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Abstract

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Laboratory and Field Studies of the Piezoelectric Effect of Rocks Containing Nepheline

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Laboratory studies of quartz-bearing rocks have shown that, with a definite orientation of quartz grains, a piezoelectric effect is observed ($^{1-4}$). On the basis of this property of rocks, a geophysical method is being developed for prospecting quartz and pegmatite veins (^{5,7}). In connection with the prospect of practical use of this new property of rocks, the question arose of studying the piezoelectric effect of rocks containing other minerals—piezoelectrics. For this purpose, samples were taken of igneous alkaline rocks whose composition includes nepheline, which possesses a piezoelectric effect. The most widespread of these rocks are nepheline syenites, khibinites, foyaites, lujavrites, ijolites, urtites, etc. In connection with the development of methods for enriching nepheline rocks and the technology of extracting aluminum from nepheline, some rocks of this group have acquired industrial significance as raw material for aluminum. In addition, nepheline is used to obtain silica gel, alum, glass, cement, aluminum oxide, etc. The growing industrial significance of nepheline requires a comprehensive study of its physical properties, including the piezoelectric effect of nepheline-bearing rocks.

The piezoelectric effect of a single crystal of nepheline has been detected only qualitatively (^{8}); there are no data on the magnitude of the piezoelectric moduli of this mineral. In work (^{9}), on the basis of the theory of piezoelectric textures created by A. E. Shubnikov (^{10}), the possibility was established of formation, from nepheline crystals, of a piezoelectric texture of symmetry $(\infty)T$. The piezoelectric moduli of such a texture, with ideal orientation of all nepheline grains relative to the sixth-order axis, are equal to the piezomoduli of a nepheline single crystal, with the exception of d_{31}. The piezomodulus d_{31} is equal to one half of the piezomodulus d_{31} of nepheline.

In studying the piezoelectric effect of rocks, it is first of all necessary to represent the piezoelectric properties of the texture in an arbitrary coordinate system. In this connection, the piezoelectric tensor of a texture of type $(\infty)T$, expressed through the piezomoduli of nepheline, was calculated in an arbitrary coordinate system $x'y'z'$. According to this tensor, when a sample is cut in the coordinate system $x'y'z'$, both longitudinal and transverse effects should be observed on any pair of faces. Thus, the piezoelectric effect of nepheline-bearing rocks can be established by measuring the longitudinal piezoelectric effect in any of the directions.

The study of the piezoelectric effect and the determination of the piezomoduli of samples of nepheline rocks, cut in the form of parallelepipeds with a volume of about 100 cm^3, were carried out by the dynamic method using an ultrasonic seismoscope (^{11}). Table 1 gives the values of piezomoduli in the CGSE system, measured in an arbitrary coordinate system $x'y'z'$ for the longitudinal effect of the samples. The dynamic method used made it possible to determine the values of the piezomoduli with an accuracy of ±15%.

From this table it follows that the piezoelectric effect of the rocks under consideration is insignificant and is close in magnitude to the piezoelectric effect of most granites and gneisses (3). The reason for the small magnitude of the longitudinal piezoelectric effect is apparently the imperfect orientation of the piezoelectric mineral, and not a weak piezoelectric effect of the single crystal, since the piezoelectric modulus d'_{33} of a monomineral nepheline specimen cut at an angle of 2—3° to the axis of the sixth order has a value of approximately the same magnitude as the piezomodulus d_{11} of a quartz single crystal.

Table 1

Rock	$d'_{33} \cdot 10^{10}$	$d'_{22} \cdot 10^{10}$	$d'_{11} \cdot 10^{10}$
Mineral nepheline	400	61	68
Monomineral rock 328	54	9.9	11.0
Nepheline rock 513	6.6	1.3	1.4
Nepheline-apatite rock	0.8	0.7	0.7
Ijolite-urtite 497	0.5	0.25	0.3
Ijolite-urtite 497	1.2	0.5	–
Nepheline-apatite rock	0.5	0.5	0.3
Khibinite 500	~ 0.3	~ 0.2	–
Foyaite 403	5.3	–	–
Foyaite 401	0.8	–	–

Along with the laboratory studies, an investigation was carried out of the piezoelectric effect of nepheline rocks in their natural occurrence. Field studies were conducted on outcrops of ijolite-urtites and khibinites in the vicinity of the town of Kirovsk on the Kola Peninsula. The piezoelectric effect of rock masses was

Fig. 1. Electroseismogram obtained on an outcrop of ijolite-urtites. *a* —recording of piezoelectric oscillations; *b* —recording of elastic oscillations; *o* —mark of the moment of impact

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studied by recording the electrical component of the electromagnetic field arising due to the piezoelectric effect of the rock during the propagation in it of elastic waves (5). The latter were excited by the impact of a copra weight: a load weighing 60 kg fell from a height of 3 m. The apparatus used provided simultaneous recording of elastic (seismic) and electrical oscillations.

Fig. 1. Electroseismogram obtained on an outcrop of ijolite-urtites. *a* —recording of piezoelectric oscillations; *b* —recording of elastic oscillations; *o* —mark of the moment of impact

For receiving elastic oscillations, SPM-16A seismic receivers were used, and for electrical oscillations—electrodes in the form of plates $15 \times 10 \times 0.4$ cm^3. The seismic receivers and electrodes were installed side by side on the surface of the rock mass. The received signals went to amplifiers assembled on resistances with amplification factors of 3400 and 1000. The former were used in channels, intended—

intended for recording electrical oscillations, the second for recording elastic oscillations. The amplifiers had band-pass filters with frequency ranges of 250-600 Hz and 500-740 Hz. The amplified signals were recorded with a POB-14 oscillograph.

Measurements of piezoelectric oscillations were carried out along longitudinal profiles. This method made it possible to trace the change in the intensity of the electrical oscillations with increasing distance from the impact point. To mark the moment of impact, a seismic receiver was used, which was installed at a distance of 0.5 m from the sledgehammer. The profile step was from 1 to 2 m.

At the outcrop of ijolite-urtites, observations were carried out along three mutually perpendicular longitudinal profiles. Piezoelectric oscillations on all three profiles could be traced at distances up to 10 m. At greater distances, useful signals could not be distinguished because of the high level of industrial interference, which in this area reached 100 μV, and sometimes more. The magnitude of the recorded potential difference at equal distances from the impact point in all three directions was approximately the same. At distances up to 4 m, an intense near-impact electromagnetic pulse was usually recorded, reaching a magnitude of several millivolts. It had also been observed earlier on all the studied outcrops of quartz-bearing rocks ([5]). The amplitude of the electrical oscillations at distances of 4-10 m from the impact point decreased within the range 700-200 μV. Fig. 1 shows one of the records of elastic and piezoelectric oscillations obtained at this outcrop. From the oscillogram it is evident that electrical oscillations arise at the moment when the elastic wave approaches the electrode. The frequency of the oscillations is about 400 Hz.

The structure of the second outcrop—khibinites—made it possible to carry out observations only along one profile with a length of up to 13 m. The absolute magnitude of the electrical signal was considerably smaller. At a distance of 10 m it fluctuated around 60 μV, and at $l = 13$ m it did not exceed 40 μV. The small magnitude of the electrical signals recorded at this outcrop is explained by the low values of the piezomoduli of khibinite (see Table 1). Near the impact point ($l = 3 \div 4$ m), an electromagnetic pulse was also recorded upon impact, which was an order of magnitude smaller than in the ijolite-urtites.

Laboratory and field studies of rocks containing the piezoelectric mineral nepheline have expanded the list of rocks possessing the piezoelectric effect and have shown the possibility of recording the piezoelectric effect of nepheline rocks under natural conditions. The latter gives grounds to assume the possibility of developing a new geophysical method for identifying rocks with a high nepheline content.

In conclusion, I take this opportunity to express my gratitude to Prof. M. P. Volarovich and G. P. Volarovich for suggesting the topic and for consultations during the work, and also to A. T. Bondarenko and V. A. Pavlogradskii for assistance in carrying out the field investigations.

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