

Unknown Ancient Funerary Structures Discovered in West Saqqara (Egypt) Using Ground-Penetrating Radar (GPR)

FABIAN WELC, RADOSŁAW MIESZKOWSKI

Abstract: The ground-penetrating radar (GPR) survey conducted in the south-eastern part of the Polish archaeological concession in West Saqqara confirmed the high usability of the GPR method in non-invasive prospecting of desert archaeological sites. The survey has allowed to confirm the location of one and the discovery of two so far unknown funerary structures characterized by significantly large dimensions. Analysis of the reflection profiles allow to conclude that these anomalies are generated by rock-hewn burial shafts. Only one of these tombs can be dated with high confidence to the end of the Old Kingdom. Precise determination of the chronology of the two other structures is not possible without archaeological verification.

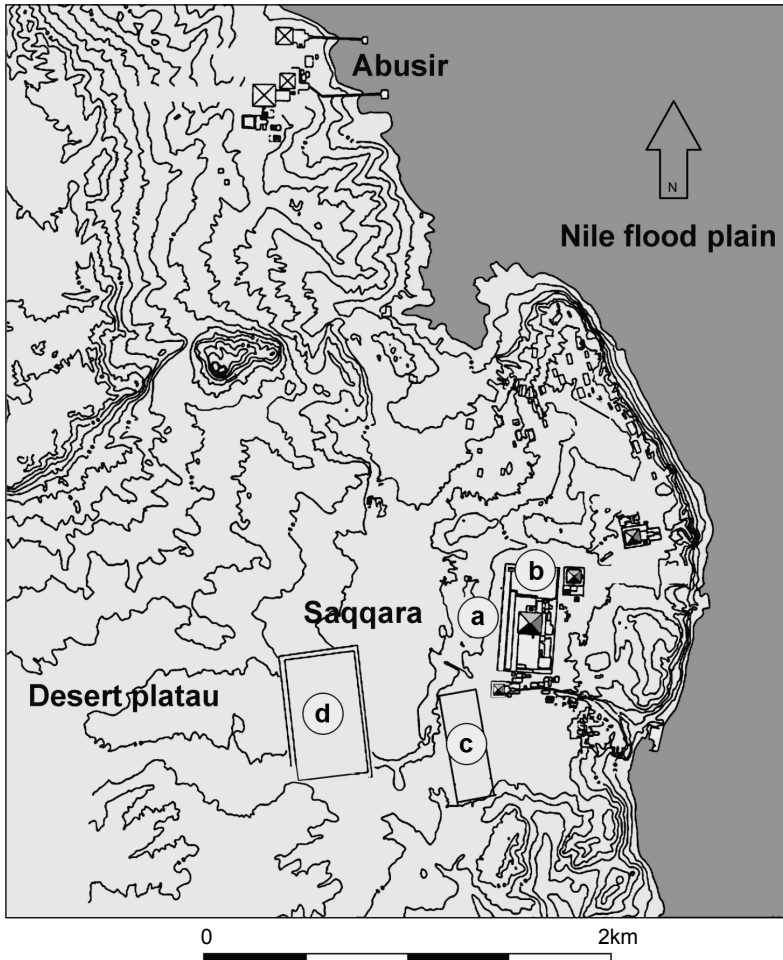
Keywords: ground-penetrating radar (GPR), funerary architecture, Saqqara, Old Kingdom Egypt

Fabian Welc, Instytut Archeologii UKSW, Warszawa; f.welc@uksw.edu.pl

Radosław Mieszkowski, Instytut Hydrogeologii i Geologii Inżynierskiej, Wydział Geologii UW, Warszawa; r.mieszkowski@uw.edu.pl

The Saqqara necropolis is located on the west bank of the Nile River (*c.* 23km to the south of Cairo) directly on a limestone massif elevated at 40 to 58m above sea level and *c.* 20m above the level of the Nile River alluvial valley. From the east the site is bordered by a steep embankment separating the plateau from the river flood terrace (**Fig. 1**). The plateau is covered by thick Quaternary deposits representing various lithologies overlying the top of Upper Eocene carbonate rocks. The latter are represented by hard and compact, light-creamy to brownish sandy-pelitic limestones interbedded with soft and poorly compact marly limestones; the complex represents the Upper Calcareous Beds of the Saqqara Member of the Maadi Formation.¹

¹ Cf. Welc, Trzeciński 2013: 323–343.



1. Sketch plan of the Saqqara archaeological site: a. area excavated by Polish-Egyptian archaeological mission; b. Step Pyramid funerary complex; c. Sekhemkhet pyramid complex; d. enigmatic Gisir el-Mudir structure (Drawing: F. Welc).

Numerous royal funerary structures from the Old Kingdom (c. 2600–2100 BC) are preserved in Saqqara, with the Step Pyramid complex built for Pharaoh Djoser-Netjerykhet during the Third Dynasty (c. 2650 BC) overshadowing the entire necropolis.

The area located directly to the west of the Step Pyramid complex is since 1987 under the systematic excavations of the Polish-Egyptian archaeological mission headed by Prof. K. Myśliwiec from the Institute of Mediterranean and Oriental Cultures of the Polish Academy of Sciences. In the course of dozens field seasons, the team of archaeologists has uncovered a part of a large necropolis dated to the Old Kingdom and the Greco-Roman period (the so-called Lower and Upper Necropolis respectively).²

² See: Myśliwiec *et al.* 2004; Radomska *et al.* 2008: 11–28.

The area investigated by the Polish-Egyptian mission is located on limestone slope partly transformed by human activities,³ dipping at about 7° to the west.⁴ Natural and anthropogenic deposits accumulated on the slope are of diverse thickness and lithological composition, being represented mostly by eolian sands and anthropogenic conglomerates composed of limestone – sand gravel (in Arabic – so-called *dakka*).⁵

During the last few years the area of West Saqqara, including the Polish archaeological concession, was subject of several geophysical surveys conducted with the use of magnetic as well as electroresistance methods; they were mainly focused on recognizing the archaeological structure of the site including the location of underground sepulchral structures, such as mud brick tombs and chapels, as well as burial shafts hewn in rock.⁶

Quite recently, ground-penetrating radar (GPR) has also been used in geophysical surveys in the Saqqara area.⁷ Extensive geophysical survey with GPR application was an important goal of the 2012 campaign of the Polish-Egyptian mission.⁸ The main objective of this research was to determine the relationship between the geological structure of the West Saqqara plateau and the archaeological structures located there.⁹

GPR SURVEING METHODOLOGY – INTRODUCTION

The GPR – ground-penetrating radar – is the most modern and sophisticated geophysical method that uses electromagnetic radiation in the microwave band (UHF/VHF frequencies in the range of 50MHz to 1.6GHz) of the radio spectrum to detect signals reflected from different kinds of subsurface structures and lithological boundaries. The GPR method is particularly useful in detecting buried objects and underground voids.¹⁰

The depth range penetration of the GPR is limited by the electrical conductivity of the searched medium, the transmitted frequency centre and the radiated power. As conductivity increases, the penetration depth decreases. This is because electromagnetic energy is more quickly decapitated into heat, causing a loss in signal strength with depth. Higher frequencies do not penetrate as deep as lower frequencies, but give a better resolution. Despite the fact that the principle of the GPR method is relatively simple, the measurements and data processing may be rather complicated. This is caused by the complex nature of electromagnetic wave reflection, its interference, the very low level of the registered signal and a large number of factors disturbing the signal.¹¹

³ An ancient quarry had operated there during the Third Dynasty, in effect a series of rock terraces was created, cf. Welc 2011.

⁴ On geology of the Saqqara area cf. also Youssef *et al.* 1984.

⁵ Cf. Welc, Trzeciński 2013.

⁶ Cf. Myśliwiec, Herbich, Niwiński 1995; Fassbinder, Becker, Herbich 2001; Mathieson 2007.

⁷ Carlyle *et al.* 2005.

⁸ Welc *et al.* 2013.

⁹ The geophysical team included: Dr. Fabian Welc (leader), Dr. Jerzy Trzeciński, Dr. Sebastian Kowalczyk (field measurement team) and Dr. Radosław Mieszkowski who collaborated in final data processing.

¹⁰ Cf. Conyers 2004: 16ff.; cf. also Vaughan 1986; Imai, Toshihiko, Takashi 1987.

¹¹ Cf. Karzewski 2007.

During the geophysical survey in West Saqqara, the Swedish ground-penetrating radar system was applied, based on the MALÅ GPR X3M Control Unit and MALÅ shielded antennas. The MALÅ GPR Control Unit is an integrated ground-penetrating remote equipment. The system can be quickly and easily configured for use across a wide range of applications. The MALÅ GPR is typically configured as either a push – or a pull-system. The GPR system applied in the Saqqara included:

- a control unit – MALÅ Ramac X3M,
- 250 and 100MHz shielded antennas,
- a Panasonic CF-29 computer,
- a distance measuring wheel 250–800MHz (encoder wheel).

During prospecting, for comparison, the same registering parameters of the reflecting waves were used for the 250MHz antenna, i.e. the step of inducing and registration of the emitted waves was 0.05m, at 8-ply signal stacking on the profile. The signal stacking is applied to achieve enhancement of low amplitudes of the usable reflexes and restriction of the possibility of registry of accidental and low-amplitude noises. The inline spacing between the profiles was 0.5m.

Profile registry was carried out in a wide time range of 706ns. The time window was selected according to the following formula:

$$T = 1.3 \frac{2 \cdot h}{v}$$

where:

- T – length of the expected time window,
- h – expected depth range,
- v – velocity of the EM wave in the medium.

Such range of the time window parameters firstly were established based on data obtained by the Polish-Egyptian excavations conducted for twenty years in the area close to the geophysical survey. The team of Professor Karol Myśliwiec has excavated a series of funerary structures dated mostly to the late Old Kingdom (c. 2300/2200 BC). These are generally represented by tomb shafts cut in the rock with the depth from several to over a dozen meters, however not exceeding 20m.

The applied processing procedures may be sub-divided into two groups: operations on a single GPR reflection trace, so-called *1D filter*, and operations on reflection traces group – *2D filter*.

Operations on a single ground-penetrating radar reflection trace (*1D filter*), conducted individually in each trace, include: *Running average* (i.e. calculation of the running average); *Dewow* (variant of the *running average* procedure which served to remove low-frequency noise); *DC – shift* (removal of the constant component of the GPR signal); *Subtract-mean* (removal of the component mean); *Gain* (enhancement of GPR signal); *Move start time* (procedure based on correlating the first occurrence of the GPR wave); *Bandpass frequency* (procedure used for frequency filtration).

The *2D filter* group includes: *Background removal* (procedure allow to removal of random noise); *Average xy filter* (summing of GPR traces – smoothing filtration, in effect the value of the obtained GPR image is averaged).

So-called *advanced procedures* includes: *Deconvolution* (procedure aimed at removing negative factors influencing the GPR signal in the medium, i.e. electromagnetic wave damping, non-homogeneity of the medium, etc.); *F-k filtration* (procedure eliminating the disturbing waves, whose velocity differs significantly for that of usable reflexes).

The last stage of processing selected groups of wavegrams was arranging them in quasi 3D block-diagrams or as horizontal or vertical time slices (plain view maps isolating specific depths) using the Reflex View *3D data interpretation* mode. In recent times, the time-slicing has become a standard practice in archaeological applications, as horizontal patterning is often the most important indicator of cultural activities.¹² Presentation of the processed reflection profiles in form of quasi 3D block-diagrams has essentially facilitated their further interpretation.

RESULTS OF THE GPR SURVEY

More than 30 areas have been selected for the geophysical survey in West Saqqara in 2012, located within the Polish archaeological concession. Most of them were straight strips of different length and width, orientated in accordance to the cardinal directions.¹³

In the western part of the concession the ground-penetrating radar survey was focused on recognizing geometry of the so-called Dry Moat enigmatic structure,¹⁴ whereas along eastern boundary of the area their main aim was to establish the depth of the natural rock basement as well as location of any kind of ancient funerary structures.

Accordingly, the GPR research was focused, e.g. on a fragment of the area adjacent to destroyed monumental recessed wall surrounding the Step Pyramid complex.¹⁵ Interpretation of the obtained GPR field measurements data was favoured by a geophysical survey conducted within the Polish archaeological concession with the application of magnetic methods (magnetometer) by the team of J. Fassbinder in 1997.¹⁶

A 200m long, N-S-oriented strip marked as OB. 1 was examined along the eastern boundary of the Polish concession. The obtained reflection profiles, partly discussed by Welc,¹⁷ have distinctly shown the top of the rock basement at the depth of 3m, covered by thick gravel-sand deposits. Numerous reflexes interfering the measurements have been generated by blocks and smaller fragments of a white casing limestone lying on the surface and directly beneath. The material is derived from the partly dismantled monumental niches wall surrounding the Step Pyramid from four sides. The bigger size limestone blocks – lying below – are most probably the main source of strong anomalies on depth of *c.* 1m.¹⁸

Two supplementary strips designated for the GPR prospection have been marked perpendicularly to strip OB. 1, and called as OB. 2 and OB. 3, respectively (**Fig. 2b-c**). The main

¹² Cf. Welc *et al.* 2014.

¹³ Welc *et al.* 2013.

¹⁴ Cf. Swelim 1988; Welc *et al.* 2015.

¹⁵ For more information see: Welc *et al.* 2013.

¹⁶ Fassbinder, Becker, Herbich 2001; cf. also Mysliwiec 2013.

¹⁷ Welc *et al.* 2013.

¹⁸ Cf. Welc *et al.* 2013: 105, Figs 9–10.

aim of additional GPR research near the enclosure wall was to track southward extension of the enigmatic mud brick platform discovered during Polish-Egyptian excavations.¹⁹ Its presence in vicinity of OB. 2 and OB. 3 GPR survey areas has been confirmed by small archaeological preliminary sounding. The platform is formed by a single layer of mud bricks covered with plaster composed of the same material. Ceramic sherds have allowed to date the platform to the New Kingdom period, but its function remains still unknown. According to Prof. K. Myśliwiec, the structure may cover (mask) an unknown funerary complex.²⁰ The second aim of the GPR measurements was to detect any archaeological structures situated near the enclosure wall of the Step Pyramid, particularly those that can be linked with enigmatic mud brick platform discussed above.

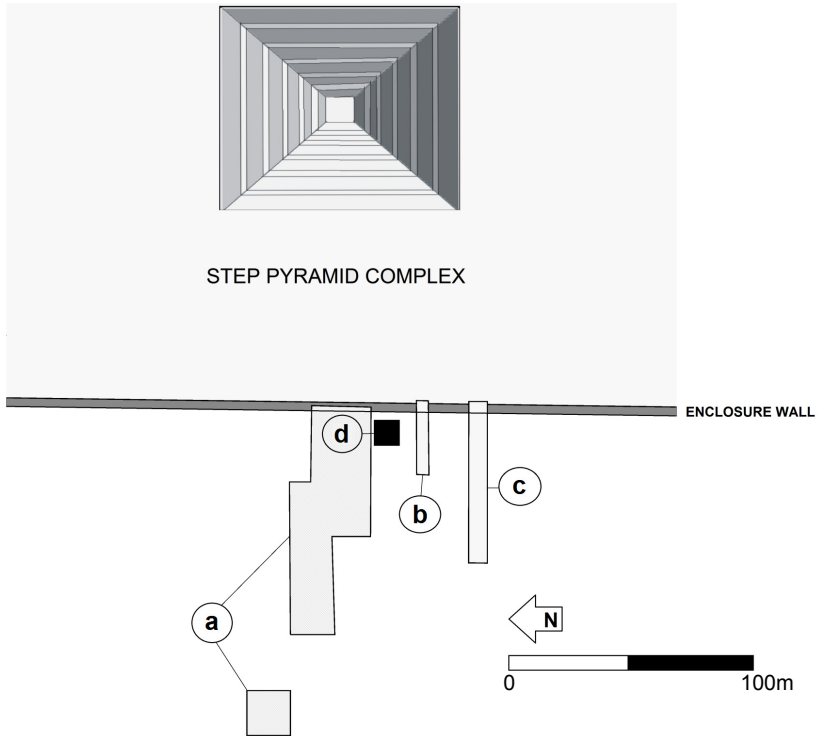
Area OB. 2 was located directly to the south of a small store house built *c.* 70 years ago and only 20m from the southern concession border (**Fig. 2b**). This is a 28m long and 4m wide, W-E-oriented strip, dipping at *c.* 5–7° to the west (**Fig. 3**). Both the horizontal reflection profiles as well vertical time slices obtained with application of a 250MHz antenna have revealed (from the top) slightly oblique reflection surfaces generated by the boundaries of sand-gravel beds of a total thickness of 1.5–2m (**Fig. 4a-b**). These deposits dip to the west at low angles. At least three separate generations of the accumulated debris and sand can be distinguished. Between the 23rd and 28th meter (from the east) a synclinal depression is visible, filled with a similar deposit to the one described above (**Fig. 4c**). Below of these echograms reveal another concentration of anomalies, generated by a large and deep, rock-hewn burial shaft (**Figs 5–6**).

The area OB. 2 encompasses southern and eastern wall of the newly identified burial structure. The thickness of its southern wall can be estimated on *c.* 4m and the total depth of the shaft probably exceeds 13m (**Fig. 7**). The GPR echo of the shaft well reveals a significant detail, which is visible at the depth of 9–10m below the ground level. The processed reflection profile indicates a distinct concentration of anomalies at this depth, which are the echo of a kind of narrowing, occurring directly above the tomb chamber of many burial shafts (**Fig. 8**). The presence of this feature results from the fact that hewing of deep tomb structures in the West Saqqara necropolis in end of the Old Kingdom (i.e. during the Sixth Dynasty) was hampered by the hard beds of pelitic limestones. Depending on the location of the tomb, these beds were reached at different levels, which in turn results from the geological structure of the Saqqara area.²¹ In the upper part of the area under discussion, the hard beds of pelitic-sandy limestones are located at the depth of 7–9m below the ground and in the lower part – only 1m beneath the modern surface. Ancient ‘workers’ hewing the tomb shafts did not remove the entire cohesive bed of the pelitic-sandy limestone. Usually they hewed through it, creating a sort of an irregular opening of a much smaller dimension than the horizontal cross-section of the shaft, i.e. characteristic narrowing. On the one hand, this procedure allowed saving time and labour input, and on the other, significantly

¹⁹ Cf. Myśliwiec 2005.

²⁰ Cf. Myśliwiec 2005.

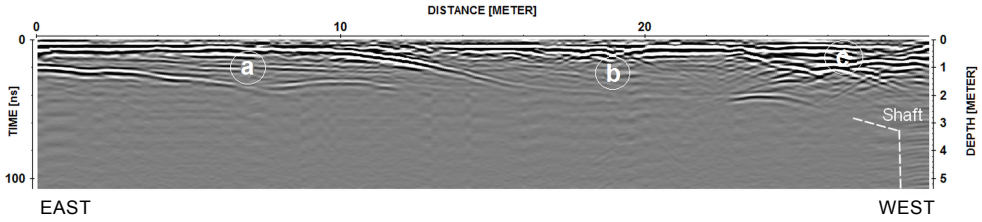
²¹ Cf. Welc, Trzeciński 2013.



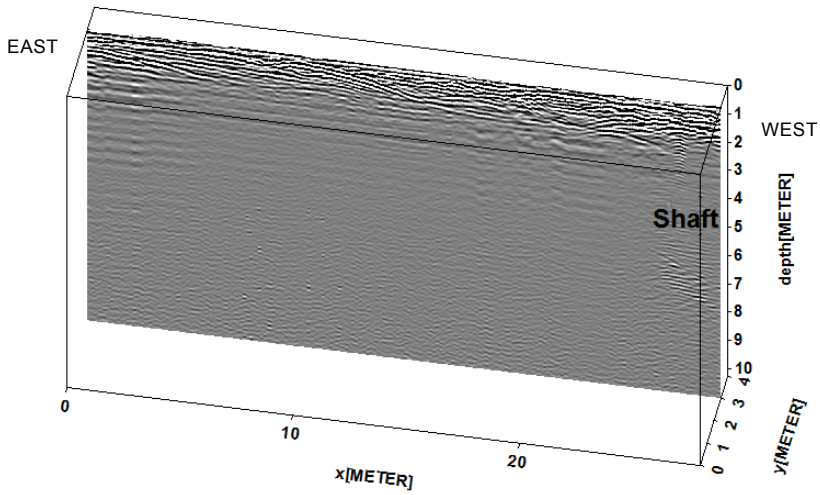
2. Area of the Polish-Egyptian excavations in West Saqqara: a. excavated areas; b. area OB. 2; c. area OB. 3; d. modern building (Drawing F. Welc).



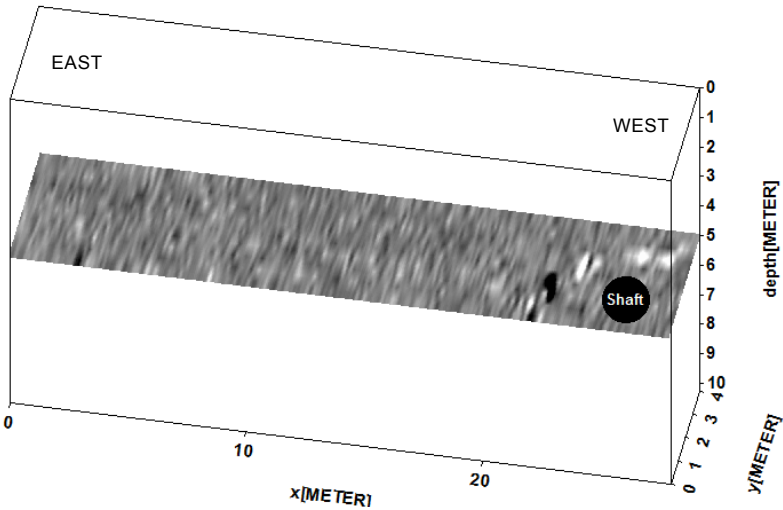
3. Area OB. 2. Performance of the GPR measurements using 250MHz antenna. View from North (Phot. J. Dąbrowski).



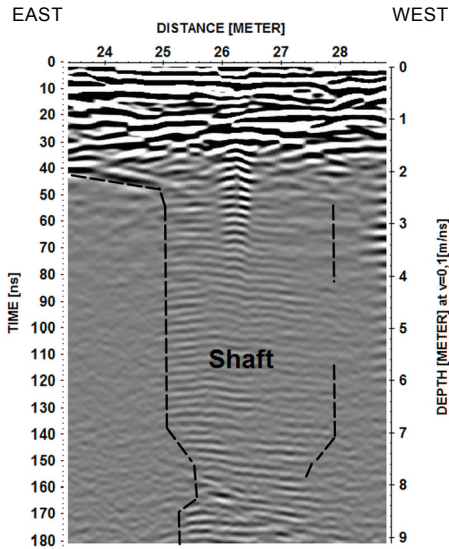
4. Area OB. 2. GPR profile displaying reflection surfaces: a-c separate generations of accumulated debris and sand (Processing and interpretation: F. Welc, R. Mieszowski).



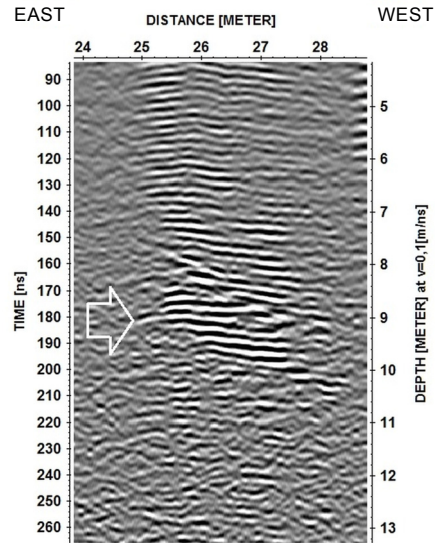
5. Area OB. 2. GPR profile revealing concentration of the anomalies generated by deep burial shaft (Processing and interpretation: F. Welc, R. Mieszowski).



6. Area OB. 2. GPR time slice revealing anomalies generated by burial shaft walls at the depth of 5.40m (Processing and interpretation: F. Welc, R. Mieszowski).



7. GPR image of the deep burial shaft in area OB. 2 (Processing and interpretation: F. Welc, R. Mieszkowski).



8. Area OB. 2. Fragment of the reflection profile showing burial shaft with characteristic narrowing indicated by the arrow (Processing and interpretation: F. Welc, R. Mieszkowski).

restricted the application of valuable copper tools used at that time.²² The presence of the narrowing confirms that the identified structure is the GPR picture of a deep and large funerary shaft from the late Old Kingdom, possibly from the late Sixth Dynasty.

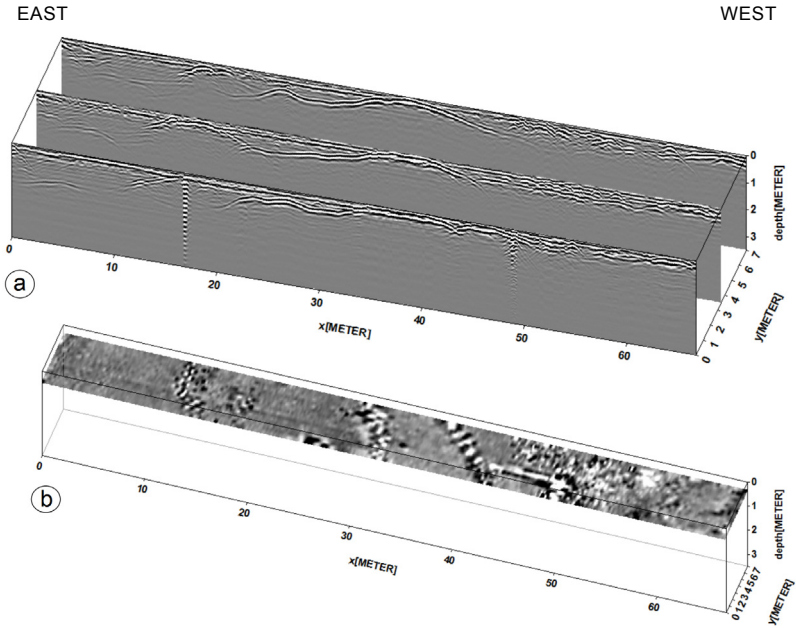
It is also worth noting that the GPR echo of the newly located funerary shaft reflects its outline in great detail, which, however, is not a standard in the geophysical surveys in the Saqqara area. This results from the specific structure of the sediments filling such kind of tombs. So far, funerary shafts discovered and searched by the Polish-Egyptian mission in West Saqqara are usually filled with sandy sediments in the upper part and a clay-sandy much more compact deposits in the lower part (so-called *dakka*).²³ Such lithological composition strongly damps electromagnetic waves generated by the GPR, what was already discussed in detail by the authors.²⁴ It can be assumed that the shaft located in OB. 2 area is filled with a sediment differing in fraction and lithology, most probably limestone blocks arranged in layers, resulting in a horizontal stratification of the material filling shaft (**Figs 7–8**). This well visible stratification in echograms suggests existence of original blockage in the discussed funerary structure.

The area OB. 3 was located several metres further to the south of the strip OB. 2 (**Fig. 2c**). Similarly, this is a 67m long, 6.5m wide and W-E-oriented strip. Processed

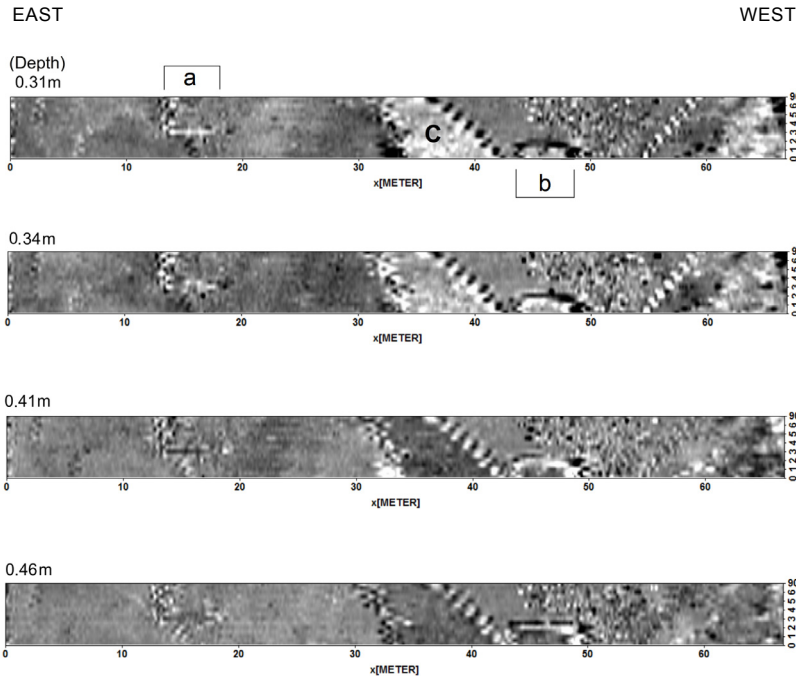
²² Cf. Welc, Trzciniński 2013.

²³ Cf. Myśliwiec, Welc, Trzciniński 2012.

²⁴ Welc *et al.* 2014.



9. Area OB. 3: a. 3D block – diagram of the area; b. GPR time slice put into a three dimensional block – diagram showing shallow subsurface structures (Processing and interpretation: F. Welc, R. Mieszkowski).



10. The GPR plans (time slices) obtained from area OB. 3. Newly discovered archaeological structures are marked as a-b. burial shafts, and c. mud brick platform? (Processing and interpretation: F. Welc, R. Mieszkowski).

reflection profiles and time slices (GPR plans) from this area supply several significant data on its morphological (sub-surface) structure as well as degree of anthropogenic transformation. Worth noting is a high resolution of the obtained ground-penetrating radar images, resulting mainly from the lithological variability of the sediments covering the area in question, i.e. dry sands and debris with prevalence of carbonaceous rock fragments and mud bricks. The thickness of the Quaternary overburden can be estimated on *c.* 2.5m. Particular series of the sand-gravel beds dip at various angles to the west and east. It is, however, difficult to determine whether the depressions and elevations visible in the analysed wavegrams are of erosional or accumulation (debris heaps) origin, or have been formed in course of intentional human activity (**Fig. 9a**).

The GPR plans (time slices) obtained from area OB. 3 have revealed two funerary structures of large sizes, located at a distance of *c.* 25m from one another (**Fig. 10a-b**). The outline of the first one is visible as a set of linear anomalies in the south-eastern part of the strip, between the 10th and 20th meter (**Fig. 10a**). An contour of the crown of walls located directly below the surface, i.e. at the depth of 0.30m, can be seen in this area, whereas their foundations can be observed to the depth of 0.97m. The northern wall of the discussed structure is *c.* 5m long. The entire feature was erected on a square plan, suggesting that this is the upper part (mouth) of a large funerary shaft, analogous in size to the tomb discovered in adjacent area OB. 2.

The structure was for the first time located during geophysical (magnetic) survey conducted by the team of Fassbinder, Becker and Herbich in 1997 (**Fig. 11b**).²⁵ At that time, the measurements covered almost the entire area of the Polish concession in West Saqqara.²⁶

The next giant archaeological structure is located in the north-western part of strip OB. 3 (**Fig. 10b**). In the processed reflection profiles its subsurface outline is visible between the 40th and 50th meter. The wall crown is located *c.* 0.34m below surface and its foundation – at the depth of 1m. The northern wall is about 7m long. Similarly, this structure was erected on a square plan, suggesting that this is also a large funerary shaft.

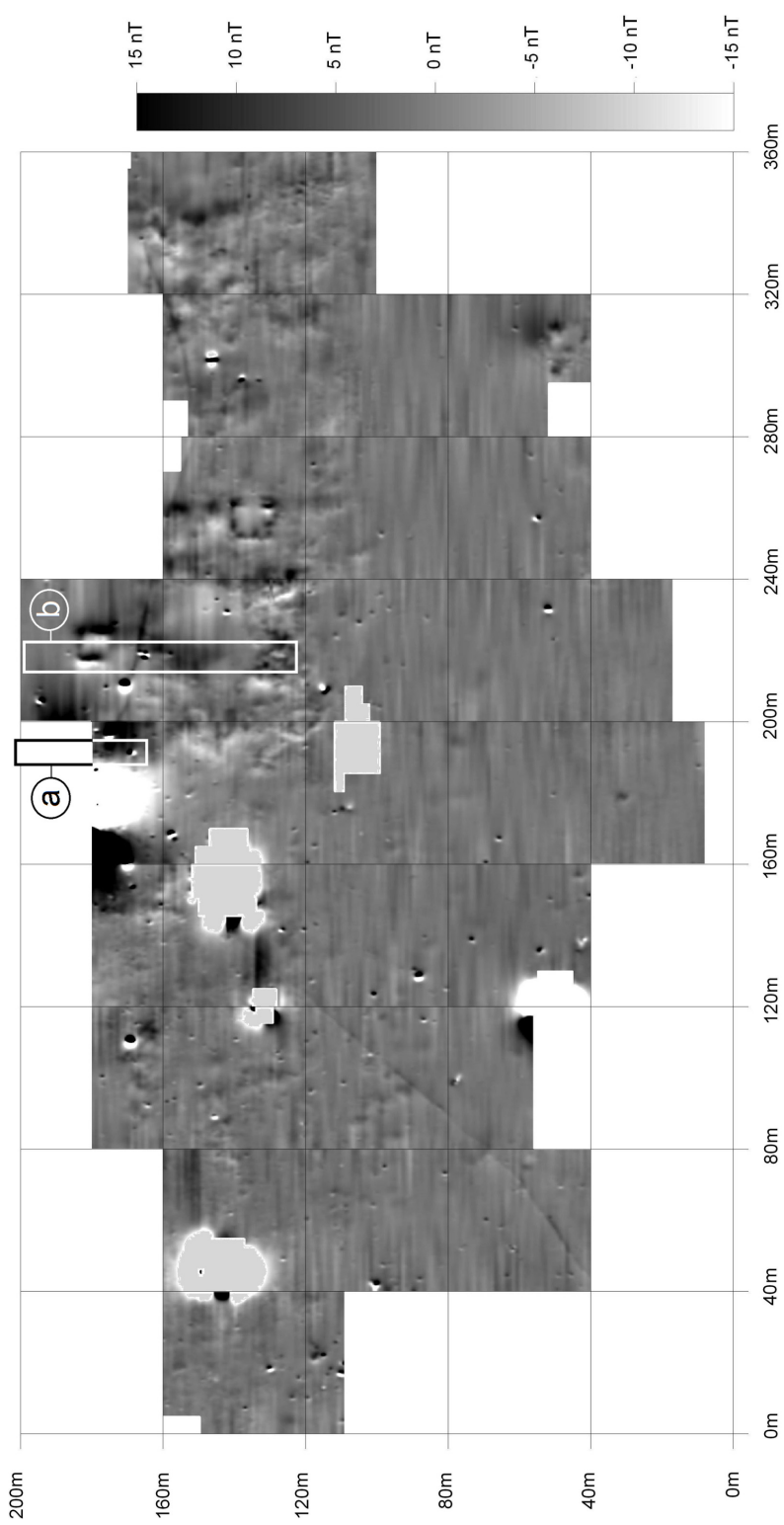
It is worth mentioning that although the upper parts of both shafts are well manifested in GPR reflection profiles, whereas their lower parts – below 1m – are difficult to trace. According to the authors, this might result from the lithological composition of the deposits filling both structures. Probably tombs are filled with sandy and clay-sandy sediments, which strongly damp electromagnetic waves; in effect the GPR image resolution as well as the depth range of the survey were strongly reduced.²⁷

The last issue in the case of the examined strips OB. 2 and OB. 3 is the lack of a distinct echo of the brick platform from the New Kingdom period. It cannot be excluded that this structure is preserved only fragmentarily in the examined areas. Most probably, the N-S-oriented zone of significant anomalies, determined between the 35th and 45th meter

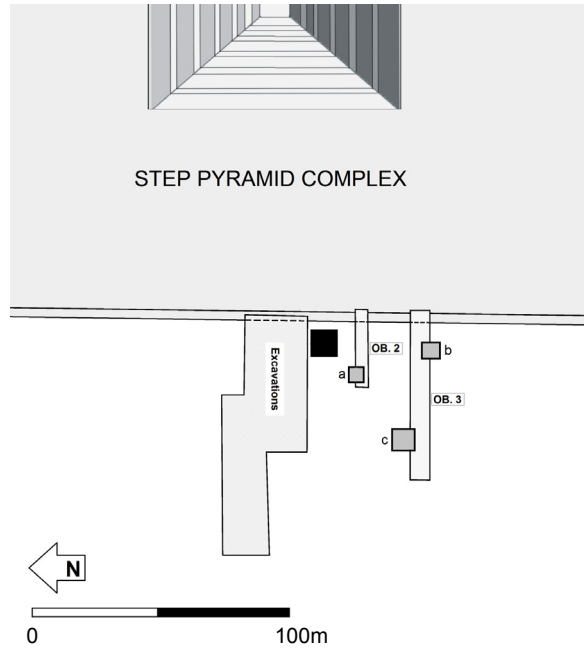
²⁵ Fassbinder, Becker, Herbich 2001.

²⁶ Cf. also Myśliwiec 2013.

²⁷ Cf. Welc *et al.* 2014.



11. West Saqqara, results of the geophysical survey conducted by the team of Fassbinder, Becker and Herbich with marked areas searched by GPR in 2012: a. area OB. 2; b. area OB. 3 (based on: Fassbinder, Becker, Herbich 2001: Fig. 2).



12. Location of the large funerary shafts (a-c) identified during GPR survey in West Saqqara (Drawing: F. Welc).

at the depth of *c.* 0.3–0.5m, is the echo of the platform (**Fig. 10c**), whose presence was confirmed by five soundings located along the enclosure wall to the south of the area of the Polish-Egyptian excavations.²⁸

SUMMARY

GPR surveys conducted in the south-eastern part of the Polish archaeological concession in West Saqqara have confirmed the high usability of the GPR method in non-invasive prospecting of desert archaeological sites, particularly with application of a 250MHz antenna. Of crucial importance was correct planning and conducting of the measurements in order to obtain sets of reflection profiles in form of 3D block-diagrams. 3D visualization significantly favoured the interpretation of the results, essentially distinguishing between natural and anthropogenic features. Particularly usable was the possibility of constructing time slices, i.e. GPR plans at different depths.

Worth noting is also the high resolution of the processed reflection profiles and time slices, which directly results from the geological structure of the examined area (limestone basement) and the lithological composition of the covering Quaternary deposits, in this case, mainly eolian sands and limestone debris, i.e. media characterized by highly differing values of the dielectric constant. In turn, the factor negatively influencing the range of

²⁸ Cf. Myśliwiec 2005.

GPR prospection in the analysed areas is most probably presence of the clay-sand fraction in deposits filling discovered structures. In effect it is very difficult to trace the course of deeper anthropogenic structures, in this case – ancient funerary shafts.

The survey has allowed to confirm the location of one and the discovery of two so far unknown funerary shafts characterized by significantly large dimensions in area OB. 3 (**Fig. 12b-c**). Taking into account the thickness of their side walls, it can be assumed that the tombs have funerary chambers located at depths exceeding 20m. Only the shaft located in strip OB. 2 (**Fig. 12a**), based on the analysis of its general outline (echo) can be – with high reliability – dated to the end of the Old Kingdom. Precise determination of the chronology of the two other structures, whose upper parts have been noted in area OB. 3, is not possible, however, without archaeological surveys or excavations.

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