Solving of Hydrogeological Problems in Permafrost Zone Conditions of the Polar Part of Western Siberia by the TEM Method

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Introduction

The number of factors (lithology, mineralization etc.) that affect the electrical resistivity of rocks in permafrost is growing, as well as the ambiguity of the geological interpretation of geoelectric results increases. Promising for fresh water horizon, on the one hand, should have an increased resistivity (Sands in clay cross-section). On the other hand, it should be a thawed zone and have a lower resistivity than the surrounding frozen rocks. In the context of such ambiguity, it is important to use additional independent information and additional criteria for interpretation. Such information capabilities are provided by fast-decaying induced polarization associated only with the frozen state of rocks.

Such polarization is observed both in galvanic and induction methods (Ageev, 2012; Kozhevnikov and Antonov, 2006; Kozhevnikov and Antonov, 2012). The fast-decaying induced polarization process is very specific, characterized by a small time constant, and a very high intensity (polarizability can reach tens of %). Laboratory tests on frozen samples have shown that the phenomenon of fast-decaying induced polarization is observed in both clay and sand frozen samples. The intensity of the induced polarization is determined primarily by ice content, cryostructure, quantity and mineralization of the unfrozen moisture.

The most complete and reliable information about the parameters of the fast-decaying induced polarization during field work can be obtained from data of galvanic methods. But mostly works in the Arctic have to be carried out in the winter and induction contactless methods have to be used. Therefore, in this work the examples using only the TEM (Transient electromagnetic method) are described.

The device "TEM-FAST 48" developed in “Applied ElectroMagnetic Research” (the Netherlands) was used for TEM-method. A combined single-loop installation with a loop size of 50 meters was used.

TEM-data analysis

Let’s consider three examples of search of inter-frozen and under-frozen aquifer. This is necessary for the arrangement of water intakes on the territory of the Novourengoy gas field.

According to the existing scheme of permafrost zoning in the North of Western Siberia, the work area is characterized by intermittent two-layer distribution of permafrost. Features of the permafrost structure of Quaternary and Oligocene rocks are determined by the geological structure of the area, as well as the presence of rivers and lakes.

The Oligocene thawed aquifer is the most promising for water intake. It consists of sands of different grain with gravel, and its thickness is 20-40 m. The water of this horizon is very fresh with a mineralization value of 0.02-0.05 g/l. The intensive water movement in this horizon prevents its freezing. From the depth of 100-150 m the croos-section becomes clay, saturated with water with increased mineralization.

Ground electrical prospecting by TEM solves two main tasks – the search of talik areas and the allocation of promising horizons according to the filtration characteristics. The traditional solution of only the first problem is not enough. Figure 1 shows a fragment of a geoelectric section according to TEM-data at one of the sites. It is characterized by a simple geoelectric situation with an obvious isolated talik and bottom of permafrost. The Western points 23, 24, 25 are in the oval basin. Perhaps it is a depression on the site of the former lake, under which talik was formed. The upper part of the cross-section (20-25 m) has already started to freeze. And the lower part is thawed, but it is represented by clays with low resistivity and is not promising for water.

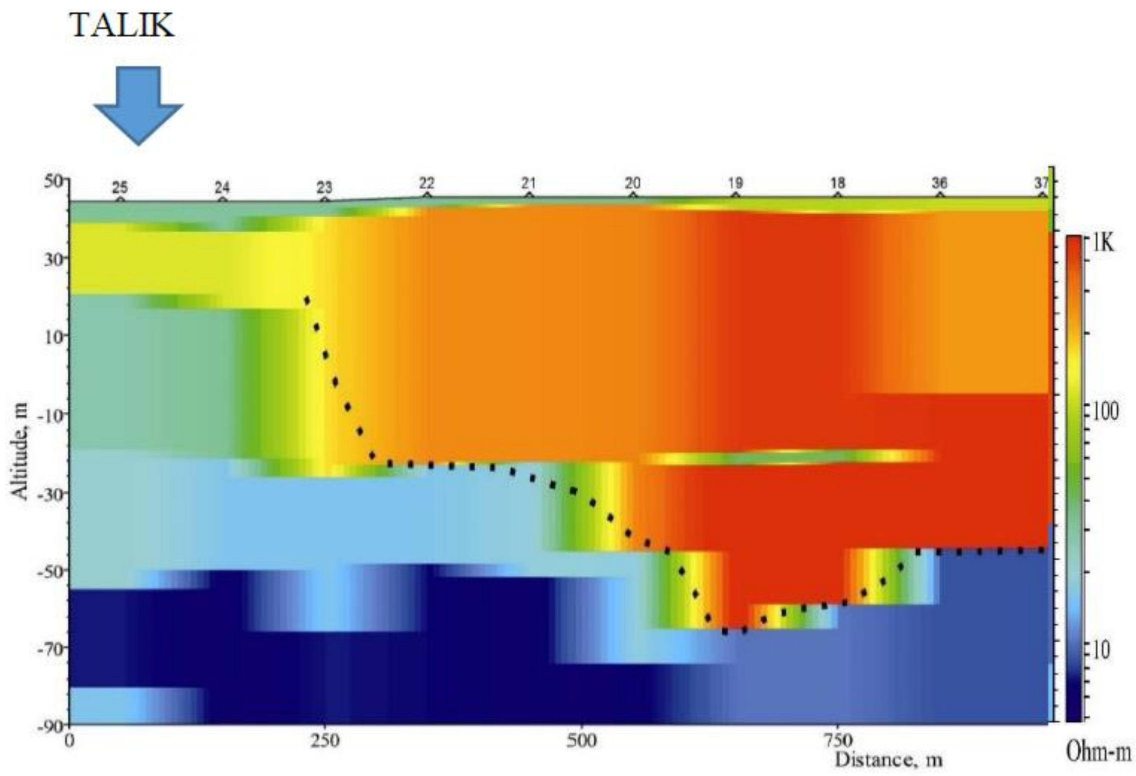

Figure 1. *A fragment of a geoelectric cross-section according to TEM-data. Points allocated to permafrost bottom.*

In another site of work we have less definite geo-electric situation. The results are shown in Fig.2. The Eastern part of the profile ends in the lake. TEM-data distorted by the influence of fast-decaying induced polarization from point 18 to 10 (Fig.2a). The intensity of fast-decaying induced polarization decreases when approaching the lake. On points 18-16 there is a change in the sign of the curve, on other points there is only a weak extremum. This indicates that far from the lake the cross-section is frozen, and there is a talik on the shores of lake and under the lake.

Analysis of the boundary configuration on the geoelectric cross-section (Fig.2b) and information about fast-decaying induced polarization suggest that the high-resistance horizon, located under the lake at absolute levels from -30 to -70 m, is represented by thawed sands and can be promising for water drilling. The well, shown in Fig.2b, confirmed the position of the permafrost bottom, as well as the presence of thawed Sands saturated with water.

The most difficult to make a decision was the third site of the work. All allocated at the site taliks were located beneath rivers and lakes and had low thickness. They were in 100 meter water protection zone of water reservoirs, in which water intake is prohibited. The rest of the territory had a frozen (according to numerous drilling) upper part of the cross-section to a depth of 120-150 m and a thawed clay base. TEM-data are everywhere distorted by the influence of fast-decaying induced polarization with the change of the curve sign.

The exception was the site of work presented in Figure 3. Figure 3 above the geoelectric section shows the fast-decaying induced polarization intensity values selected in the interpretation of the TEM-data and shows TEM-data for two characteristic points.

According to TEM-data upper 120-140 m of cross-section have high resistivity about 500-600 Ohm*m and are not divided into layers. In some parts of the profile it is possible to allocate 20-30 meters loams with resistivity of 90 Ohm*m in the top of cross-section. But some areas with high resistivity are characterized by a complete absence of influence of fast-decaying induced polarization. The absence of influence of fast-decaying induced polarization indicates the absence of permafrost.

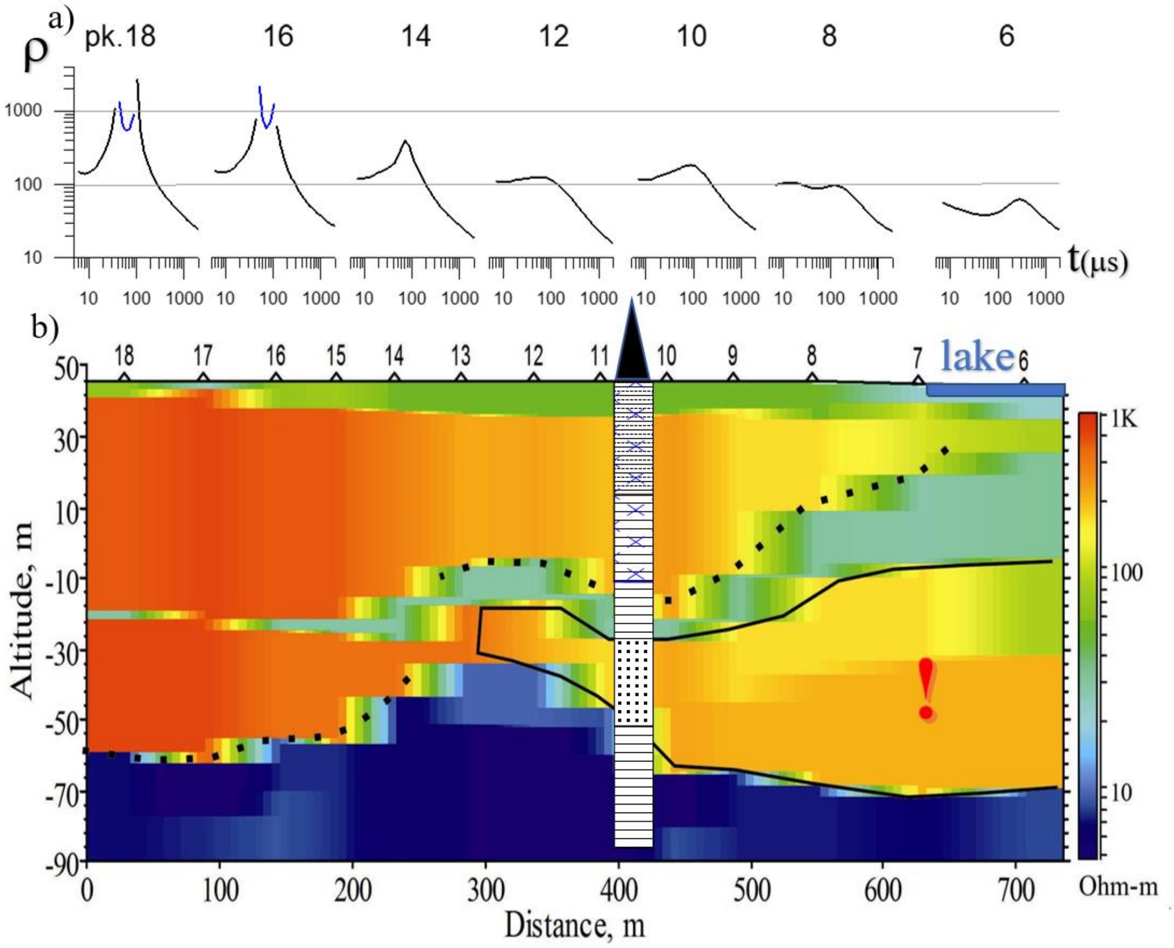

Figure 2. TEM-data (a) and the geoelectrical cross-section (b) according to TEM-data with a dedicated thawed sand aquifer. Points allocated to permafrost bottom.

High resistivity of the upper part of the cross-section is possible in the case of clean sands saturated with ultra-fresh waters. The coincidence of these two factors is optimal for the water intake. Fresh water is suitable for drinking water supply, and the sand composition provides high water content and yield.

To confirm this assumption, several nuclear magnetic resonance (NMR) sensing points were performed at these sites to determine groundwater parameters. The device " Hydroscope" developed in Institute of Chemical Kinetics and Combustion of Siberian Branch of the Russian Academy of Sciences was used for sensing (Bulgakov et al., 1992; Palkin et al., 2014). NMR data showed high volumetric water content (up to 32.2 %) in thick (more than 30 m) aquifers. The results of NMR sounding are shown on the section in fig.3. In the surrounding frozen points NMR signal was absent.

The specified complex of data allowed to define with confidence a place for water intake. In the test well marked in Fig.3 interval 13 – 74 m was melted, whereas interval from 38 m to 74 m is represented mainly by clean sands. The boundary at a depth of 74 m between the thawed and frozen sands on the logging data has a weak contrast in the electrical resistivity and cannot be determined from TEM-data.

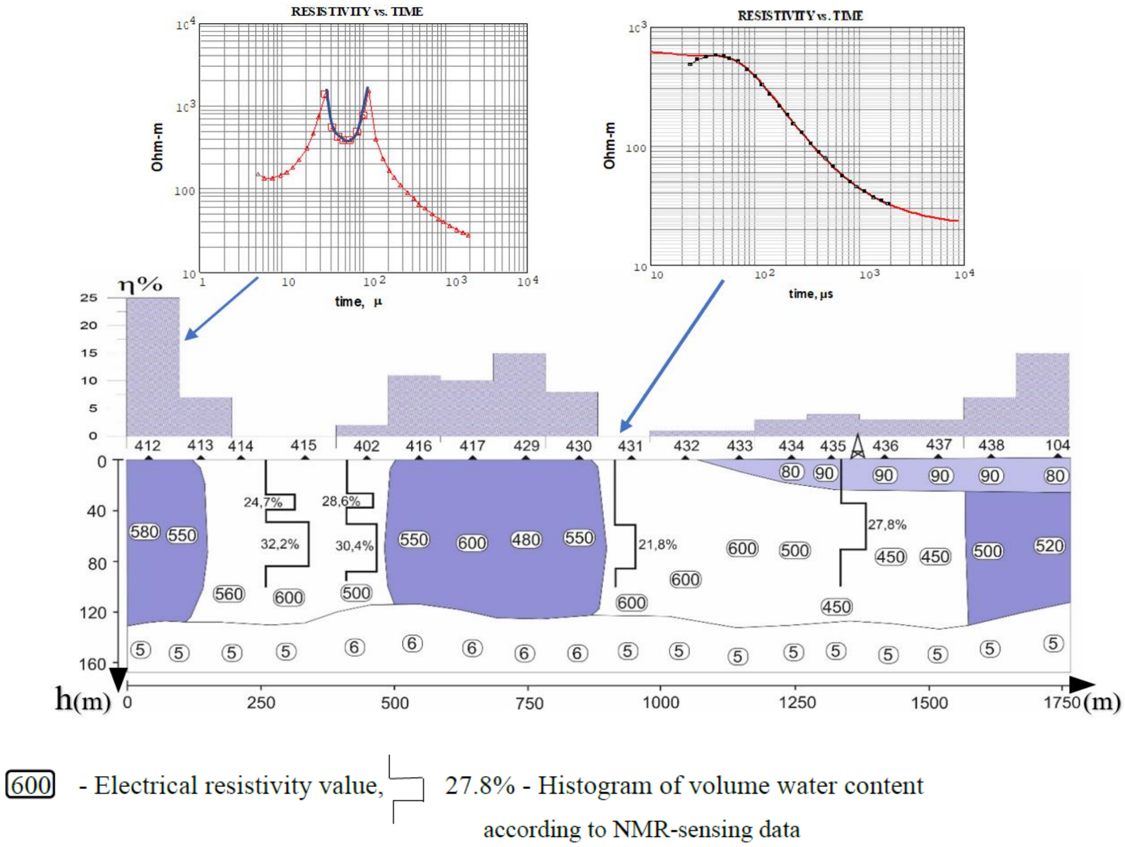

Figure 3. *TEM-data for the two characteristic points (frozen and thawed), the value of fast-decaying induced polarization parameter and the geoelectric cross-section according to TEM-data.*

Conclusions

An additional independent parameter of fast-decaying induced polarization in the TEM-data made it possible to assume the presence of a high resistivity talik with improved filtration properties in addition to the traditional taliks of a reduced electrical resistivity in complex geocryological conditions. NMR sensing, as a direct method aimed at detecting free water, confirmed the presence of talik and helped to isolate aquifers in a high-resistance cross-section. The complex of TEM and NMR made it possible to confidently recommend the allocated site as a priority for drilling a water intake well.

References

Ageev V.V. 2012. Induced polarization processes study for geocryological tasks solution. Prospect and Protection of Mineral Resources 11, 46-49.

Bulgakov Y.U. I., Ickovich G.B., Pusep A.YU., Storozhev A.V. 1992. Mathematical modeling of NMR signal in search of water in a conducting medium.. Rus. Geology and Geophysics 12, 133-140.

Kozhevnikov N.O. and Antonov E.Y. 2006. Fast-decaying IP in frozen unconsolidated rocks and potentialities for its use in permafrost-related TEM studies. Geophysical Prospecting 54, 383-397.

Kozhevnikov N.O. and Antonov E.Y. 2012. Fast-decaying inductively induced polarization in frozen ground: a synthesis of results and models. Journal of Applied Geophysics 82, 171-183.

Palkin S.S., Kozak S.Z., Ageev V.V. and Kalneus E.V. 2014. Subgelisol identification experience in a permafrost zone of Yamal peninsula. Prospect and Protection of Mineral Resources 5, 57-61.