Frozen mounds in Gorny Altai: geophysical and geochemical studies

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Abstract

The importance of pre-excavation permafrost detection within ancient burial mounds in the Altai by geophysical methods is hard to overestimate. There was no way of detecting small quantities of frozen ground or ice under stone mounds, and this is a topical issue in Russian archeology. Frozen mounds, which retain organic matter owing to natural processes, are an exceptional source of information about historical and cultural processes in the Early Iron Age. Pre-excavation geophysical prospecting is especially important in the context of global warming, which might destroy a whole layer of cultural and historical information.

The integrated geophysical studies conducted in recent years focused on a group of archeological sites of the Pazyryk culture whose burial constructions are very likely to contain frozen artifacts. As a rule, such burial mounds are located at a considerable altitude and contain permafrost, which creates unique conditions for the preservation of artifacts. Such localities include the Ukok high plateau (southern Altai) and the northwestern part of Mongolian Altay. Systematic field studies were conducted on the Ukok Plateau in 2003 and 2007 and in the adjacent territory of Mongolian Altay in 2005 and 2006. The following geophysical methods were used: vertical electrical sounding (VES), electrical tomography (ET), shallow frequency scanning, georadiolocation, magnetic susceptibility measurements, gamma-ray spectrometry, and chromatography. The field works were planned with a heavy reliance on the 3D mathematical simulation of electric and EM fields, which is meant for a realistic estimate of the possibilities of geoelectrics and the best ways of its application to burial-mound studies and data interpretation.

The excavations conducted in 2006 in northwestern Mongolia within the Altai Mts. confirmed the geophysical prediction of permafrost at all the sites identified by the geophysical studies in 2005. In one of the mounds, they yielded a unique intact tomb of a Scythian warrior. © 2012, V.S. Sobolev IGM, Siberian Branch of the RAS. Published by Elsevier B.V. All rights reserved.

Keywords: archeological and geochemical studies; resistivity method; frequency sounding; chromatography; Pazyryk burial mounds

Introduction

Long-term studies of Scythian burial mounds on the Ukok Plateau (Gorny Altai) revealed unique complexes of the Pazyryk culture with perfectly preserved organic objects: human mummies and items made of textile, wood, leather, etc. The natural low-temperature conservation of organic matter became possible after the formation of a nonmelting ice lens under the masonry in the log construction of the burial chamber. These lenses give archeologists highly valuable artifacts, which make it possible to reconstruct many historical and cultural processes of the Early Iron Age. Note their good ethnographical integrity for 2.5 kyr. Also, frozen burial mounds have become an exceptional source of information for a whole range of multidisciplinary studies: anthropological, paleogenetic, microbiological, palynological, paleobotanical, dendrochronological, physicochemical, etc. Pre-excavation permafrost detection within Altai ancient mounds by geophysical methods is one of the most important factors in developing an efficient strategy for planned archeological studies.

In turn, the natural conditions favoring the formation of permafrost lenses in the burial chambers of the high-mountain Pazyryk mounds yield criteria for differentiating ice-containing burials by resistivity.

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Permafrost-containing Pazyryk mounds in Gorny Altai

Burials of the Early Iron Age, or the so-called Scythian epoch, in Gorny Altai have been studied for more than a century. More than 1000 mounds of the 9th–2nd centuries have been studied by archeologists, especially in the 1970s–1990s. The enormous body of diverse data made it possible to reconstruct many aspects of the material and intellectual culture of early nomads. Burials with permafrost lenses, undoubtedly, play a special role among Pazyryk artifacts.

Previous studies. Studies of mounds were begun at the Institute of Archeology and Ethnography by V.D. Kubarev in the 1970s. Among small mounds for common people, complexes with permafrost were also found (Kubarev, 1987, 1991). At that time it became clear that permafrost in log constructions can occur not only in large mounds with much masonry and deep graves.

The large-scale archeological studies on the Ukok Plateau (southern Altai) conducted by N.V. Polos’mak and V.I. Molodin in the 1990s opened a new stage in studying the Pazyryk frozen mounds. The excavations were accompanied by prospecting work with the mapping of all the objects found. The Pazyryk complexes (6th–2nd centuries B.C.) were the most representative by the number of artifacts and by materials. The burials yielded unique complexes with perfectly preserved textile, wooden, and leather items. In two cases human mummies were also found. Such natural conservation of organic matter became possible after the formation of non-melting ice under the masonry in the log construction of the burial chamber. The archeological data served as the basis for extensive multidisciplinary research (Derevyanko, 2000; Molodin et al., 2004; Polos’mak, 2001).

Let us focus on the group of mounds whose log constructions are very likely to contain ice. These are located at quite a high altitude, where permafrost is present. Such localities are the Ukok high plateau (southern Altai) and the river valleys in northwestern Mongolian Altay, including the Olen Kurin Gol River valley. On the Ukok Plateau, the mounds are located on the surface formed by moraines and temporary mountain streams. In Mongolian Altay, the mounds are located at second river bottoms.

Despite their variability in parameters and constituents, the nomadic burials were predominantly mounds with stone piles from the first meters to 20 m high. Log constructions, which could have a wooden floor and ceiling, were built in the graves under the stone piles. Less often, the graves contained stone boxes and frames as well as other constructions (masonry, wooden box etc.). The stone mound of a burial in the Olen Kurin Gol Valley (Mongolian Altay) is shown in Fig. 1. Afterward, its structure was studied by the resistivity method.

The archeological studies of the Ukok Plateau showed that permafrost is not a permanent factor under almost similar conditions in the same area (elevation, mound structure, mound exposure, and others). Therefore, pre-excavation geological prediction of permafrost became an important issue.

Analysis of the position and structure of the burials. Detailed studies of the burials of the nomads who had lived in the Altai Mts. in the 6th–2nd centuries B.C. revealed their characteristic features (Tishkin and Dashkovskii, 2003). Most of them consist of a stone mound (sometimes, rimmed by masonry) and a grave with a log construction at the bottom. The construction could have a wooden floor and ceiling. Such burials, so-called classical ones, are known throughout Gorny Altai but concentrated in central and southeastern Altai. The main Pazyryk burials in Gorny Altai are mapped in (Polos’mak, 2001).

Fig. 1. The Olen Kurin Gol River valley (northwestern Mongolian Altay). Electrical tomography equipment with an survey system located along the mound perimeter.
**Geoelectrical models for the mound and its surroundings.** Geoelectrical models for the mound and its surroundings are necessary for the theoretical analysis of the electric and EM fields excited by geophysical studies. The geologic environment around the mounds can consist locally of horizontal beds, like on the Ukok Plateau. On the other hand, the deposits near the mounds in relatively narrow river valleys squeezed between steep stony ridges, across the valley strike, are banded owing to water flowing down from the surrounding mountains. Also, their structure might be chaotically clastic, as is typical of moraine deposits.

In some mound localities, there might be a fertile soil layer several centimeters thick. Therefore, the upper part of the section sometimes has quite a high conductivity (resistivity less than 50 $\Omega \cdot$ m). In other places, there is a clay component, though the deposits consist of pebble gravel and boulders. Clay ensures moisture accumulation and the considerable conductivity of these deposits. Sometimes, the deposits consist only of pebble gravel and boulders almost without cement, and such places are barren for lack of moisture. Their resistivity is more than 1 k$\Omega$-m. In most of the areas, permafrost or seasonally frozen ground is present.

Considering the above, the following geoelectrical models were chosen for the mound surroundings: horizontally layered and tilted layered. The former corresponds to flat horizontal areas. Also, a sectionally layered model can be used for river valleys, which are dissected by the streams flowing down from the mountains. A block model consisting of a finite number of rectangular cuboids with a specified resistivity can be used for modeling and interpretation in the most difficult cases.

The stone mound is modeled as a horizontal disc of specified thickness and diameter located on the day surface. The grave and log construction can be described roughly as rectangular cuboids of specified size located at a certain depth under the stone mound. A mound model with a horizontally layered host medium is shown in Fig. 2, a.

**Methods**

The stone mound, located over the grave, rendered electrode grounding on the mound surface impossible. Therefore, a special electrode configuration was proposed (Figs. 1, 2, b). Transmitting electrodes (A, B) were placed in pairs at diametrically opposite sites, on different sides of the stone mound. The diameter was chosen so that it was slightly larger than that of the mound. Measuring electrodes were placed at equal intervals at several sites on parallel segments tangent to the mound. In this unit, the mutually orthogonal horizontal components of the electric field ($E_x$, $E_y$) were measured (more precisely, the corresponding potential differences). Measurements were taken for each pair of transmitting electrodes. For conversion to the electric field, they were normalized to the measuring equipment and then brought to single current. Thus, $m \cdot 2n$ measurements were taken for two electric-field components ($m$, number of transmitting-electrode pairs; $n$, number of receiving electrode pairs; the coefficient 2 takes into account the fact that the measurements were taken on two opposite sides of the mound). However, it is difficult to use data obtained in this way for the model, because the host medium structure is unknown. This problem was solved with the help of a reference site with an unaltered host medium structure. Note that one of its sides coincided with the line along which the measuring electrodes were placed. Thus, a reference set was obtained, which consisted of $m \cdot 2n$ measurements over the host medium. To obtain mound-related signals, the array of measurements over the reference site was subtracted from that of measurements over the mound. The result was presented as distribution maps of absolute and relative signal differences in mV/m and percent, correspondingly. Note that, when they were compiled, the values were correlated vertically not to the measuring couple but to the transmitting one. Let us call these signal distributions absolute (relative) displaced anomalies of the electric field.

Along with the resistivity method, we used frequency EM sounding (FES) with induction excitement in the EMS hardware–software system (EM scanner) (Balkov and Manshtein, 2001). This method, used repeatedly in archeological-geophysical studies (Balkov et al., 2006; Epov et al., 2000; Molodin et al., 2001), makes it possible to do a geophysical survey over the mound. However, high resistivity, typical of most media, and target objects (graves, log constructions), which also have a high resistivity, limit the application of this method, because the signals measured have too low values.
Therefore, georadar sounding (GROT-12 georadar), especially efficient in high-resistivity media, was introduced in 2007.

The use of various geoelectrical methods permits reliable detection of ice lenses (insulator powerful enough) in the mound. However, the likelihood of finding artifact-unrelated ice lenses is quite high. Geoelectrical studies do not permit the classification of ice lenses on the basis of this criterion. To solve this problem, it was suggested, for the first time in world practice, that gas chromatographs be used. There are two factors justifying their use: the absence of forest vegetation in the locality of high-mountain mounds and the presence of characteristic compounds in larch wood.

To do this, we used a highly sensitive EKhO-FID gas chromatograph, a KT-6 magnetic susceptibility meter, and an MKS AT-6101D gamma-ray spectrometer. The chromatograph detects aromatic hydrocarbons with exceptional sensitivity (\(10^{-12} \text{ g/cm}^3\)). The gamma-ray spectrometer measured the gamma-ray background with a radiation spectrum from three main isotopes: \(^{40}\text{K}, {^{226}\text{Ra}},\) and \(^{232}\text{Th}\).

Larch wood from the log construction has a unique smell, which can be recorded on a chromatogram. As stated above, trees, including larches, do not grow on the Ukok plateau. Before field studies, we analyzed the smell of larch samples (untreated with chemicals) from the log constructions of Pazyryk mounds on the Ukok plateau. The localization of an organic-matter accumulation in a small volume gives rise to its dispersion halo. This changes the redox conditions in the environment, thus forming a characteristic geochemical barrier to radioactive isotopes. It is natural that there will be a corresponding anomaly over mounds rich in organic matter. Therefore, radiation-background and magnetic-susceptibility measurements were included in the studies along with chromatography (Epov et al., 2008).

Mathematical simulation

To study the possibilities and peculiarities of the resistivity method in the modification proposed, we conducted a mathematical simulation of the electrostatic field. The geoelectrical model for the mound was three-dimensional; therefore, a forward problem of the same dimensions was solved (Kovbasov, 2006).

Mathematical simulation of anomalous fields in the presence of a high-resistivity insulating lens. Simulation was conducted for a four-layered model for the host medium with a resistivity of 100, 200, 300, and 1100 \(\Omega\cdot\text{m}\) (from the top down). The most conducting upper layers were \(-1\) m thick. This model was based on geophysical studies of one of the Ukok mounds in 2003 (Epov et al., 2003). An insulator imitating an ice lens (\(2 \times 1 \times 1\) m) was located in the mound center, at a depth of 1 m (upper limit) from the day surface. The results of the mathematical simulation are shown in Fig. 3. Here, one can see distribution maps of the absolute values of anomalous fields \(E_x\) and \(E_y\), brought to single current for different positions of transmitting electrodes. The anomaly is located over the inhomogeneity epicenter, and the signal has a dipole character. Note that the largest axis of the anomaly is orthogonal to line AB. The maximum \(E_x\) values are concentrated within the mound and cannot be measured. Outside this area, the anomalous signals measured are concentrated near the current-flow line. Note that the displacement of line AB from the central inhomogeneity axis does not change the qualitative distribution pattern of the anomalous signal but only reduces its value.

The distribution of anomalous signal \(E_x\) (Fig. 3, d–f) has not a dipole but a quadrupole character. Consequently, it shows high geometric attenuation, and its maximum values are concentrated in the stone mound.

The largest \(E_x\) anomalies are observed if the transmitting electrodes are placed asymmetrically with respect to the ice lens (Fig. 3, g–i). Thus, component \(E_x\) in the vicinity of the current-flow line is the most convenient one for measurement.

Lens detection and location (from synthetical data). The distribution of absolute field anomalies \(E_x\) was studied for different positions of transmitting electrodes. The anomalous signal was found to increase as they approach the insulator from any direction. The electrode configuration used in the 2003 work on the Ukok plateau presupposed several positions of the transmitting electrodes, with one fixed measurement line.

The distribution of the absolute displaced field anomaly \(E_x\) is shown in Fig. 4, a. The configuration was like that in the 2005 studies of the Olon Kurin Gol-6 mound. The anomaly center coincides with the ice lens epicenter. The shape and size of the object are difficult to estimate from these data. However, there is a new possibility of locating the insulator epicenter on the basis of the displaced anomalies constructed from the measurements along the object perimeter.

Mathematical simulation of anomalous fields for two or more asymmetrical generator electrodes. Signals were modeled for the case with the transmitting electrodes located asymmetrically with respect to the insulator. This configuration is the closest to practice, because the real electrode configuration is very likely to be asymmetrical (Fig. 3, g, h). The anomalous \(E_x\) values increase considerably, and this must improve the quality of experimental data in the long run. Note that the largest signal anomalies remain over the insulator even if the transmitting electrodes are moved. This is further evidence that the anomaly epicenter remains over its source. Signals were modeled for different multielectrode configurations. The distribution of \(E_x\) values with six pairs of transmitting electrodes is shown in Fig. 3, i. With this configuration, a considerable increase is observed in the anomalous signal, which ensures accurate measurements under unfavorable conditions (large stone mound diameter, high resistivity, etc.). However, a configuration with many transmitting electrodes does not permit the measurement of \(E_x\) values over the mound to pinpoint the insulator center. Therefore, it can be used only to detect the insulator at low signal values.

Comparison of the resistivity experimental data and mathematical simulation. In summer 2003, members of the Institute of Archeology and Ethnography and the Institute of Geophysics conducted joint field studies on the Ukok plateau.
Techniques for identifying frozen burials were tested, and promising geophysical techniques were selected (Epov et al., 2003). Along with direct-current sounding, field studies were conducted with an EMS system. In summer 2005 and 2006, similar work was done in the Mongolian Altay (Epov et al., 2005, 2006), on the mounds revealed by an archeological survey in the Olon Kurin Gol Valley (2004).

The first modeling objective was to verify the experimental data. The geoelectrical model for the medium surrounding the mound had to be identified. It was based on VES along the profiles surrounding the mound. Quantitatively, the 3D modeling data correspond to the experimental data (Fig. 5, a, b). However, the latter ($E_y$) showed a long narrow inhomogeneity along the $y$-axis. This was attributed to the near-surface path along which cobblestones for the mound had been, most probably, dragged. The model included a linear hollow in the topography. We managed to fit its parameters (oval section 0.5 m wide and 0.25 m deep, filled with ground with a resistivity of 40 $\Omega\cdot$m; the host medium has a resistivity of 50 $\Omega\cdot$m). The synthetical data for such a model correlate with the measurements, suggesting that the model is correct.

The areal distribution of $E_y$ is asymmetrical with respect to line $x = -1$ (Fig. 5, c). According to calculations, the asymmetry is due to a slight inclination of the boundaries between layers with different resistivities. The distribution of $E_y$ for the case when the boundaries are inclined at 10° is shown in Fig. 5, d. The introduction of a zenith angle helped to correlate the synthetical and experimental data. Thus, the host medium structure at this site was determined.

At one of the sites (2005, Ulan-Daba-1 mound), the distribution of $E_x$ over the surface behind an unexcavated part of the medium differed considerably from that over the horizontally layered medium. Morphological analysis of the topography in the study area revealed meltwater-related inhomogeneities. Thus, a 2D model was accepted for the medium from the reference area toward the mound. In the case of a reversal, the corresponding inhomogeneities were placed between layers 1 and 2. As a result, we selected the parameters of the model for the medium surrounding the insulator in the mound. The results of the reversal are given in Fig. 5, e, f.
Fig. 4. Distribution of the absolute field anomalies of $E_x$: $a$, Based on synthetical signals for the Olon Kurin Gol-6 mound; $b$, based on the experimental data on the Ulan-Daba-1 mound.

Fig. 5. Verkh-Kal’dzhin-2, mound 4 ($a$–$d$, $g$, $h$); Ulan-Daba-1 ($e$, $f$). Normal fields of the experimental components of the electric field $E_x$ ($a$, $e$), $E_y$ ($c$) and the corresponding synthetical data ($b$, $d$, $f$). Displaced anomalous experimental and synthetical distributions ($g$, $h$) of $E_y$. 
Detection of the ice lens on the basis of the experimental data and its size estimate. The second problem was to determine the position, size, and orientation of the burial chamber. The criterion for its solution was a coincidence between synthetical and measured signals within the measurement accuracy. We were unable to fit all the model parameters because of the high resource efficiency of theforward problem. A qualitative confirmation was obtained for the absolute and relative displaced anomalies—$E_x$ (Fig. 4) and $E_y$ (Fig. 5, g, h), respectively.

Field studies

Comprehensive field studies by the above techniques were conducted on the Ukok Plateau in 2003 and 2007 and in the adjacent territory of Mongolian Altay in 2005–2006.

Studies on the Ukok Plateau, 2003. For the first geophysical prospecting, we deliberately chose Pazyryk mounds at the burial sites already subjected to archeological studies.

The Verkh-Kal’dzhin-2 burial site on the northern Ukok Plateau, on the right bank of the Kal’dzhin River, was discovered and partly studied by V.I. Molodin (1994–1995). It consists of five mounds aligned from north to south. The stone piles consist of jagged schist and coarse boulders, and the floor is very turfy. Mounds 1–3 was unearthed. In all of them, permafrost lenses were found in the burial chambers. The remaining unexcavated mounds 4 and 5 were subjected to geophysical studies.

The Bertek-1 burial site is located in the Bertek Valley, on the left bank of the Ak-Alakha River. It comprises five mounds consisting of rounded boulders and aligned from northeast to southwest. The mound floor is turfy. Mound 1 was studied by V.I. Molodin, and no permafrost was found in the burial chamber. Mound 4 was chosen for geophysical studies. At that time, archeological studies of burial sites of different ages in the Bertek Valley had shown that none of them contained permafrost.

Thus, the first geophysical studies aimed at practicing the technique for permafrost detection were planned at fundamentally different sites. In the first case, the presence of permafrost was very likely, whereas, in the second one, the absence of ice or frozen ground was almost obvious. Such structurally and physically disparate objects were chosen for an accurate comparison of geophysical models (Epov et al., 2003).

We studied mounds 4 and 5 from the Verkh-Kal’dzhin-2 burial site by the resistivity method using the above technique. In the central part of the map (Fig. 5, g), there is an appreciable anomaly (360 rel.u.), associated with a nonconducting object in the mound center. The resistivity method on mound 5 and the Bertek-1 mounds did not reveal any anomalies similar to that detected on mound 4 in size or shape.

A modification of the resistivity method revealed a high-resistivity area in the host medium which was associated with ice in the burial. According to measurements, of three objects studied, only mound 4 of the Verkh-Kal’dzhin-2 burial site showed a high-resistivity anomaly, confined to the mound center. The dimensions of this anomaly were close to the expected size of a frozen burial chamber (Epov et al., 2003). Archeological studies are required at these sites to confirm the results and refine the geophysical techniques.

On the basis of frequency sounding data, an attempt at determining the lens parameters was made. Owing to the joint interpretation of signals and the resistivity data, frequency sounding signals were correlated by depth. A map of apparent resistivity over the mound, with a high-resistivity object, is shown in Fig. 6, a. As a result, an isosurface with a resistivity of more than 500 $\Omega$·m inside was constructed (Fig. 6, b). Its size can help to estimate that of the permafrost lens.

Studies in Mongolian Altay, 2005–2006. The subsequent geophysical studies, based on the experience of work on the Ukok Plateau, were conducted in northwestern Mongolia in 2005–2006. They drew on the 2004 archeological survey done in the high-mountain zone of the Bayan-Ölgii aimag, one of the least studied regions of Mongolia in this respect (Molodin et al., 2004). The subjects of study were chosen on the basis of morphological analysis, which permitted their preliminary assignment to the Pazyryk culture, always with regard to elevation. Comprehensive geophysical studies were conducted at some objects to detect permafrost in the burial chambers.

Six burial sites were studied in the Ulan-Daba, Olon Kurin Gol, and Tsagaan Salaa River valleys in 2005: Olon Kurin Gol-6 (mound 2), -7 (mound 1), and -10 (mound 1); Tsagaan Salaa-1 (mound 1) and -2 (mound 1); and Ulan-Daba-1 (mound 1). As a result, the most promising mounds were identified at an elevation of 2500–2600 m a.s.l. (Epov et al., 2005).

Anomalous electric fields were measured on an areal grid. Analysis revealed closed anomalous zones represented by more than one row or column of anomalous values. Both absolute and relative displaced anomalous electric fields were studied, and direct mathematical simulation was used to interpret the most pronounced ones. We ignored long, banded anomalies, associated with the high grounding resistivity of some electrodes, and those near the transmitting electrodes.

Evidence suggesting the presence of nonconducting ice lenses was obtained in studies of Ulan-Daba-1 and Olon Kurin Gol-10 and Olon Kurin Gol-6. The anomaly on mound 1 of Ulan-Daba-1 (Fig. 7, a) was the most pronounced one. Judging by its areal distribution, the epicenter of the insulator, which corresponds to a permafrost lens, is located at a site with the coordinates (6.5). The anomaly on mound 2 of Olon Kurin Gol-6 was less pronounced (Fig. 7, c). An "inverse" anomaly with a low absolute value and high background values was detected on mound 1 of Olon Kurin Gol-10 (Fig. 7, e). That one also permitted the assignment of this mound to promising ones. The anomaly was "inverse," because a regular shift took place in the field values in the reference and study areas because of a resistivity difference in the host medium.

The following mounds were studied in 2006: Olon Kurin Gol-9 (mounds 3, 4), Olon Kurin Gol-3 (mound 1), Olon Kurin Gol-12 (mounds 1, 4), Olon Kurin Gol Mouth 2 (mound 1), and Ulan-Daba-1 (mound 1) (Epov et al., 2006).
Areal measurements by the resistivity method were conducted on five of the mounds studied.

Comprehensive electrical prospecting with direct and alternating current revealed considerable anomalies of high apparent resistivity on two mounds: Olon Kurin Gol-3 (mound 1) and Olon Kurin Gol-9 (mound 4). Also, the resistivity method revealed an anomaly with a high apparent resistivity in Olon Kurin Gol Mouth 2. However, its shape did not provide evidence enough for the presence of an ice lens within the mound.

The stone pile of mound 4 (Olon Kurin Gol-9) was considerably demolished by the locals. This made it possible to conduct electrical profiling with a Wenner electrode system (spacing 0.7 m) directly through the mound. The data of FES and electrical profiling along the mound central axis agree with the resistivity data and suggest that a high-resistivity anomaly with a low-resistivity framing is present within this mound (Epov et al., 2006).

Apparent-resistivity maps were compiled for mound 1 of Olon Kurin Gol-3. According to the VES data, the loose deposits at the reference site were ~1 m thick. The resistivity under the mound is higher than that of the host medium. This might be due to massive ground freezing at depths of more than 1 m (Epov et al., 2006).

Studies on the Ukok Plateau, 2007. Geophysical studies of the following burial sites were conducted: Bertek-1 and Bertek-10; Verkh-Kal’dzhin-2 and Verkh-Kal’dzhin-3; Verkh-Kal’dzhin-6; and Verkh-Kal’dzhin-13—the new burial site discovered by V.I. Molodin in 2007.

The preliminary results showed that the following mounds might contain ice in their burial chambers: mound 4 of Verkh-Kal’dzhin-2, the western part of mound 3, and the center of mound 4 of Verkh-Kal’dzhin-3.

Verkh-Kal’dzhin-2 (mound 4). According to the VES data, the geoelectric section outside the mound is a 1.2-m-thick layer with a resistivity of 34.3 $\Omega\cdot m$, which overlies half-space with a resistivity of ~5000 $\Omega\cdot m$. Multielectrode array measurements revealed a resistivity increase in the middle of the area (mound center), which might be due both to ice and masonry. The same conclusion had been made in 2003. Comparison of within- and outside-mound radargrams showed large oscillation periods outside the mound, which corresponded to low-contrast boundaries. Under the masonry, the oscillations contracted with time, reflecting clearer boundaries with different resistivities and permittivities. A series of clear long oscillations was traced in the northwestern part of the mound along two profiles. Since this area is poorly defined in electrical measurements, the absence of an object with a highly contrasting resistivity can be presumed here. A less pronounced anomaly of the same type is localized in the southeastern part of the mound (Epov et al., 2007).

Verkh-Kal’dzhin-3 (mounds 3, 4). According to the VES data, the outside-mound geoelectric section consists of the 0.6-m-thick upper layer with a resistivity of 56 $\Omega\cdot m$, the 2-m-thick middle one with a resistivity of 85 $\Omega\cdot m$, and the underlying half-space with a resistivity of more than 5000 $\Omega\cdot m$. The distribution maps of the relative anomalies of the multielectrode array over mounds 3 and 4 (Epov et al., 2007) show high-resistivity areas. Measurement with the EMS system along the profile passing through the center of mound 3 also shows a high-resistivity area. Outside-mound radargrams feature two reflecting boundaries, which agree with the
VES data. The profile between the mounds features a region with lowered contrast (decreasing arrival time and radargram oscillation width) (Epov et al., 2007).

Here, the gas component was analyzed for the first time in the stone mounds. Larch wood in the log construction was presumed to emit a characteristic spectrum of substances, which could be recorded on a chromatogram. Again, we emphasize that the Ukok Plateau is treeless and, therefore, does not have a natural background. The smell of larch samples from the Pazyryk mounds on the Ukok Plateau was subjected to preliminary studies (Epov et al., 2007). To do this, samples untreated with chemicals were selected and packed in plastic film. Spectrum analysis of the latter showed that it was inert at 20 °C but began to emit hydrocarbons (mainly benzene and toluene) actively if heated by 15 °C. Thus, only cumene, absent from the film, remained of the rich hydrocarbon spectrum as a reliable marker of larch wood.

Ground samples for chromatography and magnetic susceptibility analysis were taken from under a thin sod layer or large stones if sod was absent. The ground was placed in a special container and exposed until vapor–gas equilibrium was reached. Afterward, this air was chromatographed. At the sampling sites, the magnetic susceptibility of the general gamma-ray background was measured and then a spectrum was recorded for three isotopes (\(^{40}\text{K}\), \(^{232}\text{Th}\), \(^{226}\text{Ra}\)). Several tens of measurements were taken for the gamma-ray background over the mound area.

The first samples from mounds 3 and 4 of Bertek-10 yielded similar results. They were taken along two profiles at intervals of 2 m, starting from a distance of 10 m from the mound boundary. From then on, it was enough to take samples at three sites: at a distance of 10 m, at the mound boundary, and in its center. In the latter, the magnetic susceptibility of soil turned out to be half that at the periphery. The gamma-ray background in the center (12.5 µR/h) had larger values than outside it (9–10 µR/h). Note that the contents of \(^{40}\text{K}\) and \(^{232}\text{Th}\) increased on average, whereas that of \(^{226}\text{Ra}\) decreased.

The chromatograms of the samples at the periphery almost did not change as one approached the mound. Only the samples taken at the mound boundary and in its center yielded several new substances. Two of them were interpreted as m-xylene and cumene, which had been detected previously as a reference. Thus, it can be presumed that these mounds contain larch wood.

The subsequent studies confirmed the original observations. In almost all the measurements, the ground samples taken from the mound center had a lower magnetic susceptibility than those from the periphery. This might be due to the intense outwash of heavy iron minerals in the mound cavity. Radioactivity increased in reversed order. The gamma-ray background in the mound center (areas 2.5–3 m in diameter) sometimes had values more than twice larger than those at the periphery. The maximum values reached 19 µR/h (Verkh-Kal’dzhin-2, mound 4), the background being 7–9 µR/h. The
radioactivity of all the types of stones in the mounds and bedrock outcrops was no more than 12 µR/h. Consequently, the radiation anomalies detected over the mounds are most probably due to the filling of the burials.

Chromatograms of the mound center, as a rule, contained very small amounts of m-xylene (up to traces), whereas cumene, if any, was present exclusively in trace amounts. Note that even its traces were absent from the samples taken outside the mound boundary. Such contents of the substances key to these studies can be explained by the fact that low temperatures under the stone mound hampered the formation of a hydrocarbon dispersion halo.

Archeological testing of the geophysical results

For archeological studies, one object was chosen from each of three mound complexes in which the geophysical results indicated the presence of permafrost: mound 1 of Ulan-Daba-1, mound 2 of Olon Kurin Gol-6, and mound 1 of Olon Kurin Gol-10. Also, mound 2 of Olon Kurin Gol-7 was unearthed, in which no geophysical survey was done.

The excavations of 2006 confirmed the presence of permafrost in all three objects identified by geophysical methods. However, its nature and scale were different. The anomaly on mound 1 of Ulan-Daba-1 (Fig. 7, a) was the most pronounced quantitatively and qualitatively. Here, an exploration shaft $4 \times 3.5$ m in size was driven to detect the anomaly source (Fig. 7, b). Indeed, a permafrost lens was found at a depth of 2–2.5 m in the undisturbed layers underlying the mound. However, it was of natural origin: a pocket consisting of boulders and stone debris was formed on a stone base by morainal or mud flows; it accumulated water, which then froze.

In mound 2 of Olon Kurin Gol-6, frozen ground was also found in the grave and the log construction. Besides, a narrow lens of pure ice was localized in the log construction, along its northern wall. Its position correlates with the displacement of the nonconducting anomaly to the northern part of the hole, detected by geophysical methods (Fig. 7, c, d).

Finally, permafrost was present on the largest scale and in various forms (Fig. 7, e, f) in the mound of Olon Kurin Gol-10, in which an intact tomb of a Scythian warrior was found. The content of the grave around the log construction was frozen. Inside the log construction, ice was present in its northern part. Also, an ice hill formed in almost the entire log construction on the ground filling under the funeral bed and pressed the boards upward. It was permafrost that ensured the exceptional integrity of this grave.

Thus, the geophysical techniques used for detecting ice in burial complexes passed archeological tests successfully (Epov et al., 2006).

Conclusions

More than 20 Pazyryk mounds were studied by various geophysical and geochemical methods. It was shown that the resistivity and frequency sounding methods are highly efficient in detecting large high-resistivity anomalies—ice lenses—in mounds.

Archeological excavations in Mongolia fully confirmed comprehensive geophysical predictions of ice in burial mounds. On the other hand, a geophysically predicted natural ice lens was detected in the Ulan-Daba mound. These circumstances formulated the problem of identifying not only ice but also log constructions under stone mounds. Geophysical methods revealed the features of larch constructions typical of high-mountain Pazyryk mounds and ways to their identification. However, the results call for further archeological studies to validate the technique chosen and make the necessary corrections.

A cycle of experimental, theoretical, and verification work confirmed the efficiency of the comprehensive geophysical-geochemical technique for detecting permafrost lenses and larch constructions in the burial chambers of Pazyryk mounds. Note that such geophysical studies on the Ukok Plateau and in Mongolia were conducted for the first time in the world practice.

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