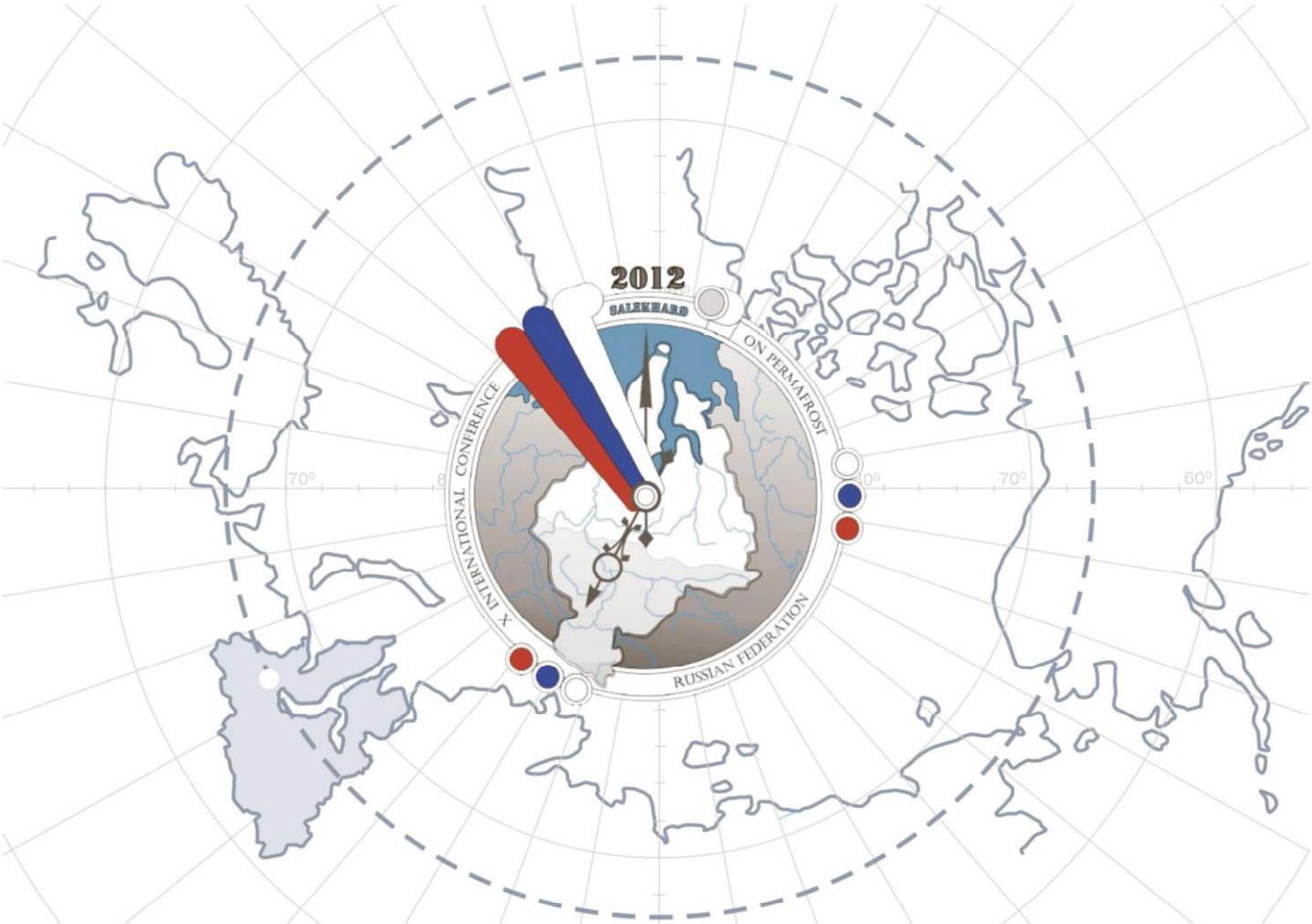

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Experience in Application of Borehole Geophysics Methods for Studying the Thawing of Permafrost Located Near Production Oil Wells at the Multiple Well Platforms of the Fields in Western Siberia

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Oil in the Far North regions is produced by multiple drilling method. Injection wells participate in the production cycle. Heated solution with the temperature of 120 ºC is pumped through their wellheads. The process of such facility operation is accompanied by thermal interaction with grounds, which causes the changes in geocryological conditions. This results in formation of a thawing zone that can transform into a thermokarst pit. Merging of such zones around production wells is not permitted, as this is an extremely adverse factor for stability and long service life of the multiple well platform facilities.

The report surveys the results of using a set of borehole geophysics methods. During the period from 2010 to 2011 the research and production company Radionda LLC conducted works at some producing fields located within Krasnoyarsk Krai and Yamalo-Nenets Autonomous District, beyond the Arctic Circle, for studying geocryological composition of the upper part of the section and assessing a thawing process of permafrost at the multiple well platforms of producing fields.

Geophysical investigations included:

Well temperature survey;

Gamma-ray logging;

Electromagnetic well logging by method of one-hole radio-wave profiling (ORWP);

Interwell space examination by method of radio-wave geointroscopy (RWGI)

On the multiple well platform of the first field the fact of thawing was confirmed by positive temperature anomalies in the inspection well located in the immediate vicinity of a high-temperature injection well. For other investigation wells located at a distance from the heat source, the temperature was negative (Fig. 1a). Figure 3 presents a layout of wells.

For lithologic differentiation of rocks the gamma-ray logging was used. It detected great differences of strata by clay content. Natural radioactivity value (γ) does not depend on the frozen-thawed condition of rocks.

OWRP is a high-frequency electromagnetic method, but, unlike electric resistivity logging, it can be used in dry wells or wells with polyethylene pipe casing, and, if compared with the induction logging, it has a wider range towards high resistances, therefore it can be used for permafrost studies.

When comparing the OWRP data and the gamma-ray logging data, a close correlation between electric properties and clay content was found. In the wells where a thawing process was detected, abnormal increase in electrical conductivity is registered (red area in Fig. 1b) Thus, electric characteristics of grounds depend not only on the lithological type of grounds but also on their physical state.

The interwell space was studied by method of radio-wave geointroscopy (RWGI) based on evaluation of the rate of radio-wave energy absorption by grounds located on the wave propagation path from the source to the receiver (grounds with low values of $w\rho_{eff}$ and ε_{eff} are characterized by more intensive radio-wave absorption). Fan-shaped layout of measuring equipment ensures high density of studies (Fig. 2).

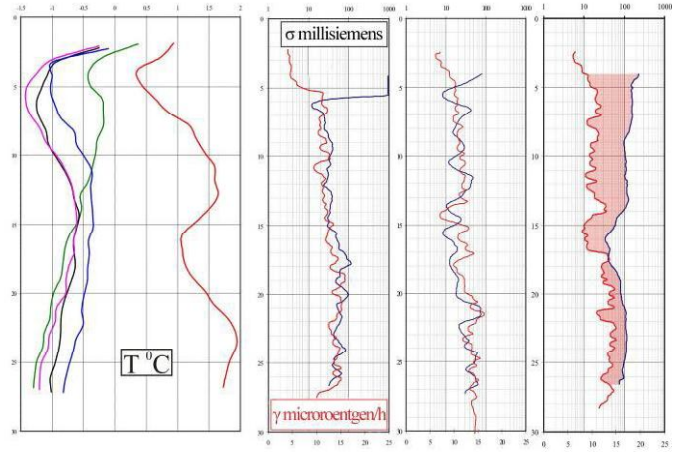

Figure 1. Data comparison of: well temperature survey (1a); gamma-ray logging and OWRP (1b).

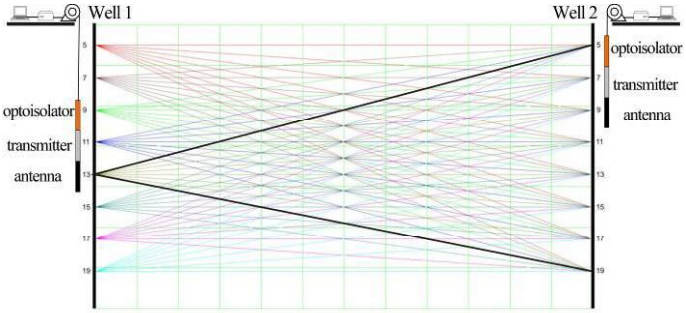

Figure 2.Fan-shaped layout of measurement.

During interpretation the interwell space was divided into equal cells. Multiple ray intersection within each cell makes it possible to calculate effective electrical resistance.

RWGI data are processed by known methods [*Radcliffe 1979*] with the help of software package developed by Radionda LLC.

Figure 3 depicts the instance of fragments taken from a 3D geoelectrical map created with wave algorithm of data processing. Comparison of the RWGI data with logging data makes it possible to relate low-resistivity regions (T) to the area of spread of thawed grounds near the high-temperature injection well.

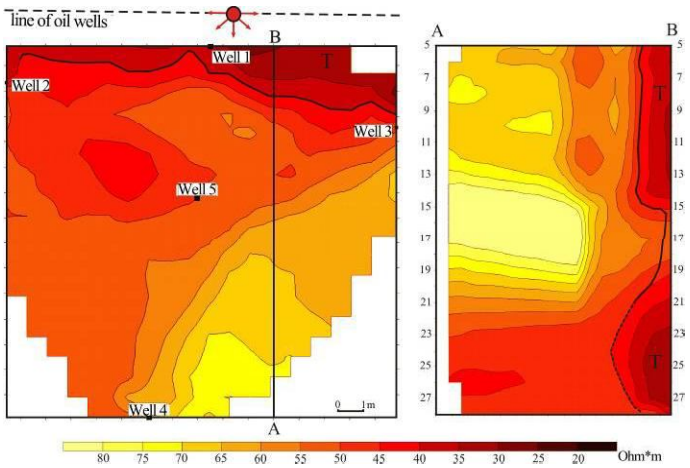

Figure 3. Fragments of the 3D geoelectrical map (horizontal plan at the depth of 13 m and section along the AB line).

Measurements with the use of RWGI method within the frequency range of 5 ÷ 31 MHz, when jointly processed, made it possible for the first time to make a 3D map of specific inductive capacity (Fig. 4). As is known, ε of water and ice differ 40-fold in such frequency range, which allows one to use this parameter for evaluation of frozen-thawed condition of the grounds at the foundation of multiple well platforms.

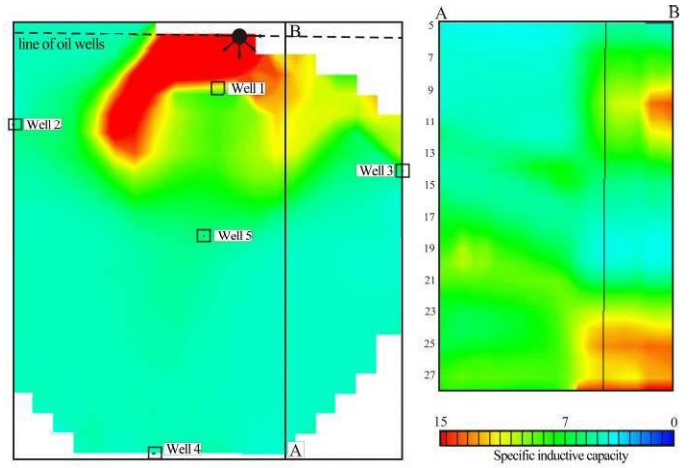

Figure 4. Fragments of 3D map of specific inductive capacity. (horizontal plan at the depth of 10 m and section along the AB line)

At another field, when conducting investigations for multiple well platforms, the described complex was accompanied by collecting of core samples for subsequent laboratory analysis of petrophysical and thermophysical properties in the frozen and thawed states (thermal diffusivity coefficient (a), thermal conductivity coefficient (λ), volumetric heat capacity (Cρ)). The analysis of the population of obtained data made it possible to find out correspondence among individual engineering-geological elements (EGE) and geophysical data (ρ_{eff}, ε_{eff}, γ). (S.V. Bomkin)

Table 1. Parameters of engineering-geological elements

	$\rho_к$ Oh m•m	ε	γ micro-roentgen per hour	ρ g/cm 3	a m^2/s	λ W/m •K	C J/m^3 K
EGE1	400	6	6	1.96	1.14	2.15	2.59
EGE2	30	30	13	1.97	0.63	1.46	3.01
EGE3	90	10	10	2.24	0.86	1.92	2.87

On the basis of these data and RWGI data, a real three-dimensional thermophysical model of the designed working site was created, which became the material for calculation of a thawing process during operation of a facility with the help of numerical mathematical methods.

Summarizing the results of the performed works, it is possible to draw basic conclusions that the proposed complex:

- Enables assessment of frozen-thawed state of grounds at multiple well platforms in conditions of complex geology of the permafrost upper layer;
- Three-dimensional study of grounds in the direct vicinity of producing wells will make it possible to monitor the condition of multiple well platforms and to track the dynamics and spatial spread of a thawing process;
- The information obtained through interwell methods is necessary for mathematical modeling of changing thermal conditions near producing wells.

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