Geophysical Research Abstracts, Vol. 7, 00154, 2005
SRef-ID: 1607-7962/gra/EGU05-A-00154

Geodynamics and structure of the upper Earth's crust: data obtained from the Russian superdeep borehole drilling programme

F. Gorbatsevich (1), F. Mitrofanov (1), C. Gillen (2), D. Guberman (3)

(1) Geological Institute, Kola Science Centre of the Russian Academy of Sciences, Russia,

e-mail: gorich@geoksc.apatity.ru,

(2) The University of Edinburgh, Office of Lifelong Learning, Edinburgh, United Kingdom,

e-mail: C.Gillen@ed.ac.uk,

(3) Scientific Industrial Centre "Kola Superdeep", Russia, e-mail: SD3KGL@com.mels.ru

The Russian superdeep boreholes drilling program (RSBDP) has included projects for drilling deep and superdeep boreholes in sedimentary basins and in crystalline basement massifs [1]. A full set of investigations was carried out on the Ural, Tyrnyauz, Vorotilov and Kola holes that penetrated crystalline massifs. These included geological, geochemical, geophysical, petrophysical and other investigations of massifs in the holes and in their vicinities. The results obtained allow common and distinctive features in the structure of the crystalline crust near these boreholes to be analyzed. Here we consider features of crust of difference ages in these borehole sections.

The Ural superdeep borehole (SG-4) has been drilled in the western part of the Tagil megasynclinorium [2]. One of the objectives was to obtain data on the deep structure of rocks, the nature of seismic boundaries, palaeogeodynamics of the southern Urals, parameters of modern stress, physical properties of rocks *in situ*. SG-4 cuts Palaeozoic rocks (~340-440 Ma), to a depth of about 5.4 km. An analysis of the data shows that the section of SG-4 down to 2.87 km contains comparatively homogeneous and strongly isotropic solid rocks. A volcano-sedimentary rock unit (0.43-2.6 km) is more homogeneous and is characterized by a slight increase in density, velocities of compressive and shear waves. The modern stress field in this interval is quiet. Very weak elastic anisotropy in these rocks has been registered. Below a depth of 2.87 km, rocks with high elastic anisotropy have been found. The prevailing symmetry type in rocks is transversal isotropic. Analysis also shows that the main component of the palaeostress field at a depth of about 2.87 km was directed to the vertical at an angle of 57-76^0.

The Tyrnyauz deep hole (TGS) is located near the ore field of the large-scale Tyrnyauz deposit of wolfram and molybdenum, in the north-western part of the Caucasus [3]. The hole penetrated the central part of the 1.2–2.5 Ma Eljutin granite intrusion. The depth of the borehole is 4.0 km. A peculiarity of the TGS section is the fact that it contains granite of high geological homogeneity. On the background of this homogeneity, advanced fissuring and tectonic zones are observed. Rocks of the TGS section exhibit a marked level of elastic anisotropy. The analysis has shown that the main component of the palaeostress field was directed in a near east–west direction. Modern stresses in the TGS massif are strong. The predominant orientation of the main component of the stress field is near north–south. It is remarkable that the azimuths of the palaeo- and modern stress orientations differ by an angle of about 90^0.

The Vorotilov deep borehole (VGS) is situated in the Puchezh-Katunki impact structure (central part of the Russian plate, to the North of Nizhny Novgorod) [4]. The maximum depth of VGS is 5374 m. Down to $\sim$550 m the hole intersects Jurassic, Cretaceous and Cenozoic sediments. Down to $\sim$1.6 km the hole penetrates breccias of Triassic, Permian, Proterozoic and Archaean rocks. The Archaean crystalline basement was found at a depth of about 1.6 km. Our results show that below the depth of 2 km, the mechanical influence of impact on massive rocks was not registered. The Archean crystalline basement in the interval of 2.0–3.0 km comprises dense homogeneous, weak elastically anisotropic biotite–amphibole gneisses and amphibolites. From a depth of 3.0 km the same rocks with a marked and high level of elastic anisotropy occur. The direction of the palaeostress field main component is mainly quasi-horizontal. The predominant orientation of the main component of the modern stress field is almost north–south (as for TGS).

The Kola Superdeep Borehole (SG-3) has been drilled in the northern NW-trending (300-310^o)and SW-dipping (30–50^o) limb of the Pechenga rift structure, composed of rhythmically alternating volcanic and volcano-sedimentary sequences [5]. The section of SG-3, whose pilot borehole reached 12,261 m, is represented by two rock complexes: Proterozoic (0–6842 m) and Archaean (6842–12,261 m). The data obtained enable one to subdivide the SG-3 section into 10 anisotropic-structural stages that differ in spatial characteristics of their occurrence, the strike azimuth of the elastic anisotropy plane, and its average dip. The analysis of the palaeostress directions suggests repeated changes in the force vectors during the Proterozoic and Archean stages of evolution. Except for the ore interval (1.7–1.9 km), the Proterozoic rocks in the SG-3 section originated under relatively stable tectonic conditions and weak horizontal forces. Variability in directions from stage to stage in the Proterozoic section indicates that the anisotropy registered in the rocks was formed by the palaeostresses alone, since the modern stress field in this region is NW–SE-striking.

There are some common features in the structure of the Earth's crystalline crust of different ages in the sections of boreholes SG-4, TSG, VSG and SG-3. The orientation of palaeo- and modern stress components does not coincide. Older rocks have higher levels of elastic anisotropy, therefore higher levels of palaeostresses acted in the past.

Finally it should be noted that deep and superdeep boreholes are a single tool fit for collation of information obtained at the surface by various seismic methods, such as the reflection method, common depth point method, deep seismic sounding, earthquake reflection method, refraction method etc.

The work has been done in the framework of INTAS-01-0314 and RFBR 03-05-64169.

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