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ERT AND MAGNETIC SURVEYING: THE CASE STUDY OF KHAYRABADTEPA SATTELMENT (SOUTHERN UZBEKISTAN)

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Abstract **– The use of geophysical methods has become an integral part of the work at all stages of archaeological research. Geophysics contribute to the efficient and rapid detection of buried objects.**

One of the effective methods for mapping archaeological sites is an areal magnetic survey that reveals anomalies associated with the residual magnetization of such objects. To study the deep structure of complex objects in conditions of variable relief, the method of electrical tomography (ERT) has been well recommended.

Geophysical work was carried out within the boundaries of the settlement of Khayrabadtepa, which is a monument of the Kushan period in the territory of Northern Bactria. The settlement is located 1 km southwest of the city of Angor, 30 km northwest of the city of Termez.

I. INTRODUCTION

Khayrabadtepa is an ancient settlement located in the Surkhandarya region of the Republic of Uzbekistan. It was founded in the 4th-3rd centuries BC and is one of the most ancient archaeological sites in the region (Fig. 1).

The settlement is located on a high hill, which is surrounded by a wall about 800 meters long. Inside the walls are the ruins of ancient structures such as buildings, baths, temples and other.

Archaeological research has shown that Khayrabadtepa was a large and prosperous city that played an important role in the trade and culture of the region. Various items have been found in the city, such as pottery, metalwork, jewelry, and ancient coins.

Today, the ancient settlement of Khayrabadtepa is a popular tourist attraction.

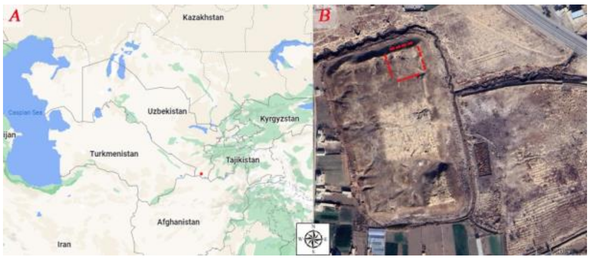

Fig.1. Overview of the site and measurement area. (A) Location of ancient settlement Khayrabadtepa (basemap: Map data ©2023 GeoBasis-DE/BKG (©2009), Google, Mapa GISrael); (B) Google Earth image of the site (basemap: Imagery ©2023 CNES / Airbus, Maxar Technologies, Map data ©2023). The area of interest is visible inside the red square.

The first studies of the fortress were made in 1953 by the staff of the Institute of History and Archaeology of the Academy of Sciences of the Republic of Uzbekistan L.I. Albaum and V.D. Zhukov, who studied the citadel and shahristan [1], and in 1975 in order to clarify the construction of the fortress walls the wall section was made, which revealed four construction periods [2].

The settlement is rectangular in plan, oriented from north to south with some deviation from north to west; its length in this direction is 150 m, and from west to east - 100 m. The walls in the form of melted ramparts are preserved at a height of 6-9 m. On the outer side they rise at an angle of 35°-45°, on the inner side they are at the same level with the surface of the settlement [3]. There is a characteristic feature of the shahristan, which consists of two parts: southern and northern. The wall separating these parts runs approximately in the middle of the settlement. It remains in the form of a low rampart about 1 m high can be seen even today.

Early research indicates that the southern part of the hill fort may have contained large structures, while the northern part may have contained traces of pottery, which can still be traced today by ceramic slags in the north-eastern part of the settlement. Unfortunately, the entire surface of the settlement is covered by a layer of loose soil. It is mainly connected with agricultural works and irrigation of vegetable gardens of local residents located to the south and west from the site [3].

For an extended duration, archaeologists were unwavering in their belief that geophysical prospecting outcomes on their own would provide limited contributions to solving intricate archaeological puzzles. However, contemporary consensus underscores the routine integration of some form of geophysical exploration as an essential precursor to initiating modern archaeological excavations [4,5,6,7], marking a shift in perspective where geophysical prospecting has seamlessly evolved into an indispensable foundation of standard excavation protocols.

The primary purpose of using geophysical methods to address archaeological tasks is to predict the spatial distribution of anomalies within the research site and to identify signs of anthropogenic influence. During the investigations at the archaeological site, a complex of geophysical methods was employed, including magnetic surveying and ERT. Both of these methods are widely utilized in modern archaeological geophysics and yield promising results. It's worth noting that a comprehensive interpretation of the data allows for more detailed investigation, which is a crucial advantage when mapping and studying cultural heritage objects [8].

ERT enables the detection of structural disruptions in the upper layers of the soil, identified by zones of localized changes in resistivity (in comparison to the surrounding section). Such anomalies can indicate the presence of archaeological features and even help refine their dimensions. Local increases in resistivity may suggest the existence of stone structures. Such enhancements are often observed in areas where stones were used in the construction of buildings [9].

Magnetic surveying often detects abrupt changes in the magnetic field in areas of main and entrance pits, and localized changes in the magnetic field signify the presence of large metallic objects. Local increases in the magnetic field are frequently registered in locations with accumulations of burnt stones and stone structures.

Geophysical work has focused on studying a hill fort, where early research, as mentioned above, suggests that there may be significant differences in the types of structures present in the southern and northern parts of the site. While pottery traces have been identified in the north-eastern part of the settlement, loose soil has covered the entire surface of the site, making investigation challenging.

II. METHODS AND METHODOLOGY

Investigations using geophysical methods were concentrated in the north-eastern corner of the fortress, in order to study the node of defense, namely fortifications - walls, towers, as well as the adjacent inner-city development. Photogrammetric survey was performed to create an orthophoto model of the work area (Fig. 2).

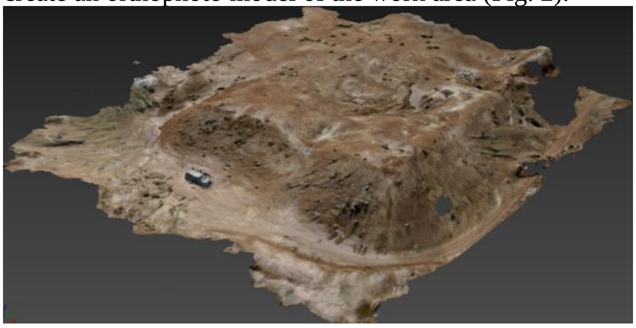

Fig. 2. Orthophoto of the work area (A. Zakirov)

The area of geophysical works by magnetic survey was 50×50 meters. The magnetic survey was carried out using Geometrics 856AX proton magnetometers. Two sensors connected to one magnetometer were used for field measurements, which allowed to measure two profiles at once in order to increase the efficiency of the work. The distance between the sensors was 50 cm, so the step between the measurement points and the profiles was 50 cm (fig 3). Another magnetometer was installed to measure daily changes of magnetic field.

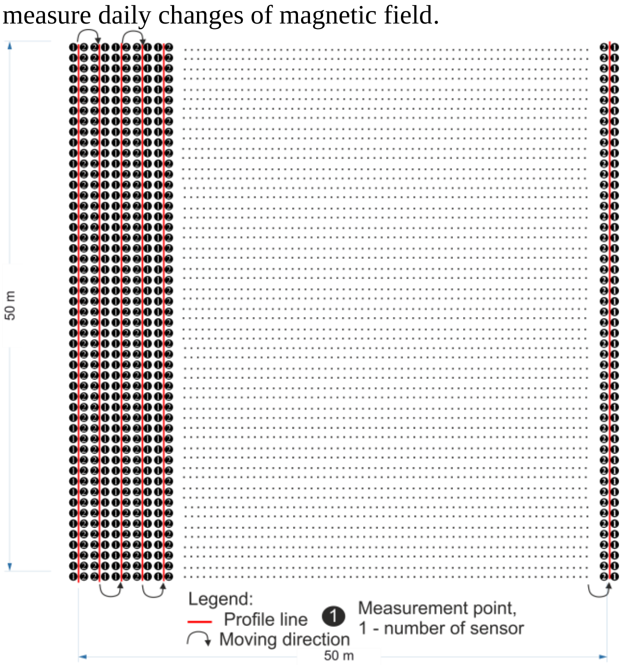

Fig. 3. Scheme of magnetometry measurements

However, it needs to be noted that for the detection of archaeological objects, conducting fieldwork with a magnetometer of this type is a quite labor-intensive process that takes a lot of time. The proton magnetometer produces discrete data records only at the observation

point, not allowing continuous data recording between observation points. Despite this, various objects are clearly distinguished on the map of magnetic anomalies even without serious processing of field data.
ERT was carried out in order to detect large objects, as well as objects located at a deeper level for further detailed work.

Electrical prospecting was carried out along two profiles. The first profile crossed the settlement diagonally in the direction from northeast to southwest; the second was performed along the northeast wall, in the direction from northwest to southeast. ERT was conducted with a 72 electrode georesistivimeter M.A.E. X-612EM, with 5 m electrode spacing, Dipole-Dipole protocol was used.

Processing of **magnetic survey data.** Data processing was carried out using standard procedures, which included: the subtraction of the daily geomagnetic background, the binding of the results obtained, the construction of maps of geomagnetic field anomalies (Fig. 4).

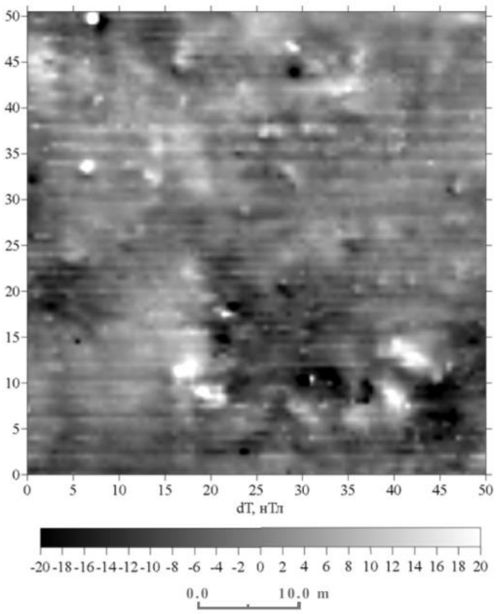

Fig. 4. Map of magnetic anomalies.

In Fig. 4, observes a number of anomalies caused by metallic objects (debris) on the surface, which create false anomalies. Also, there is a "banding" in the profiles, probably caused as a result of a zero shift during the measurements due to the heating of the device.

Processing of ERT data. The software package x2ipi was used to assign elevation values to each survey point and to edit the data. Data editing included elimination of anomalous measurement results and elimination of P- and C-effects caused by weak grounding of the supply and receiving electrodes (fig 5). These procedures are conducting to stabile inversion procedure and get more informative resistivity sections.

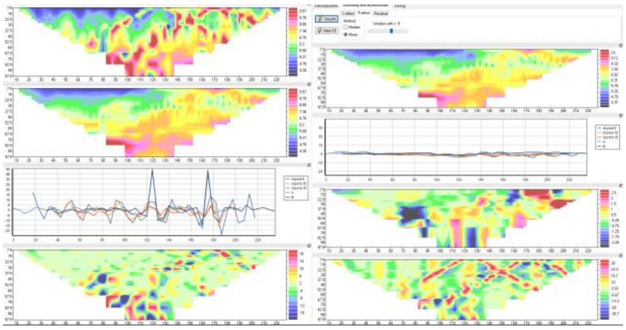

Fig 5. ERT field data filtering in X2IPI software

The further process of data processing consisted in calculating the inversion based on the model in the software package Res2DInv. The algorithm for calculating the inversion consists in fitting the model of the apparent resistances to the measured data with the calculation of the degree of inconsistency.
As a result of field data processing, the ERT method, resistivity sections and inversion models were obtained (Fig. 6).

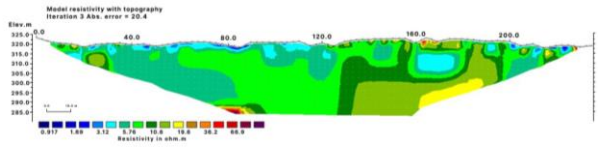

Fig. 6. Resistivity section along the profile I.

Various filtering, smoothing, and correction procedures were used during processing. Different methods of model calculation were used based on the specificity of each profile, i.e. the length and the corresponding number of electrodes and, as a consequence, the depth of the study. Taking into account the trapezoidal shape of the obtained resistivity section, the maximum number of iterations in model calculation was used to obtain the most effective and reliable result.
As a result of the interpretation of magnetic and electrical survey data, the most pronounced areas were identified (Fig. 7).

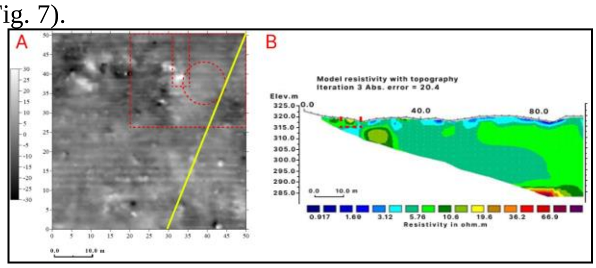

Fig. 7. Comparison of magnetic survey and ERT results (profile 1): A - map of magnetic anomalies in the area (yellow color indicates profile 1 ERT); B - fragment of the ERT section.

As can be seen in Fig. 7, anomalies are clearly observed in the plan, characterizing the various objects, hidden by cover deposits, which form different geometric shapes. In particular, in the north-eastern part of the map of magnetic anomalies observed objects repeating the shape of a circle and rectangle. Comparing the results of magnetic survey and electrical tomography, we can note that the area of elevated magnetic field values, identified by the data of magnetic survey, correlates well with the results of ERT. Geometric forms of these anomalies, i.e. angularity, length or roundness, distinguish them from the background of others [4]. Such a manifestation of anomalies may correspond to structures or other objects of life activity in the past. According to archaeologists in the north-eastern part of the wall it is assumed the presence of a defensive tower, which may correspond to the highlighted anomalies in the form of a circle.

III. CONCLUSION

The reliability of the results of geophysical methods can be confirmed only after the excavations. In the area, excavations were carried out after careful processing of magnetic survey and ERT data using a priori archaeological information about the geometry (shape, depth of occurrence, orientation, etc.) of the object of interest. Four 8×8 m squares were laid down. A comparison of the geophysical data with the results of the excavation is shown in Fig. 6.

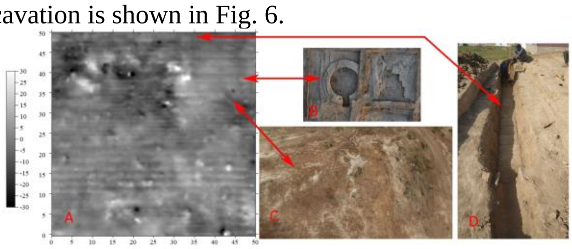

Fig. 6. Joint analysis of the results of excavations and geophysical methods of the studied area: A - map of the geomagnetic field anomaly; B - supposed base of the defensive tower; C - result of photogrammetry on the surface of the area; D - supposedly a drainage structure.

Fig. 6. shows that through the excavations two objects were found. The first is the base of the tower, the contour of which spatially coincides with its position of the magnetic anomaly on the map. In addition, this area can be traced on the orthophoto model created by photogrammetry. The second object in the form of a rectangular, elongated shape, identified on the magnetic survey data, most likely, is a drainage structure for water diversion. At the 11th and 15th meters of the profile I of ERT observed high resistivity anomalies relative to the surrounding rocks. When excavating in this area, it was found that the profile ran along the edge of the base of the tower.

The excavations of the upper horizon of the corner tower showed that the last period of its habitation can be dated to the late Middle Ages by the presence of the remains of the hearth. The hearth was found literally on the surface, lined with fragments of burnt bricks measuring 28×28×6 cm. Several small fragments of glazed pottery (mostly corolla) with white glaze and blue color on the corolla were found near the hearth. In addition, slags from ceramic production were found in this layer. Note that according to preliminary work and analysis of the materials found, this tower, and possibly the rooms where traces of short-lived inhabitation were found, date back to the X-XII centuries. In addition, this structure was cut into the wall of Kushan period, erected of raw material measuring 32×32×12 cm, traces of which were recorded to the left of the entrance to the room.

The magnetic properties of archaeological objects depend on the composition of the material from which they are made. If the walls contain magnetic minerals such as magnetite or hematite, then they will have magnetic properties. However, if the walls are made of non-magnetic materials, then they will not have magnetic properties.

If objects have magnetic properties, then they can create magnetic anomalies on the surface of the earth. On the magnetic anomaly map, walls will appear as areas of higher or lower magnetic strength than the surrounding area. In addition, the shape and size of the anomalies may indicate the location of the walls and their geometry. However, if the archaeological objects and the soil covering them are identical in composition, then this makes it difficult to visualize these objects. In such cases, it is necessary to use a rational complex of geophysical surveys. In addition, before starting magnetic survey, it is desirable to measure soil indicators with a kappameter.

Thus, we can conclude that methods of exploratory geophysics, such as magnetic surveying and ERT, can effectively solve the most complex archaeological problems.

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