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TEXTURE ANALYSIS AND INVESTIGATION OF PIEZOELECTRIC PROPERTIES OF NATURAL QUARTZ

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INTRODUCTION

Very often quartz-bearing rocks show the piezoelectric effect. Therefore the investigation of their properties is important for the interpretation of the physical kind of the piezoelectric effect in the polycrystalline multiphase medium. Moreover, the texture of rocks inherits the information on the deformation processes and the tectonic field which had acted during the various stages of the geological evolution of the structural elements in the lithosphere.

Recently it has become a common practice to use the results of the texture analysis for the quantitative solution of some problems of the tectonophysics and structural geology. On the other hand the recent development in the field of texture analysis is influenced by the demands of the modern geological science.

The investigation of the internal structure of the earth includes both the problem of the determination of the mineral composition in the depth of the earth and the construction of regional petrophysical models of the lithosphere. The basis of the geophysical research of the deeper structure of the earth is the interpretation of the seismic wave parameters.

Another geophysical problem is to interpret the anisotropy of physical properties of rocks and to find the possible formation processes.

The knowledge on the orientation dependence of the properties of the rocks allows to reconstruct the paleotectonic stress state in the blocks of the earth crust quantitatively[1,3].

THE PIEZOELECTRIC EFFECT OF QUARTZ-BEARING ROCKS

The piezoelectric effect of the rock samples was found and studied by M. P. Volarovich and E. I. Parkhomenko in 1953 [4]. In contrary to the pole figures the orientation dependence of piezoelectricity of rocks shows a lower but true symmetry. This is the consequence of the fact that diffraction experiments always "feel" a centre of symmetry [5] and can not distinguish between polar and bipolar axes.

Figure 1 represents the models of mutual orientations of structural elements in the quartz polycrystal generating various orientation dependencies which are found in natural rocks.

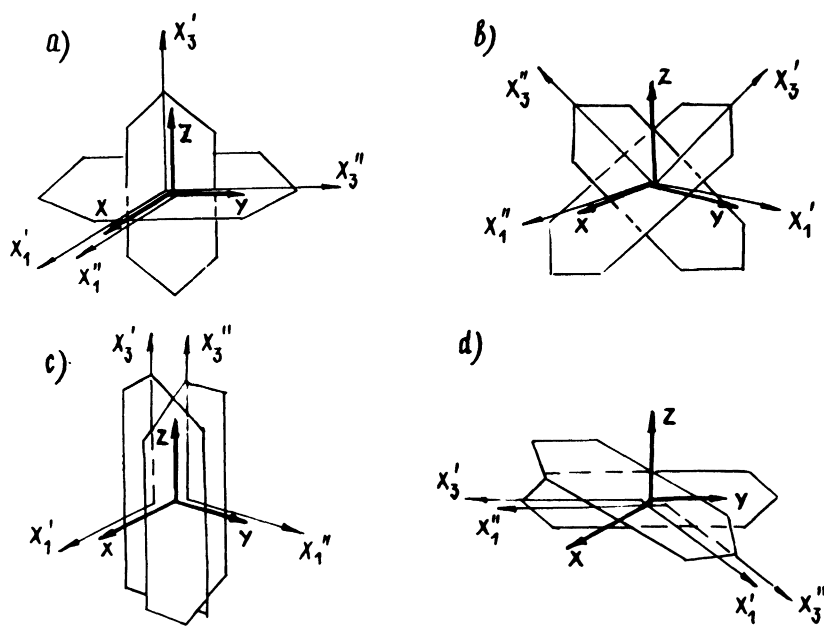

Figure 1. The orientations of crystallograghic axes of structural elements which cause various orientation dependencies of the piezoelectric properties (point groups):
a) 4mm b) m c) $\bar{6}$m2 d) 2mm

The geometric models combine two structural elements which are described by two coordinate systems $X_1X_2X_3$ and $X''_1X''_2X''_3$. Each structural element is a block consisting of two quartz crystals with various enantiomorphous modifications. These crystals are oriented so that the block has a 3-fold symmetry axis. The physical interpretation of the resulting orientation dependencies is given in [6].

THE SYMMETRY PECULIARITIES OF THE ORIENTATION DEPENDENCE

It is known that the physical properties of quartz crystals own various symmetries. We have investigated the connection between piezoelectric and elastic properties for those cases where the orientation dependence of piezoelectricity shows m, 2mm, 4mm, and $\bar{6}$m2 point symmetry. The geometrical models allow to determine the rotation angles defining the ideal orientation of crystal symmetry elements in respect to the main tensor axes.

Assuming a constant stress field in a polycrystalline aggregate we have calculated the effective elastic compliancies by means of Reuss approach [7]

$$S^{*R}_{ijkl} = \overline{S_{ijkl}} = \frac{1}{8\pi^2} \int_0^{2\pi} \int_0^{\pi} \int_0^{2\pi} f(\psi,\theta,\varphi)\ S'_{ijkl}(\psi,\theta,\varphi)\ \sin\theta\ d\psi\ d\theta\ d\varphi.$$

For the elasticity the number of independent components $\overline{S_{ij}}$ and the correlations between them do not correspond to symmetry of piezoelectric properties. If the piezoelecticty has a point symmetry of 4mm or 2mm the symmetry of the orientation dependence of elasticity will be 4mm. An axial symmetry of the piezoelectricity correspondents to a 2mm symmetry of elasticity but the $\bar{6}$m2 point symmetry of piezoelectricity will correlate with axial orientation dependence of the elasticity.

TEXTURE ANALYSIS AND RECONSTRUCTION OF PALEOTECTONIC STRESSES

The the reconstruction of paleotectonic stresses on the data on the crystallographic textures includes three main stages.

At the first step the crystallographic texture and the orientation dependens of elastic and piezoelectric properties for the chosen rock samples are measured with respect to the geographic coordinate system.

In the second stage the orientation of main axes of elastic and piezoelectric tensors are to be adjusted .

The third stage includes the calculation of parameters which define the position of main axes of stress tensor (field tensor) in respect to the axes of tensor of elastic constants (material tensor) for the rock sample.

The physical interpretation and the method of calculation of orientation parameters are described in [1,8]. Here we consider the experimental method for determining of piezoelectric symmetry of rock samples and of orientations of piezoelectric and elastic main axes.

Starting from the structure of quartz aggregate represented in figure 1c it follows that axes of piezoelectric and elastic tensors will coincide. Therefore the symmetry types of piezoelectric and elastic properties and the orientation of main axes of material tensors may be determined only on the basis of electric measurments.

The figures 2,3 represent the sections of indicator surfaces of the longitudinal piezoelectric effect for textures which cause $\bar{6}m2$ and axial symmetries of the piezoelectric effect. The sections of indicator surfaces of the C_{33} elastic module for the same orientation are shown in figure 4 and 5.

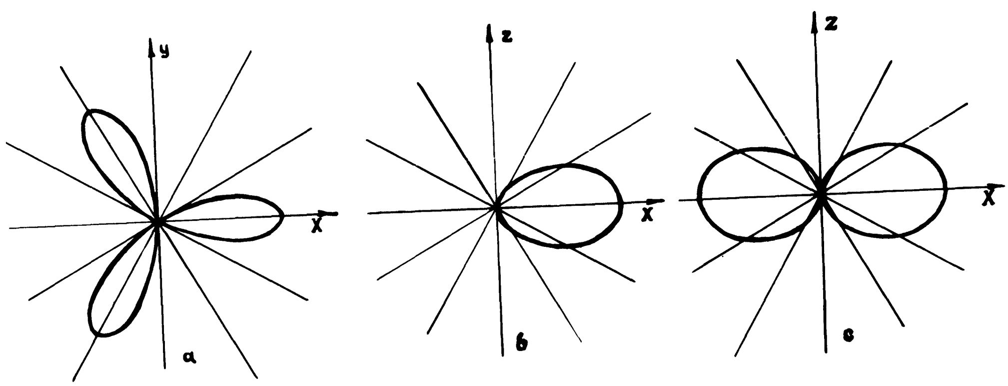

Figure 2. The sections of indicator surface of longitudinal piezoelectrical effect for the $\bar{6}m2$ symmetry of properties: a) xy section; b) xz section; c) xz section of indicator surface of transverse piezoelectrical effect.

For our experiments we use models consisting of 12 quartz cylinders (25 mm height, 5, 35, or 40 mm diameter) in a plexiglass matrix. These cylinders are cut from an artifical growen monocrystal with the cristallographic y-axis as cylinder axis and arranged strongly parallel to this axis within the matrix. Crystallographic axes of all bars had orientations with the precision of 1'.

The model for an ideal orientation dependence of the piezoelectricity has all electric axis parallel. The quartz crystals were fixed in the matrix by an adhesive lubricant.

The angular dependencies of the transverse piezo-electric effect was measured according [9].

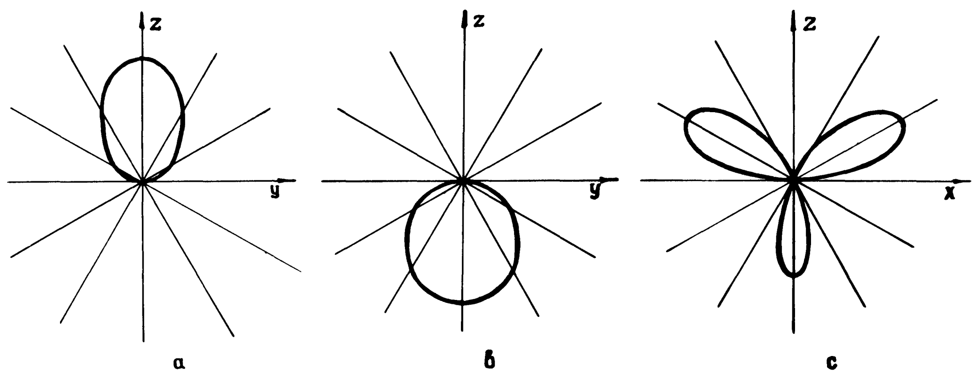

Figure 3. The sections of indicator surfaces of piezoelectric effect for an axial symmetry of piezoproperties: a) yz-section of longitudinal piezoeffect for d_{33} piezomodule; b) yz-section of transverse piezoeffect for d'_{31} piezomodule; c) xz-section of transverse piezoeffect for d_{31} piezomodule

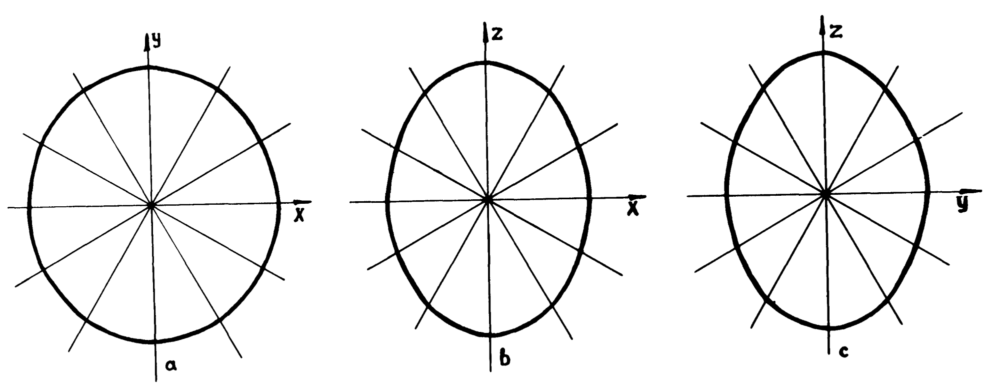

Figure 4. The sections of indicator surface of elastic module C'_{33} for axial symmetry of elastic properties: a) xy-section; b) xz-section; c) yz-section.

Then one grain was successivly turned so that its electric axis would be oriented to the direction of electric axes of the others under 30^0, 60^0, 90^0, 120^0, 150^0, and 180^0 (denote this angle as α). The angular dependencies of piezoelectric effect were measured for each position. Then the measurments were repeated for various numbers of grains with characteristic orientation. Let us denote with n the ratio of the number of grains with changed orientation to the whole number of grains.

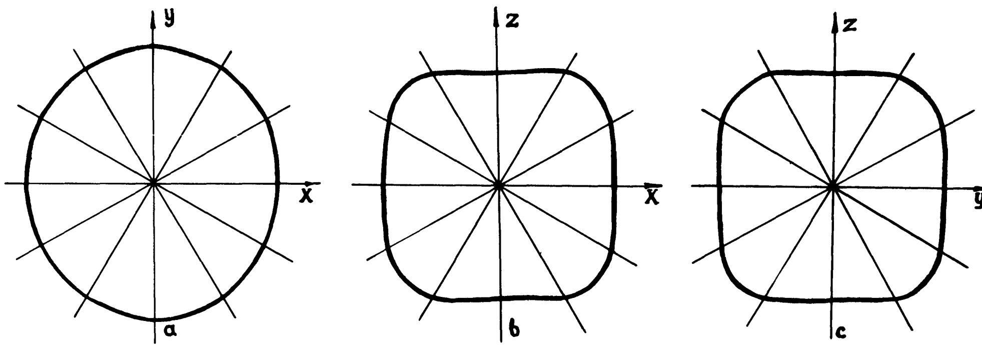

Figure 5. The sections of indicator surface of elastic module C'_{33} of textured quartz aggregate with the 4mm symmetry of elastic properties: a) xy-section; b) xz-section; c) yz-section.

The experimental data got for model (figure 6) looks like the theoretical section of indicator surface of transverse effect with a $\bar{6}$m2 point symmetry (figure 2c).

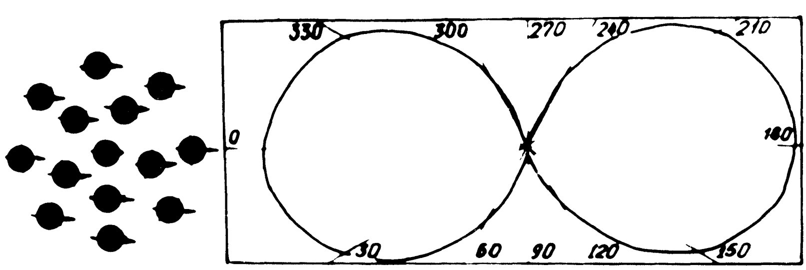

Figure 6. The angular dependence of electric field potential for the transverse piezoelectric effect which is obtained in the ideal model of grain location corresponding to the $\bar{6}$m2 symmetry type.

The figure 7 shows data for the electric field for different α angels, but for constant n which is equal to 33% and 50%. We found that for n=33% a increasing of α from 0 to 180^0 did not change the dipole character of the electric field, but influences slightly on its shape. For n=50% (figure 8) the field shape have become quadrupole beginning from α= 60^0.

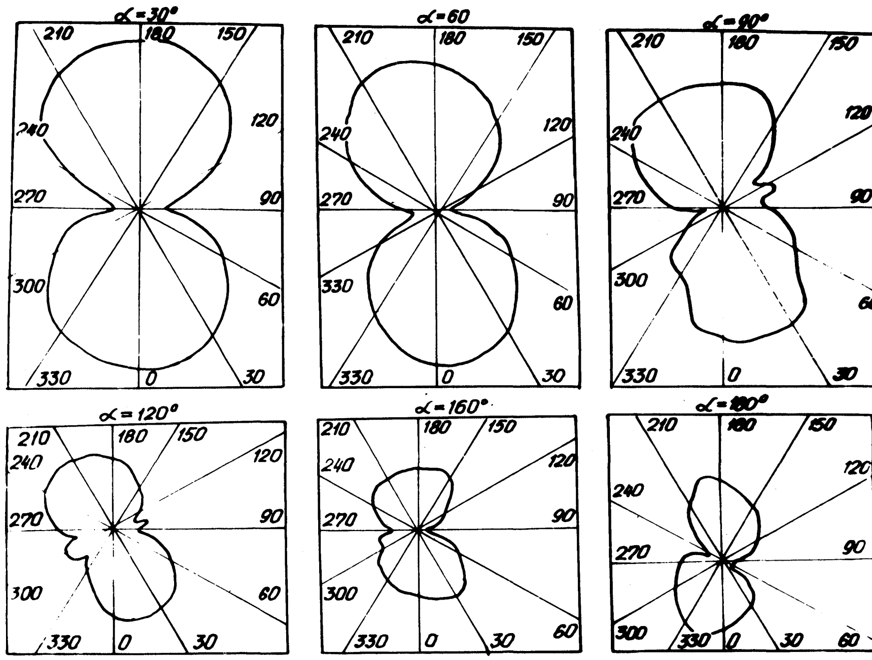

Figure 7. The angular dependencies of the piezoelectric field potential which is obtained in the piezotexture model for partly scattered electric axes (n = 30%).

In the cases of piezoelectric neutrality the symmetry type of physical properties and the orientation of the main axes of the elastic tensor in rock sample are determined from pole figures which are measured by means of neutron diffraction. The exact decision of this question is achieved by means of ODF which is used for calculation of the effective moduli of material tensors with the help of theoretical-probably methods [10,11].

A veined quartz sample taken from one gold-containing deposit of Uzbekistan was chosen for determination of the symmetry of piezoelectric properties both on the basis of the piezoelectric field configuration and on data from neutron diffraction.

The experiments have been carried out at the pulsed reactor IBR-2 of the JINR Dubna [12]. Figure 9 represents 8 pole figures which have been obtained by time-of-flight technique. The distribution of normals to the rhombohedral planes ({10$\bar{1}$1} - pole figure) is characterized by high density. The maxima of pole density are at angle distances of 60^{0} to each other. The similar result occurs in the {11$\bar{2}$0}-pole figure. That are the 6 maxima which are connected with

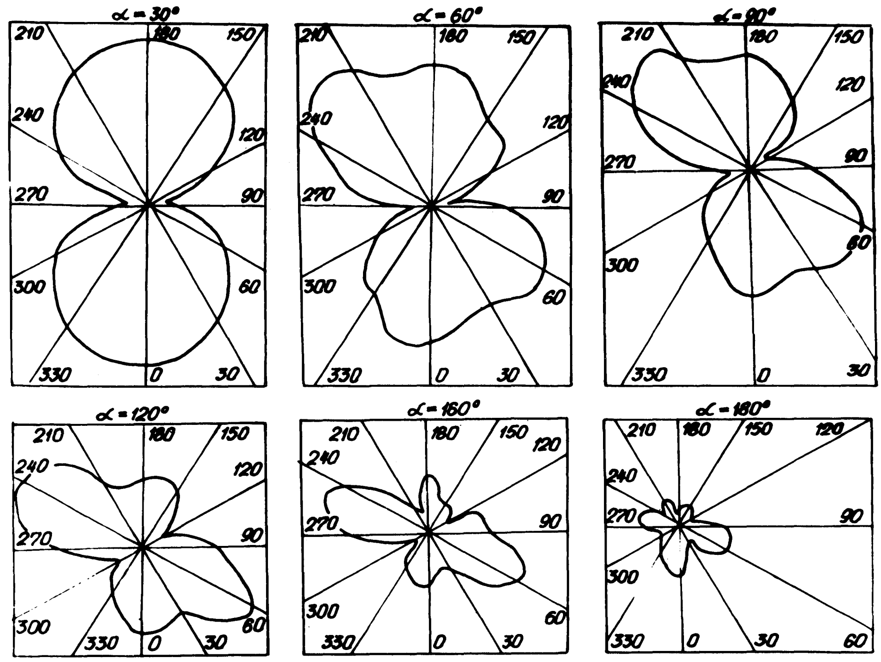

Figure 8. The angular dependencies of the piezoelectric field potential obtained in the piezotexture model for partly scattered electric axes (n = 50%).

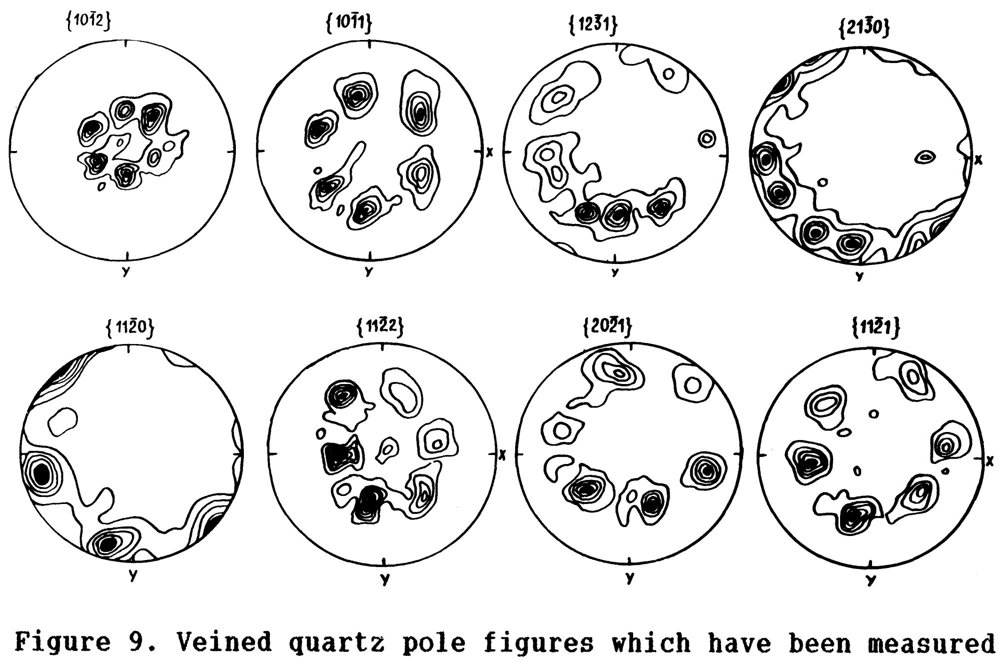

Figure 9. Veined quartz pole figures which have been measured by neutron diffraction method.

the electric quartz axes. Such density distributions are usually interpreted as the presence of symmetry axis of either the 6^{th} or the 6^{-th} order. The measured sample shows piezoelectricity and its symmetry axis is normal to the $u_x u_y$-plane. Rotation about 120^0 on the axis normal to the $u_x u_y$-plane is considered to be a physical invariant transformation. It has been proved by means of electric measurements that the order of symmetry axis is equal to 3.

The above-described methods of texture analysis have been used for reconstruction of paleostress state of tectonic block in the zone of Kochkar gold-containing deposit (South Urals)[2] and published elsewhere[13]

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