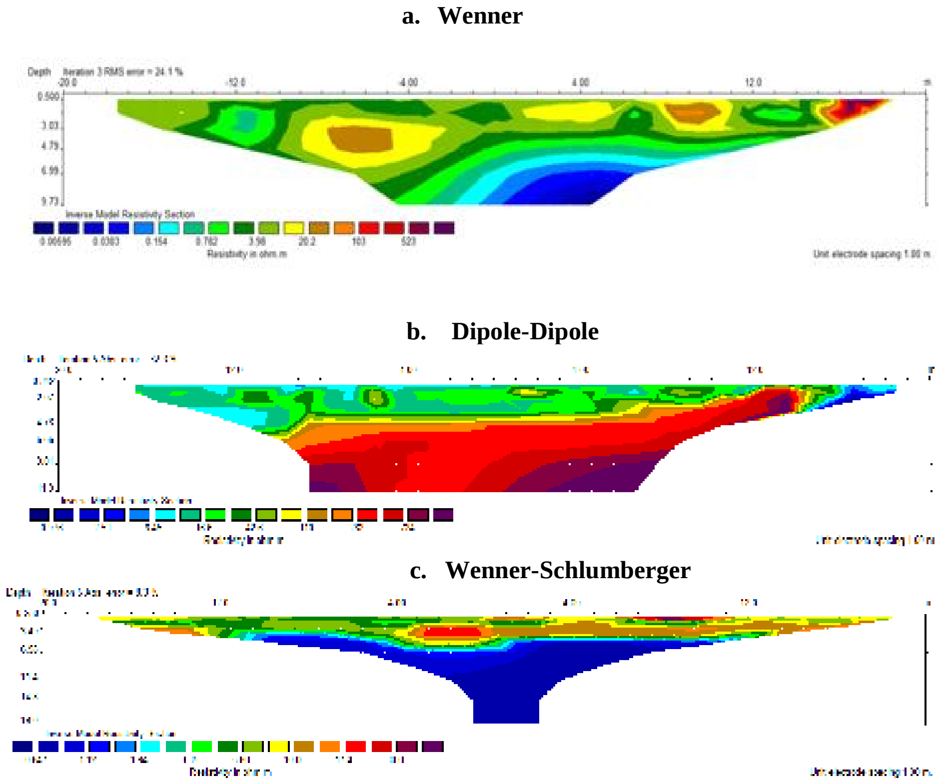


Figure (18) Changing the thickness of layers: (a) Wenner; (b) dipole-dipole And (c) Wenner-Schlumberger.