J. of university of anbar for pure science : Vol.7:NO.3: 2013

ISSN: **1991-8941**

Evaluation of different electrode arrays in delineation subsurface cavities by using 2D imaging technique

Jassim M. Thabit[*] **Ali M. Abed**[**]
[*] Baghdad University - College of Science,.
[**] Anbar University - College of Science
Received:28/1/2013 Accepted:19/8/2013

Abstract:

The 2D imaging survey was conducted across a known cavity, called the Um El-Githoaa cavity, and it is located in (Hit area-Western Iraq). The synthetic sequences of electrodes of various electrode arrays were generated to select the suitable array parameters such as a- spacing and n- factor to survey. 2D measurements are collected along traverse above the cavity for Dipole-dipole with an n-factor of 6, Pole-dipole with an n-factor of 8, and Wenner- Schlumberger with an n-factor of 8, while the a-spacing equals 2m for all arrays. The inverse models clearly showed that the resistivity contrast between the anomalous part of cavity and background resistivity is about 700:100 Ωm, 550:100 Ωm, and 500:100 Ωm of Dipole-dipole, Pole-dipole, and Wenner- Schlumberger arrays, respectively. Therefore, these models indicated that all electrode arrays can detect the subsurface cavity with different shape and accuracy. But, the Um El-Githoaa cavity is well defined from 2D imaging with Dipole –dipole array. Another Dipole-dipole survey with n-factor value of 8 is done along the same traverse. The interpretation data shows that the results to be rather noisy, with increasing negative observed data, as well as the location and size of Um El-Githoaa cave being made different from the actual situation. So, it is not advisable to use the value of n-factor greater than 6 especially with shallow targets for Dipole-dipole array. We concluded that 2D imaging is a useful technique and more effective for determining and mapping subsurface cavities, when taken in consideration using the suitable a-electrode spacing and n-factor for each electrode array, especially with the Dipole –dipole array which provides the best subsurface cavity imaging.

Keywords: 2D imaging technique, electrode arrays, cavity.

Introduction

Cavities have become an increasing problem as more karst terrain is developed. Human activity can trigger the collapse of a subsurface cavity that was previously stable. With development in karst areas comes the increased need to detect subsurface cavities and map depth to bedrock for geotechnical applications such as foundation planning and construction. Delectation and delineation of subsurface cavities and abandoned tunnels using geophysical methods have gained wide interest in the last few decades.

The most widely geophysical methods include electrical resistivity, electromagnetic, gravimetric, seismic techniques and recently ground penetrating radar (GPR) method. Of these methods, the electrical resistivity has been the most extensive in detecting cavity(1,2,3,4,5,and6).

The study area is located within Hit area-western Iraq to detect subsurface cavity, called Um El-Githoaa cavity with 3.8m depth, 2.2m height, and 12.5m width within Fatha Formation in Hit area (Fig. 1). Fatha Formation is one of the most aerially widespread and economically important formations in Iraq, and it includes enormous sinkholes and cavities within gypsum rock. It comprises of anhydrite, gypsum, and salt deposits, interbedded with limestone and marl (7), as shown in (Fig.2).

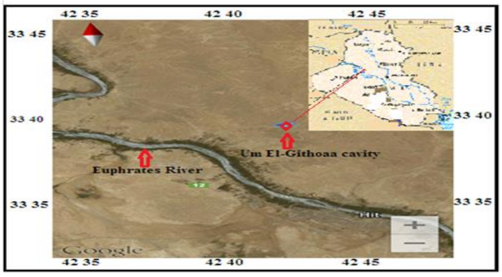

Figure (1): Location map of the Um El-Githoaa cavity

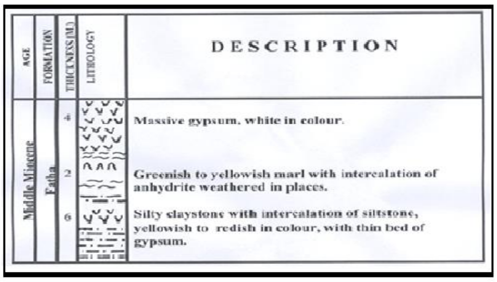

Figure (2): Stratigraphic succession of the Fatha formations in Hit area (8)

There are few previous studies in Iraq that used resistivity method for detecting subsurface cavities, such as (9) used Wenner array to detect the cavities in Hmam Al-Alel, north Iraq. The Resistivity map was drawn, and displayed high positive anomalies, where the cavities were present within gypsum rocks. (10) Measured two sounding stations, one over the known cave in Rawa area (W- Iraq), and the other at a distance of 80m west of the cave were carried out using Wenner and Schlumberger arrays. Also, twelve horizontal profiles, along each profile the resistivity measurements were carried out using Wenner, Schlumberger and Pole-dipole (Bristow̓s method) arrays. The best result was obtained from the Pole-dipole array by using graphical Bristow method.

Most 2D (Two Dimension) imaging surveys had been used for shallow engineering and environmental studies, and in the following some previous studies are used in detection of subsurface cavities in the world (11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22). 2D imaging is considered as one of the most powerful techniques to detect cavities in karst region, due to low coast and high resistivity between cavity and background formation (14, 23, and 24).

The purpose of this study was to evaluate the usefulness and suitability of different electrodes arrays of 2D resistivity imaging technique in detecting and delineating subsurface cavities.

Selection of array parameters

ElectrePro program is used to select the parameters such as a-spacing, n-factor, and depth of investigation before carrying out the field work (this program is designed by IRIS Instruments, and it a software allowing us to create 2D /3D and borehole sequences of resistivity measurements). We used three electrodes arrays to determine which array best in detected the cavity. Each array has 22 electrodes with a-spacing of 2m for Dipole-dipole and Pole-dipole arrays, while Wenner- Schlumberger has 24 electrodes with a-spacing of 2m. The most important parameters are a-spacing and n-factor. The main object of these parameters is to select the suitable sequence to achieve real subsurface imaging. In 2D imaging each array has advantages and disadvantages for investigation depth, data coverage, signal strength, and sensitivity function to vertical and horizontal change in resistivity (14 and 25). In Dipole-dipole array, when the n-factor changes from 1 to 6, , the maximum estimated depth of investigation reaches 8.29m with coverage data equals to 171 reading, but when the n-factor changes from 1 to 8, the maximum estimation of investigation depth become 9.7m with 197 reading. This means that by increasing the n-factor, greater estimated of investigation depth and more horizontal and vertical coverage data can be obtained. But, it is not preferable to increase the n-factor to more than 6, for Dipole-dipole array because after this value, the accurate measurements of the potential decreases, and the noise will increase (25).

The Pole-dipole and Wenner-Schlumberger arrays, when the n-factor changes from 1 to 8, the maximum estimated depth of investigation is 14.9 m with data coverage of 195 reading and 8.4m with 118 reading respectively. Therefore, the depth of investigation between 8.4m and 14.9m is suitable for delineating the subsurface cavities in this study.

Field work

The Um El-Githoaa cavity is located at (N 33° $42^{-}52^{=}$, E 42° 48^{-} $55^{=}$) about (5Km) to the north of Hit. It is situated in an area surrounded by gypsum within the Fatha Formation.

The shape of the cavity is ovulate, maximum diameter is about 19.3m (286° direction) while the minimum is 15.8m (perpendicular to the first diameter). The depth from the surface to the roof of the cavity is 3.8m and to the bottom is 5.6m. While, the height decreases from 2m to 0.4m and the width from 6.7m to 19.3m to 13m.

Two-dimension imaging survey is done along a traverse which runs over the minimum diameter of cave room. The Terrameter SAS 4000 instrument was used for measuring apparent resistivity in the field. The 2D survey was carried out by Dipole-dipole (n-factor=6), Dipole-dipole (n-factor=8), Wenner- Schlumberger (n-factor=8), and Pole-dipole (n-factor=8) arrays (Fig.3).When the data is collected by these arrays the maximum electrode spacing (a) is equal (2m) with a total array length of (44m).

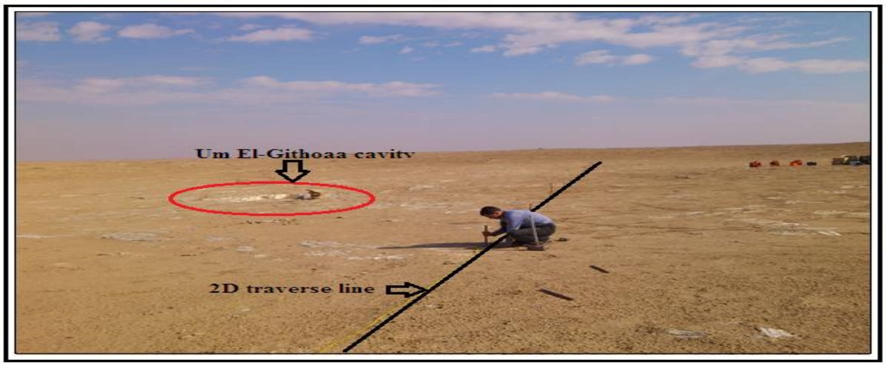

Figure (3): Location of traverse survey over Um El-Githoaa cavity (Hit area).

Data Processing

The bad data is usually more common with arrays such as the Dipole-dipole and Pole-dipole arrays (Fig.4, 5), that have very large geometric factors, and thus very small potential measurements for the same current compared to other arrays such as the Wenner-Schlumberger array, which has less bad data (Fig.6).

The conventional least-squares method will attempt to minimize the square of difference between the measured and calculated apparent resistivity values (26 and 27). This method normally gives reasonable results if the data contains random noise come from the effect of telluric current. However if the data set contains nonrandom(systematic)noise from sources such mistakes or equipment problems, this situation is less satisfactory, and such data points could have a great influence on the resulting inversion model. To reduce the effect of such data points, an inversion method where the absolute difference (or the first power) between the measured and calculated apparent resistivity values is minimized can be used (28).

In general, before carrying out the inversion of a data set, it should first take a look at the data as a pseudo section plot (Figure, 4a,5a) as well as a profile plot (Figure, 4b,5b), as an example for Dipole-dipole and Pole-dipole array. In measured apparent resistivity pseudosection, the bad data points with systematic noise show up as spots with unusually low or high resistivity values (Figure, 4a, 5a). In profile form, they stand out from the rest and can be easily removed from the data set. Another example for Wenner-Schlumberger array shows less bad data from Pole-dipole array (Fig.6a, b), the data set contains nonrandom noise may form sources such mistakes in measurements or equipment problems, while the bad data in profile form of Dipole-dipole and Pole-dipole arrays may due to lateral inhomogeneity of sediments .The negative apparent resistivity data is appeared in dipole-dipole and pole-dipole, while they don’t appear in the Wenner-Schlumberger measurements. This is because the measurement signal will decreases with increasing the distance between current and potential electrodes and / or with the noise level increased.

The figures (4, 5, and 6) show that the data coverage of Dipole-dipole array more than Wenner-Shlumberger array, but less than Pole-dipole array.

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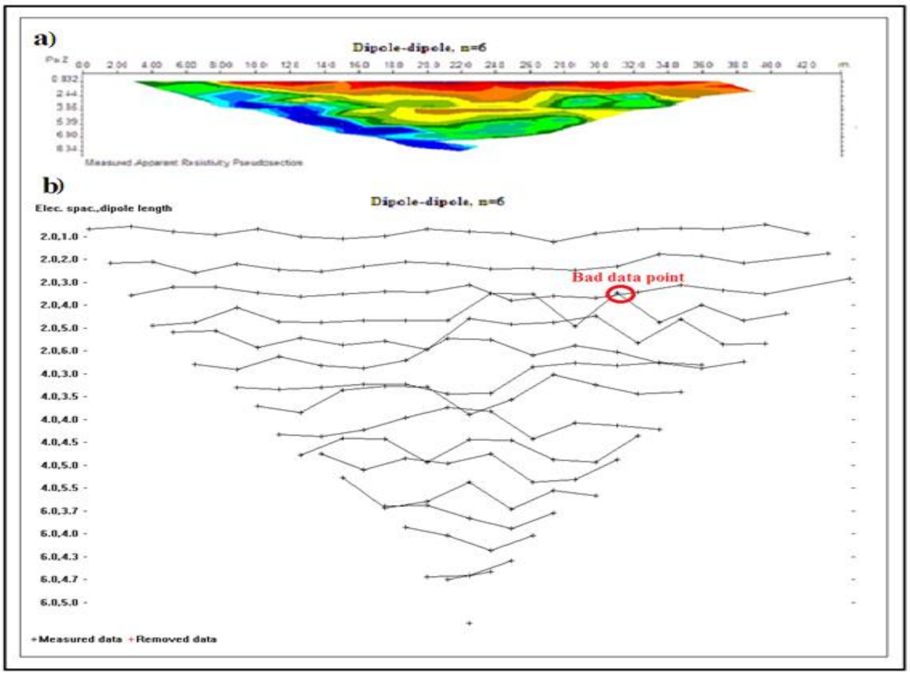

Figure (4): field data set with a few bad data points of Dipole-dipole array traverse above Um El-Githoaa cavity. The apparent resistivity data in (a) pseudosection form and in (b) profile form.

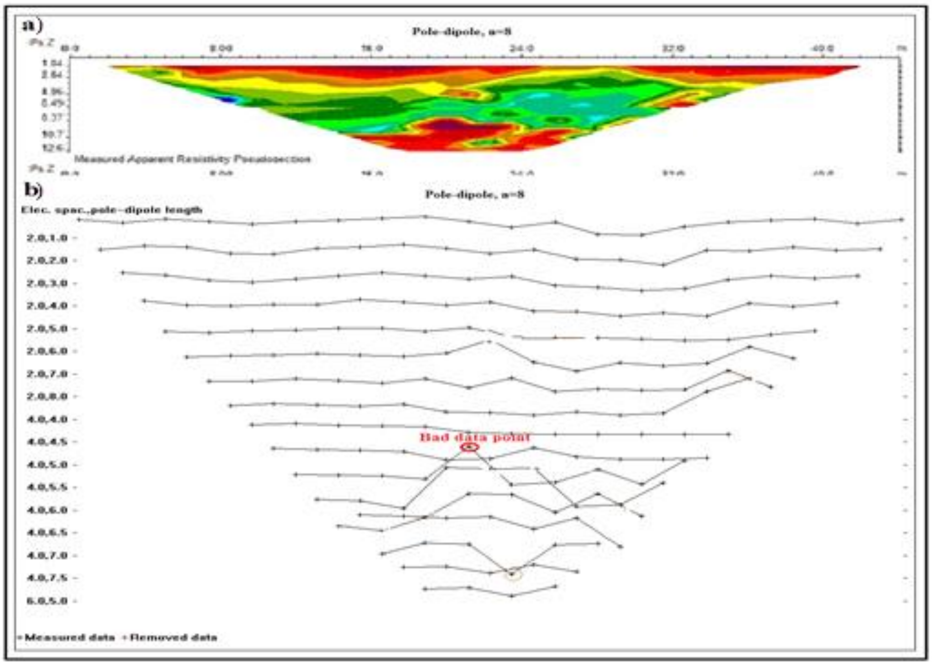

Figure (5): Field data set with a few bad data points of Pole-dipole array traverse above Um El-Githoaa cavity. The apparent resistivity data in (a) pseudosection form and in (b) profile form.

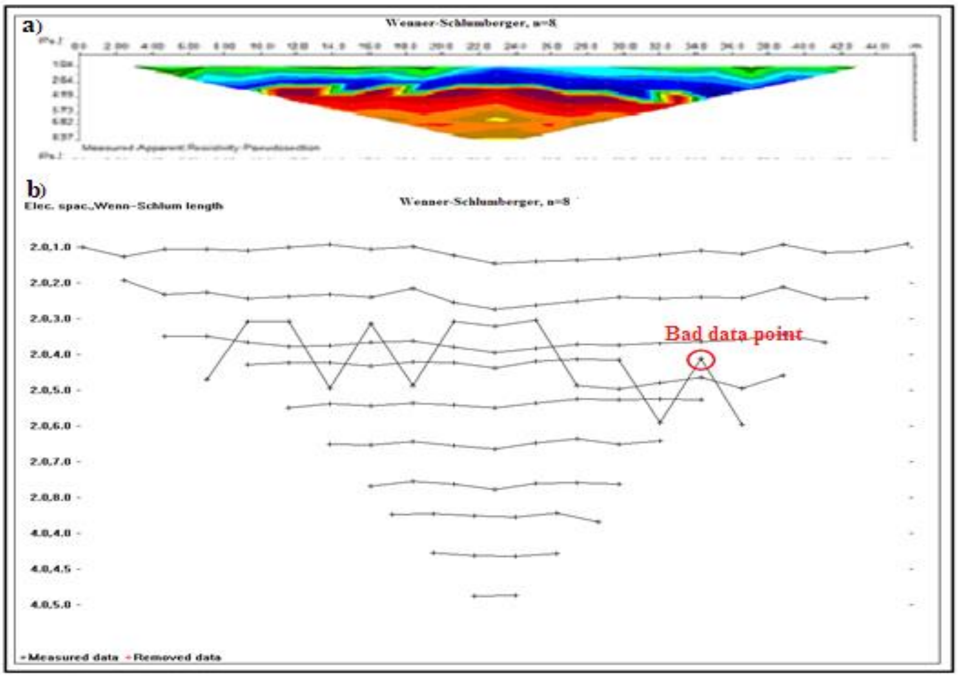

Figure (6): field data set with a few bad data points of Wenner-Schlumberger array traverse above Um El-Githoaa cavity. The apparent resistivity data in (a) pseudosection form and in (b) profile form.

Interpretation and results

The 2D resistivity data were interpreted using the RES2DINV program (Geotomo Software) version 3.56.22(26 and 29). A forward modeling is used to calculate the apparent resistivity values, and a non-linear least-squares optimization technique is used for inversion of data (30).

Apparent resistivity measurements of 2D imaging need to further process to model the true distribution of resistivity values for the specific geology. The

Inversion programs use mathematical algorithms to produce a subsurface resistivity model that will best fit the apparent resistivity data set. To overcome the problem of non-uniqueness (many models fit the data equally well), the regularized least-squares optimization method is commonly used in the inversion algorithms (26).

If the data set is very noisy, a relatively larger damping factor (for example 0.3) is used. If the data set is less noisy, use a smaller initial damping factor (for example 0.1), as mentioned in (25). Here because of noisier data near surface, a higher initial damping factor was used to be (0.15), and higher minimum damping factor to be (0.02). Additionally a higher damping factor was used for the first layer to be (2.5).The inversion subroutine will generally reduce the damping factor after each iteration. However, a minimum limit for the damping factor must be set to stabilize the inversion process. The minimum value should usually set to about one-fifth the value of the initial damping factor.

Another important sub option is (Vertical / Horizontal flatness filter) ratio weight of 1. If the main anomalies in apparent resistivity pseudo section are elongated horizontally, it must choose a smaller weight than vertical filter (25). So, the flatness filter was used weight of 0.5.

2D Inversion of Dipole-dipole Data for n=6

To generate the inverse model section of the true subsurface resistivity distribution, a starting model of the subsurface is used to calculate the distribution of apparent resistivity pseudosection, and compared with the apparent resistivity values measured in the field.

The inversion results of 2D imaging Dipole-dipole data along the traverse above Um El-Githoaa cavity as shown in (Fig. 7), it clearly indicates that the resistivity contrast between the anomalous part of cavity and background resistivity is about 700:100 Ωm.. The inverse model produced by the standard least-squares method has a gradational boundary for the cavity (Fig.7). Also, we used robust model inversion method for inversion 2D data .The comparison between two methods appeared that the invers model produced by the robust model method (Fig. 8) has sharper and straighter boundaries. So, we used least square inversion method in interpretation other 2D resistivity data.

The inverse model is the true image that is used for interpretation. The RMS error indicates how well the calculated pseudosection is fit to the measured pseudosection, so it is preferable to reduce it as much as possible. But in some cases this is not true, especially if there is a high amount of geological noises, and the noise is usually more common with electrodes arrays such as Pole-dipole and Dipole –dipole arrays that have a very large geometric factor, and thus very small reading between potential electrodes (25). From the inverse model (Fig. 7), the Dimensions of the cavity appeared approximately equal to 11m width, 2m height, and 4m depth. So, the Um El-Githoaa cavity is well defined from 2D imaging with Dipole –dipole array in comparison with the actual dimension of this cavity, which is equal to 12.5m width, 2.2m height, and 3.8m depth under the survey traverse. The RMS error is fairly high, equal to 56.2% of this model, which may be a result of near surface inhomogeneity of Gypsum rocks, and some of these rocks visible on ground surface.

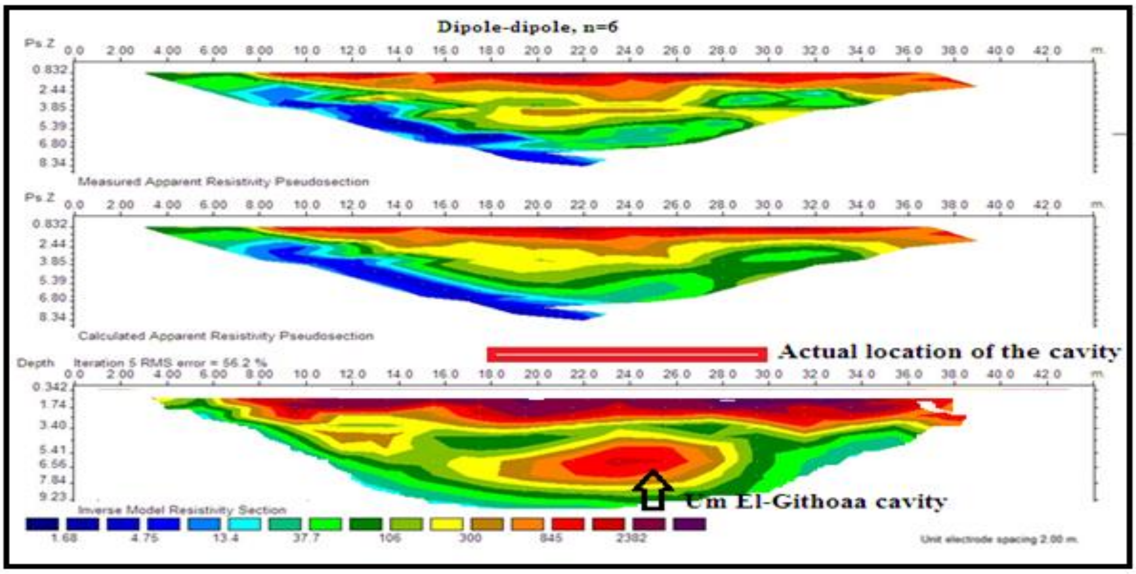

Figure (7): Measured and calculated pseudo sections and inverse model of Dipole-dipole resistivity section along traverse (Standard least-squares inversion method).

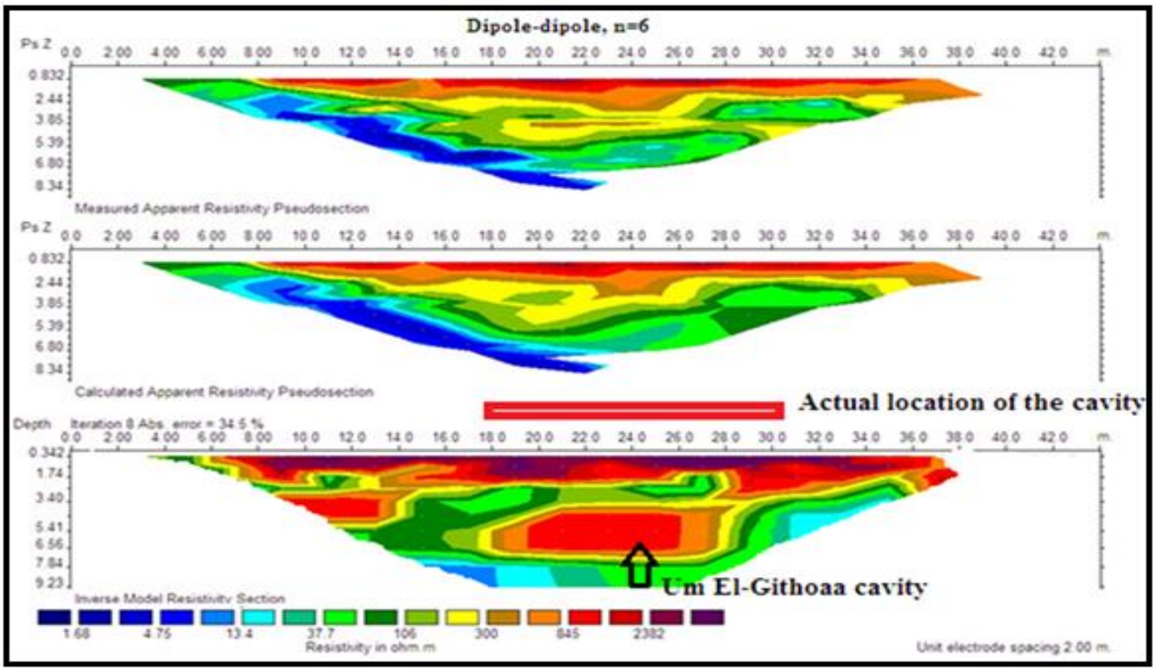

Figure (8): Measured and calculated pseudo sections and inverse model of Dipole-dipole resistivity section along traverse (Robust inversion model method).

2D Inversion of Pole-dipole Data for n=8

The 2D inverse model of Pole-dipole with a=2m and n-factor= 8 for the subsurface Um El-Githoaa cavity is adjusted iteratively until the desired fit is achieved. In (Fig.9) the top section shows the measured resistivity pseudo section. The middle section shows the calculated apparent resistivity pseudo section based on the distribution of resistivity values in the inverse model which is shown in the bottom section. The (Fig.9) shows the inversion results of 2D inversion Pole-dipole data along traverse, which clearly shows that the resistivity contrast between the anomalous part of cavity and background resistivity is about 550:100 Ω However, the anomaly of the Um El-Githoaa cavity, which appeared in the inverse model is very small in comparison with the actual dimension, and the RMS error has a high value. This is due to the large effect of noise (25), and as aforementioned of 2D inverse of the Dipole-dipole array.

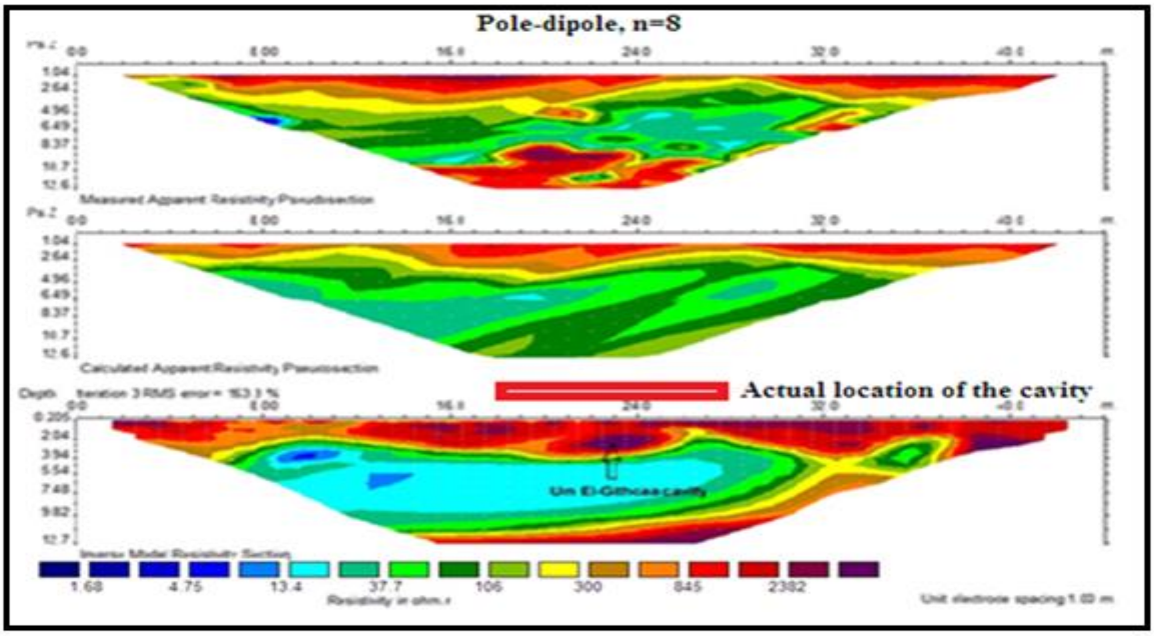

Figure (9): Measured and calculated pseudo sections and inverse model of Pole-dipole resistivity section along traverse

2D Inversion of Wenner-Schlumberger Data for n=8

The results of inversion 2D imaging data for Wenner-Schlumberger electrode array along traverse above Um El-Githoaa cavity as shown in (Fig. 10).The 2D survey was collected with electrode spacing (a) of 2m and an n-factor of 8 .The invers model (Fig.10) shows the true distribution of subsurface resistivity contrast between the anomalous part of cavity and background resistivity, which is nearly equal to 500:100 Ωm. The anomaly of the cavity has a size, shape, and depth less accurate than that of the anomaly, which is displayed in the inverse model of Dipole-dipole data.

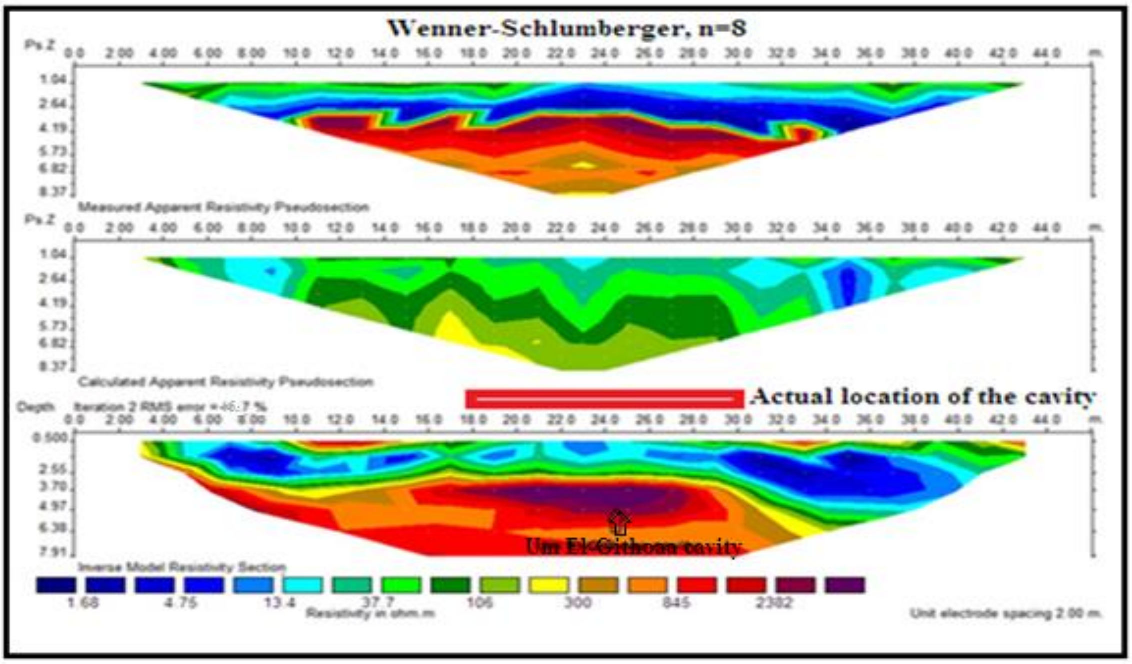

Figure (10): Measured and calculated pseudo sections and inverse model of Wenner-Schlumberger resistivity section along traverse.

2D Inversion of Dipole-dipole data for n-factor of 8

Another Dipole-dipole 2D resistivity imaging survey with factor (n) value of 8 is done along traverse Um El-Githoaa cavity in Hit area, and along the same Dipole-dipole traverse with factor (n) of 6. The inverse model of 2D Dipole-dipole data in (Fig.11) shows that the resistivity contrast between the anomalous part and background resistivity is about 800:100 Ωm.

The data measurements indicate an increase of observed negative bad data. The negative data measurements could have occurred for two reasons. The first is the current or the potential electrodes are connected with reversed polarities. Meanwhile, the second is the high amount of noise due to the large geometric factor of Dipole-dipole (25), in the present data; the second reason is the cause of negative signs. Additionally, (Fig.11) shows the results were the rather noisy, because very high RMS value which is equal to 148.4%. This noise is caused by high lateral inhomogeneity of Gypsum rocks near the ground's surface.

The comparison between (Fig.7)and (Fig.11)shows that the quality of data measurements are better taken by Dipole-dipole 2D resistivity imaging survey with an n- factor of 6 than an n-factor of 8 .Also, the location and size of Um El-Githoaa cave are different from the actual situation (Fig11). Then, it is preferable to increase an n- factor to 2, 3 and so on until a maximum value between 4 and 6. This is because when the dipole distance(an) between pairs electrodes is increased, the potential measured between electrodes P_1 and P_2 decreases rapidly with increasing n-factor, and the measurements values would have higher noise levels (30). For this reason, it is not advisable to use a value of n-factor greater than 6 especially with a shallow target as the present study.

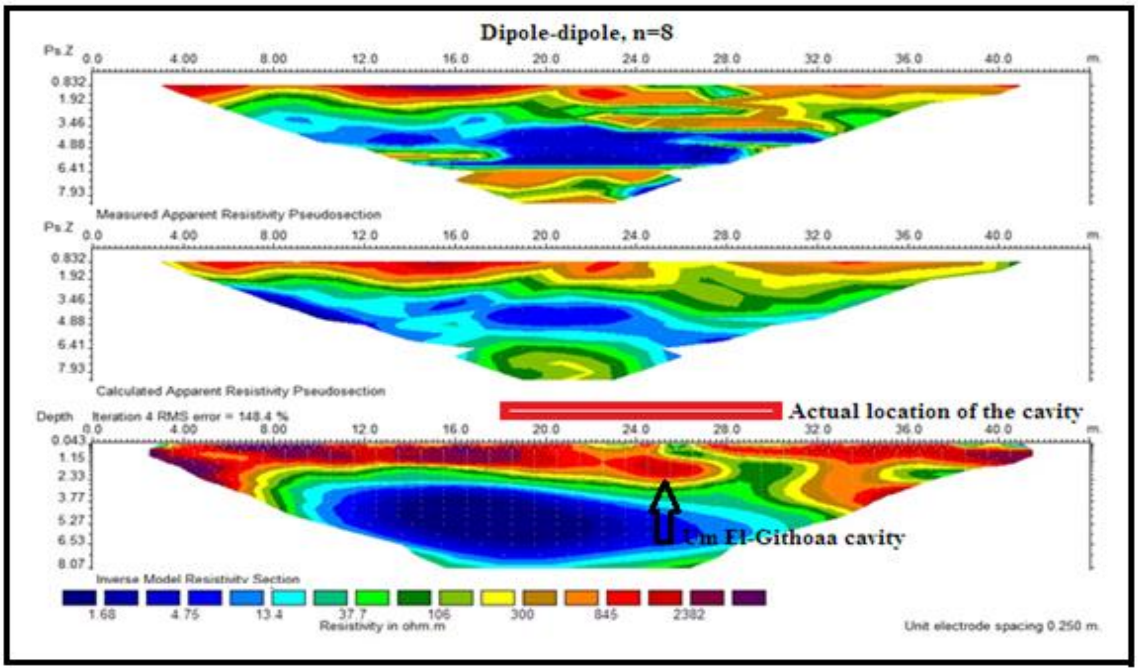

Figure (11): Measured and calculated pseudo sections and inverse model of Dipole-dipole resistivity section along Traverse with n value of 8.

Comparison between Electrode Arrays in 2D Imaging

The inverse models of 2D imaging survey from the various electrode arrays, Dipole-dipole with n-factor of 6,Pole-dipole with n-factor of 8,and Wenner- Schlumberger are used with n-factor of 8 along the traverse Um El-Githoaa cavity in Hit area, as shown in(Fig.7,9,and10)respectively. The invers models show that all electrode arrays can detect the underground cavity with different form and accuracy.

Of these various arrays, the Dipole-dipole array provides the best subsurface cavity imaging (Fig.7). The underground cavity can be considered as a lateral anomaly in a homogenous medium. An anomalous zone of the cavity can be distinguished as the higher resistivity zone and surrounded by lower background resistivity.

The depth and dimensions of Um El-Githoaa cavity are well defined from 2D imaging with Dipole –dipole array (4m depth, 2m height, and 11m width), these results agree satisfactory with the depth and dimensions (3.8m depth, 2.2m height, and 12.5m width) as it is known from the mapping of the cave under the traverse in the field.

Conclusions

1. The inverse models of the various 2D imaging electrode arrays, Dipole-dipole array with an n-factor of 6, Pole-dipole array with an n-factor of 8 and Wenner-Schlumberger array with an n-factor of 8 clearly show that the resistivity contrast between the anomalous part of cavity and background resistivity is about 700:100 Ωm, 550:100 Ωm, and 500:100 Ωm of Dipole-dipole, Pole-dipole, and Wenner-Schlumberger arrays respectively. Therefore, all electrode arrays can detect underground cavities but with different accuracy of cavity depths and dimensions.
2. The Um El-Githoaa cavity is well defined from 2D imaging with Dipole –dipole array, the depth equals 4m and dimensions equal 2m height and 11m width. These results agree satisfactorily with the dimensions and depth as it is known from the mapping of cavity under the traverse in the field, which is equals 3.8m depth, 2.2m height, and 12.5m width.
3. Another 2D imaging survey of Dipole-dipole array with n-factor of 8 is done in Hit area, along the same Dipole-dipole traverse which has an n-factor of 6. The interpretation of 2D data shows the results to be rather noisy, and increasing negative observed resistivity data. The location and volume of Um El-Githoaa cave are different from the actual situation. So, it is not advisable to use a value of n-factor

greater than 6, especially with a shallow target. This is because the measurements with higher n values would have higher noise levels.

4. We concluded that the 2D imaging survey is a useful technique and more effective for determining and mapping subsurface cavities, when taken in consideration using the suitable a-electrode spacing and n-factor for each electrode array, especially with the Dipole –dipole array which provides the best imaging of subsurface cavity.

Acknowledgments

The authors are grateful to thank the college of science and head of geology department – Baghdad University. Also, we would like to thanks dean of Science College and the staff of applied geology department – Anbar University for providing requirements for achieving the field work. Finally we would like to thank my friends, senior geologists (Mohammed M. A. Al Hameedawie, and Ahmed Srdah AL-Zubedi), and Baraa Y. Hussein for helping us in field work and providing necessary information concerning the studied area and this work.

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تقييم ترتيبات أقطاب مختلفة في تحديد الفجوات التحت سطحية بأستعمال التصوير الثنائي البعدين

جاسم محمد ثابت   علي مشعل عبد

E.mail : ali_mishal2001@yahoo.com

الملخص

تم أجراء المسح الثنائي البعدين فوق فجوه أم الجذوع الواقعة في منطقة هيت .وقبل تنفيذ العمل الحقلي تم تحديد المسافة القطبية (a) والعامل (n) لكل نوع من ترتيبات الأقطاب المستخدمة في هذا المسح. وبعد تحديد هذه العوامل أخذت القياسات الحقلية للمسح الثنائي البعدين باستعمال ترتيبات الى ثنائي القطبين، ثلاثي الأقطاب، وترتيب فنر– شلمبرجر. أظهر الموديل المعكوس للترتيبات المذكورة أعلاه وجود فرق في قيم المقاومة النوعية بين شذوذ الفجوة والصخور المحيطة بها، وكان هذا الفرق بحدود 100:700، 100:550، و100:500 لترتيبات ثنائي القطبين، ثلاثي الأقطاب، وترتيب فنر– شلمبرجر على التوالي. أي أن جميع هذه الترتيبات تمكنت من اكتشاف الفجوة ولكن بأشكال ودقة مختلفة، ولكن ترتيب ثنائي القطبين كان أفضلهم في تحديد عمق وشكل هذه الفجوة. وبعد ذلك تم زيادة العامل(n) من 6 الى 8 لترتيب ثنائي القطبين بامتداد نفس المسار لمعرفة تأثير هذه الزيادة. وتبين من تفسير القياسات الحقلية بأن النتائج كانت أكثر ضوضاء ،وكذلك هنالك زيادة في عدد القراءات السالبة. أيضا هنالك اختلاف في الموقع وحجم الفجوة .لذلك لا يفضل زيادة العامل n أكثر من 6 خصوصا للأهداف القريبة من السطح وعند استعمال ترتيب ثنائي القطبين .وتم ألأستنتاج من هذه الدراسة أن التصوير الثنائي البعدين يمكن أن يكون تقنية مفيدة وأكثر فعالية في تحديد وتخطيط الفجوات التحت سطحية ،عند ألأخذ بنظر ألأعتبار أختيار الفاصلة القطبية a والعامل n المناسبين لكل ترتيب من ترتيبات الأقطاب ،وخاصة الى ترتيب ثنائي القطبين