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Abstract

Full Text

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The widespread development of geological and geophysical surveys in the polar regions of the Earth requires the development of special exploration methods that ensure the rapid collection of information on the structure and state of the near-surface layers of the Earth' s crust. The initial data for developing methods of electrical and radio exploration are the electrical characteristics of these layers, which must differ substantially from those for middle latitudes. The present work is devoted to the study of the electrical properties of rock-ice systems, such as are permafrost and moraine-bearing formations in glaciers, and also to an assessment of the possibility of using radio methods for the introscopy of permafrost.

Fig. 1. Frequency dependences of ε' and $\operatorname{tg}\delta$. **A** —for andesite powder $d = 1.8$ g/cm^3; **B** —for pure ice (1) and andesite-ice systems with $P_m/P_{\text{tot}} = 0.48$ (2) and $P_m/P_{\text{tot}} = 0.72$ (3). $t = -10°$

Rock-ice systems may form in nature by two principal methods or by their combination. The first method, consisting in the mechanical mixing of rock with snow or ice followed by compaction, reflects, for example, the process of formation of moraine-bearing layers in glaciers. The second method is the freezing of rock, co-

containing water—basically corresponds to the formation of permafrost.

Studies of the electrical properties of rock-ice systems were carried out under laboratory conditions using an E8-2 bridge and an E9-4 Q-meter. Powders of Andean granite, glassy porphyritic basalt, and pyroxene andesite with grain diameters of 0.5–1.5 mm were used to prepare the specimens, as were distilled water with a specific electrical conductivity of $3.5 \cdot 10^{-6}$ $(\Omega \cdot \text{cm})^{-1}$ and ice prepared from this water. The powders were thoroughly washed and kept in distilled water for several weeks. The specific gravities of the minerals ρ were, respectively, 2.66, 2.76, and 2.43 g/cm^3.

Fig. 2. Concentration dependences of ε' and $\operatorname{tg}\delta$. **A** —for andesite-ice systems obtained by pressure molding, $t = -10°$. **B** —for andesite-ice systems obtained by freezing,
$f = 300$ Hz

The frequency dependences of the dielectric permittivity ε' and of the tangent of the dielectric loss angle $\operatorname{tg}\delta$ of andesite powder at a temperature of 20° are presented in Fig. 1. The course of the frequency dependences of ε' and $\operatorname{tg}\delta$ for granite and basalt powders is analogous, and their difference from the values shown in Fig. 1 does not exceed ±10%.

In accordance with the main modes of formation of natural systems, two methods were used for preparing the specimens. According to the first method—

according to the first method, samples were formed in a measuring capacitor under a pressure of 300 atm from a mixture of rock powder with ice shavings. According to the second method, samples were prepared by freezing mineral powder saturated with water. To exclude the possibility of electrode polarization (as a result of partial leaching of soluble components from the minerals), the sample was quickly frozen to the electrodes with water, which were covered with a thin layer of ice.

Figures 1 and 2 present the dependences of ε' and $\operatorname{tg}\delta$ of samples obtained by molding, in the frequency range 300 Hz–30 MHz at various weight $(P_\text{m}/P_\text{tot})$ and volume $(V_\text{m}/V_\text{tot})$ concentrations. It follows from the figures that in the low-frequency range there is a decrease, and at high frequencies an increase, of ε' with increasing concentration of mineral in the sample. This effect is explained by the decrease in the amount of ice in the sample as the concentration of mineral increases; the value of ε' of the mineral is greater than ε' of ice at high frequencies and smaller at low frequencies. The experimentally obtained values of ε' for rock-ice systems agree well with the values calculated by the Lichtenecker formulas.

Table 1

f	ε'	$\operatorname{tg}\delta$	N
10^5	6	0.4	1.6
10^6	3.7	0.18	6.3
10^7	3.65	0.09	31

f	ε'	$\operatorname{tg}\delta$	N
$3 \cdot 10^7$	3.6	0.08	83

The concentration dependences of ε' and $\operatorname{tg}\delta$ of rock–ice systems obtained by freezing (Fig. 2) have a qualitatively different behavior at low frequencies. The increase in ε' and $\operatorname{tg}\delta$ with mineral concentration can be explained by the influence of migrational polarization, which, as the experiments showed, decreases with increasing frequency and ceases to appear appreciably at frequencies of about $5 \cdot 10^4$ Hz. As can be seen from Fig. 2, during molding, migrational polarization can also appear at low frequencies at intermediate weight concentrations; however, its influence is less significant than in the case of freezing.

In the frequency range considered, the interval 10^5–$3 \cdot 10^7$ Hz is the most stable. The values of ε' and $\operatorname{tg}\delta$ in this interval, at equal mineral concentrations, have the same values for both methods of preparing the samples. The difference in ε' and $\operatorname{tg}\delta$ for systems with different minerals does not exceed ±10%. In addition, the frequency dependence of the electrical characteristics of the systems is manifested in the range considered more weakly than at low frequencies. Since the propagation velocity of radio waves in a (nonmagnetic) medium is determined unambiguously by its electrical characteristics (ε' and $\operatorname{tg}\delta$), the range from 10^5 to $3 \cdot 10^7$ Hz may be regarded as promising for developing methods of radio-wave introscopy of permafrost.

Table 1 presents the values of radio-signal attenuation caused by absorption in a layer of the rock–ice system 100 m thick. The calculations were made from the data of curves 3 in Fig. 2 according to the formula:

$$N(\text{dB}) = 8.68\,\frac{2\pi f}{C}\sqrt{\varepsilon'}\ \operatorname{tg}\delta \cdot h,$$

where f is the operating frequency, Hz; $C = 3 \cdot 10^8$ m/s is the electrodynamic constant; h is the layer thickness, m. The formula takes into account that the signal passes through the layer twice.

The attenuation values given show that the development of methods of radio-wave introscopy of permafrost may prove successful.

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Note: Figure translations are in progress. See original paper for figures.

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