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3D electrical resistivity imaging and GPR to re-explore ancient mounds near Suzdal in Russia

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INTRODUCTION

The investigation site is located 40 km north-west of Suzdal near Shekshovo village in the Ivanovo region. The site lies in a typical plain landscape of central Russia and is comparatively flat. Regular cultivation has ensured that nothing except grass and planted crops grows in the survey area.

Diverse natural and historical factors have conditioned habitation in the Suzdal region since ancient times. One of the most interesting periods is from the end of the first and in the beginning of the second millennium AD, when Vladimir-Suzdalian Russia emerged. Numerous burial mounds of the 10th–11th centuries are among the most important evidence of this period, particularly in conjunction with a study of the corresponding historical processes. The mounds were first investigated archaeologically by A.S. Uvarov in 1851–54. He excavated 7729 burial mounds, 244 of which were located at Shekshovo. But the excavation documentation was neither exhaustive nor informative enough. The excavated sites were poorly located on the maps, classification of the mounds was not precise and the dimen-

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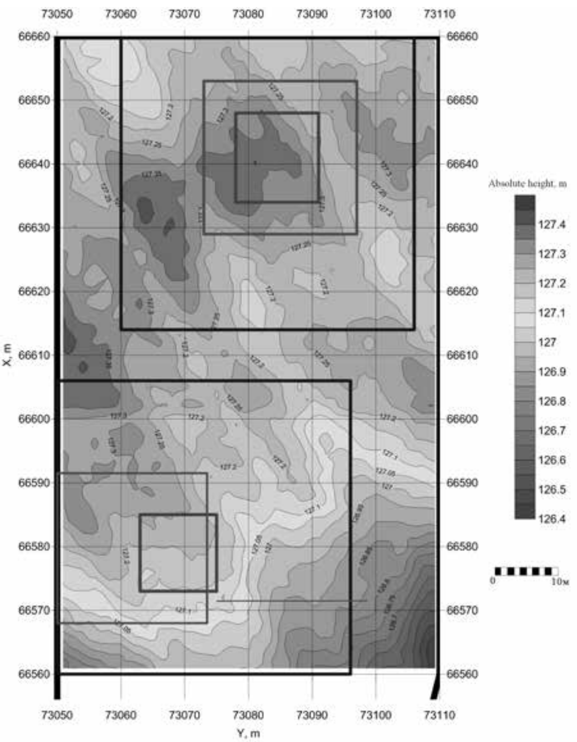

Fig. 1. Microrelief of the area investigated with geophysics in 2013. Solid black lines – areas covered by raw geophysical survey, dashed line – detailed survey areas, dotted line – excavations in 2013

sions specified for only 1% of the features; the collected artifacts were hastily described and no drawings exist. Ten years ago investigations were initiated by the Suzdal Archaeological Expedition of the Archaeological Institute of the Russian Academy of Sciences under the direction of N.A. Makarov. The exploration has focused on the settlement and burial ground near the site of the present Shekshovo village.

One of the main difficulties encountered by modern research is the absence of any sign of buried mounds on the modern surface. Agricultural activity for centuries, Uvarov's excavations and natural processes have deleted all signs of the buried mounds. There is no information about the quantity of burial mounds, their location, the distance between mounds and the morphology of the ground between them. The geophysical survey was designed to guide the excavations by obtaining information about the location of the burial mounds. The geophysical methods applied included magnetic prospection, detailed topographic survey, ground penetrating radar (GPR) and areal electrical resistivity tomography (ERT).

The investigations were conducted in 2013 and 2014. The total area covered by the geophysical survey was approximately 9500 m^2 (Fig. 1). The survey area of 2014 was roughly of the same size as in 2013 and was located slightly to the west of it.

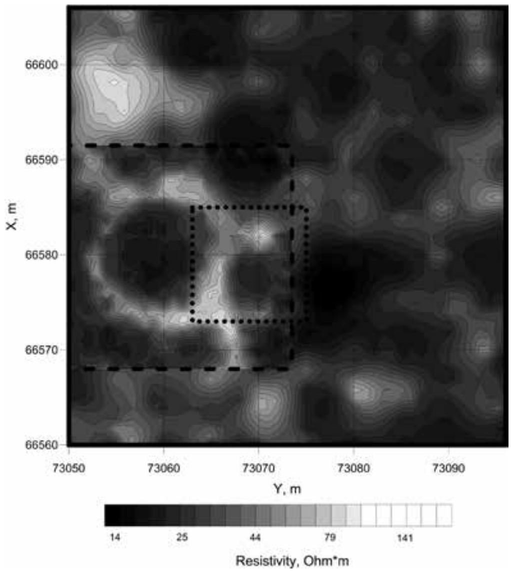

Fig. 2. Resistivity map at 60 cm depth; area of detailed survey (inside the dashed line) integrated into the raw survey map

RESULTS

Resistivity imaging is one of the basic methods in archaeological geophysics (Griffiths, Barker 1994; Erokhin *et al.* 2011). In the current study, ERT was supposed to define the thickness of the cultural layer in the area and to map its spatial structure, including its inhomogeneity. Two ERT survey configurations were used: a raw survey with 1 m spacing between the electrodes and a larger step between the profiles (from 5 m to 1 m), and a detailed survey with 0.5 m electrode spacing and a smaller step between the profiles (from 1 m to 2 m). In both cases, the system with two perpendicular profile directions, as described by Pavlova and Shevnin (2013), was used. Independent 2D inversion for each profile was done in most cases and then the resistivity values for the corresponding depths were extracted from the inversion model. For the detailed survey areas with 0.5 m spacing between the electrodes and 1 m spacing between profiles, both the described technique and the 3D inversion of all data points (for all profiles) were used simultaneously. While ERT supplied the most conclusive results concerning burial mound mapping, the comparison of these two approaches shows that neither can be called the best. Instead, both need to be used as they tend to emphasize small features on resistivity maps in slightly different ways. This observation is important for the interpretation.

The resistivity map at 60 cm depth for the raw survey 1 m × 5 m shows several circle-like structures (Fig. 2); the most distinct of these was chosen for a detailed survey 0.5 m × 2 m (results shown inside the dashed-line square in Fig. 2). The interpretation of the high-resistivity circular zone as the ditch around the burial mound was verified by subsequent excavation in July 2013, covering

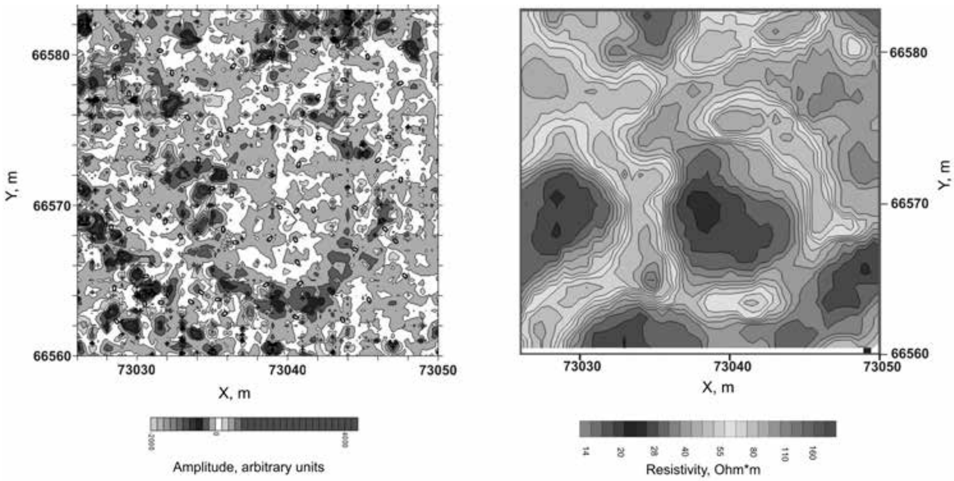

Fig. 3. Detailed survey area in 2014: GPR slice at 25 ns (left) resistivity at 60 cm depth (right)

the western part of the circle. This indicated that ERT technology was capable of reliable burial mound detection in the area of investigation. In 2014, the raw net was made denser: 1 m between the electrodes and 1 m between the profiles, as well as with two profile directions (polarizations).

The GPR prospection was carried out despite the satisfactory ERT result, because the survey time in this case could be decreased substantially. For the GPR investigation, the area was divided into squares 20 m × 20 m, the maximum distance at which the positioning could be done manually, while retaining acceptable accuracy. For improved accuracy, measurements were made with a 1 m step between the profiles and in two perpendicular profile directions. After the individual radar traces were processed, signal amplitude for the needed reflection time was extracted and a map for the area was generated.

A comparison of the GPR map for one square area (Fig. 3 left) with the ERT raw map (1 m × 1 m survey) of the same area (Fig. 3 right) demonstrated that the most distinct circular high resistivity structure on the ERT map could also be seen on the GPR map. This demonstrates the applicability of the GPR to achieving survey objectives, at least, in the small-scale raw surveys. Unfortunately, the magnetic surveys, which have been carried out in the area for many years (Klein *et al.* 2007), have shown less than satisfactory results concerning burial mound detection: the "ditches" surrounding the mounds do not possess anomalous magnetic properties. Two main classes of objects visible on the magnetic map are the relict ice wedges and iron objects, a substantial part of which are artifacts of archaeological interest.

CONCLUSIONS

Circle-like structures, which are interpreted as the remains of "ditches" around the burial mound, were detected with geophysical methods. In 2013, at least nine such structures of different sizes were detected. The diameter of the smallest one is 7–9 m, of the largest 11–13 m. Areal ERT (Pavlova, Shevnin 2013) and GPR were the most informative geophysical technologies applied in this case.

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