Deep Structure of the Eastern Margin of the Siberian Craton, NE Russia: Evidence from Analysis of an Anomalous Gravitational Field

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Abstract. The paper presents the results of a study of the anomalous gravitational field of the Verkhoyansk fold-and-thrust belt. The belt is located on the eastern margin of the Siberian craton and represents the frontal part of the accretion-collision Verkhoyansk-Kolyma folded area (Northeastern Russia). The base of the fold-thrust belt is the pre-Mesoproterozoic crystalline basement, overlain by sedimentary strata. The purpose of this study is to clarify the features of the deep structure of the Verkhoyansk fold-and-thrust belt based on an analysis of modern geological and geophysical data. According to the results of the analysis of the gravitational field $\Delta g$, the Yana, Tompo-Gornostakh gravity maxima and the West Verkhoyansk, Derbekin and South Verkhoyansk gravity minima are identified. Regional anomalies $\Delta g$ reflect relatively upstanding and downdip blocks of the Verkhoyansk fold-and-thrust belt basement. The maximum subsidence of the surface of the crystalline basement is observed in the South Verkhoyansk sector, the minimum – in the Sette-Daban tectonic zone. The Adycha-Elgin tectonic zone is characterized by a heterogeneous block structure of the basement. In the area of the Kitchensky uplift, a subvertical scarp is identified in the crystalline basement relief. Gravitational anomalies corresponding to magmatic plutons and regional fault structures are identified. The confinement of anticlinoria of the West Verkhoyansk sector to local gravitational anomalies of a negative sign is noted. The correlation of the boundaries of tectonic zones with linear alternating anomalies $\Delta g$ is determined.

1. Introduction

The Verkhoyansk fold-and-thrust belt (VFTB) is located on the eastern downdip margin of the Siberian craton and represents the frontal part of the accretion-collision Verkhoyansk-Kolyma folded area [1-3]. The base of the VFTB is the pre-Mesoproterozoic crystalline basement, overlain by up to 28 km thick Upper Proterozoic, Paleozoic, and Lower Mesozoic sedimentary strata. A number of researchers [4-10, etc.] were involved in determining the depth of the basement and thickness of the VFTB Earth’s crust. Seismic studies were conducted to the north of the VFTB in the Laptev Sea – MAGE 87722 and LARGE profiles, as well as in the South Verkhoyansk – 3-DV profile [11-15]. These works created ideas about the structure of the crystalline basement relief, determined the position of regional faults and unexposed magmatic plutons. In this report, based on the analysis of
modern geological and geophysical data, the features of the deep structure of the outer (Western Verkhoyansk, Southern Verkhoyansk sectors) and the inner zones of the VFTB are specified.

2. Materials and research methods.
Geophysical information was analyzed on the basis of schemes of gravitational anomalies at a conditional level of different scales [16-19], digitized and built in three-dimensional 3D form. The gravitational anomalies were linked according to the gravimetric map in the Bouguer reduction (σ = 2.67 g / cm³) of a scale of 1: 500000 [20-22]. In order to clarify and decipher the deep structure of the Verkhoyansk fold-and-thrust belt, a qualitative interpretation of gravitational anomalies was carried out by identifying regional, local maxima and minima, determining of the shape and nature of anomaly-forming objects.

3. Results and discussions
The gravity field of the VFTB is divided into a number of regional anomalies – minima and maxima. Tompo-Gornostakh, Yana gravity maxima, Western Verkhoyansk, Derbekin, South Verkhoyansk gravity minima are identified.

The West Verkhoyansk gravity minimum is located in the same name sector of the VFTB (Figure 1). It is traced in the submeridional direction from the Laptev Sea to the south along the eastern margin of the Siberian platform, with a distance of about 700 km and a maximum width of about 180 km. According to [6], the depth of the trough basement is 12-14 km. Structurally, it covers the Kharaulakh, Orulgan, northern flank of Kuranakh, western flank of Omoloy tectonic zones [23].

The gravity minimum narrows from 132 in the north to 52 km in the south and is limited by the positive anomalies associated with the Kitchans transverse uplift. The calm level of the gravitational field is complicated by local isometric anomalies corresponding probably to unexposed granitoid plutons. Large-scale granitoid magmatism occurs on the border of the Orulgan and Omolon tectonic zones [24], where the area of intrusive formations according to gravimetric data is more than 2000 km². A spatial correlation of local negative gravitational anomalies with anticlinoria is noted.

Derbekin gravity minimum. In the area of the Kitchan uplift, the southern closure of the Western Verkhoyansk gravity minimum is replaced by the Derbekin minimum. The border between regional anomalies is drawn along a zone of high gradients up to 0.42 mGal / km. The thickening of the gravitational field isoanomalies reflects a subvertical scarp in the crystalline basement relief. The calculated step height is 2 km. The reduced level of anomalies of the regional Derbekin minimum corresponds to the downdip block of the basement.

Derbekin gravity minimum is traced eastward at a distance of about 450 km with a width of up to 185 km. It spatially coincides with previously identified the same named graben [22, 10]. Structurally, it covers the Kuranakh and Barain, the southern flank of the Sartang and the western flank of the Adycha-Elgin tectonic zones. The local isometric anomaly of the negative sign of the gravitational potential (Echiy minimum) is noted within the Kuranakh tectonic zone (TZ). The anomaly intensity is – 54 mGal (at a conditional level), an area of 111x41 km. In the northwest of the anomaly, the apical part of the Khoboyotu-Echiy granitoid massif is exposed. The wide development of granitoid magmatism is assumed in the Barain TZ at the border of the junction of the VFTB with the Priverkhoyansk foredeep.
Figure 1. Gravity anomalies of the Verkhoyansk fold-and-thrust belt, 1 – boundaries of tectonic zones; 2 – faults; 3 – granitoids: a – identified, b – supposed; 4 – subvolcanoes; 5 – boundaries of regional gravity anomalies: WV – Western Verkhoyansk, DE – Derbekin, YA – Yana, TG – Tompo-Gornostakh, SV – Southern Verkhoyansk.
Tectonic zones (letters in squares): TS – Tuora-Sissk, ChU – Kharaulakh, Or – Orulgan, Om – Omoloy, Kr – Kuranakh, Kt – Kitchan uplift, Sr – Sartang, MY – Middle-Yana, Br – Barain, AE – Adycha-Elgin, SD – Sette-Daban, KI – Kylakh, Kb – Kobyumin, SL – Suntar-Labynkyr, Ku – Kuydusun depression, SV – Southern Verkhoyansk, KN – Kular-Nera terrane.

Faults (letters in circles): WV – Western Verkhoyansk, EV – Eastern Verkhoyansk, EH – Egehay, Ha –Haltysin, NT – North Tirehtyakh, ST – Southern Tirehtyakh, H – Khunkhandin, Al – Allakh, DN – Derbeke-Nelgesin, Du – Dulgalkh, AT – Adycha-Taryn, K – Kylakh, A – Akrin, ED – Eastern Sette-Daban, Yu – Yudoma, M – Minor, Bl – Bilyakchan.

Shcherbakov O.I. et al., (2008) [22] link the disturbing effect of the Elchiy gravitational minimum with the total influence of the Khoboyotu-Elchiy pluton, including its hidden part, as well as with an increase in the thickness of the Mesoproterozoic (?) – Middle Paleozoic deposits in duplex structures. They also suggested the distribution of granitic plutons in the upper horizons of sedimentary complexes in the Kuranakh and Barain TZ.

In the eastern part of the gravity minimum, linear anomalies are identified that correspond to deep faults – sub-longitudinal (Allakh, Dulgalkh, Hunhadin) and north-eastern (Derbeke-Nelgesin) orientations [25]. The depth of the basement roof within the Derbekein gravity minimum is 14-16 km [6, 10].

The Tompo-Gornostakh gravity maximum is located to the south of the Derbekein minimum. A regional anomaly combines the Tompon and Gornostakhs maxima. The gravity maximum includes the southeastern flank of the Barain, Killakh and Sette-Daban TZ. In the junction zone of the Barain and Sette-Daban TZ, the regional anomaly has a west-north-western strike, and on the border of the Killakh and Sette-Daban tectonic zones, it is sub-latitudinal.

The gravity maximum from the west is limited by a narrow-extended zone of negative anomalies of the Aldan-Maisky trough. A high level of gravitational anomalies is observed in the junction zone of the Barain and Sette-Daban TZ and the Gornostakhs anticlinorium of the Killakh TZ. An uneven decrease in the values of the gravity field from 10 to -71 mGal in the east direction is noted. At the latitude of the river Tyra, gravity maximum is complicated by the zone of lower values of the gravitational potential up to 50 km wide.

The Tompo-Gornostakh gravity maximum corresponds to a high of the crystalline basement with a length of 520 km and a width of up to 90 km [26]. The surface of the crystalline basement is complicated by depression at the latitude of the river Tyra. The basement high of the Killakh and Sette-Daban TZ is characterized by an asymmetric structure – subvertical in the west and gradually plunging in the east. Based on the results of seismic sounding, the basement lies in the axial part of the Sette-Daban TZ at a depth of 1.5 - 2 km [13, 14].

The South Verkhoyansk gravity minimum is identified to the east of the Tompo-Gornostakh maximum. A gravity minimum with a length of about 440 km and a maximum width of 267 km is characterized by the lowest level of the VFTB gravity field. It covers the same name South Verkhoyansk sector and the western flank of the Kuidusun depression of the Okhotsk-Chukotka volcanogenic belt. The minimum is limited by the conditionally positive anomalies of the Okhotsk terrane in the southeast and the Suntar-Labynkyr uplift in the northeast.

In the central part of the gravity minimum, local isometric anomalies that reflect magmatic formations are identified. Faults are defined by linear anomalies $\Delta g$ or by the displacement of the isoanomalies of the sub-latitudinal and northeast strike.
The basement within the South Verkhoyansk gravity minimum is characterized by the maximum plunge. The surface of the consolidated base is complicated in the Kuidusun depression by the large Suntar-Khayat gravity minimum [19]. According to data [10] and the intensity of gravitational anomalies, the depth of the basement on the northern flank of the South Verkhoyansk TZ is more than 16 km. According to the results of seismic observations on the reference profile 3-DV, the thickness of the rocks increases in the southeast direction. Here, the depth of the occurrence of surface of the crystalline basement varies from 22 to 28 km [12, 13, 15]. Towards the Okhotsk terrane, the surface of the consolidated crust tends to smoothly uplift.

The Yana gravity maximum is identified in the north-eastern part of the Verkhoyansk fold-and-thrust belt. The regional anomaly is about 460 km long and 350 km wide. Structurally, it corresponds to the Middle-Yana, Sartang TZ and the northwestern flank of the Adycha-Elgin TZ, as well as to the northern fragments of the adjacent Kular-Nera and Inyali-Debin terranes. The Yana gravity maximum is fixed by a high level of the gravitational field.

The Middle-Yana, Sartang TZ are characterized by a low-intensive linear and isometric anomalies. Linear anomalies reflect determined and supposed faults of the sub-longitudinal strike, isometric – non-eroded intrusions.

The nature of gravitational anomalies changes in Adycha-Elgin TZ. The field of gravity is complicated by linear local anomalies of the negative sign of sub-latitudinal and northeastern strike. The identified anomalies trace the known faults that control the position of granitoids of the transverse magma belt (Egehay, North- and South-Tirekhtyakh, Derbeke-Nelgesin granite series).

It is noted that the boundaries of tectonic zones within the Yana gravity maximum are linked to the extended gradient zone of the gravity field, which is divided into a number of segments. The southern segment of the anomaly, with a length of 280 km, fragmentarily coincides with the Allakh fault and corresponds to the junction of the Adycha-Elgin and Sartang TZ. The central segment is 78 km long and has a sub-longitudinal strike. The northern segment corresponds to the Egehay fault, as well as the border of the Middle-Yana and Adycha-Elgin TZ and stretches in the north-east direction, crossing the Adycha-Taryn fault. The gradient zone traces the deep fault zone, which combines the Allakh and Egehay faults.

To the east of the Allakh and Egehay faults, a series of gradient zones of sub-longitudinal and north-east orientation is observed. In the northwestern part of the Adycha-Elgin TZ, the amplitude of the gravitational steps is 4-12 mGal. The southern gradient anomaly correlates with the Derbeke-Nelgesin fault, where the difference in Δg values is 18 mGal. A decrease in the level of values of the gravitational field in the southeast direction is noted.

The Adycha-Taryn fault, bordering the VFTB in the east, does not create a contrasting gravitational disturbance. It is located in linear positive low-intensive anomalies and isoanomalies displacement.

The depth of the basement within the Yana gravity maximum is 8-10 km [6, 10]. A close occurrence of the surface of the crystalline basement is typical for the Middle-Yana TZ. Intensive subsidence of the consolidated crust is observed in the junction zone of the Middle-Yana and Sartang TZ. In the Adycha-Elgin TZ, the block structure of the basement is fixed, which gradually plunges into the southeast direction.

4. Conclusions
The performed studies allowed us to identify regional anomalies of the gravity field, reflecting the deep crustal heterogeneities of the Verkhoyansk fold-and-thrust belt. Gravity maxima correspond to
relatively raised blocks of the basement, and minima correspond to the downdip ones. The position of the surface of crystalline basement of the Verkhoyansk fold-and-thrust belt is clarified. In the area of the Kitchan uplift, a subvertical scarp was determined in the crystalline basement relief about 2 km high. The maximum plunge of the crystalline base is observed in the South Verkhoyansk sector of the Verkhoyansk fold-and-thrust belt, where the thickness of sedimentary deposits is 22-28 km.

High-intensive anomalies Δg form granitoids of the transverse belt. According to the gravimetric data, the boundaries of tectonic zones within the Yana gravitational maximum are controlled by deep faults. Regional faults are notable for low-intensive alternating linear anomalies and extended gradient zones.

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