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Evaluation of Three Important Electrode Arrays in Defining the Vertical and Horizontal Structures in 2D Imaging Surveys

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Abstract
Three important electrode arrays in 2D imaging surveys were tested in this study through synthetic model to determine which array is the most successful in defining the vertical and horizontal geological structures. These arrays are Wenner-Schlumberger, Wenner and Dipole - dipole. The numerical modeling was created through vertical fracture zone and three separate cavities surrounded by horizontal layers. The results showed that the Wenner-Schlumberger is the most suitable electrode array when both vertical and horizontal structures are present in the subsurface. It is the best in imaging the vertical and horizontal contacts and represented these structures more accurately than the Wenner and Dipole-dipole arrays.

Keywords: Electrode Arrays, Synthetic Model, 2D Imaging Surveys.

تقييم ثلاثة ترتيبات كهربائية مهمة في تحديد التراكيب العمودية والافقية في المسوحات ثنائية البعد

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الخلاصة:
اختبرت في هذه الدراسة ثلاثة ترتيبات كهربائية مهمة تستعمل في المسوحات ثنائية البعد من خلال موديل صناعي لتحديد الترتيب الاكثر نجاحا في تصوير التراكيب الجيولوجية العمودية والافقية. هذه الترتيبات هي فنر– شلمبرجر , فنر و ثنائي القطب. صمم الموديل العددي من خلال طبقات افقية تحتوي على نطاق تكسر عمودي وثلاثة فجوات متفرقة. اظهرت النتائج ان ترتيب فنر– شلمبرجر هو الاكثر ملائمتا" في حالة وجود مثل هذه التراكيب الجيولوجية معا , حيث صور الحدود العمودية والافقية بينها وبين الطبقات بدقة اكبر من باقي الترتيبات.

Introduction

2D resistivity imaging is one of the electrical survey techniques. It is based on an old technique called Pseudosection. This technique had been used until the early 1990s, and it includes the using of Vertical Electrical Sounding (VES) and Constant Separation Traverse (CST) techniques together to determine the lateral and vertical changes of subsurface apparent resistivity in the same time [1-3].

The 2D resistivity imaging technique is developed in the last decade, as a result of the advances in the field equipment design capability and computer algorithms to become one of the most significant electrical survey techniques because it gives very approximate image of the underground structures [4-9]. However, there are 92 electrode arrays used in the electrical resistivity method [10]. But the

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types of these arrays that are the most commonly used in 2D imaging surveys do not exceed ten arrays. These arrays are Wenner-Schlumberger, Wenner, Dipole – Dipole, Pole-Dipole, Pole-Pole, and Multiple gradient arrays [11].

The choice of best the array for a 2D imaging surveys depends on different factors, such as the investigation depth, sensitivity function that is connected with type of structure to be mapped, vertical and horizontal data coverage and the resolution of array. In addition to, the sensitivity of resistivity meter and background noise level [12, 11]. Depending on these factors, there are many studies that have been carried out to determine which of these arrays respond best in imaging shallow targets in different situations, [13-16]. These studies indicated that the higher resolution and high sensitivity to geologic detail for shallow investigation offered by the Dipole-dipole array outweighed the fact that it used more measurements than the Wenner or Wenner-Schlumberger arrays.

Therefore, we will be evaluated these arrays through a theoretical comparison depends on synthetic model, then the results are compared with published field results of several authors to determine which arrays are the most successful in defining the vertical and horizontal contacts in deep investigations in 2D imaging surveys.

Synthetic Model Description

In order to investigate the capabilities of different electrode arrays in 2D imaging surveys, one synthetic model represents different geological or environmental conditions was designed. Forward modeling was done using the 2D forward modeling software RES2DMOD, created by [17]. The arrays supported by the software are the Wenner-Schlumberger, Wenner, and Dipole - Dipole.

The forward model was designed with survey line (600m) length and with the unit electrode spacing equal (10m). The numerical modeling is created through vertical fractures zone locates between electrodes (28-31) at a depth (3m) and it extends with increasing size with the depth to end at a depth (80m).

This fracture zone has resistivity value (10 Ω.m) and surrounded by horizontal layers with resistivity values ranging between (15 – 60 Ω.m), figure. 1. In addition, this model includes three cavities locate at depth (3m) within layer have resistivity value equal to (60 Ω.m). The first locates under electrode location (4) and extends to a depth (10m) with resistivity value (1 Ω.m). The second locates between electrodes location (15-17) and extends to depth (10m) with resistivity value (5 Ω.m). The third locates between electrodes location (52-55) and extends to a depth (20m) with resistivity value (5 Ω.m). All the cavities and vertical fracture zone are covered by a thin layer with high resistivity value equal to (250 Ω.m).

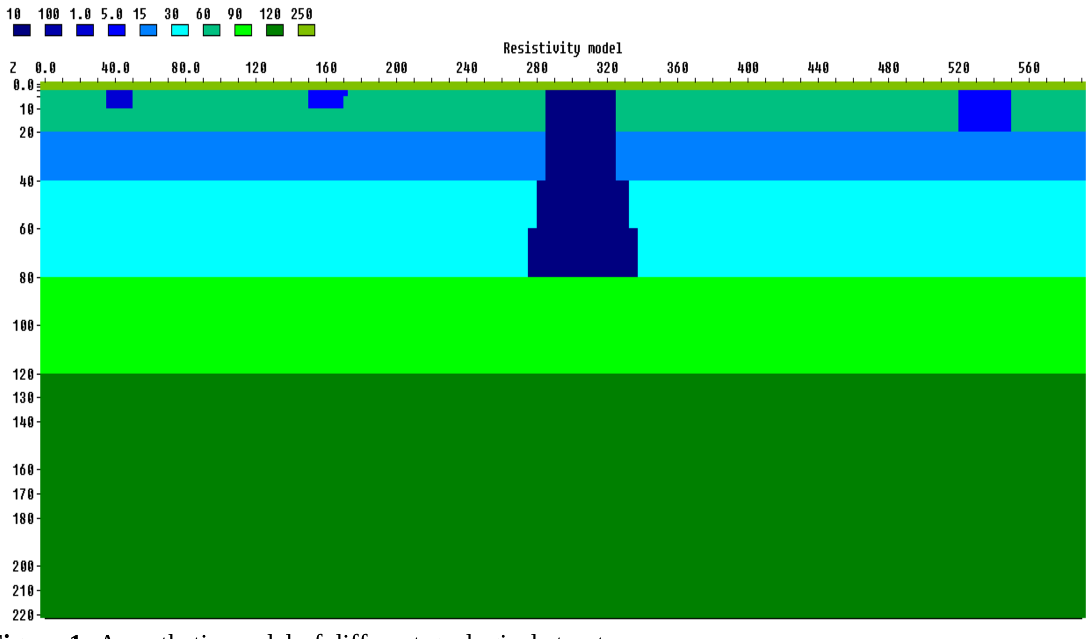

Figure 1- A synthetic model of different geological structures.

The Rustles and discussion

Inverse models were carried out using the RES2DINV ver. 3.59 Software [18], by used the robust inversion option (blocky optimization). This option is used when sharp boundaries are present [19, 20, 8], and since the cavities and fracture zone have sharp geologic boundaries, so it used.

Three forward models of the Dipole - dipole, Wenner and Wenner-Schlumberger arrays were created from the synthetic model. The Wenner survey was performed using (20a). While Wenner-Schlumberger and Dipole-dipole arrays were performed with increasing values from (1) to (6n), and from (1) to (5a), figure 2, to provide a higher resolution earth model and maximizes the depth of investigation. Random noise of (10%) was added to the apparent resistivity values of the Dipole – dipole array because it has the weakest signal strength than Wenner and Wenner-Schlumberger arrays [15, 21, 22].

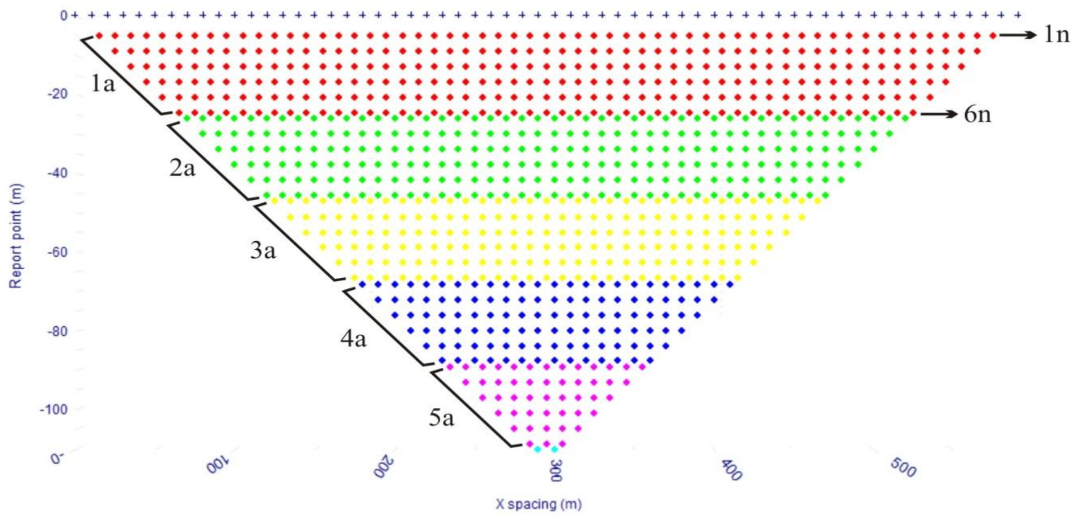

Figure 2- Pattern levels of (n) value from 1n to 6n, and a-spacing from 1*a* to 5*a* for Wenner-Schlumberger and Dipole-dipole arrays.

The inverse model of the Dipole-dipole array after five iterations with RMS errors (8.4%) was succeeded in imaging the cavities that are located under electrodes location (4) and (15) respectively, but it is less accuracy in imaging the vertical fracture zone and cavity that is located between electrodes location (52-55), figure 3a. This model reveals that the Dipole-dipole array is more sensitive to horizontal changes (two small cavities) in subsurface resistivities, and it is less sensitive to vertical changes (large cavity). This cavity represents the vertical changes because it is extended from top to the bottom of the layer. However, this array was less accuracy in imaging the vertical fracture zone despite it represents horizontal changes because it is located within horizontal sedimentary layers. This means that this array is poor in imaging horizontal changes (vertical structures), if these structures are intrusions with horizontal sedimentary layers. However, this array gave lowest depth of investigation than other arrays and that reach to (94m).

[23] Evaluated the suitability of different electrode arrays (Wenner, Schlumberger, Pole-Pole and Dipole-dipole) during ERT surveys in Karoo rocks, South Africa, to image dykes, sills, fault and fractures at different depths (40-95m). The results indicated that the Dipole-dipole array is not recommended for such structures due to its lower sensitivity to vertical changes in resistivity. This means that the resolution of this array will be decreased rapidly with depth. Therefore it is the best for shallow investigation.

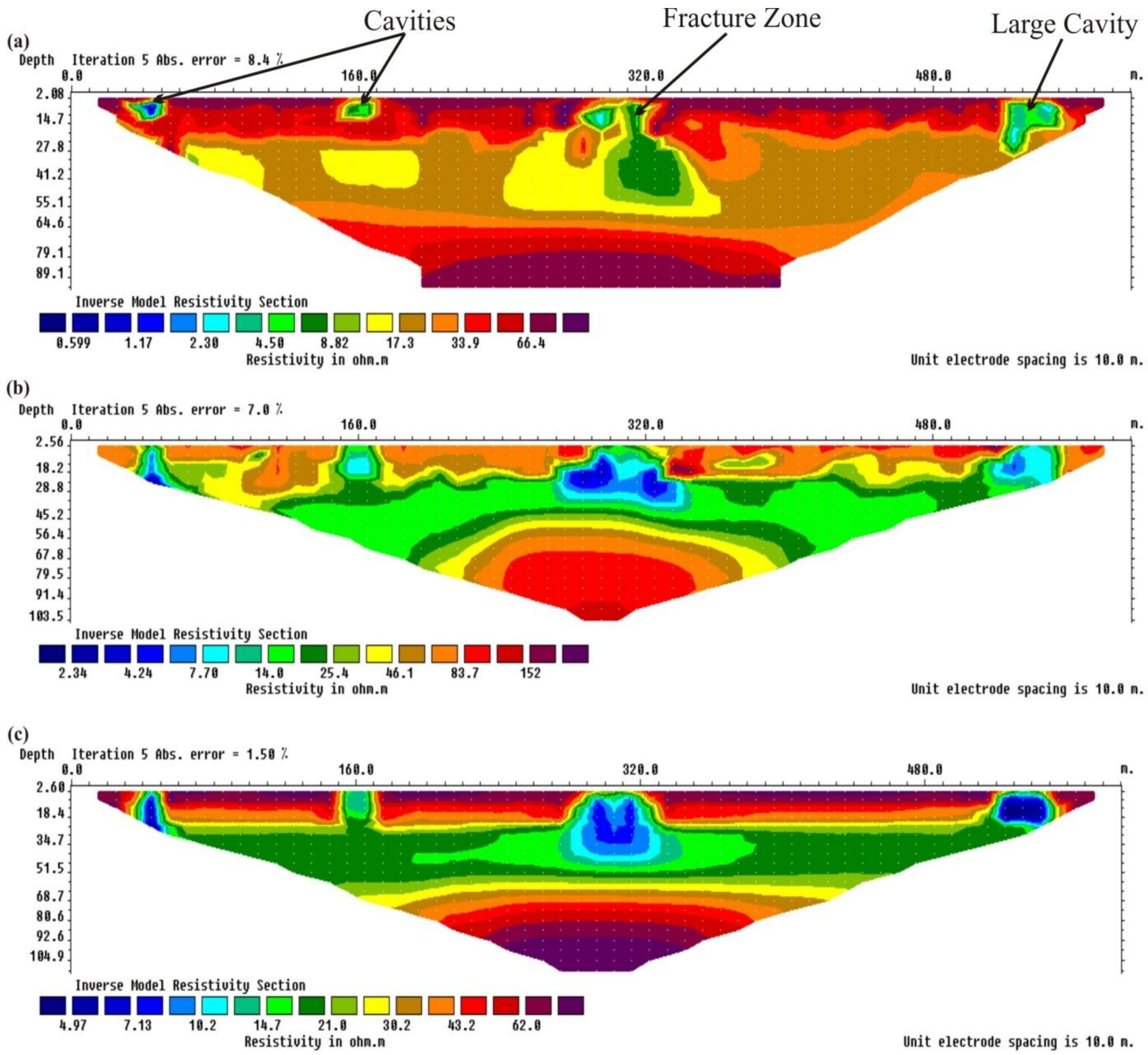

Figure 3- Inverse models of synthetic model for (a) Dipole – dipole, (b)Wenner and (c)Wenner-Schlumberger arrays.

After five iterations with RMS errors (7%), figure 3b, the inverse model of the Wenner array was inexact in imaging the vertical fracture zone and cavities due to it given distorted image about extension and thickness of these structures. This array may have difficulties in simultaneously imaging both horizontal and vertical structures. These results confirm the theoretical results of [15, 17], and with practical results of [24]. Those authors indicated that the Wenner array is relatively sensitive to vertical changes in the subsurface resistivity.

With an RMS error equal to (1.5%) obtained after five iterations, the inverse model of the Wenner-Schlumberger array was the most successful in imaging the vertical fracture zone, cavities and horizontal sedimentary layers, figure.3c, except the cavity located under electrode (4) may be due to the high resistivity contrast between it and host layers. In addition to, it gave the greatest depth of investigation than the Dipole-Dipole and Wenner arrays, and which equal to (111m).

All inverse models of these arrays are not imaging the actual extension of fracture zone with depth may be due to the presence of low resistivity contrast between fracture zone and host layers. However, the theoretical comparison between the results depends on synthetic model showed that the Wenner-Schlumberger is the better than Wenner and the dipole-dipole arrays. On the other hand, a practical comparison that has been carried out by [24] using four arrays, which are (Wenner-Schlumberger, Wenner, Schlumberger reciprocal and Dipole – dipole arrays), has shown that the Wenner-Schlumberger is the best than other arrays for deep investigation.

As a result, Wenner- Schlumberger array is good in imaging both horizontal and vertical structures for deep investigation, especially if these structures are intrusions with horizontal sedimentary layers because it starts by Wenner and ends with Schlumberger array. This is in agreement with the results of [17], this array might be a good compromise between the Wenner and the Dipole-dipole arrays in areas where both types of geological structures are expected.

Conclusions

This comparison showed some important results, which are given in the following points:

1- The Dipole-Dipole array was less accurate in imaging the vertical structures (vertical fracture zone and large cavity) due to these structures are intrusions with horizontal sedimentary layers. Therefore, the Dipole-dipole array is not recommended for deep investigation (60 -100m), especially if both types of geological structures are expected.

2- The Wenner array was inexact in imaging the vertical fracture zone, cavities and horizontal sedimentary layers. So, this array is not recommended for deep investigation in presence of such geological structures.

3- The Wenner-Schlumberger is the most suitable electrode array when both vertical and horizontal structures are present in the subsurface. It defined both the vertical and horizontal contacts and it represented the vertical fracture zone and cavities more accurately than the Wenner and Dipole-dipole arrays. In addition to, it gave the greatest depth of investigation than the Dipole-dipole and Wenner arrays.

4- All arrays are not imaging the actual extension of fracture zone with depth. This indicates that the sensitivity and resolution of arrays are decreasing in the areas that have high resistivity contrasts in subsurface layers.

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