Geophysical methods in the study of the ancient metallurgical complex in the Western Baikal region (section Barun-Khal II)

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Abstruct

In many places of the Olkhon region (the western coast of the central part of Lake Baikal), ancient iron-making complexes have been discovered, iron products are found in archaeological sites, and metallurgical slags are found throughout the territory.
This is due to the fact that from the end of the 1st millennium BC. objects made of iron become an important component in the composition of the tool complex of the inhabitants of this territory. It is likely that most of these items were made locally, as evidenced by the remains of metallurgical production recorded in different parts of the region.
In this work, on the example of one of the objects of the Barun-Khal II monument, the results of a complex of geophysical studies are analyzed, including ground and UAV-magnetic survey, electrotomography.The geological background for identifying objects is the folded framing of the Siberian platform, represented by deeply metamorphosed rocks of the Olkhon crystalline complex. Performed modern 3D inversion of magnetic and electromagnetic data. It made possible to evaluate the effectiveness of each of the methods, to compare the reliability and information content of the observed data and the resulting 3D models of the hidden object.

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Introduction

On the western coast of Lake Baikal near the village of Shara-Togot, Olkhonsky District, in 1977, a monument to the ancient metallurgy of iron Barun-Khal II was unveiled, Figure 1 (a). According to the radiocarbon method, the age of the monument is 2180-1750 years [3,4,8].

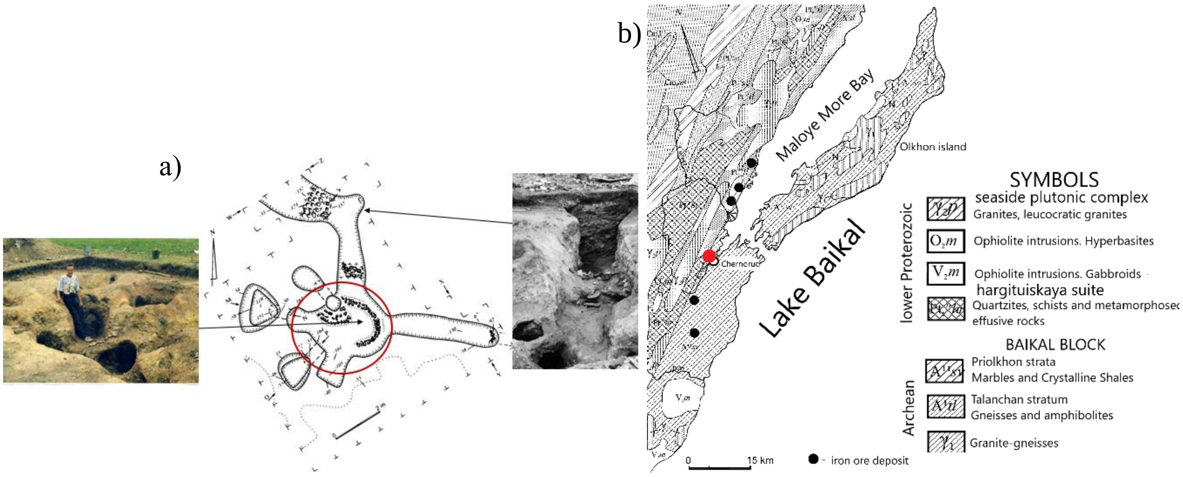
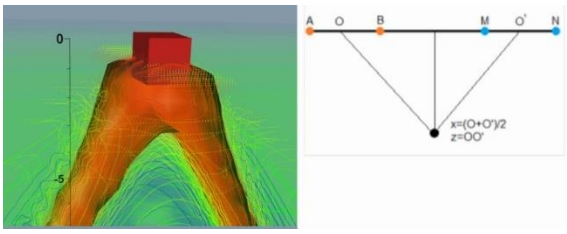


Figure 1. *Excavation of one of the iron furnaces in the metallurgical center Barun-Khal II (a); survey geological map of Priolkhonye (b).*

A possible way to optimize searches, as well as to study archaeological sites without excavating them, are geophysical methods - magnetic prospecting [7] and electrical prospecting. In this case, surveys were carried out on the reference object by methods of ground and UAV magnetic prospecting and electrical prospecting.

Electrical exploration

For the Barun-Khal II object, an analysis of the results of electrotomography was carried out, the direct problem was calculated for a high-resistance cube with dimensions of 2x2x2 m, the choice was made on a dipole installation, Fig. 2. For it, the optimal distance between the profiles of 2-2.5 m was selected.



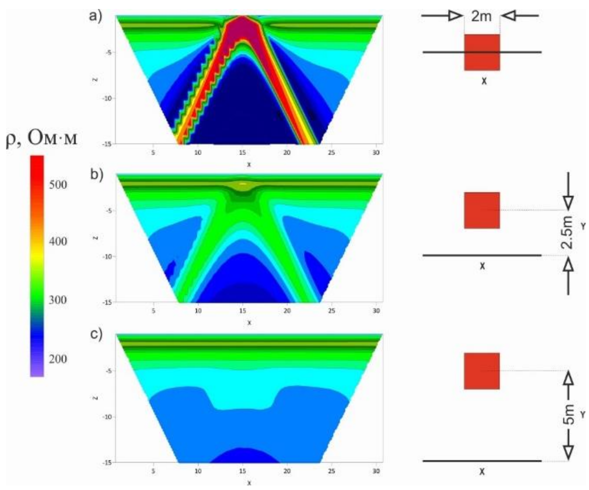


Figure 2 *Results of direct modeling of the dipole installation of electrotomography for a cube. UES sections directly under the object (a), at a distance of 2.5 m from the object (b), at a distance of 5 m (c).*

To detect archaeological objects, namely, metallurgical furnaces, electrotomography was used with the Skala-64 dipole installation, Fig. 3a. The results obtained are presented in the form of a section in Figure 3b, where the unexcavated boundaries of the remains of a metallurgical furnace are distinguished by an anomaly.

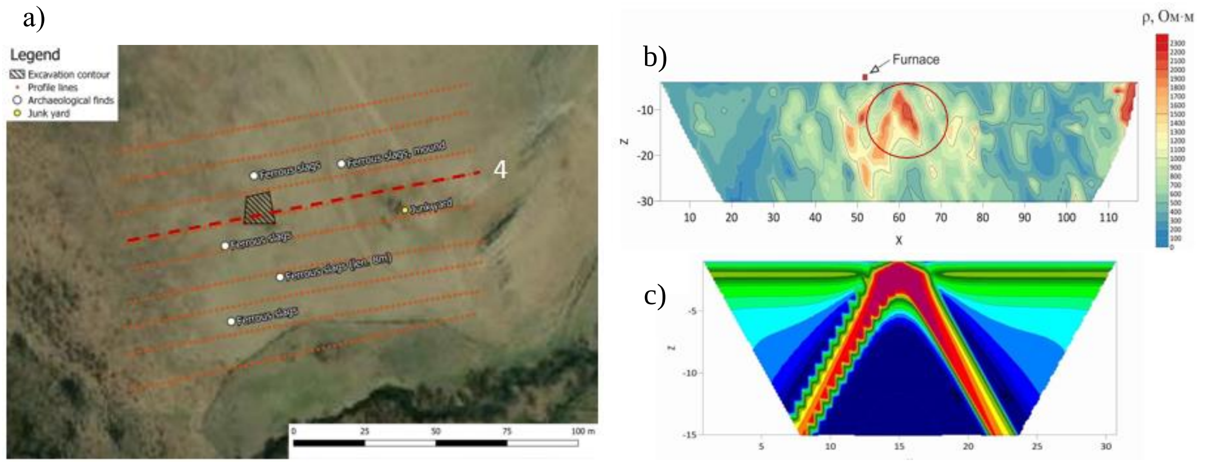


__Figure 3.__ Survey scheme and archaeological objects (a); section of resistivity on profile 4 (b); anomalous effect from the cube (c).

Furnace magnetic model and results of magnetic survey data interpretation

The assessment of possible magnetic effects for ground and UAV surveys was carried out for a physico-geological model of a furnace with a characteristic size of 2 × 2 × 2 m with a depth of the upper edge of 0.5 m and an average value of the effective magnetic susceptibility $\varkappa = 0.025$ units SI. Taking into account the significant effect of thermo-remanent magnetization, the following parameters were taken for this characteristic: Koenigsberger coefficient Q = 1; declination Dr = 270º and inclination Ir = 270º. The parameters of the current normal magnetic field for the region: T_0 = 60700 nT; D_0 = -6 º; I_0 = 73º.

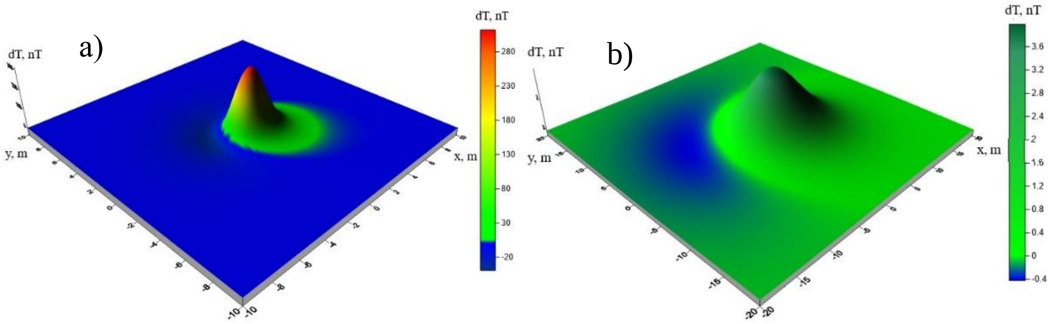


__Figure 4.__ Magnetic fields at a height of 0.5 m (a) and 7.5 m (b) for a model of a simplified iron-making furnace.

An unmanned system SibGIS UAS [5] with an Overhauser magnetometer was used to perform the magnetic survey. The measurement scheme is shown in Figure 5a. The height of the sensor was 7.5m

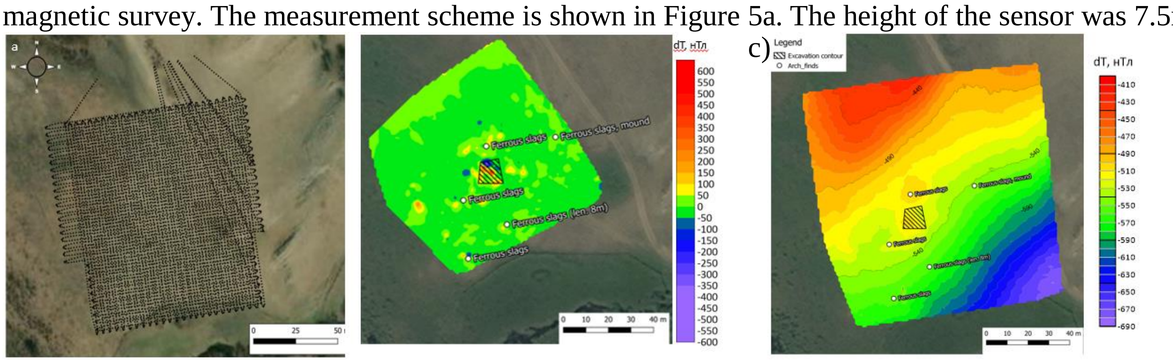


__Figure 5.__ Results of magnetic surveys: a) - UAV survey observation network; b) ground magnetic survey c) - magnetic field according to UAV survey data

The applied inversion method makes it possible to select magnetized objects based on anomalous magnetic field zones, to determine their geometric and magnetic parameters using criteria that limit the areas of possible compact solutions based on regularization by the elastic network method [2, 10].

The results of the inversion of the UAV-magnetic survey show the coincidence of the obtained model of the object with the contours of the anomalous zone of the magnetic field. The elongated, branched form of the anomalies is presumably associated with a system of trenches connecting the iron-reduction and blacksmith's furnace.

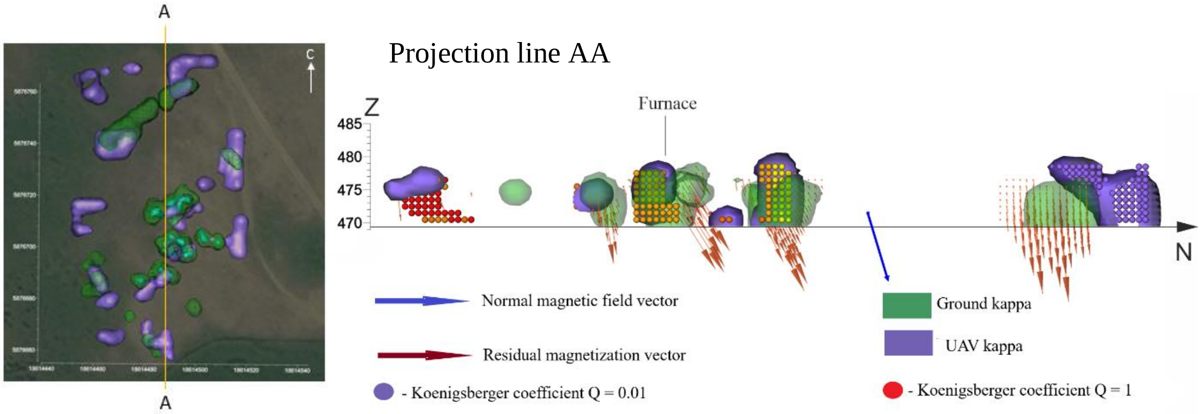


***Figure 6** Comparison of 3D magnetic field inversions for ground survey and UAV survey.*

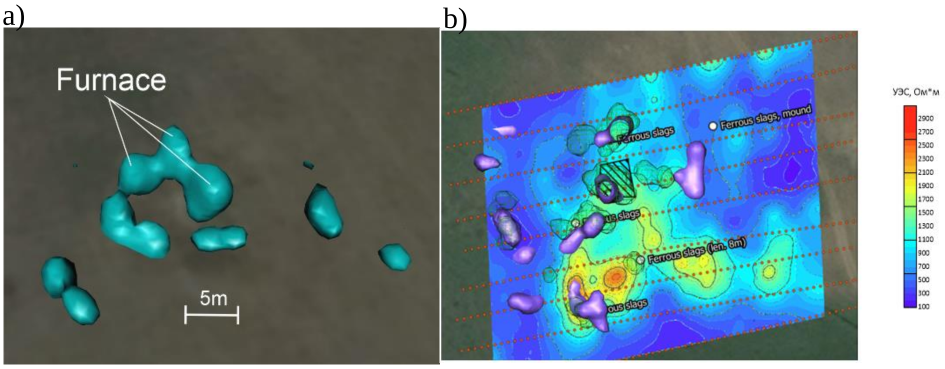


***Figure 7** Magnetic susceptibility anomalies. Top and side view over the excavation (a); Comparison of the results of three-dimensional inversion of electrotomography and survey of the magnetic field of the UAV (effective magnetic susceptibility) and ground magnetic survey (b).*

Conclusions

As a result of the work, an assessment of the anomalous effect for pedestrian and UAV magnetic surveys was carried out for a typical model of a metallurgical furnace in a given area. Both methods of magnetic prospecting made it possible to accurately identify anomalous objects. With a ground survey, the amplitude of the anomaly is more than ten times higher than with a survey at an altitude of 7.5 meters. However, the amplitude of the anomalies recorded from the air, taking into account the high accuracy of the UAV magnetic survey, is sufficient for mapping objects and performing 3D inversion. Using the method of 3D magnetic field inversion, three-dimensional models of the distribution of magnetic susceptibility have been created, which make it possible to study the structure of an archaeological object without excavating it, at that quality of restoring the magnetic properties of the desired objects does not actually depend on the method of survey.

The work using the electrotomography method also made it possible to create maps and 3D models of electrical resistivity. The reference metallurgical furnace is manifested by an anomaly of increased resistance (2100 to 3200 Ohm m) against the background of a host medium with a resistance of 200 Ohm m.

The objects identified by the methods of electrotomography and UAV-magnetic prospecting, on the whole, coincide, with a correction for a much rarer network of electrotomography measurements.

Thus, to identify and study metallurgical furnaces, one can use both magnetic prospecting (both ground-based and using UAVs) and electrotomography. These methods have the necessary sensitivity and resolution for shallow research.

As a result of a set of works, it was possible to identify not only the contours of the reference object, but also to discover new ones, previously unknown.

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