ГЕОЛОГИЯ И ОХРАНА НЕДР

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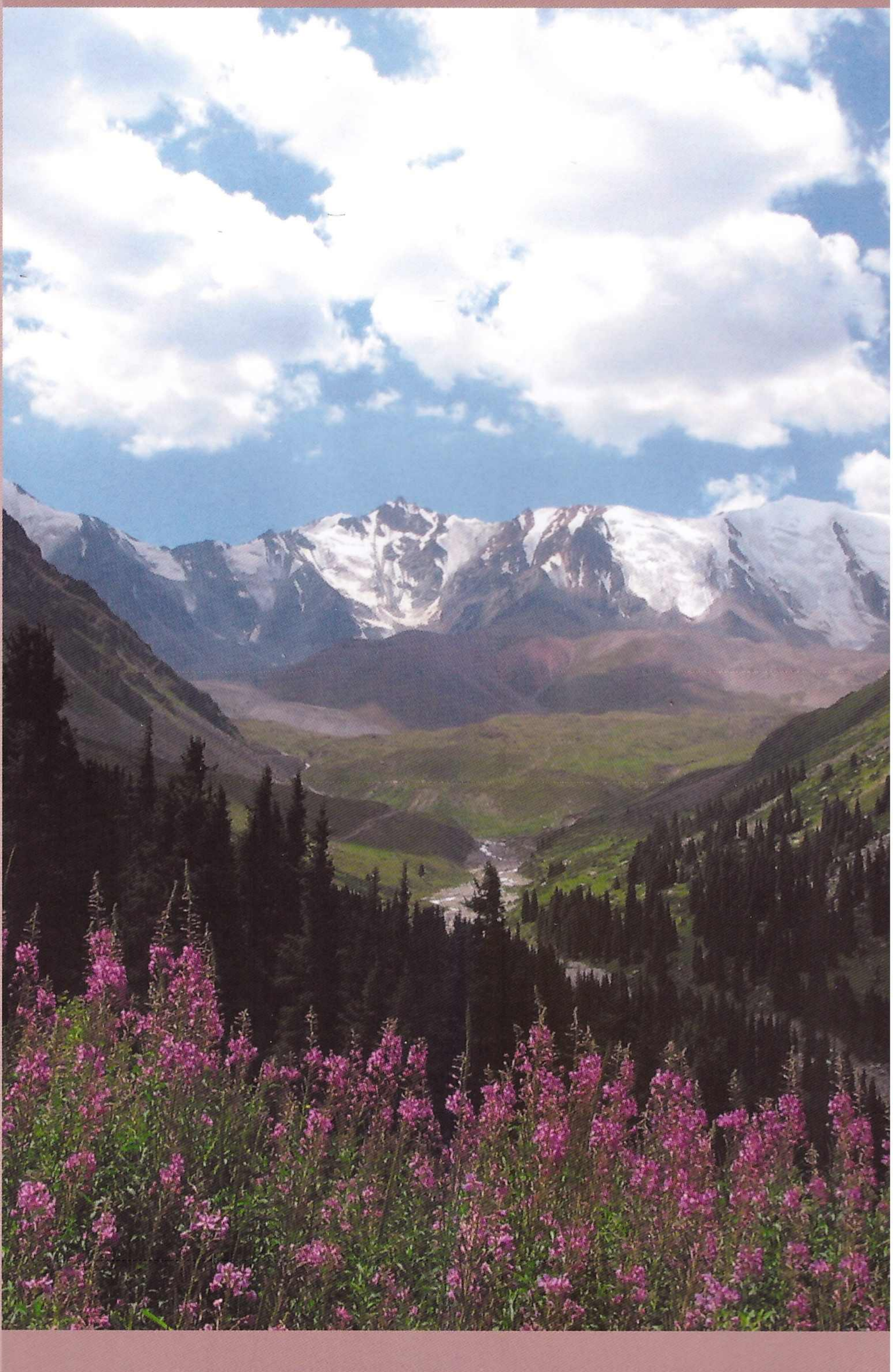

Research Paper

Searching for subsurface copper and gold resource with Terravision Radar

Introduction

Due to the depletion and scarcity of surface ore deposits, discovery of mineral potential is possible only by conducting expensive search techniques to depth, to identify objects of interest.

Geophysical methods are included in the search: gravimetric, magnetic, in various modifications, accompanied by deep geochemical survey and a substantial amount mapping and exploration drilling. Geophysical methods historically give very indeterminate results in areas with for example:

- complex geology
- multi-zoned areas,
- disturbed or loose overburden
- in the lignites, oolitic ore horizons,
- aquifers with highly mineralized water and others.

In this case, the main effective method of deep structure searching is drilling on a grid pattern, combined with, for example, geochemical mapping of the search area.

Terravision Radar

Improving the efficiency of the deep searching is now possible. Terravision Radar is an innovative technological tool, where, with minimum cost information can be obtained about the geological structure of the section and prospective areas identified.

Terravision Radar can be classified as geophysical instrument designed to study the soil subsurface structure to a depth from a few meters to hundreds of meters, depending on the configuration of the device, the antenna and the parameters of the subsurface.

The principle of GPR work is based on ultra-wide band electromagnetic pulse emissions in the subsurface and records their reflections from lithological interfaces and lithological differences, layers or objects. GPR has evolved; classically, the transmitter used had a power transistor voltage of about 50 V. This limited performance to light soils with low signal attenuation (dry sand or frozen soils). Depth of scanning in this case was only in the first few meters, and scanning was not possible at all if the geological section had wet clays or loam. Therefore, instruments of this type were used sparingly, and mostly to solve local tasks in engineering geology and when studying shallow objects.

In comparison with well-known Western devices, Terravision radars have a very significantly enhanced energy potential that also allows for operation in environments with high conductivity. The radar scheme has been completely revised: pulse transmitter power has been increased by a minimum of 100,000 times, and the stroboscopic transformation replaced to direct detection of signal. The antennas used by Terravision-Radar use RC-loaded dipoles. This ensures the exclusion of interference in the received signal that suppresses weak signals, whilst also permitting the reception of strong signals. The transmitter uses a high-pressure hydrogen discharge, and the transmitter operates in stand-alone mode without synchronization. This avoids the requirement for connecting lines which also introduce strong interference from the transmitter.

Depending on the geological task, the removable antennas (transmitter antenna and receiver antennas) can quickly be changed, which changes the operating frequency range of the radar.

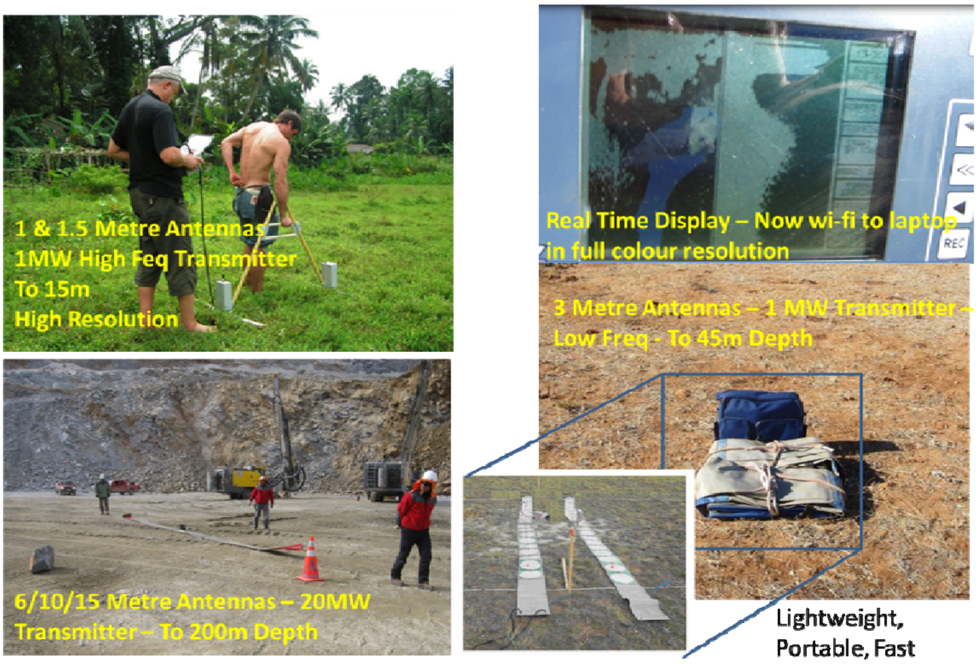

Figure 1: *Terravision Radar equipment. The Radar is configured as follows:*

- *A Transmitting Antenna*
- *A Receiving Antenna*
- *A Transmitter*
- *A Receiver*
- *Receiving Console*
- *Laptop with proprietary software*

Scanning to different depths or achieving certain resolutions, requires the same configuration with component parts changed to suit the target and objective. The Radar uses different sized antennas, transmitters, receivers and consoles.

Increasing the sounding depth is possible by reducing the frequency of the signal. Sounding signal damping depends on the frequency as a decrease in the frequency reduces the damping. Sounding signal with frequencies of 15-25 MHz and 120 dB potential can provide registration for reflection amplitude from depths of 100-250 m or more (depending on the properties of the section being surveyed).

The measurement results are displayed on the radar console as a “radargram”. This is a “real-time” functionality that the radar operator reviews whilst conducting the survey. On the radargram at each measurement point the arrival time of signal is recorded from the geological boundaries. The profile radargram is formed on the screen and shows the geological boundaries. Results of the survey, including the wave-forms for each point in the survey, are stored in the console memory.

Application of low-frequency antennas 10, 15 and 25 MHz and high-powered transmitter 10-20 MW makes this radar a unique research tool of geological structures to depths of 100-250 m. The depth to the reflected boundary is as:

h=[(vt)2-(d/2)2]1/2

Where:
V – velocity of wave signal in the overlying layer;
T - the arrival time of echo;
D - the distance between the receiving and transmitting antenna.

Calibration

The main question arising at each new survey point, is that initially the value of wave velocity V is not known at each new location. The geological section is a heterogeneous environment and the wave velocity in it is a complex function which depends on the following key measurements:

(1) dielectric permittivity (e)
(2) magnetic permeability (m)
(3) resistivity (r)
(4) frequency of the signal (w):

V = V(w, e, m, r)

Obtaining a set of “echoes” in the profile , with reference to seismic techniques, might be called a "temporary" section. Depth “calibration” of the profile and correction of the geological objects boundaries marked on radarogramm can be established by the results of drilling.

Case Study - Varvarinskoye

Terravision Radar profiling was performed in Varvarinskoye (areas South, North, A-6) and Career) in autumn 2011 and winter 2012. This work was carried out to assess the possibility of using an upgraded Terravision Radar receiver for depth searching in the area covered by unconsolidated Mesozoic-Cenozoic formations with the total thickness up to 40-50 m. The results of this work can be considered as a highly successful innovation through experimental research. (fig. 2)

Varvarinskoye copper-gold field is located in the eastern part of Ural fold system, in the Pervomaiskiy trough, dedicated to the central part of the Denisovskaya rift type eugeosynclinal structure.
The deposit was explored, reserves calculated, and approved by the State Reserve Commission of Russia in 2005. The mining has been carried out by "Varvarinskoye" company since 2007. Exploration activities were conducted on the flanks of the ore field.

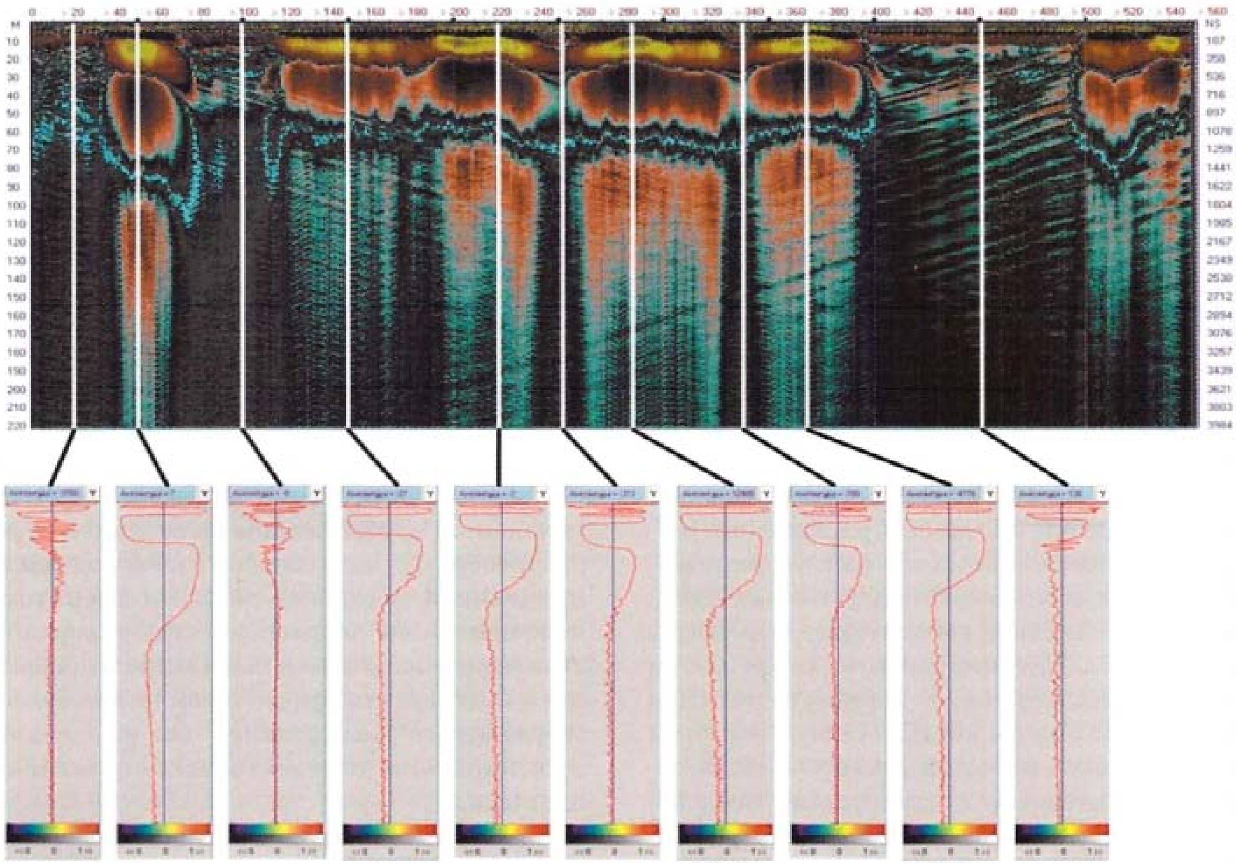

***Figure 2:** Survey 1 results - The “base profiles” Wave form measurements are presented for different sections of the profile. The signal has a bipolar structure, this structure can be preserved in reflection, but polarity can be changed. The geological image on radargram is presented by two reflected pulses from the upper and lower boundaries. Layer thickness on the image/radargram is characterized by the time delay between the first and second pulse. Thus, the increased frequency means there are more layers, and displacement of the signal wave form from the axis of symmetry in the "tail" part of various pickets of the GPR section is characterizes different conductivity in these sections.*

The ore field of the Varvarinskoye deposit is composed of basalts with rare pyritized siliceous siltstone of Middle Devonian age; flysch sandstones, siltstones, carbonaceous shales, conglomerates and marbled limestone of Middle Devonian and Lower Carbonian age; basalts with interbedded slates, polymictic sandstones, siltstones, and limestones of the Lower Carbonian age. There are two different age intrusive complexes intruded in the stratified formations: Early Carbonian ultramafic rocks forming dykes, lenses, and layered bodies; Middle Carbonian gabbro - diorite – granodiorite rocks forming lenses, rods and dikes by diorite porphyry. Basalts are commonly exposed to regional metamorphism (greenschist facies). They have chlorite and epidote. The host rocks in dikes and diorite porphyry intrusions exocontacts are hornfelsed, skarned and silicified. Quartz-feldspats and feldspat metasomatites distributed by diorite porphyry and hornfelsed rocks. Serpentinites usually has a different amount of talc, chlorite, tremolite, sometimes listwanite. Quartzites and silicified rocks are relatively locally distributed and contains quartz, albite and disseminated sulphides.

Paleozoic rocks are overlain everywhere by a layer of unconsolidated Mesozoic-Cenozoic formations. Mesozoic formations are represented by Cenomanian-Turonian and Ayatskaya suite of Santonian-Campanian weathering crusts and bauxite rocks. Weathering crust formed in the Triassic and Early Cretaceous time, and development on the all Paleozoic rocks. They are divided into areal and linear and developed along the faults. The biggest thickness has linear type crust (50-100 to 180 m). The area-type crust has a thickness of 5-50 m. They are unconsolidated ocher clay and clay-detritus formations, where relics of the original rocks structure and moving from deep became to the unaltered rocks. The mineral composition of the weathering crust represented by clay minerals, hydromicas, chlorite, semi-decomposed feldspats, quartz, oxides and hydroxides of iron and manganese. They are localized secondary oxidized and semi-oxidized, bulk copper-gold ore. Late Cenomanian-Turonian deposits represented by clays with interlayers and lenses of bauxite, sands and clays with plant detritus and Ayatskaya suite of Santonian-Campanian represented by sandstones with ferruginous-siliceous cement, black clays, oolitic iron ores are deposited on the weathering crust. Cenozoic formations are represented by Eocene-Oligocene gray, greenish-gray clays with interbedded sands and quartz sandstones, covered everywhere by thin Quaternary cover loam. The thickness of cenozoic formations fluctuates from 10 to 40 m.

Mineralization in the ore deposit is presented by minerals of copper, silver, bismuth, native gold, pyrite, etc. They are localized in the Middle Devonian hydrothermally altered basalts, diorite porphyry dikes, mainly in their exocontact parts and in metasomatic altered diorite, and in areas with actinolite (tremolite) in serpentinites. The morphology of the most copper-gold zones is band-shaped, lenticular, and has a north-south direction. There are some “ameboid” shape ore zones discovered in exploration time.

A large amount of geophysical research, including high-precision magnetic survey, gravity and dipole electric profiling was done in search operations on the flanks of the ore field. The aim of this work was detection and tracking of the area ore bearing strata represented by gydrothermally altered basalts which broken by series of diorite porphyry dikes under the thick cover of Mesozoic-Cenozoic sediments. Because of the complicated lithological composition of the Mesozoic-Cenozoic formations and Paleozoic basement rocks the results of geophysical surveys were not sufficiently informative. As result, the mining company "Varvarinskoye" decided to task Terravision Radar to work on the ore field to assess the differentiation of productive rocks under the cover of loose Mesozoic-Cenozoic formations.

Experimental work was performed by Terravision Radar with antenna complex 1000sm (15 MHz) and the transmitter with a pulse power of 20 MW (21 kW)..

These studies have shown high efficiency of the Radar in lithologic separation and study the loose Mesozoic-Cenozoic section.

- Basement rocks are often recognized as an isotropic layer under the thick cover of unconsolidated sediments, creating a shielding effect for radio waves. In this regard, structural features of the altered rocks vertical profile, developed by lithological differences, can serve as the basis for lithologic separation of the Paleozoic basement rocks.
- On the radargram, ore bearing Middle Devonian basalts are clearly seen as there is an increase in thickness of the weathered crust.

- Breaking through thick diorite porphyry dikes, including gold zone of disseminated and vein-disseminated mineralization in their contacts, usually have reduced thickness of weathering crusts.
- In this way, areas with potentially perspective copper-gold intervals have distinctly “keyboard” character. Apparently, different thickness of altered sediments, which developed on basalts and dikes, is the result of differences in the physical and mechanical properties and the degree of hydrothermal-metasomatic changes. Thin diorite porphyry dikes deposited at a [sloping] angle in stratified basalt sequences cannot be seen on radargram because the properties of the material composition of these rocks are close [there is little contrast between the diorite porphyry and basalt], and also because of pronounced hydrothermal-metasomatic processes which had affected the basalts as well as the dikes. . Zones with high conductivity which wereidentified in the vertical profile of the weathering crust, correspond to mineralized zones. They may be represented by oxidized ore zones or iron and manganese accumulation, formed by the oxidation of pyrite containing horizons. Faults can be identified in radarogramm by a sharp decrease of thickness or increasing thickness of altered rocks, or sharp folds in deposits or local increases of thickness.

As a result, experimental and methodological work allowed Terravision to define the features of the vertical profile of the weathering crust of ore-hosting basalts strata intruded by thick diorite porphyry dikes. These works allow the identification of the estimated axis of mineralized zones and confirmed the effectiveness of Terravision Radar for allocation and tracking of the perspective area by association of heterogeneity in the weathered crust.

Below are some common examples of Terravision profiling results and their interpretation, obtained during experimental and methodical work on the principal profile.

Based on the results of experimental and methodological works company "Varvarinskoye" decided to hold further Terravision surveys on the Varvarinskoye ore fields in 2012.

Terravisionreceived geological tasks on tracking the ore bearing strata under the cover of a thick mantle of unconsolidated Mesozoic-Cenozoic formations in the area, mapping the faults and identifing the estimated boundaries of mineralized zones. Terravision can define the shape of the ore zone based on the results of experimental and methodological work.

Phase 2 Survey

The survey was carried out in winter 2012 in the areas South, North, and K-6.

During the 2011 survey, Signals on the profile (time section) for the phase 1 survey were retrospectively corrected from calibration by drilling, allowing the team to tune the time-to-depth readings . Wave velocity was chosen based on the geological profile provided by the client. There were 7 boreholes on this profile and the upper and lower boundaries of the weathering crust were identified at each borehole. Wave velocity was determined as 5.5 cm / ns. Selected velocity was attributed to the full depth of the section.

The first survey was carried out in the fall (September), but the second survey was in the winter (January - March). The physical conditions of measurement had contrasting differences. In the first survey the work was carried out at high soil moisture (rain) content. During the second survey,- the soil was frozen and there was some snow cover. With such changes in the conditions of measurement, wave velocity changes significantly. Survey 1 profiles were repeated to resolve the question about comparing the results which were carried out in different weather (physical) conditions.

As expected, the wave velocity increased significantly when the soil was frozen. To clarify its value and for the hodograph construction, the measurements were made on a relatively flat section of the profile. These measurements showed an increase in the wave velocity in different layers from 6 to 7.84 and 8.1 cm/ns, and the presence of the horizon at the depth of 10-20 m, where the velocity incident (up to 2 cm / ns), that could be related with increased moisture in this layer. The average wave velocity in the soil was adopted by 7.5 cm/ns and attributed to the full depth of the section.

The second survey was 40 linear kilometers and it was done in areas Southern, Northern, and A-6.

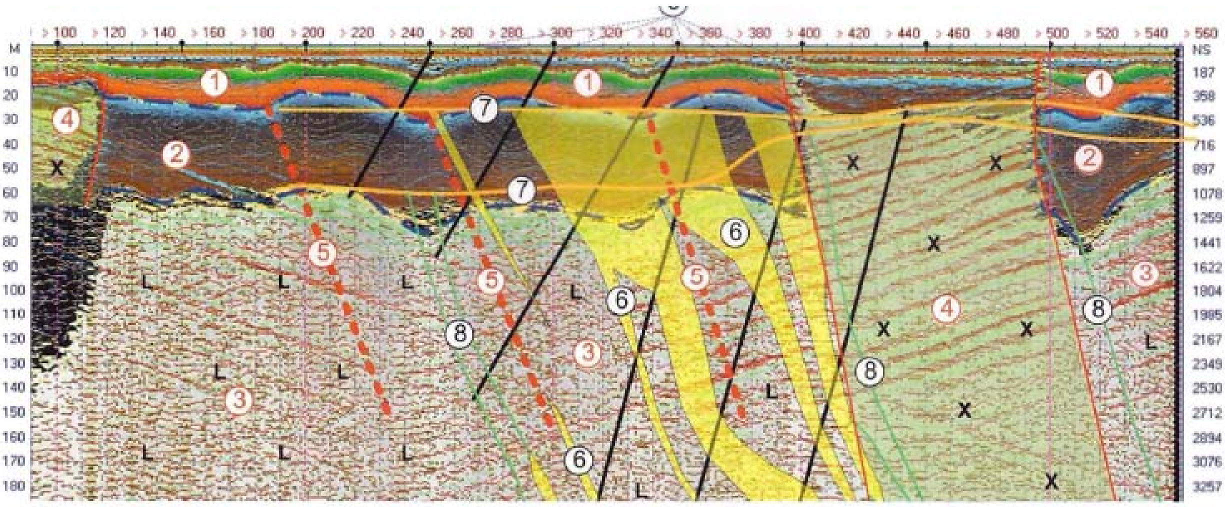

***Figure 3**. Radarogramm of the base profile (Low frequency filtering in the derivative mode) with geological interpretation and results of exploration drilling.*

1-5 - expected geological boundaries according to GPR sounding;

- *1 - Cenozoic sediments undivided (loam, clay, sand);*
- *2 - Triassic - Early Cretaceous gravelly – clay weathering crust;*
- *3 - Middle Devonian hydrothermally altered basalts (ore bearing layer);*
- *4 - Middle Carbonian dykes of diorite porphyry intrusive complex;*
- *5 - perspective intervals for gold - copper mineralization;*

6-8 - geological boundaries defined by exploration drilling:

- *6 - ore body;*
- *7 – weathering crust boundaries;*
- *8 - contours of diorite porphyry dike;*

9 - location of exploration drillholes.

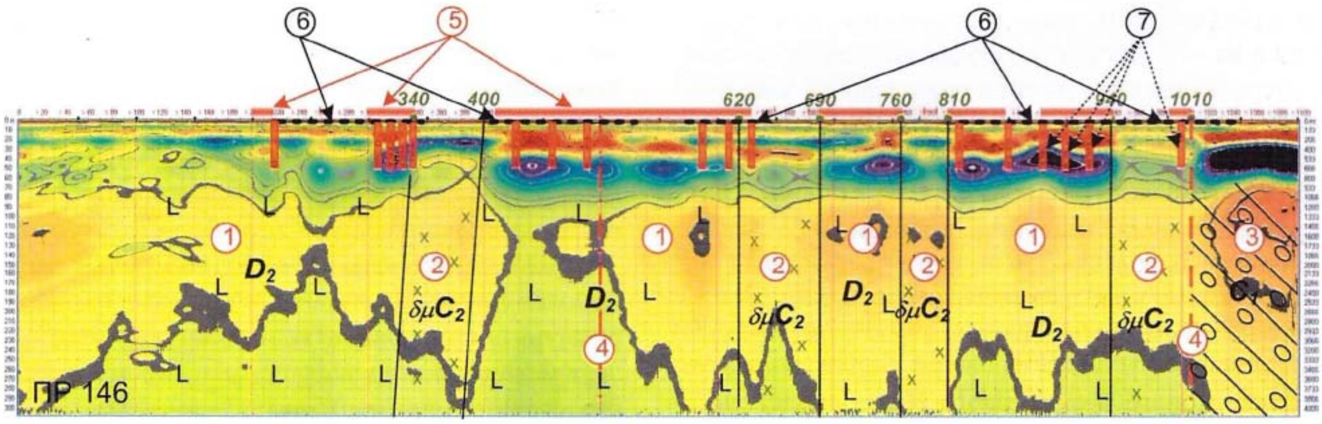

***Figure 4**: Profile 146 radarogramm, South area (amplitude filtering) with results of interpretation and drilling (Survey 2):*
1-3 - expected geological boundaries according to GPR sounding;

- *1 - Middle Devonian hydrothermally altered basalts (ore bearing layer);*
- *2 - Middle Carbonian dykes of diorite porphyry intrusive complex;*
- *3 - Conglomerates of the Lower Carbon;*

4 – faults;
5 - perspective intervals for gold - copper mineralization;
6, 7 – results of drilling;

- *6 - effectively evaluated intervals by structure drilling;*
- *7 – drillholes with copper - gold mineralization.*

Analysis
Lithological separation of deep section rocks is based on the method of analogy with the results of experimental and methodological work in survey 1. Historical data of mapping and exploration drilling are used to form a radar-shape of clastic (conglomerates, sand-shale deposits, and limestone) and intrusive rocks (diorites). Radar sounding results on profiles are presented in the form of frequency and amplitude filtering. Frequency filtering shows the best match to the observation results in this section, amplitude filtering enables us to strengthen the weak signals and to get more contrast waveform, including the suspected areas of mineralization.

Elements of the geological structure and their correlation are shown in the amplitude filtering profile, and located on the plan, in accordance with their actual position on the areas. Geological interpretation of Radar results allowed a schematic drawing to be made of the Paleozoic basement of the studied areas. There are Middle Devonian basalt intruded by dikes of diorite porphyry - "productive" deposits, clastic sediments, intrusive rocks, faults, areas with unclear geology, prospective intervals of copper-gold, skarn and stockwork mineralization shown on the maps.

Based on survey 1, profiles were ranked according to levels of prospectability.

The effectiveness of GPR surveying in deep exploration has been confirmed by drilling of searching and mapping drillholes. Fig. 4 shows a fragment of amplitude-filtering radargram on which the lithological boundaries were marked, as well as the intervals selected by sounding which may contain mineralization. Also shown are boreholes which confirmed mineralization in these intervals. .

Conclusion:

1. Terravision Radar has significant advantages in geological exploration in relation to other geophysical methods due to the high energy capability.
   Standard interval of GPR “shot” measurements (20-70 cm) guarantees a continuous vertical geological section or profile, with detailed characteristic of its subsurface structure in contrast to the current geophysical methods with “point” character observations.
2. Terravision Radar surveys should be carried out in two consecutive steps. In the first step experimental and methodological work should be done in close proximity to “calibration points”. This is necessary to determine the wave velocity calculations for deep level sounding results, and the characteristics of major lithologic types of rocks and mineralized zones, expected on the section. Once calibration is completed, surveys can then be conducted on poorly studied areas, and geological interpretation of the radargram can be carried out by analogy with the base profiles.

3. The Radar delivers very high information content and there is no reason why this method cannot be adapted for widespread use in exploration work.

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