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PRESENT PETROPHYSICAL RESEARCH OF DEEP AND SUPER-DEEP BOREHOLES

M. V. Kovalevskiy, F. F. Gorbatsevich, O. M. Trishina
Geological Institute of the Kola Science Centre of the RAS
14 Fersman street, 184209 Apatity, Russian Federation; koval@geoksc.apatity.ru

The paper presents the use of the acoustopolarization method for the study of elastic-anisotropic properties of the rock samples from the Kola (SG-3), German (КТВ-НВ) and Outokumpu (OKU) boreholes. Investigations showed that using this method one can reveal elastic anisotropy, evaluate the heterogeneity of rock samples and determine orientation of the elastic symmetry elements. It is possible to determine the type of the rock elastic symmetry without defining 3D distribution for compression and shear waves. In the rock samples from SG-3, КТВ-НВ and OKU the linear acoustic anisotropic absorption (LAAA) is rather common. The results obtained can be used for better interpretation of the palaeodynamic studies of formation conditions of metamorphic rocks.

Key words: Boreholes; Elastic-anisotropic properties; Rocks; Sample; Structure; Acoustopolariscopy.

Introduction. The drilling of deep and superdeep drill holes requires great expenditures and they cannot therefore be widely applied for research purposes.

The acoustopolarization method is aimed at the study of clastic and nonclastic properties of mainly anisotropic solid media [3, 5, 7, 9]. It allows the determination the presence of elastic anisotropy, the number and spatial orientation of symmetry elements, as well as the symmetry type and elasticity constants. The method is well suited to media with transverse- isotropic, rhombic and other symmetry types. The basic pattern of observations applied in this method is similar to that applied in polarization observations in optics [14]. Acoustopolarization measurements are carried out with a specially designed device, called the acoustopolariscope [10]. Observations are made with transducers that are able to radiate and receive purely shear lincar-polarizcd waves.

In the first stage, measurements are made with the polarization planes of transducers parallel to each other (VP position). A sample is placed between the transducers and fixed on the rotating platform. In a sequence of measurements, the rotating platform is rotated through 360°, and signal amplitudes are measured on the screen of a recording device. In the second stage, measurements are carried out with the polarization planes of the source and receiver orthogonal to each other (90°, VC position). Again, the measurements are conducted through a 360° rotation of the sample. As a result of these measurements, we obtain acoustopolarigrams of anisotropic samples for parallel (VP) and orthogonal (VC) directions of transducer polarization.

It is known that in the course of investigation of rocks and massifs by seismic methods various linear (nonlinear) effects and phenomena arise during propagation of waves [5, 8]. These effects and phenomena can influence the final seismogram shape and cannot be fully defined by the existing methods. In this connection the aim of our investigations is definition of the phenomena and effects (PHE) arising during propagation of elastic shear waves in solid anisotropic media.

Kola Superdeep (SG-3). The Kola Superdeep Borehole reached a depth of 12 261 m. It was drilled in the northern NW-trending (300–310°) and SW-dipping (30–50°) limb of the Pechenga rift structure, composed of rhythmically alternating metavolcanic and metasedimentary sequences [10]. The borehole intersected the lower Proterozoic complex of the Pechenga Formation and the Archaean granite and metamorphic complex (the middle continental crust). The drilled part of the Archaean complex (6 842–12 261 m) is composed of biotite-plagioclase and biotite-amphibole-plagioclase gneisses with high-calcium minerals, gneisses with high-alumina minerals, amphibolite and metaultrabasic rocks, pegmatite and granite [4]. In the vertical section of the Archaean complex

10 geological units have been distinguished. They are characterized by various compositions and combinations of constituent rocks, type of regional and dislocation metamorphism, granitization, elements of folding and fracturing.

In the course of investigations we received over 180 acoustopolarigrams for the samples excavated from all geological units cut by SG-3 [5]. The acoustopolarigrams of gneiss, schist and amphibolite cubic samples from the Kola superdeep section (5 893–9 672 m depth range) with a high level of elastic anisotropy are presented in Figure 1. One can draw straight lines connecting the minimal amplitude of the signal passing through the sample almost everywhere on the VC acoustopolarigrams and thus determine the spatial location of the projections of elastic symmetry elements. The VP acoustopolarigrams of some samples have a distinctly flattened shape. This suggests a manifestation of the LAAA effect, see Figure 1. This effect is usually manifested in the presence of preferred orientation of elongated mineral grains and microcracks [5].

Elastic anisotropy of biotite-plagioclase gneisses, judging by their acoustopolarigrams, is well-defined. The presence of the symmetry elements on the acoustopolarigrams of samples 24996s, 28184s point to near orthorhombic symmetry type, while those of samples 30020, 24947 – to transversal-isotropic. In every sample the LAAA effect is displayed. This effect is pronounced in talc-phlogopite-tremolite schist, sample 26715s. The acoustopolarigrams representing high LAAA are typical of many schist samples, Fig. 1. The acoustopolarigrams of amphibolite, as a rule, point to the influence of four factors occurring in different combinations and rate: elastic anisotropy, the LAAA effect, microcracks and heterogeneity. The first factor and to a large extent the second one influenced the acoustopolarigrams of samples 24788s and 27026. As a rule, projections of symmetry elements stand out sharply on all the three sides of the samples. The Q-matrices of the velocities of these samples were published in [5].

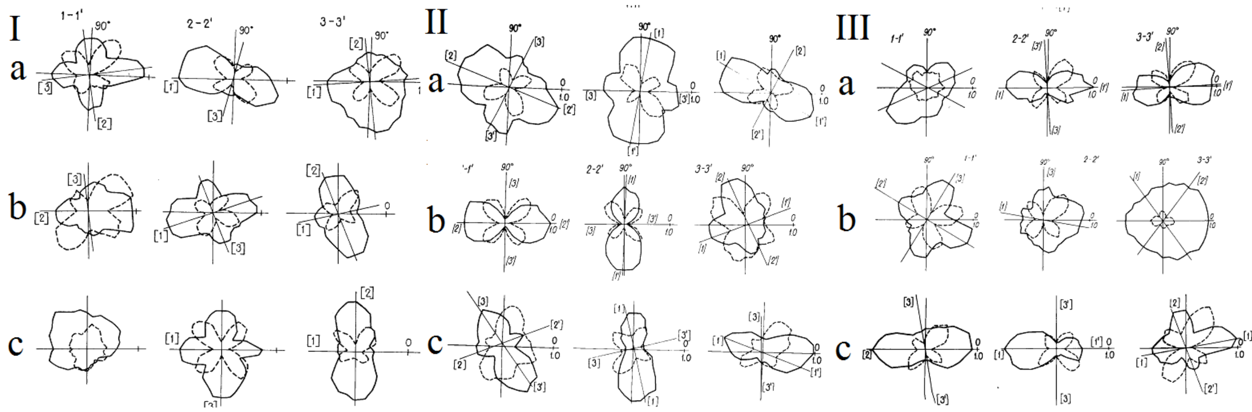

Figure 1 – Acoustopolarigrams of the samples from SG-3, 5 893-9 672 m depth range [5]

Ia – plagioclase granite with amphibole (sample 24996s); Ib – epidote-biotite-plagioclase gneiss (sample 28184s); Ic – biotite-plagioclase gneiss (sample 30020); IIa – amphibole-plagioclase schist with biotite (sample 19402s); IIb – talc-phlogopite-tremolite schist (sample 26715s); IIc – epidote-biotite-amphibole-plagioclase crystalloschist (sample 27227s); IIIa – clinopyroxene amphibolite (sample 24788s); IIIb – amphibolite with sphene (sample 24947); IIIc – cummingtonite amphibolite (sample 27026). Vectors parallel – solid lines; vectors crossed – dotted lines.

German superdeep (KTB-HB). The German superdeep borehole (KTB-HB) was drilled in the crystalline basement of the Bohemian massif in the south of Germany [1]. It is located in the tectonometamorphic massif of Zone Erbendorf-Vohenstrauss (ZEV). The main rocks composing the massif in the profile zone are paragneiss, metabasite and their interbedding, granite and metasedimentary rocks. The rocks underwent two metamorphic cycles that resulted in strongly anisotropic schistose rocks.

The samples of amphibole-biotite gneiss, biotite amphibolite, apoeclogitic garnet amphibolite, apogabbroic amphibolite etc., were excavated from the KTB-HB depth range of 4 149–7 011 m [2].

Their acoustopolarigrams are represented in Fig. 2. On the VP and VC acoustopolarigrams of most samples one can see four-petal figures, which signify the presence of elastic anisotropy in rock samples. The maximum LAAA manifestation is observed in the sample of garnet amphibolite (sample h030, axis 1-1′, D_1 = 0.45; axis 3-3′, D_3 = 0.86). It is also noticeable in the samples of amphibole-biotite gneiss (sample h001, axis 2-2′, D_2 = 0.13, axis 3-3′, D_3 = 0.14), garnet amphibolite (sample h009, axis 3-3′, D_3 = 0.2; h010, axis 3-3′, D_3 = 0.39. In the above samples, the LAAA manifestation is also associated with the presence of oriented in one direction minerals such as amphibole, biotite, chlorite and others [8].

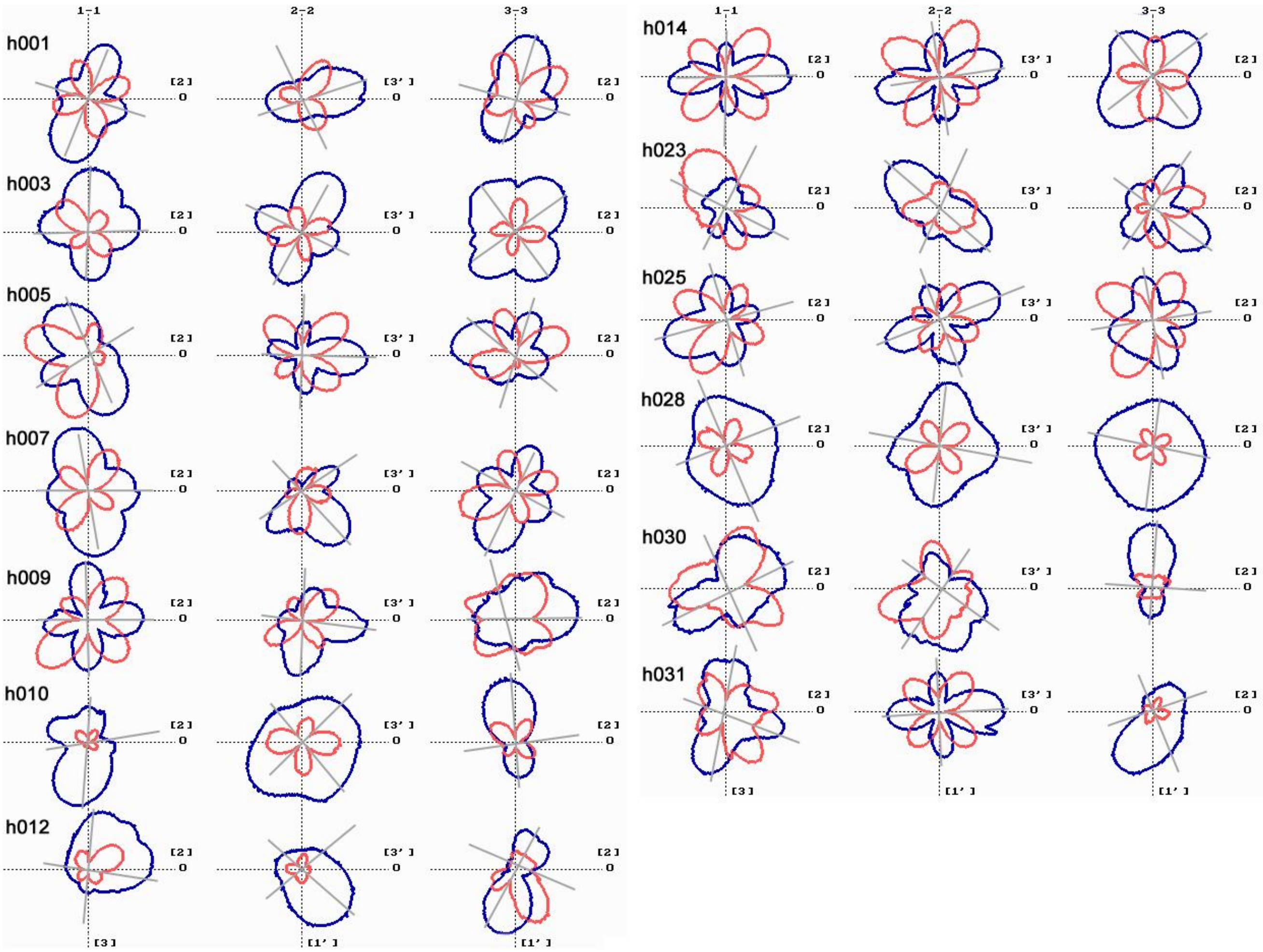

Figure 2 – Acoustopolarigrams of rock samples
from the section of the German KTB-HB superdeep drillhole [8]
Vectors parallel – solid lines; vectors crossed – pale lines.

Acoustopolarigrams of some samples (samples h009, axis 3-3′; h023, axis 1-1′; h030, axes 1-1′, 2-2′; h031, axis 1-1′) are distinguished by abnormally large VC diagrams of a rounded shape. As indicated earlier [5, 7, 8, 9], such forms of acoustopolarigrams are observed when the crystalloacoustic axes of mineral grains are distributed over a wide range of angles in the plane perpendicular to the wave direction. In this case the effect of shear wave depolarization (SWD) is manifested. Earlier a similar effect of depolarization of linearly polarized light waves as they propagate through accidentally heterogeneous media or media composed of anisotropic materials (layers) with differently oriented symmetry elements, was registered in optics [13].

Heterogeneity and differently oriented microcracks also affect the shape of acousto-polarigrams. The asymmetric angular shape of the VP acoustopolarigrams (samples h009, h030 and h031) indicates a significant effect of these factors on their elastic anisotropic properties. The smallest effect of heterogeneities is observed in the samples of biotite (h003), garnet (h014) and mineralized chloritized garnet amphibolite (h028) with a fairly strict one-way orientation of crystalline-acoustic axes in mineral grains. The outlines of the acoustopolarigrams for the last mentioned samples are close to those calculated theoretically (Fig. 2).

On the whole a comparison of acoustopolarigram shapes for different rock types (Fig. 2) shows that their shape does not allow distinguishing amphibolite from garnet amphibolite or from amphibole-biotite gneiss. Thus, the elastic anisotropic appearance of these rocks is not determined by their mineral composition but by specific palaeogeodynamic conditions of generation during metamorphic and other processes.

The Q-matrices of the velocities of these KTB samples were published in [8].

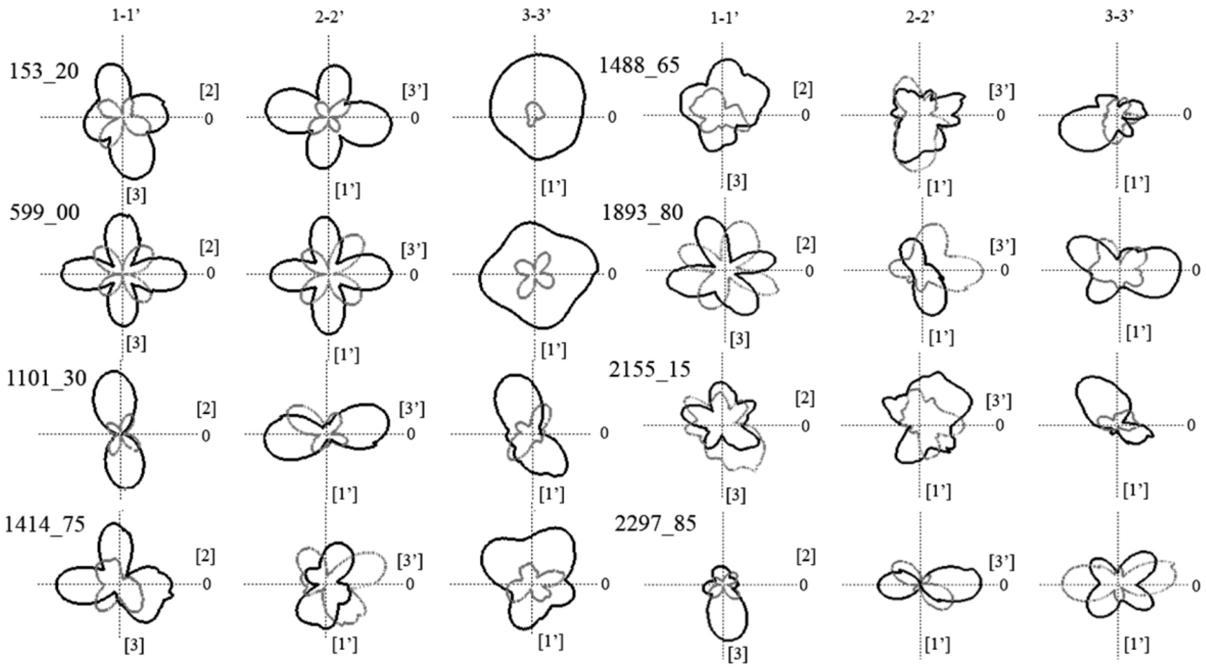

Figure 3 – Acoustopolarigrams of the rock samples extracted from the Outokumpu drill hole
Vectors parallel – solid lines; vectors crossed – pale lines.

Outokumpu deep drill hole. The Outokumpu investigation deep drill hole (OKU) reached a final depth of 2 516 m. The hole is located in SE Finland near the worked-out Outokumpu deposit. The plan of the geological structure [6] shows that the wellhead is located in the field of Proterozoic mica gneisses (schists). Archaean massifs are situated north-eastwards. The upper drill hole down to some 1 310 m has passed through mica schist with rare interlayers of biotite gneiss [12]. The 1 310–1 515 m interval is composed of alternating beds of black schist, biotite gneiss, serpentinite and diopside-tremolite skarn. Below 1 515 m mica schist with rare beds of black schist and quartz veins occur. From a depth of 1 655 m mica schist alternates mainly with the bodies of pegmatite granite and biotite gneiss. Pegmatoid granite, garnet-biotite gneiss and biotite–sillimanite schist compose the lower part of the drilled section down to the limiting depth.

In the course of investigations types of rocks, their texture, structure, composition and petrophysical properties of 43 core samples taken from different parts of the Outokumpu drill hole section were studied [7]. Then their elastic and non-elastic properties were investigated by means of acoustopolariscopy. Below are the acoustopolariscopy results for the modal rock types.

Conclusion. The results obtained for the rocks from the kola and german ktb-hb superdeep and finnish deep boreholes (biotite gneiss, schist, hornblende amphibolite etc.) Point clearly that metamorphic rocks are elastic-anisotropic. Their structure can be near transverse-isotropic or orthorhombic elastic symmetry. The linear acoustic absorption anisotropy effect (laaa) is rather common for the samples excavated from SG-3. The degree of the laaa effect manifested in the samples from the ktb-hb and oku is very variable. These peculiarities of the rock masses displaying the laaa effect should be taken into consideration when interpreting the results of seismic investigations. As a rule, the acoustopolarigrams point to the influence of four factors occurring in different combinations and rate: elastic anisotropy, the laaa effect, microcracks and heterogeneity.

A comparison of acoustopolarigram shapes for different rock types from SG-3, KTB-HB and OKU shows that their shape does not allow distinguishing gneisses from amphibolites, schists from metamorphosed granite etc. Thus, the elastic anisotropic appearance of these rocks is not determined by their mineral composition but by specific palaeogeodynamic conditions of generation during metamorphic and other processes. Thus, the acoustopolariscopy method may be useful for investigating palaeodynamic conditions of genesis of such rock masses.

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