Gravity Anomalies And Crustal Structure Of The Eastern Part Of The Verkhoyansk Fold-And-Thrust Belt, NE Russia: Evidence From The Junction Area Of The Adycha-Elga And Allakh-Yun Tectonic Zones

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Abstract. The results of geophysical studies of the junction area of the Adycha-Elga and Allakh-Yun tectonic zones of the Verkhoyansk fold-and-thrust belt located on the submerged eastern margin of the Siberian craton are presented. Three structural-mineral complexes are recognized: Archean-Paleoproterozoic, Mesoproterozoic-Middle Carboniferous, and Upper Carboniferous-Early Mesozoic. The Early Jurassic plume-related basaltic volcanism and suprasubduction Late Jurassic-Early Cretaceous granitoids, regional Brungadin and Suntar faults are identified. The goal of the research is to identify deep heterogeneities and clarify the structure of the Earth's crust in the junction area of the Adycha-Elga and Allakh-Yun tectonic zones of the Verkhoyansk fold-and-thrust belt. The analysis of gravitational anomalies is carried out, their transformations are performed – distinguishing the medium and low-frequency components, the vertical derivative Vzz, and calculating the equivalent distribution of sources of density masses at depth. It is determined that the hidden granitoids of the Adycha-Elga tectonic zone are located mainly in linear zones of decompaction at a depth of about 3.5 km. In the Allakh-Yun zone, a large gravitational minimum has been identified, where it is assumed that there is a magma granitoid chamber occurring at a depth of about 9 km. The model of the deep structure of the territory is based on the analysis of materials on the reference seismic profile 3-DV with the use of gravimetric data and the regional structure of the territory. According to the results of the wave pattern interpretation, the thickness of the lithosphere varies from 41 to 44 km. The thickness of the Upper Carboniferous-Triassic terrigenous rocks is 8-12 km, Mesoproterozoic - Middle Carboniferous carbonate-terrigenous complex is up to 12 km. The Archean-Paleoproterozoic crystalline basement occurs at a depth of 19-21 km. The Conrad discontinuity is assumed at a depth of about 30 km. Intense deformations of the crystalline basement are recognized, and trans-crust faults are identified.
1. Introduction
The Verkhoyansk fold-and-thrust belt is located on the submerged eastern margin of the Siberian Craton (Figure 1). The structures of the belt are well studied in the foreland zone, and information about the deep structure of its eastern part is limited [1, 2]. Our study revealed deep homogeneities and clarified the structure of the Earth's crust in the eastern part of the Verkhoyansk fold-and-thrust belt. In the section of the Earth's crust, there are three structural-mineral complex of the Archean-Paleoproterozoic, Mesoproterozoic-Middle Carboniferous, and Upper Carboniferous-Early Mesozoic [2]. The studied area is located on the border of the Adycha-Elga (AETZ) and Allakh-Yun tectonic zones (AETZ), separated by the Brungadin fault of the west-northwest strike (Figure 1, inset). The Suntar fault is another regional dislocation with break in continuity. It has a north-easter orientation, is well deciphered on space geological images and can be traced from the upper reaches of the Tyra river in a north-eastern direction along the Suntar river valley to the mouth of the Brungade river, where it is bounded by the Brungadin fault [3]. The magmatic formations of the territory are represented by plume-related Early Jurassic basalts and suprasubduction Late Jurassic-Early Cretaceous dikes, stocks of basic and acidic compositions [4-6]. Minerals in the studied area – numerous ore occurrences of Au, Ag and Sn [6].

2. Research methods and methodology
The paper uses digitized schemes of gravitational anomalies at the reference level of different scales, the results of geological mapping, data on the reference profile of 3-DV [5, 7-10]. Gravimetric data and their transformants allowed us to clarify the deep structure of the territory. Processing of gravimetric data included adaptive energy filtering with decomposition into high- and medium-frequency components, as well as recalculation of the vertical derivative Vzz. The processing of the geophysical data was carried out using automated program KOSKAD 3D and geoinformation system Oasis Montaj [11]. Calculation of the equivalent distribution of density mass sources at depth is based on the algorithm “Estimation of parameters of 3D gravimagnetic models by I. I. Priezzhev” [12].

The scheme of the deep structure of the territory under consideration is proposed on the basis of the interpretation of the time cross-section according to the seismic profile 3-DV [8-10]. Seismic reflectors and faults are identified and traced. The seismic boundaries were traced according to a block-layered model of the structure of the Earth's crust and upper mantle [13]. Geological maps and schemes of the deep structure of the territory were used for the interpretation of seismostratigraphic complexes [1, 2, 5, 8, 9, 10, 14, 15].

3. Research results
Anomalies of the medium- and low-frequency components of the gravitational field are caused by the structural features of the Mesoproterozoic-Middle-Carboniferous carbonate-terrirogenous complex and basement, the wide development of magmatic formations and fault tectonics (Figures 1A, B). In transformed fields in the interflue of the Kobyume-Suntar rivers and along the Indigirka, the blocks of increased Δg values extended in the north-west direction are determined. They are complicated by the extended and segmented conditionally positive anomaly of the sublatitudinal orientation in the interflue of the Kobyume-Kuente rivers. Fault structures control the identified blocks of high density and are traced along low-intensity gradient zones of the gravitational potential. There is an increase in the intensity of low-frequency anomalies Δg in the east direction (Figure 1B).

Isometric gravitational minima of varying intensity are observed, which correspond to hidden granitoid formations. The largest and deepest-lying massif is located in the Adycha-Elga tectonic zone at the mouth of the Khapchagai creek. The massif is characterized by a negative gravity anomaly with an intensity of -17 mG\(\text{I}\) (reference level) and an area of about 42.5 km\(^2\). Gravitational mass center, calculated by the inverse problem method in the KOSKAD 3D automated system, is located at a depth of about 10 km (Figure 1C). To the east of the massif, at a distance of about 19 km at a depth of about
3.5 km, there is a sub-isometric anomaly of a similar nature (7x5 km), with an intensity of -8 mGl (reference level). In the Allah-Yun tectonic zone, hidden intrusive bodies are assumed in the Suntar-Agayakan-Yuchiugei rivers interfluve, where differently oriented local gravitational minima and outcrops of granitoid stocks on the day surface are observed.

![Figure 1. Transformations of the anomalous gravitational field in the Bouguer reduction](image)

\(A\) – mid-frequency component; \(B\) – low-frequency component; \(C\) – distribution of density masses; 1 – faults (\(B\) - Brugandin, \(K\) – Kobumin, \(S\) – Suntar); 2 – magmatic formations of acidic composition; 3 – tectonic zones: \(AE\) – Adycha-Elga, \(AYu\) – Allakh-Yun; 4 – position of interpretation profiles: I-III – density mass distributions, II-II – models of the deep structure according to the seismic profile 3-DV.

The hidden granitoid intrusions of the Adycha-Elga and Allakh-Yun tectonic zones are delimited by an extended block of consolidated rocks of the sublatitudinal orientation. The increased values of the gravitational potential are related to the Early Jurassic volcanogenic-sedimentary rocks (tuff sandstones, tuff siltstones) and small bodies of the main composition (dolerites, gabbro, gabbrodolerites) of the Kobyumin graben.
To study the structure of the upper structural level, the vertical derivative \( V_{zz} \) was recalculated and two-dimensional adaptive energy filtering of the gravitational potential values was performed (Figures 2A, B). The transformed anomalies of the Adycha-Elga tectonic zone are characterized by a pronounced sublatitudinal strike. Negative gravitational anomalies with an intensity of \(-0.24 - -0.3\) mGl mark linear zones of decompaction and increased rock permeability of with unexposed granitoid intrusions \((-2.7 - -4\) mGl).

![Figure 2](image)

**Figure 2.** Transformations of the anomalous gravitational field in the Bouguer reduction

\( A \) – high-frequency component, \( B \) – vertical derivative \( V_{zz} \)

Conventional signs: Figure 1

In the Allakh-Yun tectonic zone in the Suntar-Agayakan-Yuchiugei rivers interfluve, anomalies of transformed fields correlate with granitoid intrusions. Known and hidden granitoid massifs form an annular zone of reduced values \((-0.25 - -0.3\) mGl) of transformed anomalies with a diameter of about 32 km. Outcrops of granitoid stocks – apical parts of hidden intrusions, their pronounced radial concentration suggests the presence of a large magma chamber in the Allakh-Yun tectonic zone, which occurs at a considerable depth. The magmatic formations are surrounded by a wide zone of contact metamorphism up to 8 km, which is demonstrated by anomalies of increased values of the transformed field \((1.3 - 1.7\) mGl).

Based on the results of the interpretation of the seismic section on the reference profile 3-DV, three structural-mineral complexes were identified (Figure 3). Thickness of the lithosphere varies from 41 to 44 km. The Archean-Paleoproterozoic basement occurs at a depth of about 19-21 km. Conrad discontinuity, which separates the upper and lower crust of the basement, can be traced at a depth of about 30 km. There is a wide development of faults in the lower horizons of the Earth's crust and intensive destruction of the top of the crystal foundation, that can be related to the processes of the Paleoproterozoic and Middle Paleozioc rifting [14].

The carbonate-terrigenous Mesoproterozoic-Middle Carboniferous complex has a maximum thickness of 12 km in the central part of the territory and gets thinner to 7 km in the east. The increase in thickness may be due to the large duplex structures.
Thickness of terrigenous C₃-MZ₁ rocks increases in the eastern direction from 8 to 12 km. Surface of the sole thrust (detachment) is assumed to be at the boundary of the carbonate-terrigenous and terrigenous complexes. Thrust structures of listric type and granitoid massifs are widely developed.

Figure 3. Model of the deep structure of the eastern part of the Verkhoyansk fold-and-thrust belt based on seismic data of the reference profile 3-DV
1 – upper mantle; 2-4 – structural-mineral complexes: 2 – Archean-Lower Proterozoic granite-metamorphic; 3 – Mesoproterozoic-Middle Carboniferous carbonate-terrigenous; 4 – Upper Carboniferous-Early Mesozoic terrigenous; 5 – faults, S–Suntar; 6 – granitoids; 7 – discontinuities: M – Moho, C – Conrad.

Position of the interpretation profile is shown in Figure 1.
4. Conclusions
The analysis of gravitational anomalies and their transformants allowed us to clarify the geological structure of the studied territory. The widespread development of granite intrusions, contact metamorphism zones, and faults has been established.

Thickness of the lithosphere within the studied territory is 41-44 km. The studies made it possible to specify the structure of the Earth's crust in the eastern part of the Verkhoyansk fold-and-thrust belt. Position of the Archean-Paleoproterozoic granite-metamorphic, Mesoproterozoic-Middle Carboniferous carbonate-terrigenous (7 to 12 km thick) and Upper Carboniferous-Early Mesozoic (8 to 12 km thick) terrigenous structural-mineral complexes are specified. The top of the basement is characterized by a complex relief and occurs at a depth of 19 – 21 km. There is an intense deformation of the rocks of the basement and sedimentary cover, the presence of crustal and trans-crust faults of the listric type.

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