Dakhleh Oasis Project

Columbia University

Excavations at Amheida 2006

Geophysical survey

(electrical conductivity and magnetic survey)

on the Amheida and ‘Ain el-Gezzareen sites

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Electrical conductivity and magnetic survey on the site known as Amheida (number 33/390-L9-1 in the DOP index), or ancient *Trimithis* has been carried out in January 2006 during 3 weeks. Two days have been spent for the conductivity and magnetic measurements on the neighbouring site 'Ain el-Gezzareen to compare the results, obtained on both sites. A very short magnetic "free search" has been carried out on the site 'Ain el-Gedida as well during 1,5 hour on the 1st of February.

Magnetic survey has been used on different sites in Dakhlel Oasis in previous years (in 1998 on the site Ismant-el-Kharab (Roman town *Kellis*) and on the temple in 'Ain-Birbiyeh; in 1999 and 2000 on the site 'Ain-el-Gezzareen (Smekalova, 2002; Smekalova, Milns, Herbich, 2003). On Amheida magnetic survey has been carried out by the authors in 2000 and 2005.

Since the main method in 2006 was electrical conductivity survey, we describe it below in details, while the description of the method of magnetic survey one could find in our report of 2005.

INTRODUCTION

The idea of conductivity survey on archaeological sites.

For many years the electrical resistivity and magnetic surveying were the main methods for geophysical exploration of archaeological sites. The electromagnetic surveying, or EM surveying has been comparatively recently refined to use for archaeological purposes as well.

EM instruments measures how good the earth is an electrical conductor. Unlike resistivity survey, in which four electrodes are driven into the soil, this instrument makes no contact with the earth. It is simply carried along traverse lines and the measurements are continually displayed on the instrument (Bevan, 1983, p. 47).

Electromagnetic surveying is primarily a substitute for the resistivity surveying, and this is the technique to which it must be closely compared. The measurements with EM instruments are fast, they can be performed in bushy areas, and in areas with sandy, rocky, or dry soils, or over hard pavements (Bevan, 1983, p. 50).

With the resistivity surveying, it is difficult to make an adequate electrical contact to hard or dry ground surfaces. EM surveying do not need any contacts with the earth.

While the magnetometer would be ideal if fired earth features were expected, the EM instrument would often be better if stone accumulations or voids were to be detected. Both techniques are about equally fast. The EM38RT conductivity instrument, which we used, can detect the features on the depth of about 1.5 m deep. As with all geophysical techniques, small features cannot be detected as deep as larger ones. It is approximately true that features can be detected to a maximum depth that is equal to their size.

Contour maps could be drawn from the matrix of measurements in order to reveal the pattern of change. The size and shape of these patterns can be most positive clues to the features which could caused them. The amplitude of the numerical change also provides evidence. The following Table can illustrate the approximate ordering of materials according to their conductivity (Bevan, 1983, p. 51):

Conductivity Increasing	↑	Metal
		Saline Soil
		Clay
		Organic soil
		Silt and loam
		Sand and gravel
		Rock
		Air voids

Thus, the EM surveys are fast and economical substitutes for resistivity surveys. The technique is excellent for mapping large earth features that have no surface expression. It is probably also suitable for locating concentrations of buried stone. The technique might be a particular benefit in areas with dry or stony soils; resistivity surveys at these sites are very difficult (Bevan, 1983, p. 51).

Factors, effecting soil and clay conductivity.

Most soil and rock minerals are electric insulators of very high resistivity. However, on rare occasions conductive minerals such as magnetite, specular hematite, carbon, graphite, pyrite and pyrrotite occur in sufficient quantities in rocks to greatly increase their overall conductivity.

In general the conductivity is electrolytic and takes place through the moisture-filled pores and passages which are contained within the insulating matrix. The conductivity is therefore determined both for rocks and soils by

(1) porosity; shape and size of pores, number, size and shape of interconnecting passages;
(2) the extent to which pores are filled by water i.e. the moisture content;
(3) concentration of dissolved electrolytes in the contained moisture;
(4) temperature and phase state of the porewater;
(5) amount and composition of colloids (McNeil, 1980, p. 6).

The minerals in the sand and silt fractions of the soil are electrically neutral and are generally excellent insulators. Completely dry clay is an insulator but the introduction of moisture changes the situation radically. Clay consists of microscopically fine particles exhibiting a sheet-like structure, for which reason clays are often called “layer silicates”. Composed of stable secondary minerals, such as feldspar, mica, etc., the particles are so fine-grained that they are described as micro-crystals.

Their crystalline structure is such that, as a result of crystal imperfection, the surface appears to be negatively charged. During the formation of the clay through weathering, positive charges (cations) are adsorbed to the surface. These cations (typically Ca, Mg, H, K, Na, NH_3), are loosely held to the surface and can subsequently be exchanged for other cations or essentially go into solution should the clay be mixed with water. Because of the extremely small particle size, the surface area per unit volume of clay is very large and a great many ions are adsorbed.

Humus in soils has large surface area per unit volume, takes up large large amounts of water and can develop a negative electrical charge of varying intensity.

Method and Equipment

Method of conductivity survey of archaeological sites is to measure conductivity of the earth point by point with a small step (not more than half a meter), close to the surface, and present the measurements on the conductivity maps.

A co-ordinate system was set on the site for data collecting. There were plots 40 m wide and as long, as it is necessary to cover the area of this or those part of the site. Small wooden sticks were put each meter along two opposite sides of the plot and 40 m-strings with meter marks were used between the sticks.

The conductivity survey has been carried out with EM38RT ground conductivity meter from Geonics limited GSM-19WG (Ontario, Canada). The measurements were made along straight and parallel lines (strings with meter marks); the space between the lines was 0.5 m. The distance between the measurements along the lines was 0.5 meter. The height of the conductivity meter above the surface of the ground was about 0.2 meter (see ***Photo 1 and 2***).

The data were stored in the memory of the instument; after the survey they were transmitted to a portable computer. Two different presentations of the magnetic data were prepared with help of Surfer software (Colorado, Golden): coloured contour maps and grey-scale maps. On the contour maps the positive anomalies were marked with blue colour, negative ones - with red colour. On the grey-scale maps the positive anomalies are marked with dark colour, the negative ones – with light colour.

To measure electrical resistivity of mud bricks, soil etc., we used a resistivity meter of the German firm Gossen in a four-electrode mode (see ***Photo 3 and 4***).

RESULTS

First of all, the area of the site was inspected with help of **"free search" method**. It means, that the electrical conductivity has been measured with a step of about 1 m - 1.5 m without any grid. **On the whole territory of the site only two areas with high conductivity anomalies have been found – on the Temple hill (1) and around the Pyramid (3). There are also local conductivity anomalies on the area close to the road (4) (see *Fig. 1*).** On the quarters of the Roman town the conductivity measurements are low and almost constant, see for example, area 2 on the ***Fig. 1***. Therefore we decided to carry out detail conductivity measurements on the area of Temple hill and around the Pyramid.

Area 1. Main or Temple Hill.

The magnetic survey has been carried out on a big area of the Main hill in 2000 (see ***Figs. 6, 7*** and the Report of 2005). With help of magnetic survey it was possible to reveal a **big rectangular structure, the sizes of which are about 108 meters x 56 meters** in the central part of the hill. The orientation of the short axis of this structure is about 37 degrees from northern direction towards east (see interpretation map on the ***Fig. 8***).

It would be possible to interpret this rectangular structure as an enclosure, which is earlier, than the Roman Time buildings on the site. It is very interesting, that the neighboring Early Dynasty site 'Ain el-Gezzareen, which was investigated in 1999 and 2000 with help of magnetic survey, has almost the same dimensions and orientation of the walls (see ***Fig.18***) (Smekalova, Mills, Herbich, 2000, p. 132). The dimensions of the enclosure in 'Ain el-Gezzareen were approximately 112 meters x 54 meters, and orientation of the walls was about 25 degrees from the north towards the east.

The conductivity survey has been carried out on a quite big area. The results are presented as color contour maps (see ***Figs. 2, 4***) and as a grey scale map (see ***Fig. 3***). The blue color on the contour maps marks the high conductivity measurements, and the red color marks the low conductivity measurements.

On the grey scale map the high conductivity measurements are marked with dark, and the low conductivity measurements – with light color. The area of the excavations of 2005 is marked on the maps as a red rectangle.

One could see, that there is a big and quite complicated structure, consists of several rectangular blocks and two round structures. The material of this structure is more conductive for the electric current, than the mud brick walls of Roman Time. Therefore one could observe the high conductivity anomalies over the 'early' mud brick walls and the ruins of them.

The hypothesis is that there was an earlier settlement on the Temple Hill, and we can see the contours of the enclosure walls and some inner walls. They are marked with dark color on the grey scale map (***Fig. 3***) and blue color on the contour maps (***Figs. 2, 4***). The extension of these positive conductivity anomalies gives an extension of the an early settlement.

It is necessary to notice, that the direction of the planning system of this possible 'early' settlement is the same, as we revealed with help of magnetic survey (compare the interpretation map of the ***Fig. 5*** and ***Fig. 8***).

One could suppose, that in the Old Kingdom Time people used the clay from spring mounds and may be a special technology for preparing mud bricks for their constructions. The clay was different with the one, used later in the Roman Time. Perhaps, the earlier inhabitants of Amheida settled on the hill (which we call now "Temple Hill"), which was actually a spring mound, and built their houses from the mud of the spring mound. This mud, perhaps, is very fine clay, inreached with different minerals and iron hydroxides. This led to a fact, that the mudbricks of the Old Kingdom Time has high electrical conductivity, therefore we can see the walls on the conductivity maps as high readings.

We have checked the electrical resistivity with help of Gossen resistivity meter of the Roman mud bricks, visible elsewhere in the town quarters and possible 'early' mud bricks, which are exposed at the excavations on the Temple hill and we came to a conclusion, that the Roman mud bricks do not conduct any electric current, while the possible 'early' mudbrick have rather low electrical resistivity, or, which is the same, high electrical conductivity.

One of the most interesting feature, which has been found on the Amheida Main hill, is a strong magnetic anomaly on the top part of the area. The value of the anomaly is +100 and - 60 nT, the area occupied by it is about 10 m x 10 m. It could correspond to a very big kiln (?). In any case, this is a big mass of hardly fired clay.

It would be very desirable to check the supposition about the presence of an earlier structures on the Main hill with the excavations.

Area 2. South-of the Roman villa.

The magnetic survey has been carried out on the big area south of the Roman Villa, but there are almost no anomalies of electrical conductivity there. Therefore we did not print the map, one could see the result on the ***Fig. 1***.

Area 3. The Pyramid.

Another area with high conductivity measurements, as we already mentioned above, has been revealed around the Pyramid. The detail conductivity measurements has been carried out on a quite big area, including slopes and lower flat area to the east of the Pyramid. On the ***Fig. 9*** the part of the magnetic map of the 2005 has been presented (a) and the conductivity map as well (b). On the ***Fig. 10*** the grey scale conductivity map is draw, and on the ***Fig. 11*** the results of interpretation are presented.

One could see, that there are high conductivity measurements on the rectangular area with a Pyramid in the center and there are two anomalous zones to the north-east and south-east of it. One could interpret these anomalies as structures (may be earlier, than Roman structures), which we built in Pre-

Roman time. The contours of visible structures are shown on the ***Fig. 11*** as solid green lines, while the possible structures, revealed by conductivity survey are shown as dashed green lines. We would like to emphasis, that there are underground structures not only below the pyramid and around it, but also on the southern and northern-eastern slopes of it, and may be also on the low flat area east of the pyramid.

Area 4. Possible Pre-Roman pottery kins near the road.

Area 4 has been revealed with help of "free search" conductivity survey: several quite strong anomalies has been found there. It is situated at the southern-eastern part of the site, close to the modern road, near two natural hills (see ***Fig. 17a***). After that the area was measured with help of magnetic "free search" method, and two pottery kilns has been revealed side-by-side with the conductivity anomalies.

After that a detail magnetic and conductivity measurements has been carried out on the anomalous area, and the results are presented on the ***Figs. 12-16***. The interpretation map is presented on the ***Fig. 17***.

The situation plan has been built basing on the GPS measurements of the position of the hills and channels (see ***Fig. 17a***).

The magnetic map of two areas around two pottery kilns is presented on the ***Figs. 12, 13a, 14a, 15a, 16a***. On the ***Fig. 15*** b the map of magnetic susceptibility measurements with help of EM38 are presented. On all these maps one could see strong and distinctive magnetic anomalies of the pottery kilns.

It is necessary to mark, that according to our surface observations, these pottery kilns are of Pre-Roman (possibly, Old Kingdom) Time. The structure of the kilns, different with the one of the Roman pottery kilns, and the ceramic pieces around them could tell us about it.

On the ***Figs. 13b and 14b*** one could see rather strong positive conductivity anomaly of the former spring and the beginning of the channel. The other strong positive conductivity anomaly is on the eastern part of the slope of a small hill, on which the pottery kiln 2 is situated (see ***Figs. 15b, 16 c***). The reason of these anomalies could be the same, as on the Temple Hill: the water from the spring brought fine clay with a lot of iron hydroxides and other minerals. This clay is more conductive, than the other clay, which was used by Romans to built there mud brick houses. The big anomaly near the pottery kiln 2 could be caused by the clay pit, from which ancient people took the clay for forming their vessels, which they fired in the pottery kiln (2).

Area on the site ‘Ain el-Gezzareen.

Conductivity and magnetic survey has been carried out during 29 and 31 of January on the site ‘Ain el-Gezzareen. An interesting result has been obtained on this site, to the north of the Main Enclosure (see ***Fig. 18***). There high conductivity anomalies have been found. This area was partly surveyed in 2000 with help of magnetometer, and rather special anomalies have been found there. It seems, that the rows of positive magnetic anomalies are situated along the straight lines, which have one “meeting” point, somewhere outside the plot of magnetic survey. This year it was possible to found this “meeting point”.

The results of detail electrical conductivity survey are presented on the ***Fig. 19 b***, while the results of magnetic survey of 2000 and 2006 are presented on the ***Fig. 19 a***.

One could see, that there is a big conductivity anomaly, which corresponds to the anomalies of the magnetic field (compare the ***Fig. 19a*** and the ***Fig. 19b***). One could suppose, that conductivity anomalies are caused by the mud brick walls, which were built by more conductive clay from the water spring. There are several such springs in the vicinity, and one of them is marked on the ***Fig. 19 a*** as a red dot.

A strange row of local positive magnetic anomalies seems to have a continuation further to the north-west, as the magnetic map, obtained in 2006 (see northern part of the magnetic map on the ***Fig. 19a***). One of the supposition could be, that the anomalies are produced by fires, in which ancient people fired there ceramic vessels. There is a big anomaly just north of the center of the former spring mound, which one could recognize by a concentration of black stones.

Another possible interpretation of the row of positive anomalies could be that they are cooking pits, and the whole area could be considered as the area, where ancient people had prepared their ritual common food.

Area of the early Christian Time in Gedida.

A short “free search” magnetic survey has been carried on the site Gedida, and a possible “inductrial” area has been revealed there between the Main hill and the hill to the south (?) of it. There are several local rather strong positive magnetic anomalies there, which could be caused by ovens, kilns or furnaces.

One strong positive anomaly has been revealed in one of the rooms on the Main hill. This anomaly could be caused by a kiln in the kitchen.

The magnetic survey on Gedid site showed the perspectiveness of using magnetic measurements for revealing the features, which were subjected to the fire in antiquity. It is not excluded, that it would be possible to reveal walls of the rooms by magnetic survey there.

CONCLUSIONS

Conductivity survey proved to be an efficient method for the investigation of Amheida, to reveal an early structures on it's area. It was possible to find two pottery kilns of pre-Roman time on the area south-east of the Pyramid, close to the modern road.

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Photo 1

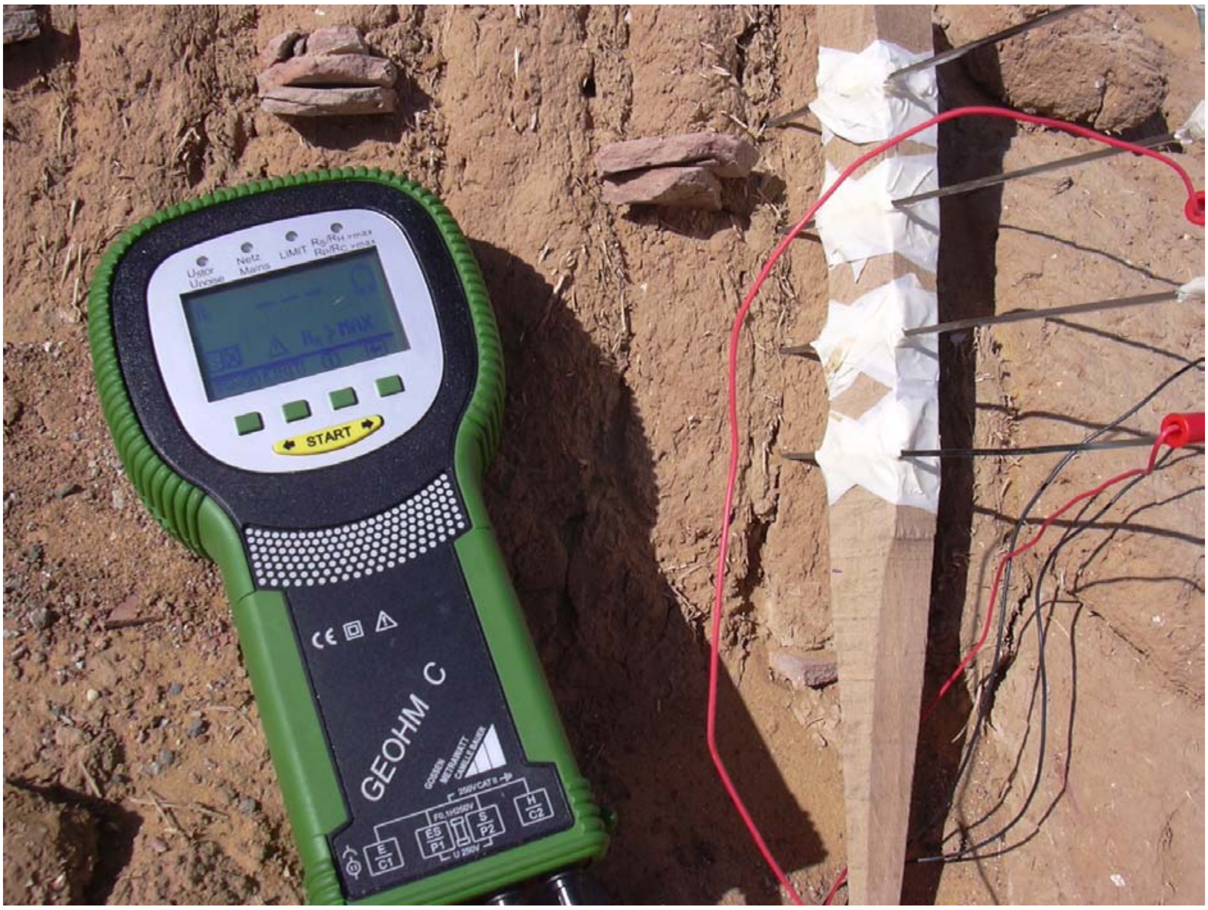

Photo 2

Photo 3

Photo 4