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Seismic and density heterogeneity distribution in the earth crust of the White Sea Region

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SUMMARY

The goal of the present project is to study the terrestrial and marine zones of the White Sea Region known as Belomorye and located in the northern East European Platform, on the eastern slope of the Fennoscandian Shield overlain by the sedimentary cover of the Russian Plate. The Barents Sea and Scandinavian ice sheets interacted here repeatedly in Pleistocene glacial epochs. New data on the deep structure of the White Sea Region have been obtained during geological and geophysical studies in the past few years. The aim of the project is to combine the results of the studies of the marine and land zones of the region to obtaine information on the ratio of different crustal megablocks at the Fennoscandian Shield-Russian Plate contact and for throwing light on the early and final stages of crustal evolution. The density and magnetic 3D – models, constructed with use of program complex INTEGRO, give additional information about the structural characteristics and evolution of the lithosphere of the region, about the layering and thickness of the earth crust and the morphology of geophysical boundaries.

Introduction. The continental crust in the region discussed is assumed to have been formed in Archean time, and the structure of Precambrian blocks has remained unchanged. The earth crust was considerably transformed more recently only in areas subjected to tectono-magmatic activation of rift-related or plume origin. This assumption is supported by the fact that the sources of large-scale gravity and magnetic field anomalies in the Fennoscandian Shield coincide in plan view and that the shape and position of the anomalies in plan view in the northeastern Mezen syneclise do not coincide, which seems to be due to rifting in the Early and Late Proterozoic followed by active tectono-magmatic processes which affected the northeastern margin of the East European Platform.
As the study of Arctic territories have become increasingly active, earlier data on the deep lithospheric structure of the region should be re-assessed and new data should be obtained. The Fennscandian Shield-Russian Plate contact zone is of great interest in this respect. The Arkhangelsk Diamondiferous Province (ADP) is now a second (after Yakutia) area in the Russian Federation with prospected reserves of bedrock diamond deposits. In addition to two bedrock diamond deposits in ADP named after M.V.Lomonosov and V.V.Grib, about 90 alkaline ultramafic rock pipes and sills are known.The last economic deposit was discovered over 20 years ago, but more deposits are likely to be discovered.
Relevant methods are described in detail and the final results, obtained by methods for integrated interpretation of seismic, petrophysical, gravimetric and magnetic data on the earth crust of the White Sea Region, are reported.

Methods and results. The region's deep structure was studied using the results of gravimetric and magnetic survey presented as 1:1 000 000 scale maps as well as earlier seismic data. A geological model of the environment was constructed, based on the results of geophysical studies (Figure 1) along geotraverses 3-AP, 1-EB, QUARTZ, AGATE, etc., and geology-geophysical summary maps and schemes were used.

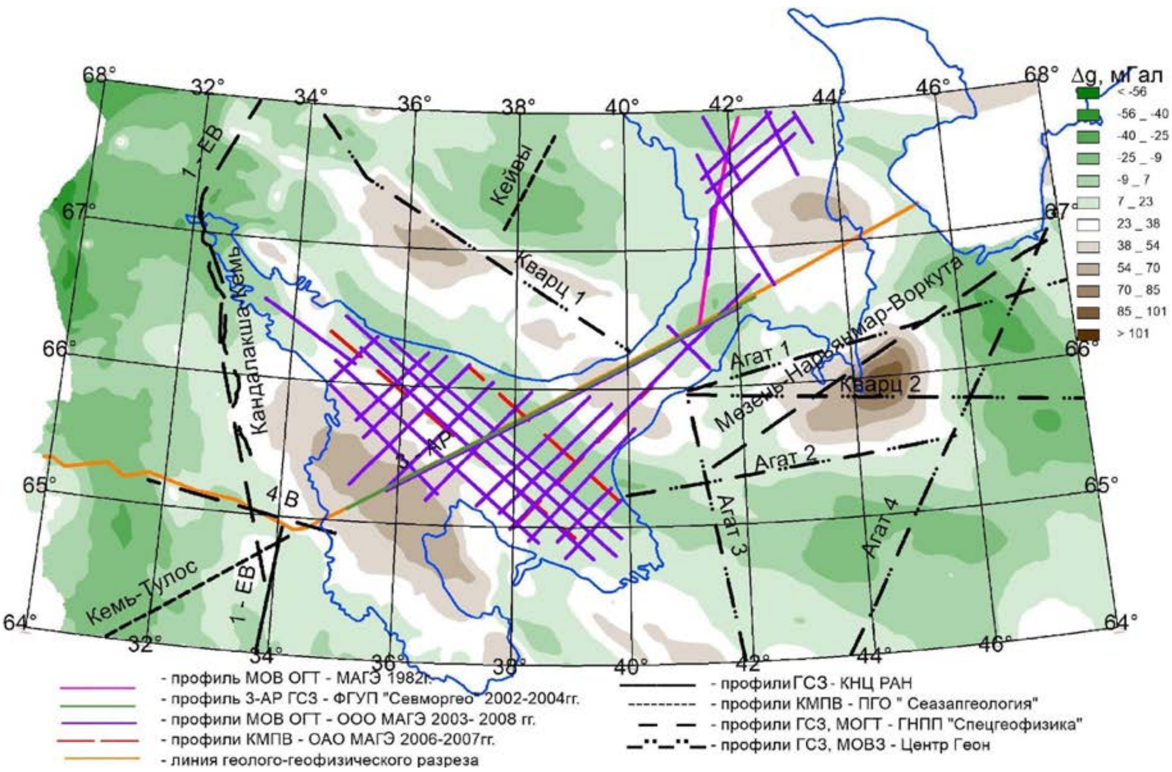

***Figure 1** Scheme showing the distribution of seismic profiles and the regional constituent of the gravity field in the White Sea Region and adjacent areas.*

A seismic and density model of the region's consolidated crust was constructed using an earlier four-layered velocity model of the earth crust as reference information (Sharov, 2017). The model has the following characteristics: sedimentary layer V_p = 3.4-5.7 km/s, ρ = 1.90—2.60 g/cm^3; upper layer (upper storey) — V_p = 5.90—6.20 km/s, ρ = 2.60—2.75 g/cm^3; middle — V_p = 6,30—6.50 km/s,

ρ = 2.75—2.90 g/cm^3; lower — V_p = 6.60—6.80 km/s, ρ = 2.90—3.00 g/cm^3; fourth high-velocity layer — V_p = 7.00—7.30 km/s, ρ = 3.00—3.20 g/cm^3; mantle — V_p = 8.00—8.20 km/s, ρ = 3.40 g/cm^3.

Seismic data were generalized, seismic- gravity modelling was carried out and a four-layered cross-section through the earth crust, in which sedimentary cover and the upper, middle and lower crusts were identified, was constructed.

The data obtained were processed and analyzed using GIS INTEGRO (VNOGNI, VNOOgeosystems Division), which contains all procedures required for calculation of density and magnetic models and their 2D and 3D visualization (Cheremisina et al, 2018).

Results of geology-geophysical 2D modelling along combined profile *4B (Kem-Kalevala) and 3-AP (Kem-White Sea outlet*). Figure 2 shows the results of density and magnetic modelling along the seismic profile. Density and magnetization distribution in the earth crust sequence is shown. The results are supplemented by diagrams showing observed, simulated and residual gravity and magnetic field anomalies.

The results of modelling are represented by density models constructed along seismic profile 3-AP (Kem-White Sea outlet) (Figure 2). The seismic profile line is shown in Figure 1. The Figure shows density distribution throughout the entire crustal sequence in accordance with proposed division into four layers based on seismic data as well as effective density and magnetic heterogeneity distribution. At stage 1, a density section, adequate with the gravity field observed, was selected with regard for the contribution of individual anomaly-forming objects to the gravity field. The boundaries of layers and tectonic dislocations mapped on the seismic profile are shown on the effective density section. The difference field, Δg, is shown in the Figure as the result of modelling. The upper portion of the section up to surface K1 is most heterogeneous. A common elevated density region is occasionally traced at depth beneath some of consolidated rock exposures by comparing with a geological map.

Seismic-density modeling of the section in the White Sea on profile 3 AP supports the existence of a magma chamber beneath the Kandalaksha and Keret rifts (Zhuravlev, 2007). The chamber can be traced into the lower crust, and seems to be connected with the mantle. At depth, the magma-feeding channel plunges northeast in accordance with the general dip of the rock complexes of the Belomorian belt. Tectonic dislocations in the upper portion of the sequence dip southwest or vertically, because the rocks are less plastic. At depth, the faults are flattened northeast due to the rheology and kinematics of rock movement (Baluev, et al., 2012).

The seismic-density data obtained for the Kalevala — Kem — White Sea outlet profile show that the region's crust is a layered-blocky medium. Variations in velocity and density in a horizontal direction are correlated with crustal heterogeneities responsible for its blocky geological structure. Lateral crustal heterogeneity is predetermined by the fact that the blocks occur as terrains which evolved in various geodynamic regimes and were combined during Neoarchean and Svecofennian collision processes.

Summary. A modern concept of the deep lithospheric structure of the White Sea Region, based on analysis of available geological and geophysical information obtained in the past 40 years, is presented. For the first time in the region, agreeable 2D and 3D geology-geophysical models of the earth crust structure over its entire length, based on interpretation of up-to-date seismic, gravimetric, magnetometric, petrophysical and geological data, were constructed (Figure 3). The flowing conclusion, based on the models, was drawn.

Comparative analysis of wave fields for all region's profiles was done to choose a general (basic) model of the earth crust, which can be used as reference to reveal general trends in variations in the physical parameters of the crystalline crust. The model is a form of approximation to the real velocity structure of the crust. It can be used to present sections for all profiles in one form and to construct a 3D velocity model.

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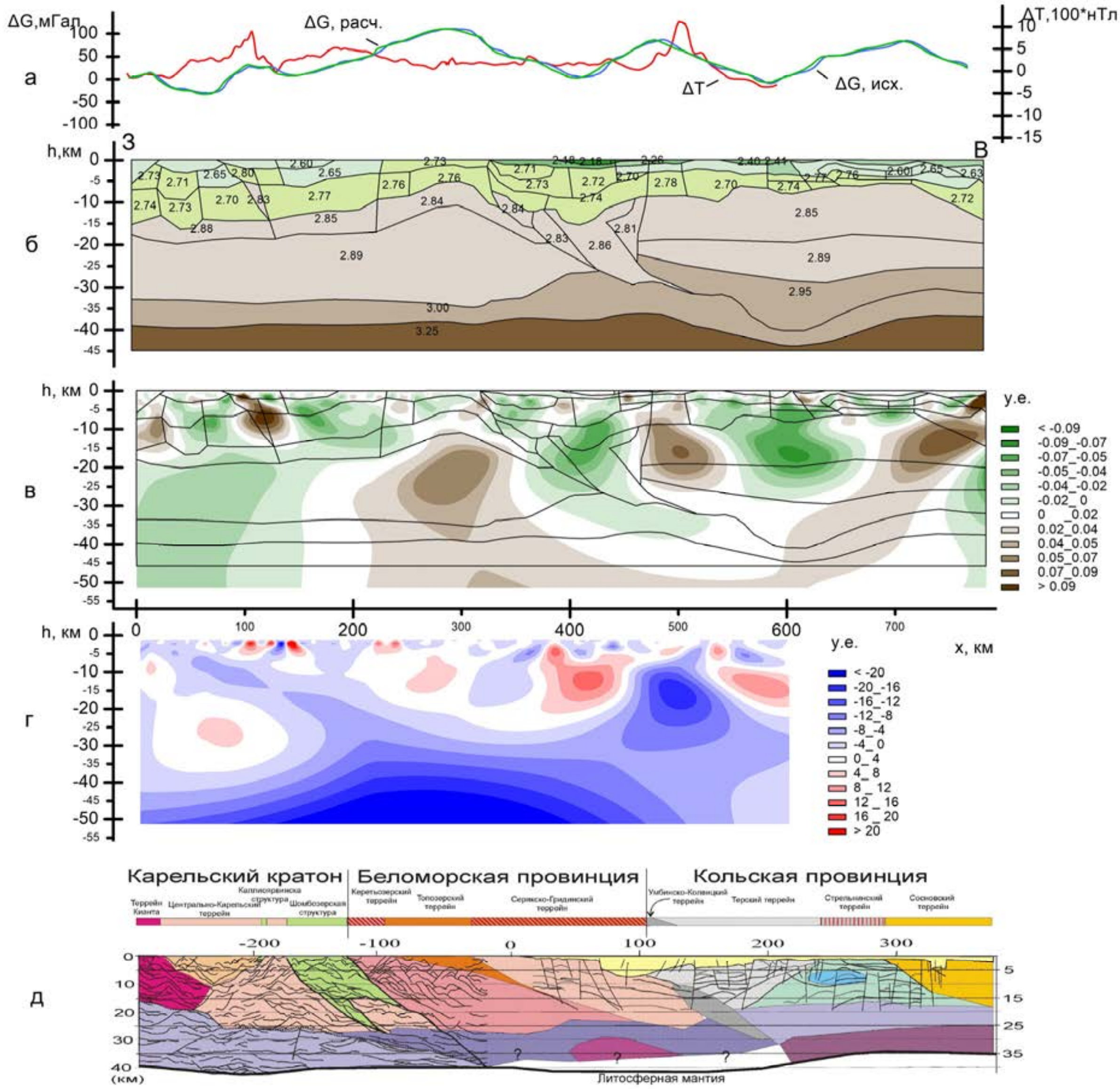

Figure 2 *Geology-geophysical models for profiles 4B (Kem-Kalevala) and 3-AP (Kem-White Sea Strait): (a) plots of observed and model fields, (b) density block model based on seismic data, (c) effective density distribution, (d) distribution of magnetic heterogeneities, (e) geology-geophysical cross-section through the earth crust.*

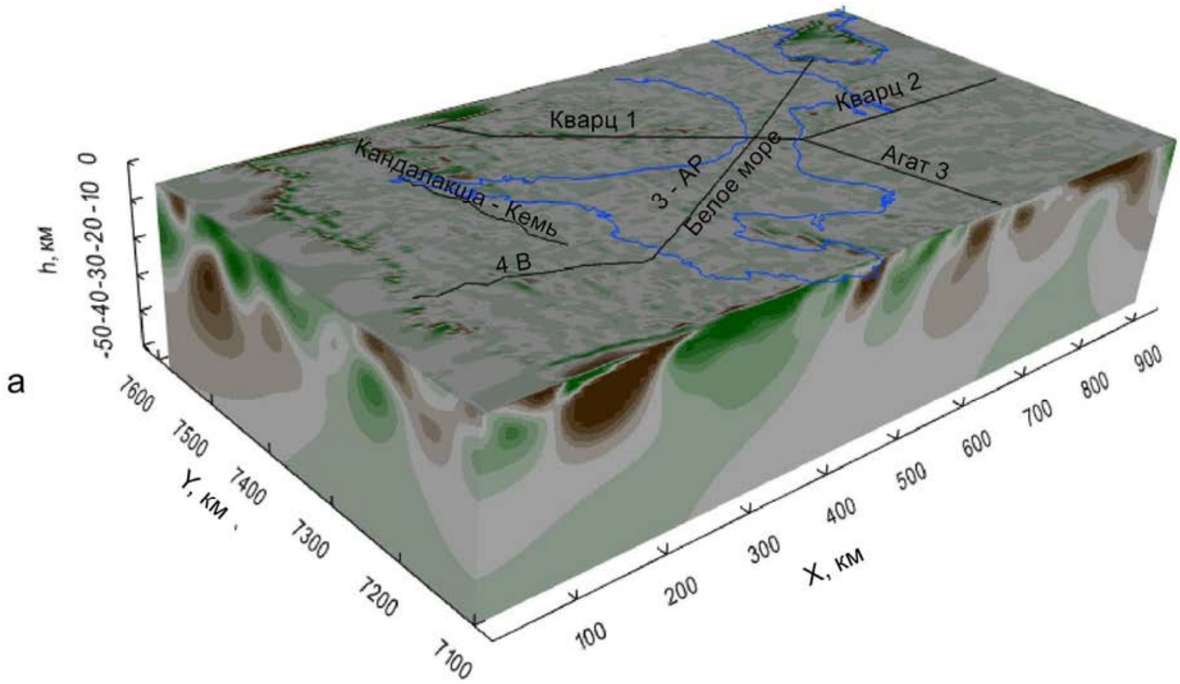

Figure 3 *3D models of effective density distribution in the earth crust of the White Sea Region. The shoreline and position of the seismic profiles are shown.*

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