The discovery of the tomb of the Great Army General Iwrhya: A quasi 3D Electrical Resistivity Tomography (ERT), Saqqara, Giza, Egypt

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Abstract: A quasi 3D electrical resistivity (ERT) survey was undertaken at a UNESCO World Heritage site, Saqqara, Giza, Egypt, during a joint archaeological-geophysical mission from Cairo University. The main objective is to detect the locations of the subsurface archaeological tombs/or crypts and to allocate any possible archaeological bodies/features buried underneath the study area. In this survey, SYSCAL Pro system with 24 electrodes and a multi-core cable is used for automatic data acquisition of profiling data. The dipole–dipole array was used to enhance resolution, 14 resistivity lines are conducted during this Survey. The processed data were analysed in order to produce resistivity tomography (ERT) for qualitative and quantitative interpretations. Inversion of the ERT data identified variation of resistivity values and the expected locations of the underground galleries and highlight the presence of regular shape structures probably due to features of archaeological interest. Excavations made accordingly in the study area led to an interesting discovery of a tomb of the Great Army General, Iwrhya. The tomb is approximately 2000 years old as it covers the reigns of both Kings Seth I and Ramesses II. Using the 3D resistivity tomography with such a multi-electrode technique proved its efficiency and applicability for non-invasive archaeo-geophysical prospecting.

Key words: archaeological prospecting, Saqqara, geophysics, electric resistivity tomography, Army General Iwrhya, the necropolis of the city of Memphis

1. Introduction

Ancient Egypt – the land of the pharaohs – is among the oldest known cultures in the world. Its tombs and temples, ornamented with reliefs and inscriptions in hieroglyphic writing, have been the basis of awe and respect

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for millennia. Nowadays, Egypt is keen on increasing the touristic activities through the development of the already discovered tombs and expand the excavation activities and discoveries of new archaeological buried treasures. The problem of traditional and random archaeological excavations has always been the controlling factor for accurate and valuable discoveries. Consuming time, efforts, and money were the major issue. Currently, geophysics is well developed and expanded the spectrum of applications to include the non-invasive archaeo-geophysical exploration. Varieties of physical properties in the subsoil are used to explore archaeological remains using common passive geophysical tools (e.g. georadar, land magnetic surveys) without destroying or digging in the archaeological site. Over the past 20 years, the acquisition and processing technology has made the geophysical approach a reliable investigative tool, both before and during excavation. The use of geophysics in archaeology dates back to the early 1950s.

On the other hand, the electric resistivity methods (ERT) are commonly applied in archaeological excavations due to its fast and accurate response. In specific locations, ERT can be utilized to measure the apparent resistivity of soil (*Tsourlos and Tsokas, 2011; Papadopoulos and Sarris, 2011; Mol and Preston, 2010*). The technique is based on detecting the contrast of electric resistivity between the soil, the sediment and the surrounding rock. Penetration depth depends on electrodes separation. The ERT response is a colour-shade image of the apparent electric resistivity. Depths and type of causative structures, and walls or tombs has long been a common practice and can be determined by ERT (*Atkinson, 1952; Monteiro and Senos Matias 1987; Ponti et al., 1996; Cammarano et al., 1997; Sarris and Jones, 2000; Thacker et al., 2002; Bernard et al., 2004; Leucci, 2006; Papadopoulos et al., 2006; AL-Sayed, 2007; Batayneh et al., 2007; Abbas et al., 2008; Drahor et al., 2008; Gaffney, 2008; Tsokas et al., 2008; Tsokas et al., 2009; Abbas et al., 2009; Leopold et al., 2010; Papadopoulos et al., 2010; Berge and Drahor, 2011; Leopold et al. 2011; Leucci and Greco, 2012; Hemeda and Pitilakis, 2017*).

Saqqara, in particular, was the necropolis of the city of Memphis, the first capital of United Egypt founded around 3000 BC. It is a destination for eleven major pyramids lying down over six miles, including the first ever pyramid, known as the Step Pyramid and funerary complex of pharaoh Djoser (or Zoser), who reigned from c. 2630 to c. 2611 BC. A critical question arises, whether there exist different burial levels representing Old Kingdom in Saqqara or not? Archaeologists believe that there might be Old Kingdom levels since the Saqqara is known to be the oldest burial place for both kings and high officials. Scientific evidences are required to support the idea. Desire to clarify this fundamental question prompted a joint archaeological-geophysical mission at Saqqara site of Cairo university located in Giza governorate to search for the hidden remains and /or tombs at all possible levels. Moreover, a specific aim is to support archaeologists future excavation planning and show if the cleared sites still contained substantial remains beneath. This paper shows the outcomes of a geoelectrical survey performed to answer the above question. The following sections describe the significance of Saqqara site, the survey plan, methodology and theory behind the technique, illustrate the features of the resistivity profiles, and then show the location and shape of the anomaly sources as highlighted by a quasi three-dimensional tomography imaging, and the location of a significate discovery based on the above survey.

2. Significance of Saqqara site

Saqqara is located in a central area between the south of Egypt and the Delta area made it a very important city that never stopped being an area used as an administrative capital where kings and high officials of the court were buried, since the beginning of historical periods up to late of the pharaonic period. Saqqara is the place where the first stone pyramid was built as a step pyramid followed by the pyramids of the kings of the fifth and sixth dynasties (Fig. 1). The area was also chosen to be the burial place of many of the high officials of the Old Kingdom and continued to be so up to the New Kingdom when many of the high officials and army generals were buried. Among those is the very well-known army general later King Horemheb, who had a very beautiful tomb as a burial place before becoming a ruling king and having a new tomb in the Valley of the Kings in Luxor. Since Saqqara is full of monuments from different periods, we always expect different stratigraphic levels that could lead us to the Old Kingdom level almost 2000 years earlier. Therefore, in Saqqara we have to deal in every area with different levels of excavations and sometimes very deep ones. The site of the faculty of Archaeology, Cairo University, in Saqqara (Fig. 2) is

Fig. 1. The Djoser Pyramid at Saqqara, Giza, Egypt (after J. K. Johnson).

dated back to the New Kingdom and its tombs follow an East–West axis located in one row beginning south and ending with a high hill, above tombs from the Old Kingdom. In the middle of this site there is a massive tomb (known as mastaba) dated to the Old Kingdom and which was not fully examined since in the previous works done on this site in the 1980's accurate surveying methods were not available below these tombs. The burial shafts at 12 metres depth are forming extended galleries underneath, since the site was plundered many times by robbers digging more and more galleries in search for treasures. Consequently, most of the burial shafts were found empty, digging more and more galleries. These underground spaces have a complex plan that need excavations on a very deep level below ground level. The role of geophysics is now essential for further excavation and discoveries of old kingdom in the Saqqara site excavations.

Geologically, the limestone plateau of Saqqara is elevated at 40 to 58 m above sea level (*Welc et al., 2015*), with geological relief of several metres, dipping at $5° - 7°$ to the west, producing an isoclinal bedrock structure. The eastern boundary of the plateau is marked by a high cuesta separating the so-called high desert from the Nile River floodplain below. The top of the Saqqara plateau is composed of carbonate rocks of the Upper Eocene (*Welc et al., 2015*), overlain by a thin layer of Quaternary sediments. The Upper

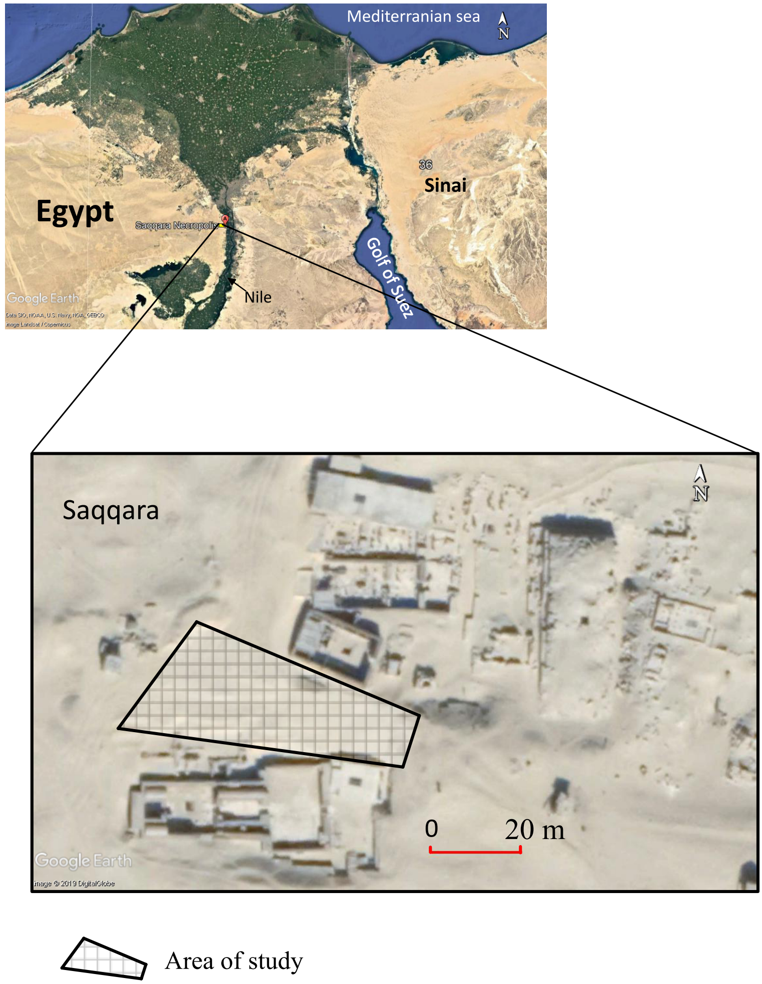

Fig. 2. Location map of the area of study.

Eocene bedrock is hard and compact, light-creamy to brownish sandy-pelitic limestones interbedded with soft and poorly compact marly limestone. The complex characterizes the upper calcareous beds of the Saqqara Member of the Maadi Formation that is about 22m thick (*Youssef et al., 1984; Squyres et al., 1987; Said, 1990; Klemm and Klemm, 2008, 2010; Welc et al., 2013; Welc and Trzciński, 2013*).

3. Survey layout and geometric design

The geoelectric geophysical prospecting methods, due to its non-invasive or destructive nature, are increasingly being used in archaeological research because they allow recognizing buried structures and morphologies without previous excavation (*Hemeda, 2013; Gaber et al., 1999; Tsokas et al., 2009; Tsokas et al., 2008; Drahor et al., 2008;* and *Berge and Drahor, 2011*). This facilitates sites' interpretation, conservation policies, and excavation planning (*Hesse, 1999; Benech and Hesse, 2007; Wynn, 1986*).

In December 2017, the joint mission of the Faculty of Archaeology and Geophysics Department – Faculty of Science Cairo University, carried out a high resolution electrical resistivity survey in Saqqara area very close to the famous step pyramid of Zoser. Fourteen resistivity profiles covering the study area were measured using Syscal Pro instrument. 24 electrodes were used to collect the resistivity data with different electrode spacing according to the required horizontal resolution and the depth of penetration (Fig. 3).

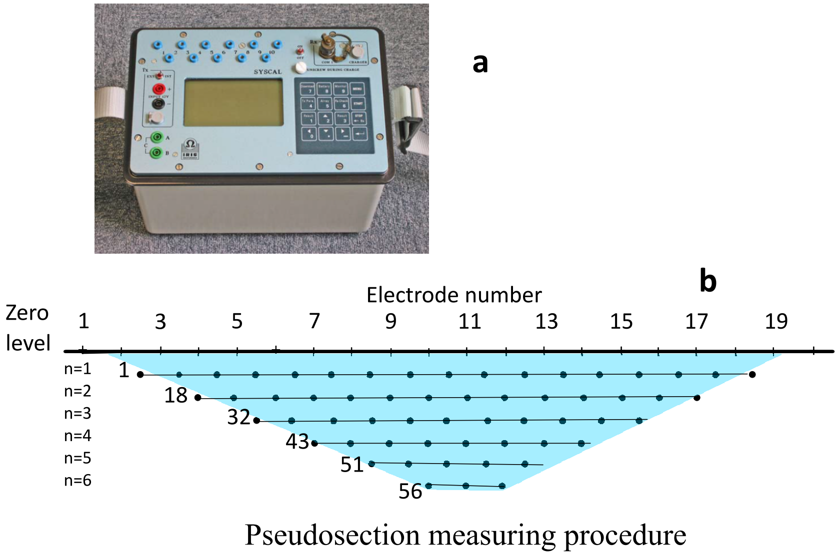

Fig. 3. The arrangement of electrodes for a 2D electrical survey. The Syscal Pro instrument (a), and the sequence of measurements to build up a pseudo section (*Dahlin and Loke 1998*), (b).

4. Multi-electrode electrical resistivity imaging

With 24 electrodes, the SYSCAL Pro Switch unit (Fig. 3a) carries out automatic switching of these electrodes for acquiring profiling data. The mixed sounding/profiling section is build-up through the various combinations of transmitting and receiving pairs of electrodes. The maximum investigation depth mainly depends on the total length of the cable (*Guerin et al., 2004*) as shown in Fig. 3b. Various types of electrode configuration can be used, such as Dipole–Dipole, Wenner, Schlumberger, Pole–Pole arrays. Each type of configuration has advantages and limitations in terms of the spatial vertical penetration and lateral resolution.

5. Field data acquisition

Due to the large number of readings recorded by the instrument during the course of acquisition of a single line, in resistivity imaging techniques, an important factor is to the control of the output power and output voltage of the instrument. The control will limits the number of stacks required to reach the expected data quality. In this case, the standard deviation plays a critical role and thus the acquisition time is minimized.

In this work, the dipole-dipole configuration is used to get higher resolution because it is very sensitive to horizontal changes in resistivity and is therefore appropriate in mapping vertical structures (*Leucci and Greco, 2012;* and *Loke, 2009*). Fourteen 2D resistivity lines (Fig. 4a) are conducted during this survey using SYSCAL Pro unit. Lines from 1–6 are acquired with 2 m spacing between the electrodes with total profile length of 46 m and estimated depth of penetration of approximately 10 m. Lines from 7–11 are acquired with 3 m electrode spacing with total profile length of 69 m and the depth of penetration will be ranging from 15–16 m. The last three lines are conducted with 1 m electrode spacing with total profile length of 23 m and estimated depth of penetration ranging from 5–6 m.

Lines 1, 2, 3, 4, 5, 7, 8, 9, 11 are acquired nearly E–W, while lines 6, 10 are diagonals (NW–SE, and NE–SW respectively). Lines 12, 13, 14 are conducted N–S perpendicular to the first lines as shown in Fig. 4b. The variability in electrode spacing and the total length between lines provides different resolution and several depths of penetration. The profiles were

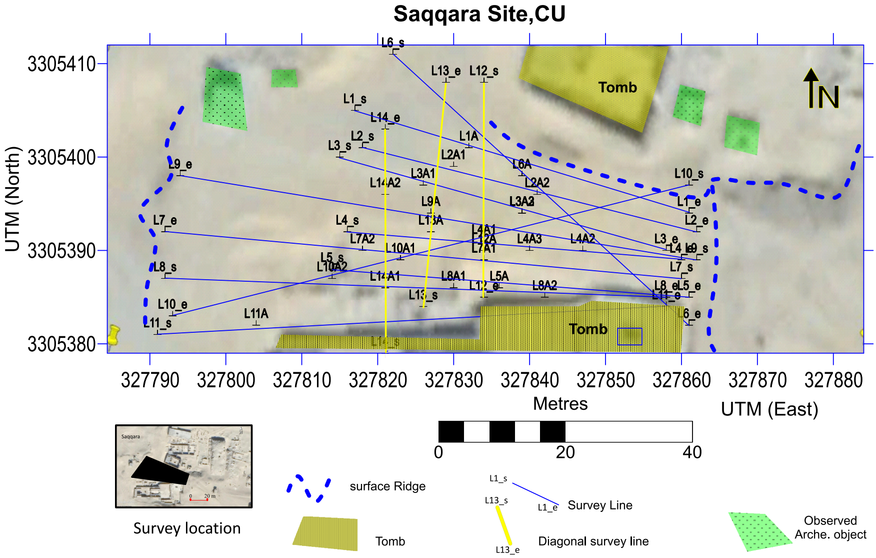

Fig. 4a. Location of the surveyed resistivity profiles in Saqqara site. Four groups of profiles are surveyed: nearly E–W, NW–SE, NE–SW, and N–S.

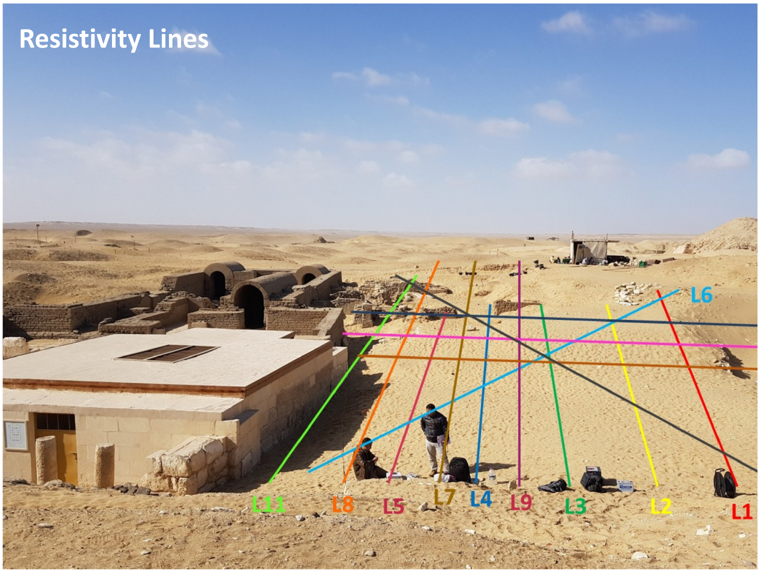

Fig. 4b. Area before excavation and the electric resistivity profile locations are posted. View from east to west.

carried out in various directions for the redundancy and quality assurance over some suspicious anomalies locations.

6. ERT data inversion and interpretation

In geophysical inversion, we aim to find a *model* that gives a response close to the actual measured values. The model is an idealized mathematical representation of a section of the earth. In the terminology of the inverse theory, the model has a set of unknowns that are the physical quantities we want to estimate from the observed data. The *model response* is the synthetic data that can be calculated from the mathematical forward problem. The inversion of the present measured data is carried out according to a robust inversion iterative process (Modified Marquardt algorithm, MMA) which aims at minimizing the difference between the measured pseudo-section and the calculated pseudo-section based on a starting model. After each iteration, this model is updated, until a threshold value is reached, which gives an acceptable difference between measured and calculated data. The RES2DINV resistivity inversion software (*Loke, 2001*) was used to invert automatically the apparent resistivity acquired data and to yield a two-dimensional earth resistivity model. The "smoothness-constrained robust" inversion method, presented by *Loke and Barker (1996)*, was applied.

Briefly, the robust inversion has proved to be useful. It modifies the normal formulation so that different elements of the model parameter change and data misfit vectors have the same magnitudes. It is given by:

$$\left(\boldsymbol{J}^T\boldsymbol{J} + \lambda\,\boldsymbol{F}_R\right)\Delta\boldsymbol{q}_k = \boldsymbol{J}^T\boldsymbol{R}_d\,\boldsymbol{g} - \lambda\,\boldsymbol{F}_R\,\boldsymbol{q}_k\,. \tag{1}$$

$\boldsymbol{q}$ is the model resistivity values, $\Delta\boldsymbol{q}$ is the model parameter change vector, and $\boldsymbol{J}$ is the Jacobian matrix (of size m by n), $\boldsymbol{g}$ is the discrepancy vector that is defined by $\boldsymbol{g} = \boldsymbol{y} - \boldsymbol{f}$, where $\boldsymbol{y}$ is the observed data and $\boldsymbol{f}$ is the predicted model parameters (resistivities). λ is the Marquardt or damping factor. The elements of the Jacobian matrix are given by:

$$\boldsymbol{j}_{ij} = \frac{\partial \boldsymbol{f}_i}{\partial \boldsymbol{q}_j}\,, \tag{2}$$

where $\boldsymbol{f} = \alpha_x\,\boldsymbol{C}_x^T\boldsymbol{C}_x + \alpha_y\,\boldsymbol{C}_y^T\boldsymbol{C}_y + \alpha_z\,\boldsymbol{C}_z^T\boldsymbol{C}_z$ and $\boldsymbol{C}_x$, $\boldsymbol{C}_y$ and $\boldsymbol{C}_z$ are the smoothing matrices in the x-, y- and z-directions. α_x, α_y and α_z are the relative weights given to the smoothness filters in the x-, y- and z-directions.

Figs. 5a and 5b display example of the pseudosections across the Line#1 and Line #12 including the measured apparent resistivities, calculated resistivities, and the final inverted resistivities, respectively. In order to enhance the resistivity contrasts, each pseudosection was assigned the same colour scale. Figure 6 shows the final inverted ERT profiles for lines 1–7 with the expected (anomalies) marked by circles. Figure 7 shows the ERT inverted profiles for lines 8–14 with the expected cavities/crypts (anomalies) marked by ellipses.

7. Results

The study area includes clear evidences of many archaeological remains buried at different levels. The possibility that these archaeological remains are mainly tomb structures containing interconnected underground burial rooms/cavities/walls/or galleries is highly supported by earlier excavation work close to the study area. The inverted (ERT) profiles showed very clear high resistivity anomalies ($>900\ \Omega$.m) which are seen on the different profiles. These anomalies could be related to the underground cavities or crypts. The interpretation of the interpreted (ERT) profiles shows that the targets from this case study are the high resistivity anomalies, which are of different dimensions ranging from 3 to 12 m and depths ranging from 0.25 to 16 m.

Figure 8 shows the 3D contouring of iso-resistivity surfaces. Resistivity values from 1.9 Ω.m to 4900 Ω.m are used as the lower and upper boundaries of this 3D representation. We focused on the iso-resistivity value 945 Ω.m as a threshold value representing the target high resistivity corresponding to the resistive cavities/crypts/voids that may be expected in this area. Different isometric views are shown in Fig. 8a–f all possible anomalies are marked. It is clear that the level of these anomalies varies with clear halls (main hall and a secondary possible one interconnected with a gallery or corridor). Many isolated objects can be seen.

Figure 9 compares between the resulted 3D representation of the inverted resistivities and a design of close tomb in the area. A good correlation can be seen. Two main halls with a corridor can be distinguished. A possible well may exist in the eastern hall. The approximate dimension of one of

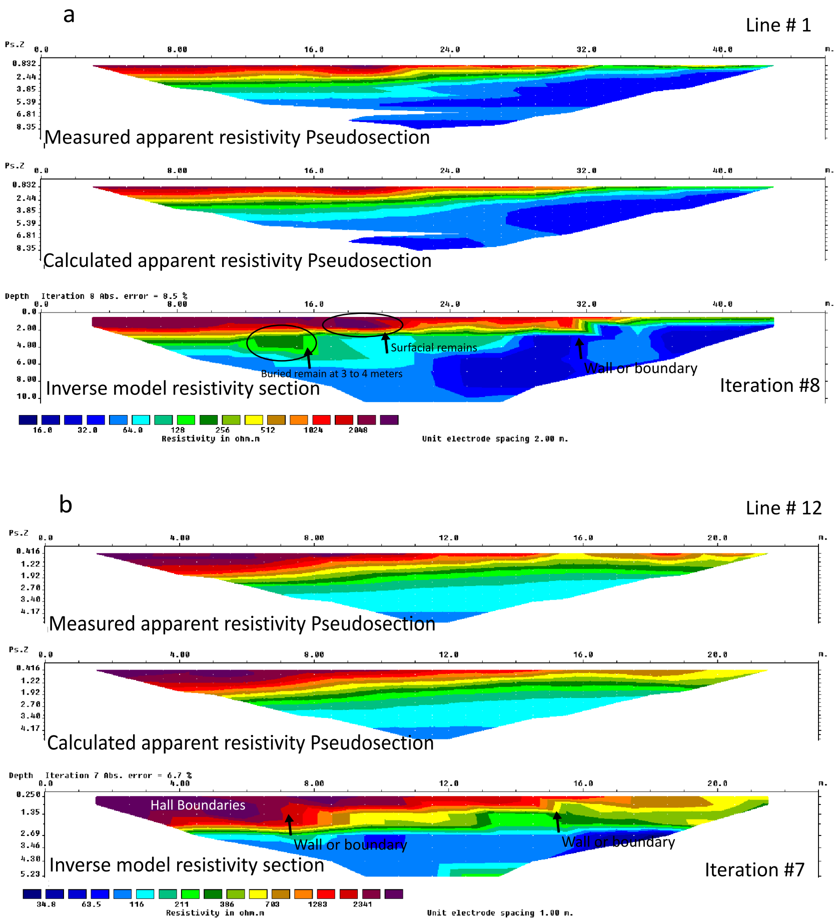

Fig. 5. The observed, calculated apparent resistivity (iteration #1), and final inverted resistivity pseudosection for the Saqqra data (Line #1) a) and (Line #12) b) set together with a model obtained by the inversion program.

these halls is about 4×4 metres at a depth of 2–4 metres.

To verify the above geophysical anomalies, some of these anomalies have been excavated by the Archaeology team. Remains of approximately 1300 years old tomb have been discovered (Fig. 10a,b). A tomb belonging to the Egyptian ancient army general, dating back to around 1290 BC, is at the burial site that belongs to the man called ‘Iwrhya’, who served under both kings, king Seti I and king Ramses II, his son, during their reign. While the

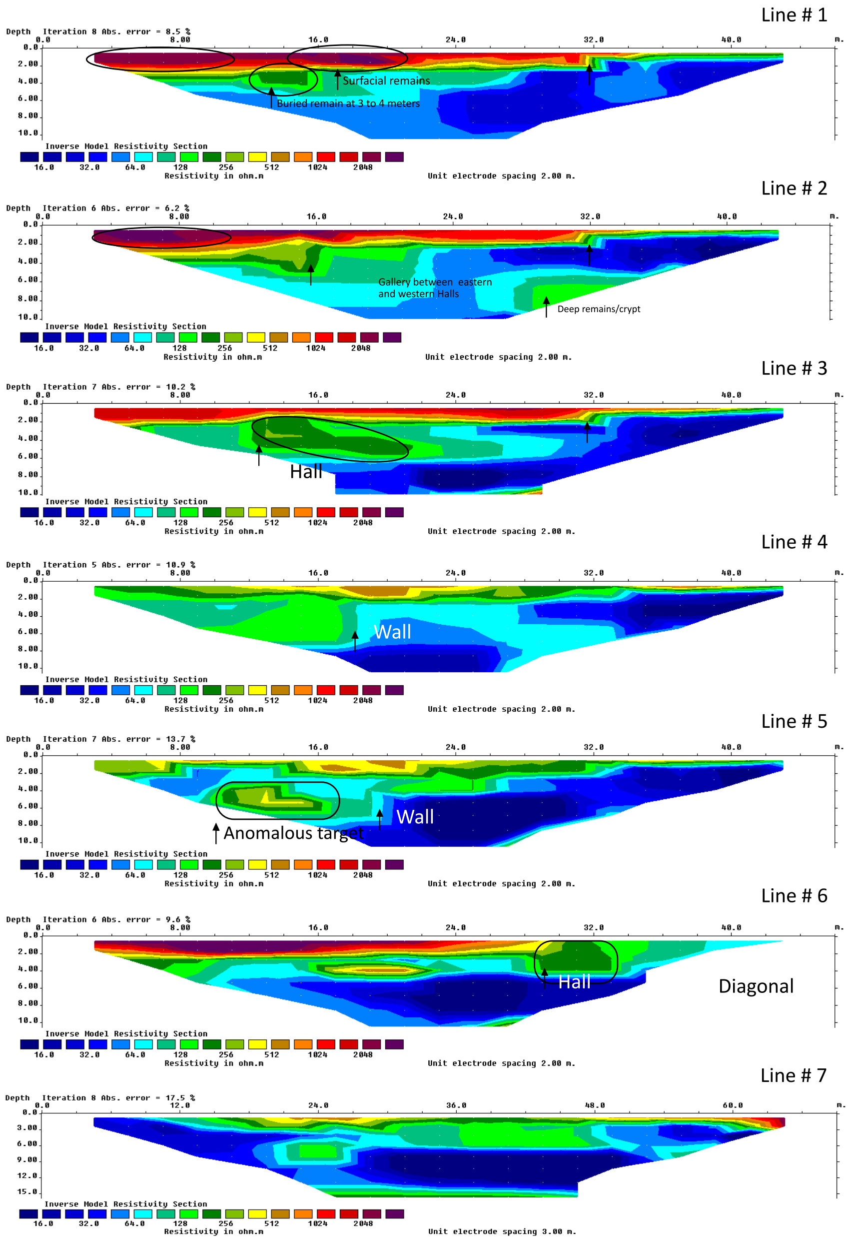

Fig. 6. Electric resistivity tomographic inversion along profiles 1 to 7, the expected locations of the subsurface cavities/walls/halls/crypts are marked with ellipses.

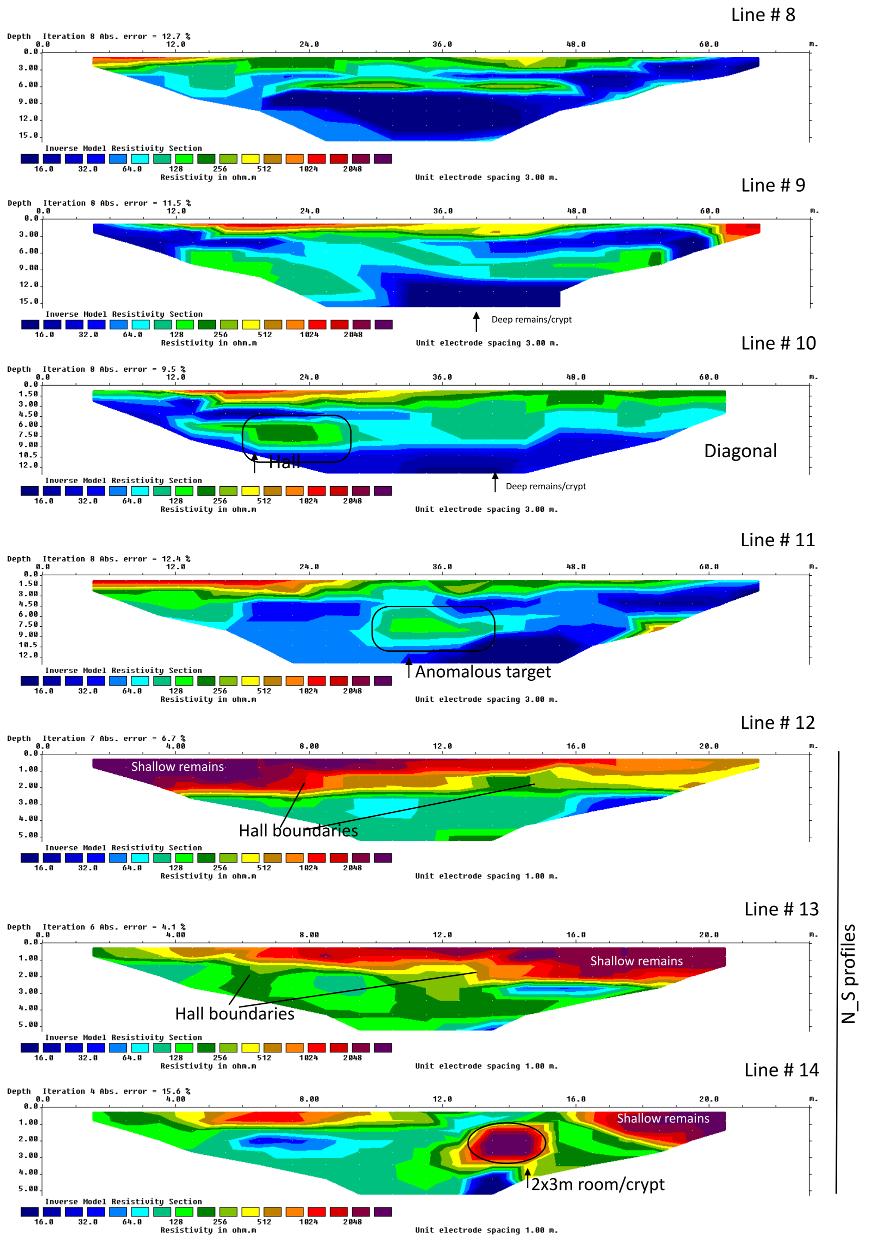

Fig. 7. Electric resistivity tomographic inversion along profiles 8 to 14, the expected locations of the subsurface cavities/walls/halls/crypts are marked with ellipses.

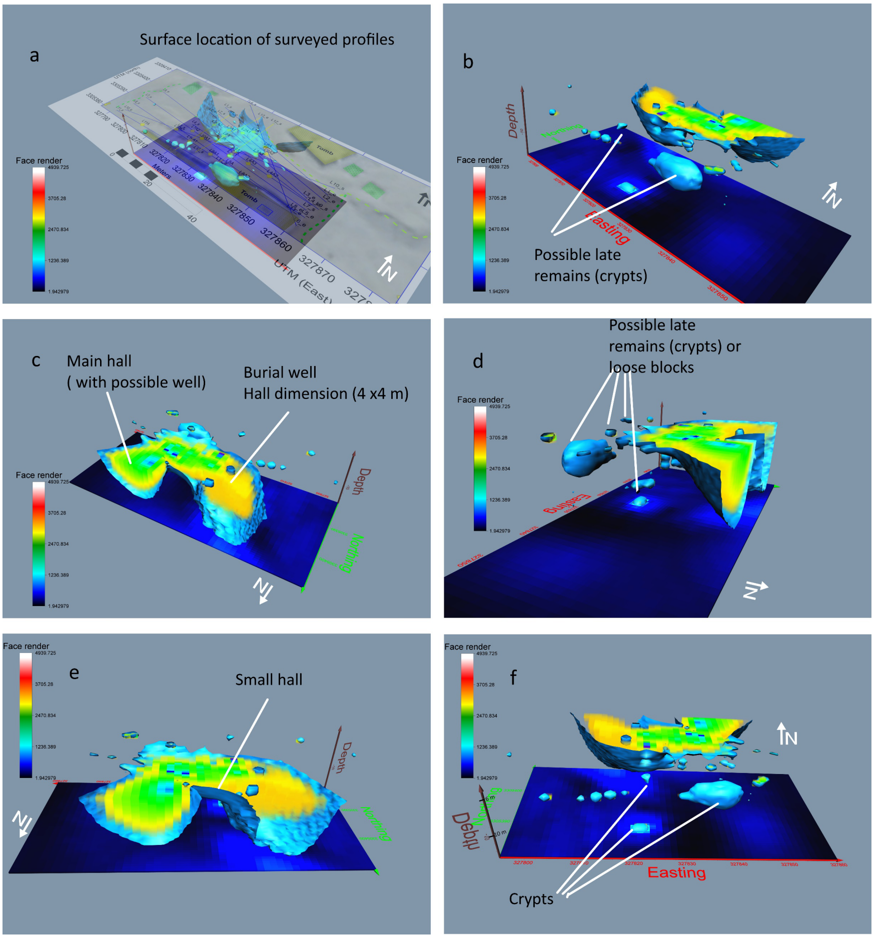

Fig. 8. A quasi 3D presentation of the iso-resistivity surface using a threshold value 900 Ω.m. All possible values of the inverted resistivities are also included from 1.9 to 4300 Ω.m. Figures from (a) to (f) represent different views for the study area.

tomb has yet to be fully excavated, preliminary discoveries already yielded many remarkable results uncovering in-situ walls with very beautiful scenes and many loose blocks in the debris, attesting the high status of the owner of the tomb and his family. For one, the name of the high army general appeared on the tomb as well as that of Yuppa, his son, and Hatiay his grandson, Hatiay, which suggests that it might be a family tomb.

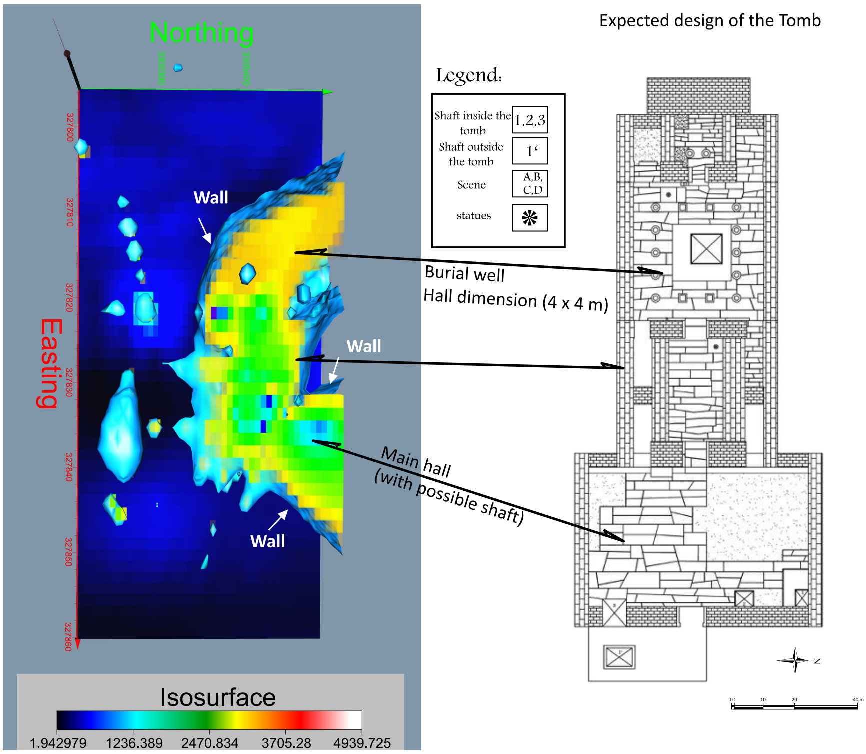

Fig. 9. A possible interpretation of the resulted 3D tomographic inverted resistivities in view of the general architecture of similar tombs in Saqqara area.

Inscriptions found on the tomb walls (Fig. 10c,d,e, and Fig. 11) indicate that Iwrhya "is a high army General, and High steward of the domain of Amun and High steward of the estates of Ramesses II in the domain of Amun". The career of General Iwrhya began during king Seti I's reign, whom ruled Egypt from (1294 BC to 1279 BC), and continuing during king Ramesses II's reign, which lasted from 1279 BC to 1213 BC. He reached the highest position in the Egyptian court. The archaeological team also found that Iwrhya was foreign-born and most likely one of the many foreigners who settled in Egypt and was prosperous enough to be given high positions in the Egyptian court during the New Kingdom (`https://www.egypttoday.com/Article/4/49630/Tomb-of-Army-General-during-King-Ramsses-II-reign-uncovered`).

Fig. 10. A comparison between the area of study before excavation (a) and after excavation (b). Ruins from the discovered burial site belongs to a man called ‘Iwrhya’, who served under the reign of Ramses II (c), (d), and (e).

Fig. 11. The inscriptions on the walls of the Iwrhya's discovered tomb.

The tomb has some rooms, a forecourt, some chapels, a statue room. The owner's military actions and his foreign relations with neighbouring countries are portrayed in the art found in the statue room. Boats are mooring and unloading a lot of Canaanite wine jars, are included in these scenes. Furthermore, a loose block discovered in the sand probably detached from the northern wall shows quite an exceptional scene of an infantry unit and charioteers crossing a waterway with crocodiles. Examination of that scene suggests the crossing took place somewhere on the eastern border of Egypt. It's believed that many family members were buried in this tomb, the son and grandson of Iwrhya, Yuppa and Hatiay, both were mentioned in the inscriptions. Inscriptions show that it's possible that Iwrhya may have also been of foreign descent. The tomb is found in Saqqara to the south of a pyramid built by Unas, who reigned in the fifth dynasty (Old Kingdom) and was the first pyramid where there were inscribed religious texts known as the "Pyramid texts". A great number of archaeological remains are found in Saqqara that encompass thousands of years of history of Egypt. More Excavations are showing human remains are yet to be found in the tomb.

8. Conclusion

The archaeological area of Saqqara (Giza, Egypt) includes clear evidences showing different burial levels that need to be excavated. A 2000 years old tomb which belongs to 'Iwrhya', who served under the reigns of both kings Sethi I and his son Ramesses II has been discovered using a quasi 3D Electrical Resistivity Tomography (ERT) survey in Saqqara.

This electrical survey, effectively and accurately shown as iso-resistivity surfaces, allows the addressing of anomalies leading to interesting buried archaeological remains (tomb) beneath the study area. Relatively high resistivity anomalies could be due to the buried halls/galleries discovered later after manual excavations.

The Electrical Resistivity Tomography (ERT) survey is proved a rapid scientific and non-destructive technique to delineate the buried archaeological features and to provide detailed information about the subsurface. An additional advantage is the speed of the obtained results. Resistivity profiles with different electrode spacing and total spread length are acquired to guarantee several resolutions and several depths of penetration depending on the dimensions of the subsurface bodies and their depths.

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