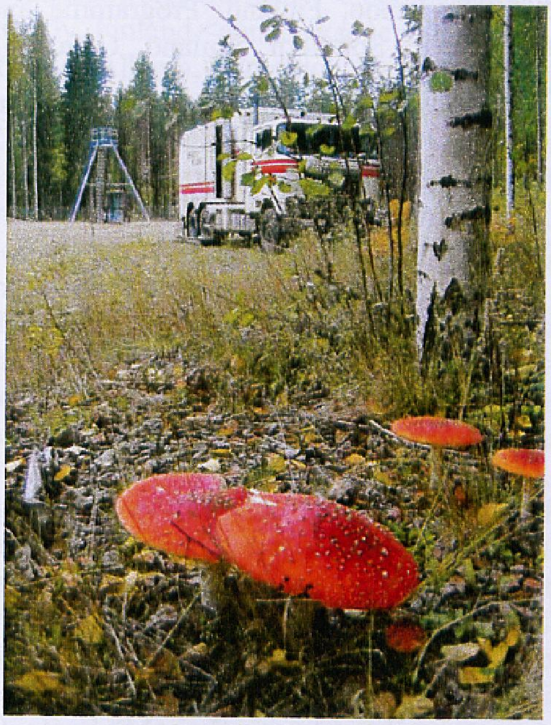
Outokumpu Deep Drilling Project



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Peculiarities of Elastic Symmetry of Crystalline Rocks in the Outokumpu Drill Hole Section

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Introduction

The investigation drill hole Outokumpu is located in SE Finland near the worked-out deposit bearing the same name. Fig.1 shows the geological structure of the drill hole and its location (Huhma, 1975). It reached a depth of 2516 m. Seismic constructions suggest that basic rocks are presented by mica and black schist. The boundary separating Proterozoic rocks from the Archaean basement is at a depth of 1.2–1.3 km. The real section showed that the upper drill hole down to some 1310 m has passed through mica schists with rare interlayers of biotite gneiss (Kukkonen, 2004). The 1310-1515 m interval is composed of alternating beds of black schist, biotite gneiss, serpentinite and diopside-tremolite skarn. Below 1515 m mica schist with rare beds of black schist and quartz veins occur. From a depth of 1655 m mica schist alternates mainly with bodies of pegmatite granite and biotite gneiss. Pegmatoide granite, garnet-biotite gneiss and biotite –sillimanite schist compose the lower part of the stripped section down to the limiting depth of 2516 m.

Methods

At the first stage of investigations we identified types of the rocks, texture, structure, composition and density of 43 samples brought from Finland. At the subsequent stages we determined the rock density and performed acousopolariscopy of the samples (Gorbatsevich, 1995). The acoustopolariscopy allows determining the presence of elastic anisotropy, a number and spatial orientation of symmetry elements, the symmetry type and elasticity constant values. The method has been approved for the media of transverse-isotropic, rhombic and other symmetry types. Cubic samples prepared for measurements were oriented in such a way that the normal to side 3 coincided with the drill hole axis, Fig. 2. The rock density was determined by the Archimedean method.

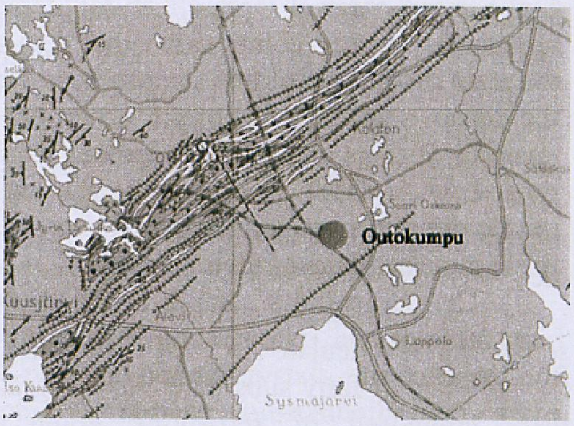

Fig. 1. Geological structure and location of the investigation drill hole Outokumpu.

Results

Figure 3 gives acoustopolarigrams of samples №№ ODB-153_20, ODB-599_00, ODB-1101_30, ODB-1414_75, ODB-1488_65, ODB-1893_80, ODB-2155_15, ODB-

2297_25. The Table presents the names of rocks, density, calculated index of linear acoustic anisotropic absorption *D,* angles α, β of the symmetry elements projections in relation to the sample sides.

According to Fig. 3 and the Table, the sample ODB-153_20 of garnet-biotite schist with graphite is an elastic anisotropic medium of transverse-isotropic symmetry type. The presence of two projections of elastic symmetry elements on the sample's first and second sides clealy points to this. On the third side formed along the normal to the drill hole axis, projections of the elastic symmetry elements have not been revealed. The rock represented by the sample ODB-153_20 formed under a stable palaeostress field action, which vertical component was prevailing.

Another sample of garnet-biotite schist with graphite - ODB-599_00 (Fig. 3, Table) is an elastic anisotropic media of orthorhombic symmetry type, as evidenced by the presence of two projections of elastic symmetry elements on all three sides of the sample. Both planes of elastic anisotropy cross at a right angle. The line of their intersection virtually coincides with the borehole axis. On the whole, the rock in the sample ODB-599_00 formed under stable and unilateral field of lithostatic palaeostresses in the presence of some tectonic forces. The direction of the palaeotectonic component was subhorizontal.

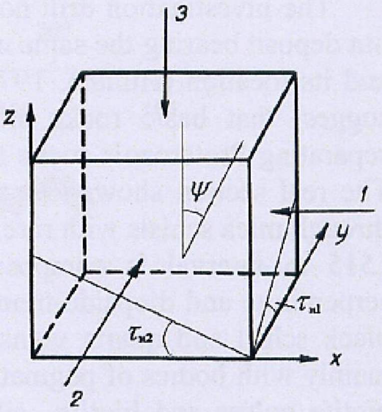

***Fig. 2.** The shape and indexation of the sample.*

The ODB-1101_30 sample of biotite-muscovite schist with gypsum-carbonaceous veinlets is also an elastic-anisotropic medium of the orthorhombic symmetry type, Fig. 3. The rock in the thin section is characterized by the presence of interbeds of biotite muscovite-plagioclase and appreciably quartz composition that determine the protolith initial heterogeneity. But the main distinction of this sample from the ODB-599_00 is substantial manifestation of the linear acoustic anisotropic absorption (LAAA) effect. The presence of a great quantity of mica and gypsum-carbonaceous veinlets is likely to be the reason for such great LAAA effect. According to the known data (Belikov et al., 1970), biotite and muscovite are characterized by a sharp distinction in elastic properties along and across the symmetry plane of their crystals.

The serpentinite sample ODB-1414_75 (Fig. 3, Table) is mainly composed of serpentine of reticulate structure. The relict porphyroid texture of the rock is caused by the presence of fully substituted coarse grains of olivine (separated by the fine grained mass composed of serpentine grains and ore mineral) by serpentine. The acoustopolarigrams reflect the rock comlicated texture. For instance, in the thin section one can single out the elements that form some trigonal symmetry.

The ODB-1488_65 sample's thin section of diopside-tremolite rock shows the presence of elements of reticulate, porphyroid, streaky texture. The mineral grains have isometrical elongated shape and greatly differ in size – from 0.2 mm to 3 mm. Accordinly, the acoustopolarigrams for all three pairs of faces, Fig. 3, reflect heterogeneity of the structure, chaotic spatial orientation of the elastic symmetry elements in the mineral grains. On the first and especially second faces of the sample the effect of depolarization of shear waves (DSW) manifests itself (Gorbatsevich, 1998). A similar effect of depolarization of linearly polarized light waves in their propagation through accidentally heteroneous media or media composed of anisotropic materials (layers) with differently oriented symmetry elements, was earlier registered in optics (Shurkliff, 1962).

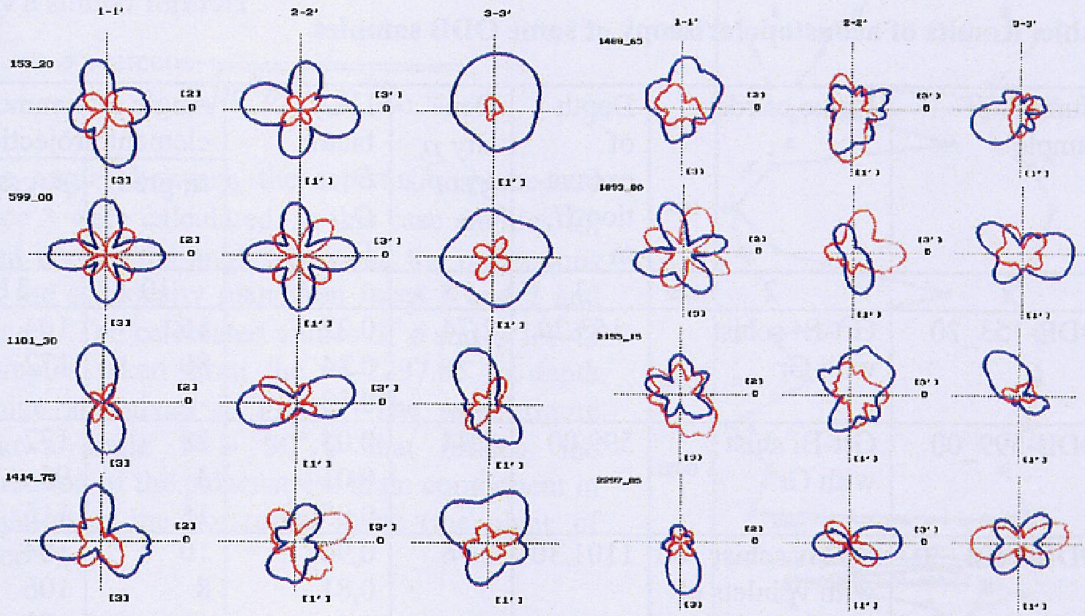

Fig. 3. *Acoustopolarigrams of the rock samples extracted from the Outokumpu Drill Hole. A blue line is for the VP acoustopolarigrams, a red line – for the VC ones.*

The acoustopolarigrams for the ODB-1893_80 sample of coarse grained muskovite-plagioclase granite with garnet show that its structure is more ordered than that of the preceeding sample. The rock is composed of large (2-5 mm) crystals of polysynthetically duplex plagioclase, maximum (lattice) microcline, wavily fading quartz grains, rare plates of muscovite. The elastic symmetry elements are conspicuous on the first face (Fig. 3). They can also be distinguished on the second and third faces. The acoustopolarigrams of the second and third faces show the presence of the LAAA effect which can be explained by the availability of plagioclase and mica. On the whole, the rock of this sample may be characterized as heterogeneous anisotropic with the LAAA manifestation.

The sample ODB-2155_15 (muskovite pegmatite with garnet) has a porphyroid structure and is composed of microcline-perthite large crystals, fine grains of plagioclase and quartz. Garnet idiomorphic grains of substantially almandine composition are included in microcline crystals. This rock is characterized, besides heterogeneities in its composition, by manifestation of the DSW effect. The third face of this sample showed the LAAA effect display (Fig. 3).

The acoustopolarigrams for the sample ODB-2297_85 of biotite schist are similar to the diagrams for schists from the upper section down to a depth of 1300 m. The sample has a conspicuous rhombic symmetry since the projections of its elements are clearly seen on every face. The presence of substantial metamorphic reworking of the sample's mineral substance is confirmed by the LAAA strong manifestation on the first ($D = 0.38$) and second ($D = 1.0$) faces (Fig. 3, Table).

Determination of the spatial location of the elastic symmetry element projections in relation to the sample faces allows obtaining the data on the direction of the palaeostress main component in relation to the horizontal plane (in this case in relation to face 3).

Table. Results of acoustopolariscopy of some ODB samples

Number of sample	Name of rock	Depth of excavation H, m	Density ρ, g/sm^3	LAA factor D_1, D_2, D_3	Angle of symmetry element projections	
					α, grad	β, grad
1	2	3	5	9	10	11
ODB-153_20	Grt-Bt schist with Gr	153.20	2,74	0.22 0.24 0.13	16 80 -	104 172 -
ODB-599_00	Grt-Bi shist with Gr	599.00	2.74	0.05 0.01 0.05	88 3 15	177 95 115
ODB-1101_30	Bt-Ms schist with veinlets of gypsum-carbonaceous composition	1101.30	2.76	0,90 0,81 0,51	10 8 110	104 106 177
ODB-1414_75	Serpentinite	1414.75	2,49	0,21 ~0,7 0,04	75 70 62	160 162 161
ODB-1488_65	Di- Trem rock	1488.65	3.26	0.11 0.21 0.23	72 50 19	162 176 128
ODB-1893_80	Mc-Pl, Grt-containing coarse granite	1893.80	2,65	0,02 0,71 0,25	13 33 75	114 127 138
ODB-2155_15	Mc- pegmatite with Grt	2155.15	2.62	0,10 0,09 0,66	- - 29	- - 121
ODB-2297_85	Bt- schist	2297.85	2.72	0.38 1.0 0.06	94 16 59	174 77 116

Note. Mineral symbols are from Kretz, 1983.

To obtain such information we have used the values of angles α and β between face 3 and the projection of the elastic symmetry element on faces 1 and 2. Of these, angles τ_{n1} and τ_{n2} of the element projections with the greatest anisotropy have been used, Fig. 2. The calculation of the angle ψ between the planes of elastic anisotropy and face 3 was done by formula (Gorbatsevich, 1995):

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4. Most important palaeogeodynamic events in the Outokumpu drill hole section took place at depths of about 800, 1330-1360, 1460 m and in the range of 1650-2300 m. Displacement of the rock individual blocks in the course of palaeogeodynamics was likely to occur in these ranges.
5. The obtained preliminary results show a possibility, with attraction of geochronological data, to reconstruct the parameters of regional palaeogeodynamics and analyse palaeotectonics in the Outokumpu drill hole section.

Acknowledgements

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