P33

# Geophysical Researches on Excavations of the Bronze Age Fortified Settlement in Southern Ural Mountains

P.S. Martyshko* (Institute of Geophysics Ural Branch RAS), V.V. Noskewich (Institute of Geophysics Ural Branch RAS), N.V. Fedorova (Institute of Geophysics Ural Branch RAS) & L.A. Muraviev (Institute of Geophysics Ural Branch RAS)

## SUMMARY

Geophysical researches were carried out on archeological excavations of one of the numerous bronze age fortified settlements discovered in Southern Ural Mountains in 60 - 90th years of XX century. The purpose of the present work was the research of the settlement fragment by non-destroying methods for revealing and mapping separate objects - the remains of dwellings, constructions of economic value, furnaces, economic pits and fortified constructions. This information was required for carrying out more purposeful excavation by archeologists.

As the most effective and economic, researches were carried out with magnetometry methods by means of two proton gradiometers and one cesium gradiometer on preliminary spaced network of 0,5x0,5m. For the account of the Earth magnetic field variations the variation station was used. Before survey, clearing of an investigated site from metal debris was performed by metal locator.

As a result of survey the map of an anomaly magnetic field was acquired, where the wall with a ditch, remains of walls of separate dwelling, the furnace and economic pits were allocated. After interpretation of anomalies received from a wall its position and a configuration were established.

## Introduction

Settlement Kamennyj Ambar (Olgino) is situated on the bank of Karagaylu-Ayat river in Kartalin district of Chelyabinsk area. The settlement was discovered by results of air photography decoding. Excavation on site has begun in 1992. Starting 2005 excavations on settlement territory performed every year (Lyudmila Korjakova and others, IHA Ural Branch of the Russian Academy of Sciences and the South Ural state university). During these activities the data on a design of defensive system (ditch and the wall strengthened by stone) and presence of the remains of metallurgical manufacture has been obtained. The settlement occupied territory of 20000 sq. m. within fortifications, the site has a steppe landscape, a relief quiet, relative excess no more than 2 m. Settlements disposition on a map of Southern Ural Mountains is shown below (Figure 1).

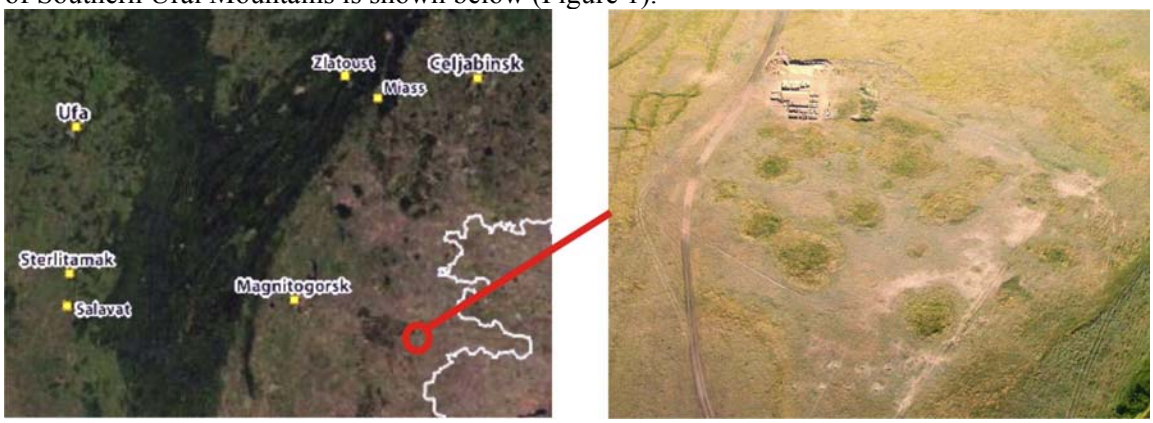


***Figure 1*** *Olgino settlement disposition. Left) Map of Southern Ural Mountains. Right) View from a glider height.*

The magnetometry method is most effective because the fast and economic from all the geophysical methods used in archeology. C. Merrony (2005) was the first geophysical researcher who has performed magnetic survey of the on settlement Olgino area by fluxgate magnetometer (Geoscan FM18, resolution - 1 point on 1 sq.m.). Magnetic field vertical components map of settlement territory was received, where settlement's common features (walls, a ditch, economic pits, hearths, furnaces) in the form of positive anomalies of magnetic field can be seen (Figure 2).

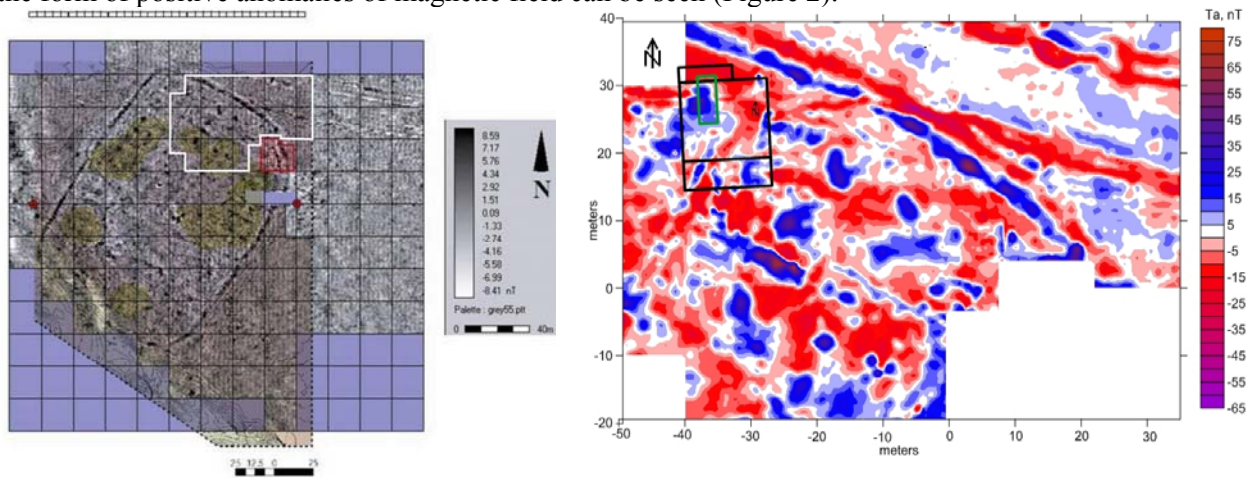


***Figure 2*** *Magnetic maps of Olgino settlement. Left) Magnetic map of the magnetic field vertical component, received by C.Meroni. Right) Map of an abnormal field of the magnetic induction full vector module (the bottom sensor).*

For improvement of a lay-out of a settlement, localization of fortified constructions and economic constructions more detailed magnetic survey of settlement was required. The area of the present examinations is shown by the white polygon (Figure 2).

Samples of the burnt clay from a settlement occupation layer were taken for magnetic susceptibility values in vitro estimation, the values fluctuates from 2,8 $10^{-3}$ to 4,09 $10^{-3}$ SI. The susceptibility values out of an occupation layer change in interval (0,7-8,9) x $10^{-4}$ SI. Such contrast range of magnetic properties created good backgrounds for conducting magnetic survey operations.

**Procedure of survey and preparative treatment of measurements**

Domestic magnetometer-gradiometer POS-1,2 Sapunov, etc., (2000), MMPG-1 (Russia, St. Petersburg, "Geologorazvedka") and the Canadian gradiometer Scintrex SM-5 were used for magnetic survey. Before conducting of magnetic survey section brushing from the technogenic iron remains which presence could garble a magnetic map was performed with metal-locator Explorer II by MineLab.
Survey sections were divided into tablets with sizes 20×20 meters. Survey was performed on a network of observations with a step 0.5 × 0.5 m. The profiles have been oriented to magnetic north. There is a smoothing of values during individual measuring if the continuous regime of measurements is using because of a data unit motion. Besides, there is no strong binding of measurements of a magnetic field to specific points in space and therefore it leads to "degradation" of the anomaly effect Bruce W. Bevan (2006). That's why another procedure of survey was used.
Measuring was made with a full stop of the device with data units over a measured point. Unlike measuring in the continuous regime the time of survey accomplishment was increased a little, however it allowed to reduce a lapse of measuring. The lapse of survey estimated by us was around ±1 nT. Measuring of the induction density full vector module was executed at altitudes of 0,35 m and 2,15 m from a surface. For recording of geomagnetic field variations during observations magnetometer POS-1 with an interval of measuring of 3 seconds was used. At entering of allowances for geomagnetic field variations in ordinary measuring the linear interpolation was used. The account of variations at survey allows to gain besides magnetic field induction vertical gradient, value of the induction module at two levels. After survey on tablets ordinary measuring were merged in one file and magnetic maps at altitudes of 0,35 m. and 2,15 m. from a surface were built, and also a map of the magnetic field full vector module gradient.

**Results of magnetic survey**

The survey area was 88 x 60 meters. For qualitative interpretation magnetic field maps at both altitudes were used. The map from the upper data unit reflected regional magnetic field of a section which tended to depression from the southeast to the northwest. For exclusion of local in homogeneities the map from the upper data unit has been handled by the filter on a method of a sliding average with a window 15,5x15,5 m. Gained map subtracted from a magnetic map gained from the lower data unit. Anomaly field map of the magnetic field complete vector module is shown at Figure 2. Two types of anomalies has shown on the map: the linear and oval shape. This gained map has been converted to a gray scale relief map for qualitative interpretation.

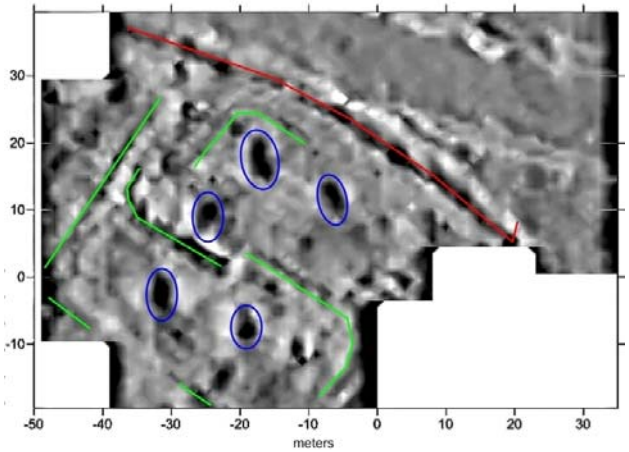


***Figure 3*** *The shaded relief map of magnetic survey section Figure 2.*

Anomaly field map was conversed to a format .wmf and was received linear features by means of the relief filter (Adobe Photoshop) (Figure 3). The wall of the fortified settlement is marked by red line, green lines shows the remains of the interior dwellings base, and dark blue ovals are places of the hearth and economic pits.

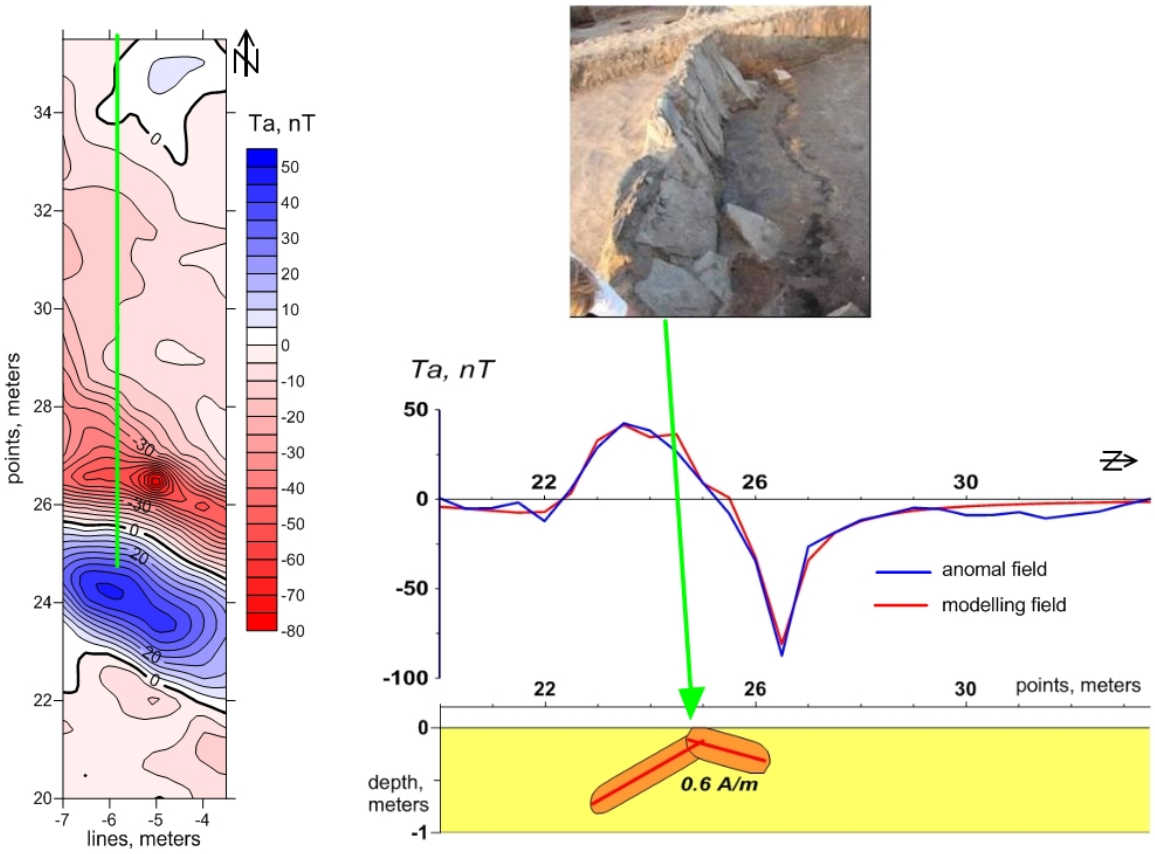


***Figure 4*** *Interpretation results of the fortified settlement wall fragment. Left) Magnetic map fragment (green colour oozes a lateral view on which interpretation was performed. Right below) Interpretation results of a lateral view. Right above) Wall fragment after digging.*

Analytical interpretation was performed along profile, traversing linearly stretched anomaly discovered over a defensive wall of Olgino settlement. This interpretation method was developed by Tsirulsky et al., (1980) and allows simultaneously performing modeling of anomaly sources both for the constrained objects class, and for demarcations of schistose mediums. In two-dimensional version of the method the anomalous magnetic field is approximated by the fields of singular sourcers (two-dimensional plates set), and then build-up of geometrical contours of the equivalent sources is made at various values of magnetization. Using such modeling objects allows to part fields from different objects and to define integral features of sources, such as a magnetic moment, a centre of gravity and a source direction of incidence. In consideration of the basic ambiguity of magnetics inverse problems, the interpreter for each modeling source can quickly count geometrical contours of constrained objects or contact surfaces of schistose medium for various values of magnetization. It allows constructing and analysing of the alternative versions of a section, equivalent by created external field, which is especially important at interpretation of geophysical fields in the conditions of a deficiency of aprioristic geologic and petrophysic information. Interpretation of the abnormal magnetic field consists of two stages. At the first stage abnormalities $Z_a$ or $T_a$ are approximated by composite field $N$ of singular plates, each of which is characterized by constant linear magnetization $A_\kappa$ and coordinates of the ends $a_\kappa$ and $b_\kappa$. The complex potential of a plate in a point $z=x+iy$ describes with the formula:

$$V(z) = A_k[\ ln\ (z-a_k)- ln\ (z-b_k)\ ],$$

The approximation problem consists from finding such set of parameters $N, A_1, a_1, в_1 ... A_N, a_N, в_N$ at which the peak value of a difference between values of the anomalous and modeling fields at points of observations does not exceed $E$. $E$ value is quite low and is set from conditions of a current task and inaccuracy of observations. At the second stage calculations of equivalent sources geometry are made. For plates the equivalent family of constrained fields or demarcations is built - depending on information that is available on surveyed region. There is a possibility of integrating of the closest plates in one source. Possibility of the analysis of all assemblage of the equivalent solutions is thus maintained. Transition from one variant of a geomagnetic section to another does not demand recurring of the first stage of interpretation, i.e. actually selection. It is necessary to mention that though the method substantiation is given for a two-dimensional case, in practice three-dimensional abnormalities are explored. Results of inaccuracy analysis of sources finding on theoretical models have shown that if a relation between length and width of abnormality K=2, the error of a source centre finding equals 15%, and in case of K=3 inaccuracy decreases to 5-8%. As archaeological objects we are interested in are not at a great depth (0,3-1m), inaccuracies at parameters finding of abnormalities sources will not appreciably influence results of examinations. Thus possibility to view the equivalent alternatives is given to the interpretive program that undoubtedly is important for definition of abnormalities nature, sources partitioning by artificial or natural origin. Interpretation by Tsirulsky method was performed on a lateral view, traversing linearly stretched abnormality discovered over a defensive wall of settlement Olgino. The magnetized plates gained as a result of automated selection lie down rather not at great depth 0,2-0,6 m (Figure 4). Their upper facets converge in one place and are very close to a land surface. Distance between the lower ends of sources about 3,5m. Results of interpretation are confirmed by the subsequent digging in 2008 on Olgino settlement. The bypass wall with width of the foundation 4-5m is combined from soil and fictile blocks (Figure 4).

## Conclusions

For archaeological objects examination the modern methods of magnetic investigations allow not only to map and localize anomalies from the tracks of ancient civilizations activities hidden underground, but also, as a result of the powerful instrument application of the magnetic anomalies quantitative interpretation developed for geophysical research, to enrich knowledge of a these historical sources structure considerably. At modeling of Olgino settlement anomaly sources it was determined that for fortifying of the defensive wall plates from crystalline soils were used.

## References

C.Merrony. Investigating the Bronze Age of Southern Siberia. URL: <http://www.shef.ac.uk/archaeology/research/siberia/olgino.html>

Sapunov V.A., Savelev D.V., Denisov O. V, Kiselev S.E., Denisov A.J., Sabanin A.A., 2000. Modern proton overhauser magnetometers: possibilities and prospects in the field of geological prospecting//Geologic service of Russia 300 years annual. The international geophysical conference: Thes. Rep. - S.-Peterburg, .290-292.

Bruce W. Bevan, 200. Understand magnetic maps. Technical report. Geosight; Weems Virginia, 30

Tsirulsky A.V., Nikonova F.I., Fedorova N.V., 1980. Method of gravitational and magnetic anomalies interpretation with build-up of the equivalent families of solutions. Sverdlovsk: USC AS USSR, 135p.