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I. Yu. RASSKAZOV[1], *Director, Doctor of Engineering Sciences, rasskazov@igd.khv.ru*
N. G. SHKABARNYA[1], *Head of Laboratory, Doctor of Engineering Sciences*
V. S. LITVINTSEV[1], *Chief Researcher, Doctor of Engineering Sciences*
G. N. SHKABARNYA[2], *Senior Researcher, Candidate of Engineering Sciences*

[1]*Institute of Mining, Far East Branch, Russian Academy of Sciences, Khabarovsk, Russia*
[2]*Far Eastern Federal University, Vladivostok, Russia*

GEOPHYSICAL SURVEY OF DEEP ALLUVIAL GOLD IN TERMS OF BOLOTISTY DEPOSIT

In spotlight of the discussion are the geological structure details of the Bolotisty Stream placer field located in the south-east of the Khabarovsk Territory, within the Sooli-Tormasin ore zone. The Lower Bolotisty block of the deposit is studied using the electrical tomography method. The section of the studied block is composed of the bottom tuffogenous silty sandstone with rock fragments surrounding a bowl overlaid by the Cenozoic clays and tuffogenous conglomerate and topped by the Quaternary alluvium. After the interpretation of the electrical tomography data from 6 survey profiles, the geoelectric and geological sections show a structure composed of four–five layers. The principal finding is the layer represented by low-Ohm clays and clay-cemented rock fragments surrounding the Cenozoic erosion tectonic bowl and underlaid by tuffogenous agglomerated breccias underlayer. The thickness of the clay and tuffogenous breccias layers reaches 30 m. Judged by the low electrical resistivity as per the electrical tomography survey data, the clay layer may contain sulfide minerals, which makes it interesting from the viewpoint of alluvial gold occurrence at the depth down to 50 m.

Key words: *gold placer, deep-level deposit, electrical tomography, electrical exploration*
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Introduction

One of the promising gold ore areas in the Russian Far East is Sooli-Tormasin zone [1, 2] holding primary deposits and placers. The best explored primary deposit is Bolotisty Stream [3–5] containing a lot of alluvial gold. This deposit is located in the south-east of the Khabarovsk Territory, in the interstream area of the Khor and Anyui Rivers. The valley of the Bolotisty Stream has a trough-and-saucer shape profile. The bottom width is 500–750 m, the surface is heavily boggy, and the longitudinal slope is not higher than 0.13 per mil . The deposit has a simple structure. Morphologically, the deposit is a single belt with the persistent width and thickness and comparatively uniform distribution of gold content. The body of the workable reserves is more than 14 km long with the width increasing top-downward from 160–200 m to 400 m and more in the middle. The belt narrows with the depth and completely thins out at the junction of the Bolotisty Stream and the Yaki River. The thickness of the gold-bearing zone varies from 0.6–0.7 m (sometimes 0.4 m) to 2.5–2.7 m (sometimes 3.5–4.0 m). The top layer of the alluvial gold deposit at the Bolotisty Stream is comprehensively explored, and the researchers from the Institute of Mining and the Far Eastern Federal University have detected some signs of the deeper gold-bearing beds.

In the late 1990s, V. M. Stepanchenko, A. I. Zambrzhitsky and V. A. Buryak examined morphology and fineness of alluvial gold at Bolotisty Stream deposit and paid attention to multi-stage and different-depth process of the placer formation [4].

Structurally and mineralogically, L. V. Eirish and A. P. Sorokin assumed Bolotisty Stream area as a medium-eroded alluvial gold deposit [6].

The recent mining practice has provided new information that revises the current view of Bolotisty Stream deposit geology. Commercial reserves of the placer have been mined out in the upper area of the Bolotisty Stream, and mining operations are now downstream. In the central 2 km-long east–west section of the Stream area, no workable reserves are revealed at the given depths. Starting from prospecting line 60 along the meridionally oriented downstream valley, the payable body appears again but it is less productive as against the upper Bolotisty Stream block. The Lower Bolotisty site features an amagmatic, heavily dislocated section of sedimentary rocks suffered from deep conversion during encrustation processes. As a result, the site has acquired the structure of “alluvial” deeply eroded pockets separated from the primary sources of gold [6]. The source of formation of placer gold is the partly washed-out top-intrusion portion of a gold ore fold localized in the Lower Cretaceous terrigenous rocks [4]. These are the alluvial placers of the gold-bearing material within the old fold and elluvial placers down the Bolotisty Stream [4, 7].

Within the late 20 years, all subsurface gold has been extracted. Considering the research information on gold content of the Bolotisty Stream field [2, 4, 8], it is advisable to carry out geological exploration of deeper levels. The investigation has been carried out by the scientists and specialists from the Institute of Mining, Far East Branch of RAS, and from the Far Eastern Federal University (participation of Candidate of Engineering Sciences R. S. Seryi and Engineer V. A. Chelpanov, Institute of Mining FEB RAS, is highly appreciated). The research findings will be relevant for the other promising areas in the Russian Far East [3, 7–9].

The mineralization depth in the chosen test ground was assessed using the integrated interpretation of the electrical survey data obtained by the vertical electric sounding (VES) and the magnetic exploration findings with regard to geological and geochemical information. As an outcome, 11 revealed structures mostly conform with the known ore zones and secondary scattering halos of gold, silver and copper. The structures mainly extend north–westward and have thicknesses in the range from 10 to 200 m.

The material constitution of the structures is prevailed by quartz-sericitic and quarts-tourmaline rocks with the increased sulfide mineralization [4, 8]. The worked-out placers are alluvial sand-and-pebble Quaternary deposits, and are in many ways unique, including accessibility and high productivity. At the given stage, in view of the data on the deep structure of the whole area and based on the uniqueness of the top section in the south-east of the Bolotisty Stream, the approach with sparse-net VES and geomagnetics is insufficient for having a detailed description of the local deep structure. The mentioned methods are suitable for determining thickness and physical properties of loose sediments, for mapping successively local bowls in parent rock mass and for detecting sulfide-enriched placer gold, but they fail to show local structural details.

For this reason, for the definite determination of deep structures and the whole section parameters in the especially promising areas, it is advisable to use the advance techniques of the electric sounding, in particular, electrical tomography. The test site was chosen within the Lower Bolotisty valley alluvium under the closing stage gold mining project by Ros-DV company.

The electrical tomography using the multichannel instrumentation and program support interpretation means a new turn in development [5, 10]. As distinct from VES, electric tomography reveals structural details of a section at the increased image definition. This method is also used by foreign specialists, and is approved in some publications reviewing gold prospecting methods and evaluating the electrical tomography efficiency [11–14].

The GPR experience (high-frequency electric survey) in studying faulting at the alluvial deposits in the permafrost zone is known as well [15].

Geological structure of the test area

Bolotisty Stream ore field occurs in the center of Pravo-Sooliy volcano-plutonic morphostructure with the outcropped gabbro-diorite bunch in the middle. The general concentrically zonal structure is distinct from the combination of the radial-axifugal and arc pattern of drainage system within the faulting framework. The Lower Cretaceous age of the terrigenous sedimentary rocks is assumed on the ground of its consistency with the modern regional stratigraphy; however, the younger age of the basement rocks is as like as not. The latter may ensue from very weak lithification of the basement rocks, susceptibility to diagenesis and initial epigenesis only, and from their general very weak dislocation. Moreover, Cretaceous rocks occur relatively persistently within the mentioned ore field, and have nearly monoclonal bedding with a gentle (10–15°) north-westward dip. The common feature of rock mass is a gradual one-way increase in the grain size bottom-up of the section together with the decrease in the organic component.

Pravo-Sooliy volcano-plutonic morphostructure is composed of the Cenozoic formations stratigraphically inconsistent with the breached surface of sedimentary rocks of the basement. The Kuznetsov and Birofeld formations at the bottom are overlaid by basalt and basaltic andesite suits of the Kizin formation.

The Cenozoic-age Kuznetsov formation within Bolotisty Stream ore field is mainly basaltic andesite and, less often, tuff. In the west of the field, sedimentary breccias occur at the bottom of the formation.

A specific place in the geological section of the Cenozoic formations within the ore field belongs to rocks outcropped and mapped along the east boundary of the field, within the Central Fault zone. As a rule, these rocks are pale and beige clays, often with fawn iron impregnation, underlaid by relics of weak decomposed siltstone rock fragments. The section of the clays contains layers with an unasserted material of different nature and size (from pebbles to large lumps).

It is suggested that the formations are the partial redepositions (generally autochthonic) of residuum products formed together with the products of gravity sliding down the slopes of paleovalleys.

In the east of the ore field, within the middle zone of the Central Sikhote-Alin Fault, the Birofeld formation fills the Cenozoic deep (20–30 m) linear erosion cut — a submeridionally oriented erosion tectonic bowl (fault trough). Here, these formations are composed of clay-cemented rock fragments of all types present in the test area (including metasomatic rocks with sulfide and quartz veins). It is likely that these formations are complete redepositions. By analogy with the earlier detected loose rocks at the top of the breached Cretaceous sediments, the redepositions are conventionally assumed the Birofeld formation.

In the most area of the deposit, the above described formations are overlaid by the Miocene age basalt of the Kizin formation. The bottom of the basalt formations is composed of tuff agglomerates replaced by basalt with tuff lenses. The top section of the basalt formation contains basaltic andesite in places. The latter occur at hill-sites of the interstream areas and have thickness up to 200 m. At the upper portion of the Bolotisty Stream, they have thickness of the first meters. In view of the radiologic age of the basalt (12–28 mln years), the increased alkalinity and presence of minerals of cavity fillings, they are assumed the analogs of the Miocene-age Kizin formation revealed in the Eastern Sikhote-Alin volcanic zone though there are the other opinions on their age.

The Quaternary formations at the bottom of the valleys and extended flat high grounds are represented by the alluvial and lucastrine bog clayey deposits as well as by diluvium (solid cover over all positive topographic forms) and by unbroken section of proluvium–diluvium shelf.

The Lower Bolotisty tectonic block examined using electrical tomography occurs in the middle of the Central Sikhote-Alin Fault. The section of the alluvium in the Bolotisty Stream valley test site is top-downward composed of soil and vegetation layer, peat, silt layer and sand-and-pebble stratum the bottom of which (pockets of bedrock formed by conglomerates) is horizontally and vertically delineated as the commercial placer body.

Research findings

The geophysical survey was carried out in the area of the gold placer with the stripped tuff layer. So, the current section top contains sand-and-pebble formations with the lenses of sand-and-clay and pockets of gravel-and-pebble rocks enclosing commercial gold reserves. According to the drill log data (prospecting lines 14–16), the parent rocks under the Quaternary formations are the Upper Miocene layer of tufaceous conglomerates weakly cemented by basal clay (west wing), tufaceous sandstone (center) and clayey shale (east wing). Cretaceous basaltic andesite basement of the erosion tectonic bowl outcrops on the steep westerns slope and partly underlies the Quaternary deposit. The roof of the parent (Miocene) rocks is detected in the sections at the depths from 3 to 5 m. Drilling was stopped as it reached the parent rocks at the maximum hole length of 8 m.

The geophysical survey was carried out using 6 straight-line profiles out of which 5 profiles (PR-1–PR-4 and PR-6) were oriented west–eastward and one profile (PR-5) was arranged south–northward and intersected all five sublatitudinal profiles. Such arrangement of the profiles was chosen with respect to the geomorphology and geology of the Lower Bolotisty block (**Fig. 1**).

The studies were aimed to determine the thickness of sand-and-pebble formations and their lithological structure, the behavior of the top bedrock and the structure of the underlying rock mass down to a depth of 25 m (along the latitudinal profiles) and to a depth of 50 m (along the meridional profile).

After the field data interpretation, the resultant geoelectric sections clearly show four layers along the sublatitudinal profiles and five layers along the meridional profile. Based on the geophysical materials, the geological sections are constructed (**Figs. 2–4**).

The first layer is composed of dens loam, gravel-and-sand, sand-and-clay and detritus loam formations with pyritization in places. The layer is 0.7 to 10 m thick, the smallest thickness values are observed in profile 3, the highest values are shown by profiles 2 and 6, the other profiles give average values. The top of the layer contains pockets of fill ground and lenses of silt-and-clayey rocks. Electrical resistivity of rocks varies from 200 to 280 Ω·m and drops to 70 Ω·m in watered areas.

The second layer is represented by gravel-and-pebble formations with the clayey filler and is the *productive gold-bearing bed*. The thickness the layer changes between 1 and 9 m, with the lowest values typical for PR-1 and the highest

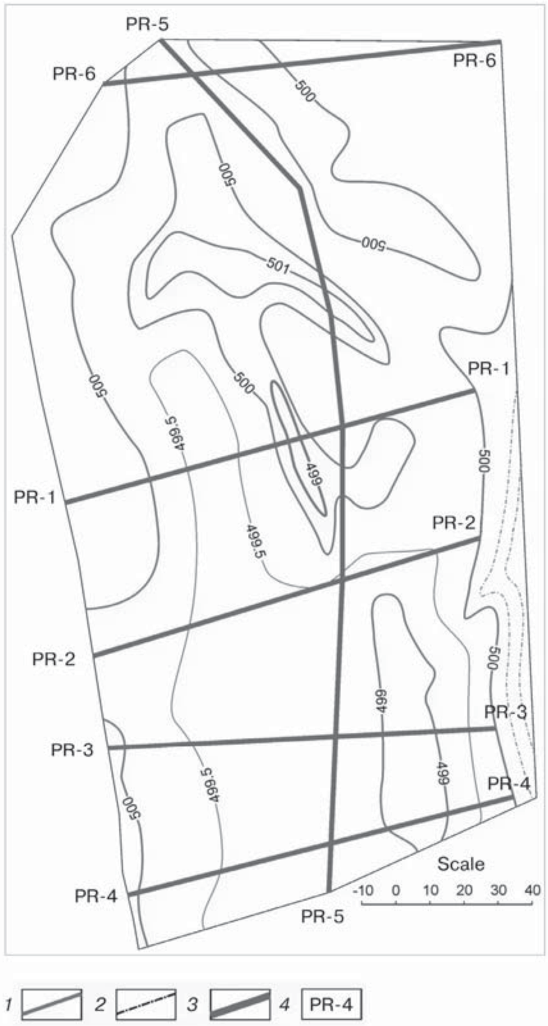

Fig. 1. Arrangement of geophysical profiles in the test area of Lower Bolotisty gold field:
***1* — surface contour lines; *2* — additional contour lines; *3* — geophysical profiles; *4* — profile number**

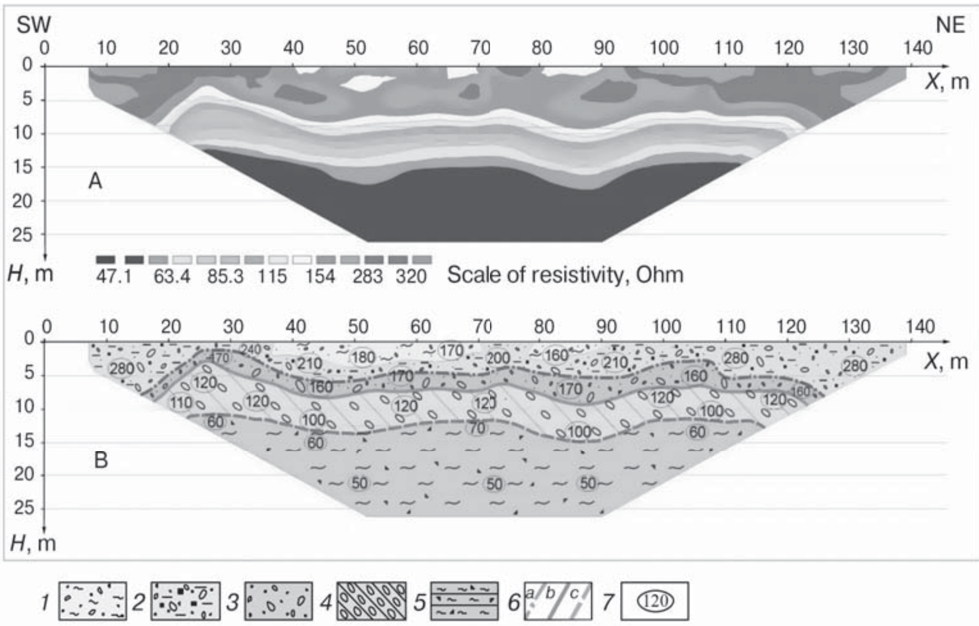

Fig. 2. Geolectrical (A) and geological (B) sections along sublatitudinal profile PR-1:
***1* — Loamy, gravel-and-sand deposits (Q_{IV}); *2* — Clay-and-sand sulfidized formations (Q_{III-IV}); *3* — Gravel-and-pebble deposits with loamy filler (gold-bearing bed Q_{III}); *4* — “Conglomerate Strata “ (N_{1k}), low gold content; *5* — “Clayey Strata” composed of clay-cemented rock fragments and metasomatic rocks ($\tilde{n}_3$ brf); *6* — Boundaries of layers: *a* — upper boundary of gold-bearing gravel-and-pebble deposits, *b* — lower boundary of gravel-and-pebble deposits; *c* — upper boundary of “Clayey Strata”; *7* — Apparent resistivity within the layer (Ω·m)**

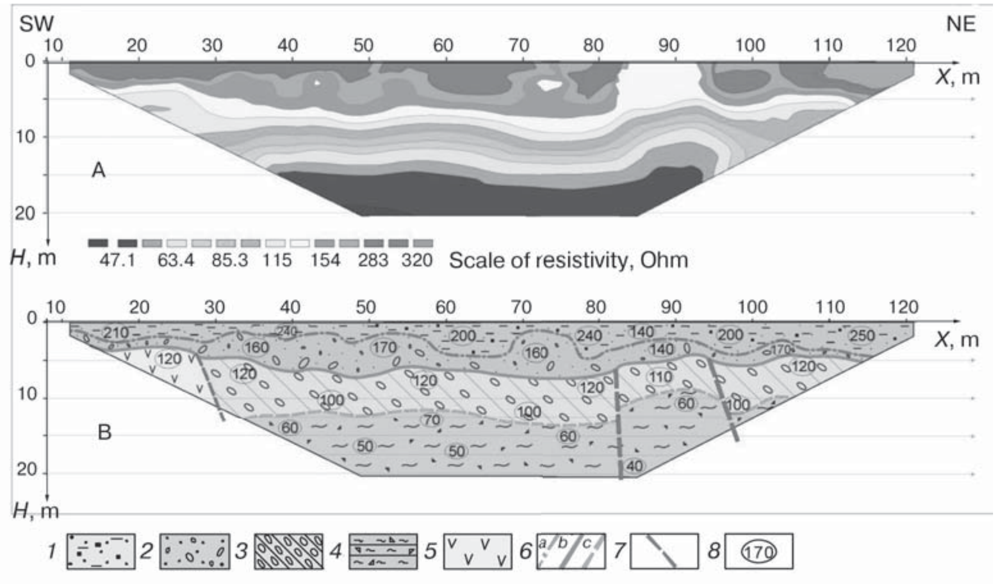

Fig. 3. Geoelectrical (A) and geological (B) sections along sublatitudinal profile PR-4:
1 **— Silty sandstone pyritized in places, silts, pebble lenses, production-generated formations;** ***2*** **— Gravel-and-pebble deposits with loamy filler (gold-bearing bed Q_{III});** ***3*** **— "Conglomerate Strata " (N_{1k}), low gold content;** ***4*** **— "Clayey Strata" composed of clay-cemented rock fragments and metasomatic rocks (ñ$_3$ brf);** ***5*** **— Basaltic andesite;** ***6*** **— Boundaries of layers: a — upper boundary of gold-bearing gravel-and-pebble deposits,** ***b*** **— lower boundary of gravel-and-pebble deposits;** ***c*** **— upper boundary of "Clayey Strata";** ***7*** **— Expected tectonic faulting;** ***8*** **— Apparent resistivity within the layer (Ω·m)**

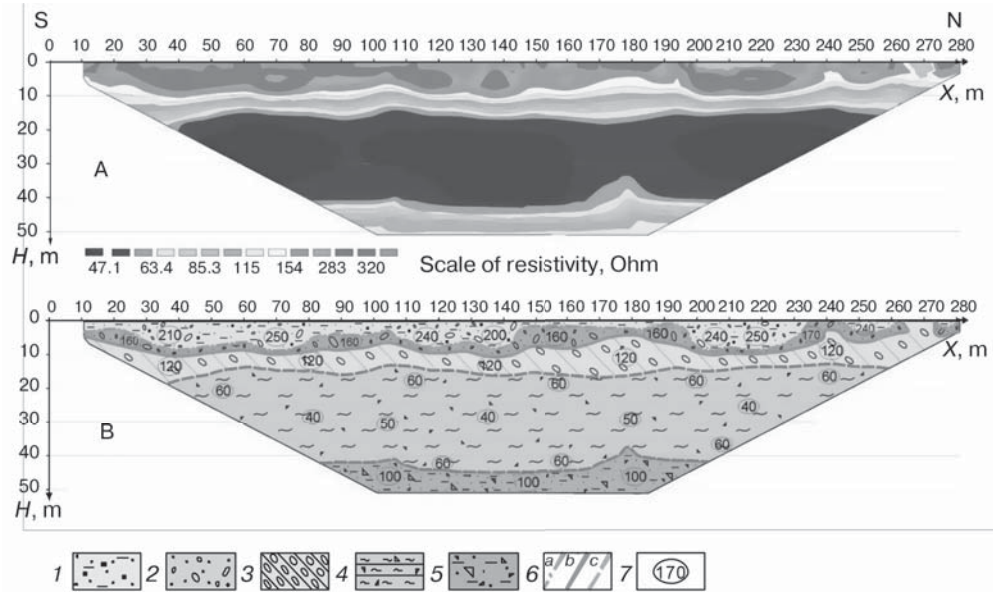

Fig. 4. Geoelectrical (A) and geological (B) sections along meridional profile PR-5:
1 **— Silty sandstone pyritized in places, silts, pebble lenses, production-generated formations;**
2 **— Gravel-and-pebble deposits with loamy filler (gold-bearing bed Q_{III-IV});** ***3*** **— "Conglomerate Strata". Tuff conglomerates with clayey cement (N_{1k});** ***4*** **— "Clayey Strata" composed of clay-cemented rock fragments and metasomatic rocks (ñ$_3$ brf);** ***5*** **— Tuffogenous silty sandstone with rock fragments around the bowl;** ***6*** **— Boundaries of layers:** ***a*** **— upper boundary of gold-bearing gravel-and-pebble deposits,** ***b*** **— lower boundary of gravel-and-pebble deposits;** ***c*** **— the top and bottom of the section are the upper and lower boundaries of "Clayey Strata", respectively;** ***7*** **— Apparent resistivity within the layer (Ω·m)**

values shown by profiles 4 and 6. On the whole, electrical resistivity is 160–170 Ω·m. In the watered gravel-and-pebble or sand-and-gravel pockets, electrical resistivity lowers to 110–130 Ω·m.

The third layer is the placer bedrock represented by the Late Miocene thickness of tufaceous conglomerate, sandstone and siltstone exhibiting facies substitution in the direction from the west to the east. Electrical resistivity in the layer varies from 100 to 120 Ω·m, which is reflective of weak diagenesis of rocks. The thickness of the layer is 7–14 m (the maximum values are in PR-3 and the minimum values are in PR-2). The bedrock roof features swells and vugs (pockets), the latter are the most distinct along the latitudinal profiles (PR-1, PR-3 and PR-6).

The fourth layer is composed of clay-cemented rock fragments around the bowl, including metasomatic rocks with the sulfide-and-quartz veins and lenses of clay. This layer is assumed as complete redeposition. The layer has a persistently low electrical resistivity of 35–60 Ω·m over the whole test area. The total thickness of the layer is only detected in the submeridional profile and reaches 30 m. As judged by the low resistivity, this layer might contain sulfide minerals.

The fifth layer is tuffogenous silty sandstone with rock fragments around the bowl. The layer is only distinguished along the submeridional profile (PR-5) owing to the increased electrical resistivity from 90 Ω·m and higher. Such resistivity corresponds to strong rocks. A more detailed understanding of the structure and behavior of the parent rocks in the bowl basement needs the more comprehensive electrical tomography survey with the verification drilling.

The tectonic disturbances are traced by the change in the specific electrical resistance along the sublatitudinal profiles in the south of the test site (Fig. 3), worse distinguishable in the center and north of the site (Fig. 2) and are undetected in the meridional profile (Fig. 4).

Conclusions

In this manner, using the method of electrical tomography, the structure of the Lower Bolotisty Stream area of Bolotisty gold deposit is successively studied. The implemented research has enabled:

- Determination of the lithology and thickness of loamy gravel-and-sand and gravel-and-pebble formations with loamy filler and with lenses of sand-and-clay and detritus loamy rocks;
- Examination of composition and thickness of the Elephantine alluvial gold bedrock represented by tuff conglomerates with the basal clayey cement; the bedrock roof has swells and vugs (pockets);
- Identification of the layer of clay (Birofeld formation) composed of clay-cemented rock fragments of all kinds of rocks typical for the test area (including metasomatic rocks with sulfide-and-quartz veins) with clayey lenses in the middle of the section, up to 30 m thick, distinguishable across the whole test site; judged by the low resistivity, the layer may hold sulfide mineralization;
- Determination of the occurrence depth of the underlying clay layer represented by tuffogenous agglomerated breccias (at the bottom) overlying the Lower Cretaceous subintrusive rocks (basaltic andesite).

The major result of the research is the detected layer represented by clay-cemented rock fragments composing the surroundings of the Cenozoic erosion-tectonic bowl of the Lower Bolotisty tectonic block and the underlying layer of tuffogenous agglomerated breccias promising deep-level alluvial gold.

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