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POSSIBILITIES OF THE ACOUSTOPOLARISCOPY METHOD IN THE PROBLEMS OF GEOPHYSICS

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The paper presents the use of the acoustopolarization method for the study of elastic-anisotropic properties of the rocks. 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 boreholes rock samples the effect 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. After William Nicol had introduced optical polarizers in 1828 microscopic studies of composition and structure of minerals and rocks went fast. Geologists are armed with quite a large set of quantitative methods to analyse the chemical and mineral composition of rocks. The situation in regards to the measurement of the peculiarities of structure and elastic anisotropy of rocks, however, is poorer, as methods and instruments suitable for this purpose are more limited. Interest in elastic anisotropy parameters aroused because natural media are very often anisotropic [2, 6, 10]. Investigations indicate that minerals and rocks have the properties characterized by various symmetry groups, including the lowest ones, and by a high degree of anisotropy. Large rock masses, especially metamorphic, can be strongly anisotropic [1, 3]. These peculiarities of big geological formations hinder their study by seismic methods [12].

The developed acoustopolariscopy method [4] has some advantages and can be widely used because unlike light rays an ultrasound can penetrate all bodies regardless of their thickness and transparence. This method solves the problem of experimental determination of spatial orientation, the type and number of symmetry elements in anisotropic heterogeneous media. One can study samples of ore rocks of 1 to 10 cm thick selected directly at the mine bottom or geological outcrop. Changing the wavelength one can trace the structure of the medium at the level of mineral grains, their associations and rock as a whole.

Acoustopolariscopy method. Observations by the acoustopolariscopy method are made with the use of transducers transmitting purely transverse linear polarized waves into a sample. Such a transducer is constructed so that compression waves convert into shear ones at the flat boundary between two acoustically different media [11]. Two transducers, a source and receiver are built in a device acoustopolariscope. The principal scheme of this device is shown in [4]. The latest version of a power-driven acoustopolariscope is interfaced with an ultrasonic flaw detector and PC [7–9]. The registered envelope amplitudes of the signal that has passed through the sample are digitized and processed. It allows making measurements automatically. The computer shows the acoustopolarigrams on the screen PC and plots them with the printer.

Before measurements, the polarization planes of transducers are brought in line (VP position). The sample is placed between the transducers and fixed in the holders. The coupling medium is put on the working surfaces of the transducers. In the first stage of measurements, the sample is rotated through 360°, and signal amplitudes are fixed on the screen of a recording device. The second stage of measurements is conducted with the polarization source and receiver intersecting at 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 intersecting (VC) directions of transducers polarization. Examples of theoretically calculated acoustopolarigrams are shown in Fig. 1 [4].

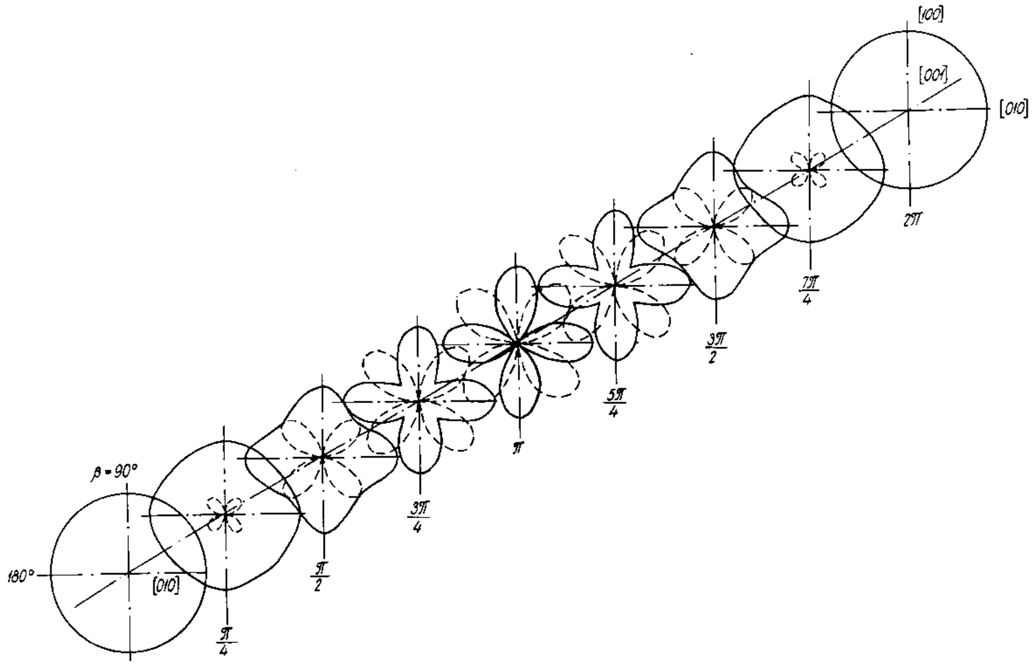

Figure 1 – Variation of maximum amplitudes (envelopes) recorded by the receiver with parallel (*VP*-solid line) and crossed (*VC*-dotted line) polarization vectors of the source and receiver of shear waves versus the sample rotation angle β and the phase difference δ [4]

As Fig. 1 shows, beyond the dependence on the rotation angle β of an isotropic sample (phase difference of the angle δ = 0) at the VP position of linear-polarized transducers of shear waves, one and the same envelope amplitude equal to VP is recorded. The configurations of the VP and VC envelopes obtained as anisotropic samples rotate, depend on the value of the angle δ. The difference δ is formed by shear wave propagation along the axis and plane of the anisotropic sample symmetry. If the sample is anisotropic, its acoustopolarigram will be similar to those in Figure 1 with δ = π/4, π/2, 3π/4. The configuration of the VC envelopes (Fig. 1) when an anisotropic sample is rotated between the transducers in the VC position is a symmetric four-petal figure independently of the phase difference 0 > δ < 2π. The amplitude minimum (VC = 0) will show the direction of the axis or plane of the anisotropic medium symmetry.

Linear (nonlinear) effects and the phenomena of elastic waves. In heterogeneous media, such as rocks, elastic properties are defined by mineral characteristics, the degree of their ordering in the rock space and the presence of preferred orientation of mineral grains. Besides, in heterogeneous materials the velocity, amplitude and phase of shear acoustic waves depend on spatial location of elastic symmetry elements. 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. 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.

Pleochroism or the phenomenon of linear anisotropic absorption is observed as the light passes through transparent media [13]. It reflects an ability to absorb a beam of polarized light in various ways when rotating its polarization vector with respect to the medium structural elements. In this case, as a rule, the largest absorption of the polarized light is observed when the polarization vector is directed perpendicularly to linearly stretched structural elements of the medium.

It is known that rocks, especially metamorphic ones, often have directed structures [1]. It is felt that in this case, by analogy with the optical phenomenon pleochroism, one can observe the phenomenon of linear acoustic anisotropic absorption (LAAA) during propagation of shear waves. Depending on the absorption degree the acoustopolarigrams will acquire the shape shown in Fig. 2 [4]. Fig. 2 shows the envelopes during the propagation of shear waves in anisotropic media with various degrees of LAAA and the phase difference δ. The degree of the observed LAAA is calculated according to the equation:

$$D = \frac{A_{ld} - A_{sd}}{A_{ld} + A_{sd}}, \tag{1}$$

where A_{ld} is the size of the largest diameter of the amplitude envelopes (VP position), A_{sd} is the diameter size of the envelopes in the perpendicular direction to the largest diameter. According to the above expression (1) the medium with a full effect of LAAA has its degree D = 1 (a full polarizer). Solids with strong LAAA act on them in the same way as a polarizer acts on light rays. With the absence of LAAA the degree D = 0.

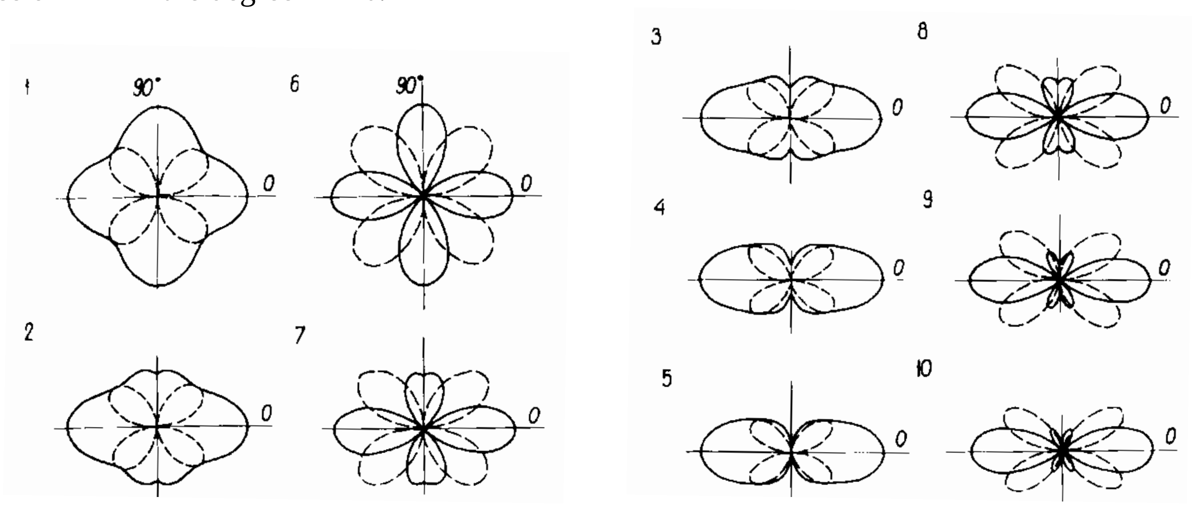

Figure 2 – Circle diagrams for variation of the amplitude of shear wave propagation in an anisotropic medium with different degrees of the LAAA effect

1, 6 – D = 0; 2, 7 – D = 0.25; 3, 8 – D = 0.5; 4, 9 – D = 0.75; 5, 10 – D = 1.0. For patterns 1–5 the phase difference is equal to $\delta = \pi/2$, for 6-10 $\delta = \pi$. Solid lines are for vectors parallel, dotted lines – for vectors crossed.

Thus the acoustopolarigrams measured in the VP position allow one to determine the availability of LAAA and other effects [4, 7, 8]. For instance, on the Fig. 3 all samples from the Finnish borehole OKU display the effect of LAAA. Sharp minimums of the amplitudes on the VC acoustopolarigrams allow one to determine the directions of elastic symmetry elements (axes and planes). Experimental measurements are made on the samples in the form of a cube or parallelepiped. It allows one to determine spatial orientation of the axes and planes of elastic symmetry. At the final stage according to the orientation of the symmetry axes and planes at each face of the cubic sample longitudinal and shear wave velocities are determined. The velocity values are recorded in accordance with the Q-matrix (quasi-matrix) V_{ij} [4]:

$$\begin{matrix} V_{11} & V_{12} & V_{13} \\ V_{21} & V_{22} & V_{23} \\ V_{31} & V_{32} & V_{33} \end{matrix} \tag{2}$$

where V_{11} is the longitudinal wave velocity in the direction along the normal to the first pair of the cubic sample sides; V_{22} and V_{33} – to the second and third pairs of the cube sides; V_{12} is the shear wave velocity in the direction along the normal to the first pair of the cube and the polarization vector directed normally to the second pair of the cube sides; V_{13} is also the shear wave velocity measured in the same direction but with the polarization vector directed normally to the third pair of the cube sides. The values of V_{21} and V_{23} are measured in the direction of the normal to the second pair of cube sides, with the vector of polarization directed to the first and third sides. The same principle is valid for the V_{31} and V_{32} values.

The phenomenon of elastc anisotropy (EA) is described in [4, 5]. In the diagrams, Fig. 3, obtained for the vectors crossed VP position one can see symmetric four-petal figures. It means that all the rocks samples studied are anisotropic to some extent.

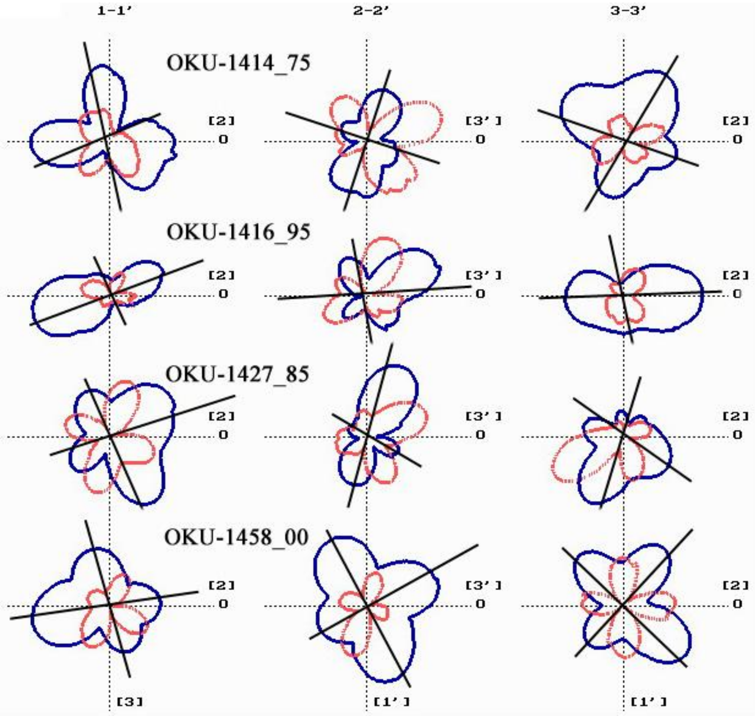

Figure 3 – Examples of acoustopolarigrams of the samples from the Finnish OKU drill hole with display of the acoustopolarization effects

OKU-1414_75, OKU-1416_95, OKU-1458_00 – serpentinite; OKU-1427_85 – serpentinite with tremolite. Blue lines – parallel vectors of polarization (VP); red lines – crossed vectors of polarization (VC); lines connecting minima of the VC amplitude – projections of symmetry elements

In some acoustopolarigrams, for example, the one for the sample OKU-1414_75, (Figure 3) the direction of the LAAA greatest transmission makes an angle with the projections of elastic symmetry elements – the phenomenon of the angular unconformity (AU). The unconformity is most often observed when the preferred orientation of microcracks does not coincide with the orientation of crystalloelastic axes of mineral grains.

The behaviour of the wave amplitude in the VC acoustopolarigrams (samp. OKU-1414_75, OKU-1416_95, side 2; OKU-1458_00, side 3; OKU-1427_85, all sides) allows one to conclude that the effect of shear waves depolarization (SWD) exists. The display of the effect is as follows: during propagation of polarized shear waves, for instance, in media with variously oriented mineral grains, depolarization of these waves occurs. The degree of the effect manifestation allows assessing the disorientation angle of elstic symmetry elements in grains (layers) of mono- and polymineral rocks.

Irregularities and breaks of the lines of VP and VC acoustopolarigrams of a large number of samples can be explained by heterogeneity of their composition and structure (Fig. 3). Irregular shapes of acoustopolarigrams of other samples can be caused by chaotic microjointing and cleavage of minerals.

Conclusion. The above-mentioned device complex gives an opportunity to evaluate properties of core samples with composite structure. The acoustopolariscopy method allows one to determine spatial orientation of the symmetry element projections, to distinguish the quasi-transverse-isotropic elastic symmetry type from the orthorhombic type. Acoustopolariscopy is a necessary intermediate stage in the investigation of an anisotropic medium. This method allows one to determine the spatial position of the symmetry elements of a rock with an accuracy of 1-2 degrees. Longitudinal and shear wave velocities measured in the directions of symmetry elements (axes and planes) allows one to determine a full set of characteristics of a solid sample.

This method can also define linear (nonlinear) effects and the phenomena of elastic waves. On the whole six factors in various combinations and degrees affect elastic-anisotropic properties of the samples from the Finnish OKU drill hole: elastic anisotropy, the LAAA effect, the effect of angular unconformity between elastic anisotropy elements and LAAA, SWD effect, microjointing and heterogeneities. These effects and the phenomena arise when carrying out investigations of massifs by seismic methods and can influence the seismogram final shape rocks. A research on linear and nonlinear effects in solid bodies, probably will allow useful methods of investigation of various microscopic structural defects of crystalline solid bodies to be devised.

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