Russian Geology and Geophysics *© 2019, V.S. Sobolev IGM, Siberian Branch of the RAS*
Vol. 60, No. 3, pp. 254–266, 2019 *DOI:10.15372/RGG2019021* *Geologiya i Geofizika*

Geodynamic Complexes and Structures of Transbaikalia: Record in Gravity Data

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Received 28 April 2018; received in revised form 23 July 2018; accepted 17 October 2018

Abstract—The Transbaikalian region comprises several known geologic structures: the Mesozoic Mongolia-Okhotsk orogen, the Cenozoic Baikal rift system, and the world largest Angara–Vitim granitic batholith. They all formed upon heterogeneous Neoproterozoic–Early Paleozoic continental-margin complexes of the Siberian craton. The region is subject to the influence of mantle plumes, which induced Mesozoic–Cenozoic volcanism and controlled structural and lithological changes in the crust in the early history.

Transbaikalia, which has been a scene of multiple tectonic events, is a model area for geophysical (in particular, gravity) surveys for various geological and geodynamic applications. As a novel approach, we interpret geological and geodynamic data from the region with reference to the pattern of free-air and Bouguer gravity anomalies revealed by satellite altimetry. Bouguer anomalies highlight large structures in the lithospheric mantle which were produced in the Cenozoic mainly by the activity of mantle plumes. Basaltic lava fields were confirmed to be almost coeval with mantle anomalies and to record the presence of the plume head at the crustal base. However, the origin of the Late Paleozoic Angara–Vitim granitic batholith was only tentatively attributed to the plume activity, based on gravity data. Mesozoic metamorphic core complexes (MCC) and basins that formed during the evolution of the Mongolia–Okhotsk orogen show up clearly on the map of free-air anomalies. Most of the MCC revealed in Transbaikalia coincide with oval gravity highs and border negative elongate features corresponding to Mesozoic basins.

The zone of Cenozoic tectonism stands out in the pattern of free-air anomalies as maximum gravity contrasts, with the values changing from –110 to –120 mGal in basins to + 90 or +100 mGal in ranges. This zone encompasses rift basins filled with Cenozoic or, locally, Mesozoic sediments, which jointly form a domino-like system of rhomb-shaped structures typical of the Baikal rift system and, in general, of Cenozoic Central Asia resulted from the far-field effect of the India–Eurasia collision.

Keywords: tectonics, geodynamics, correlation, free-air and Bouguer gravity anomalies, Baikal rift system, Mongolia–Okhotsk orogen, Angara–Vitim batholith

INTRODUCTION

Geological and tectonic structures in Transbaikalia represent Neoproterozoic–Early Paleozoic continental-margin complexes of the southern Siberian craton reactivated during the Mesozoic Mongolia–Okhotsk and Cenozoic Indian–Eurasia collisions which led to the formation of the Mongolia–Okhotsk orogen and the Baikal rift system, respectively. Late Paleozoic plutonism in the region produced the world largest Angara–Vitim batholith exposed over ~150,000 km^2, in a tectonic setting that remains poorly constrained. The region has been subject to the influence of mantle plumes which induced Mesozoic–Cenozoic volcanism and controlled structural and lithological changes in the crust in the early history.

This paper continues a series of studies where gravity data from satellite altimetry and integrated databases (Bonvalot et al., 2012; Andersen and Knudsen, 2016) are correlated with geological and geodynamic evidence (Dobretsov et al., 2016, 2017; Dobretsov and Vasilevsky, 2018). The paper addresses the relationship of Cenozoic surface topography with coeval mantle magmatism and with earlier Late Paleozoic and Mesozoic events of magmatism and surface shaping in Transbaikalia. Additionally, we analyze crust-mantle interactions in zones of activity from the Himalayas to Lake Baikal and provide explanations for the use of spaceborne gravity data.

The gravity pattern of Transbaikalia was used previously for the same purposes by one of us (Vitte et al., 2009; Vitte and Vasilevsky, 2013) and other authors (Bulgatov, 1988, 2015; Alakshin et al., 1991; Turutanov, 2011; etc.). However, comparison of different datasets and interpretations of the gravity, magnetic, and seismic data referred to in the cited and other publications is difficult because the data of-

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ten differ in scale of surveys and averaging methods, as well as in approaches to geological and geodynamic correlations (Buslov et al., 2013; Dobretsov, 2003, 2011a,b; Yarmolyuk and Kovalenko, 2003; Dobretsov and Buslov, 2007, 2011; Glebovitsky et al., 2007; Yarmolyuk et al., 2001, 2003, 2008, 2013; Dobretsov et al., 2013, 2016).

A large amount of work, including gravity surveys, has been performed for constraining the geometry and size of the Angara–Vitim batholith (Turutanov, 2011). Zorin et al. (1985) interpreted gravity data using decompensation of gravity anomalies to account for terrain effects, as well as for local density variations in the upper crust corresponding to shallow structures (Zorin et al., 1985, 1989). Currently, a wealth of satellite data is available for calculating gravity anomalies (e.g., Bouguer reduction) and solving numerous geological and geodynamic problems without cumbersome derivations for gravity decompensation.

METHODS

We interpret geological and geodynamic data with reference to digital maps of gravity anomalies based on satellite data. The gravity field is presented as maps of free-air (Fig. 1) and Bouguer (Fig. 2) anomalies. The free-air anomalies are borrowed from the recent DTU15 combined marine model (Andersen and Knudsen, 2016) obtained using land-based measurements and satellite altimetry of oceans. The 10°×14° map of Transbaikalia in Fig. 1 shows color coded free-air anomalies: yellow to red for highs, green for neutral values, and blue to black for lows. The blue and black colors mark the Baikal and Barguzin basins filled with kilometers thick sediments, as well as other Mesozoic and Cenozoic basins. The map of Bouguer anomalies (Fig. 2) compiled with data from the ICGEM website (Förste et al., 2014), based on the DTM2006 digital terrain model (Pavlis et al., 2007), presents the classical anomalies for the spherical Earth model with Bouguer correction from a uniform layer with a density of 2.67 g/cm^3.

The methodological background for the interpretation of free-air and Bouguer gravity anomalies obtained with reference to recent global models and their use in solving geological and geodynamic problems were detailed in our previous publication (Dobretsov and Vasilevsky, 2018).

Below we discuss correlation between gravity anomalies from satellite altimetry and land-based surveys used previously (Zorin et al., 1985, 1989, 1995; Turutanov, 2011) for constraining the shape and size of the Angara–Vitim batholith. Local gravity lows were interpreted quantitatively assuming that they all correspond to large granitic plutons. The theoretical and measured gravity fields were consistent within ±2 mGal. The average density of Late Paleozoic plutons that make up the batholith is almost the same: 2.62 g/cm^3, with regard to water-filled porosity. The average density of sediments and metamorphic sedimentary-volcanic rocks is in the range 2.66–2.82 g/cm^3 over most of Transbaikalia (Zorin

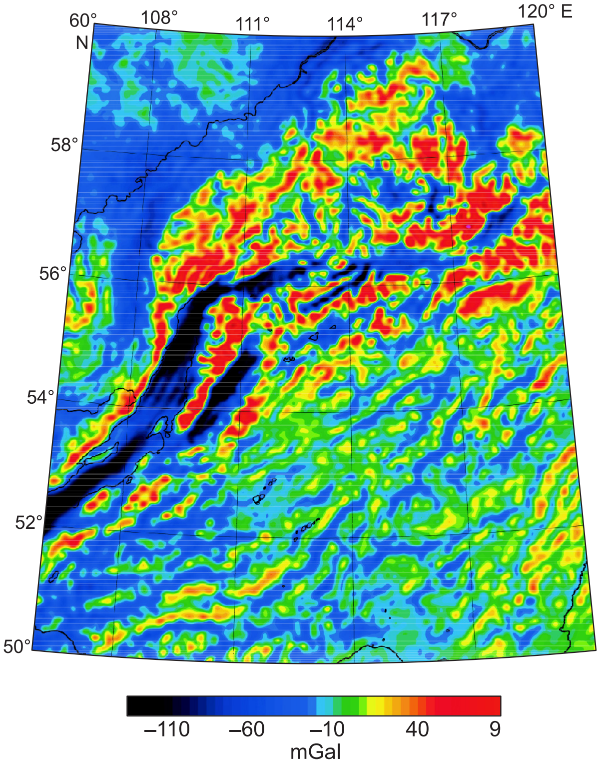

Fig. 1. Map of free-air gravity anomalies (Andersen and Knudsen, 2016).

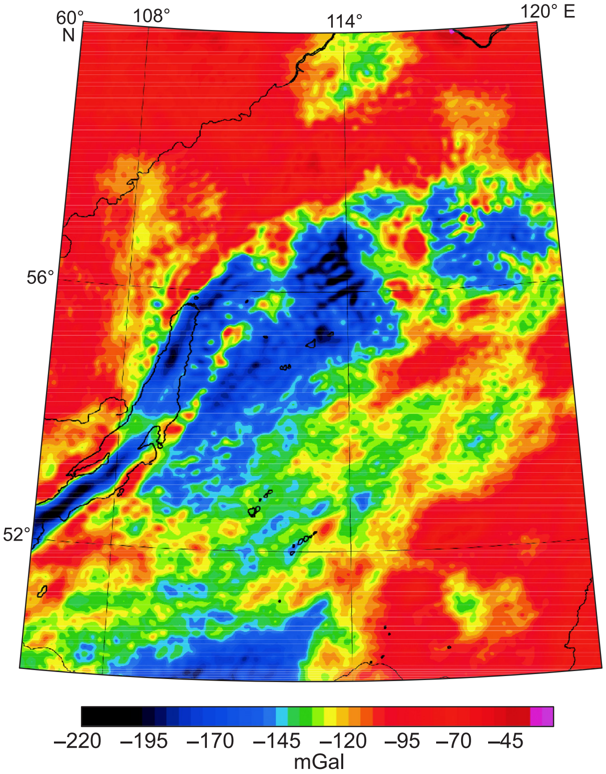

Fig. 2. Map of Bouguer gravity anomalies (Förste et al., 2014).

et al., 1988; Litvinovsky et al., 1993; Zorin and Turutanov, 2004). Therefore, the average density deficit was assumed to be about 0.1 g/cm^3. The map of decompensated gravity anomalies for the territory of the Angara–Vitim batholith was used to model its deep structure from 39 interpretation cross sections, including integrated gravity, magnetic, and seismic (reflection and DSS) data along two transects. The bodies that simulate granitic plutons are shown in Fig. 3*B*.

The system of interpretation cross sections, in its turn, was used to compile a contour line map of batholith thickness (Fig. 3*A*). All plutons within the zone of gravity lows were found out to merge at depths into a single body looking generally like a huge sheet with a curved base and a flat top (Turutanov, 2011). The batholith is about 750 km long, 250 km wide, and 2 to 30 km thick (8–10 km on average), and its projection on the Earth's surface occupies almost 200,000 km^2 (Turutanov, 2011). The local gravity map (Fig. 3*A*) compiled with the decompensation method partially coincides with the Bouguer gravity map (Fig. 3*C*) but provides a more detailed structural pattern.

GEODYNAMIC COMPLEXES AND STRUCTURES OF TRANSBAIKALIA: RELATION TO PLUMES AND RECORD IN GEOPHYSICAL FIELDS

The southern periphery of the Siberian craton (Fig. 4) is a collage of terranes (Mazukabzov et al., 2010, 2011) that accreted to it in Neoproterozoic and Early Paleozoic time (Zorin et al., 1995; Parfenov et al., 1996, 1999, 2003; Sklyarov et al., 1997; Gordienko and Metelkin, 2016). The terranes are fragments of active continental margins of different ages produced by subduction of the Paleoasian ocean plate. They were remobilized in the Middle and Late Paleozoic during subduction of the Mongolia–Okhotsk plate at the respective active margin.

Multistage subduction and subsequent crustal processes, including coeval mantle magmatism, produced voluminous Late Paleozoic granitoids over a large part of the Transbaikalian territory, while older volcanic-sedimentary rocks make sporadic isolated zones. Closure of the Mongolia-Okhotsk ocean in the Mesozoic led to a continental collision of North China and Siberia (Didenko et al., 2013) and the ensuing growth of a large Mongolia–Okhotsk orogen attendant with plutonism and formation of metamorphic core complexes (Sklyarov et al., 1997; Mazukabzov et al., 2011).

Granitoids exposed over ~150,000 km^2 in the Late Paleozoic igneous province of Western Transbaikalia (Fig. 5) formed upon a heterogeneous Paleoproterozoic continental crust with of Neoproterozoic and Early Paleozoic juvenile domains (Litvinovsky et al., 1993, 2001, 2011; Tsygankov et al., 2007, 2010, 2016; Burmakina and Tsygankov, 2013; Tsygankov, 2014). The granitoids show systematic changes in isotopic signatures toward progressive increase in the juvenile component, which suggests melting of juvenile crust and mixing of crustal and mantle magmas. However, the geochemical effect of this mixing is obscured by the Nd isotope composition of mafic rocks with negative Nd(T). The Western Transbaikalian granitoids include calc-alkaline granites of the Barguzin complex, which make at least two thirds of the total volume of Late Paleozoic plutonic rocks in the area, and several younger complexes (Chivyrkui, Zaza, Lower Selenga, and Early and Late Kunalei) of various lithologies from leucogranite to quartz syenite and quartz monzonite.

The Late Carboniferous–Early Permian Barguzin complex (325–290 Ma) consists of autochthonous and allochthonous biotite granites and remnants of a metamorphic substrate (especially among autochthonous rocks), with isotope signatures indicating magma generation by melting of Precambrian crustal protoliths (Yarmolyuk et al., 1999, 2001). The Early Permian (305–285 Ma) complexes are composed of quartz syenite and monzonite (Chivyrkui) and subalkaline leucogranite and quartz syenite (Zaza); both enclose dikes and synplutonic mafic rocks providing direct evidence of magma mixing. The Zaza leucogranites may have formed by fractional crystallization of a hybrid (quartz-syenite) melt resulting from mixing of Barguzin-type crustal magma with mafic material of the early-phase Chivyrkui complex. The Early Permian (285–278 Ma) Lower Selenga complex consists of a primary shoshonite-monzonite-syenite-quartz syenite series including synplutonic mafic intrusions. The Western Transbaikalian alkaline granitic rocks have been traditionally divided into the Late Permian and Late Triassic complexes of Early (280–273 Ma) and Late (230–210) Kunalei.

The widespread Middle–Late Carboniferous (310–330 Ma) Barguzin rocks poorly correlate with gravity anomalies. Only the youngest Kunalei intrusions (230–210 Ma) have circular and half-circular shapes often coinciding with metamorphic core complexes. In its northeastern part, the Barguzin complex matches the Vitim mantle anomaly which is prominent in the Bouguer gravity pattern (Fig. 6). The main body of the intrusion is semicircular while its oval part coincides with the central and outer zones of the gravity anomaly. The central circle of the Bouguer anomaly, in its turn, corresponds to plumes that approach the crustal base (Zorin et al., 1989). The most prominent lows of –150 to –200 mGal (blue and black) make up a chain, about 1000 km long and 200–250 km wide, and match the anomalies revealed by Zorin (Zorin et al., 1989; Zorin and Turutanov, 2004) and the oval features in Fig. 5. Zorin et al. (1989) interpreted the oval-shaped anomlaies as asthenospheric upwarps or projections of mantle plumes at 45–50 km below the crust base.

The Bouguer anomalies (Fig. 6) record large structures that appeared in the lithospheric mantle or at the crust base in the Cenozoic, mainly as a result of plume activity. The plume contours fit the fields of Late Cenozoic volcanism and the Angara–Vitim, Hentiyn and Hangayn batholiths (Fig. 5). Most of volcanism belongs to the South Baikal and South Hangayn areas which constitute a single East Sayan–

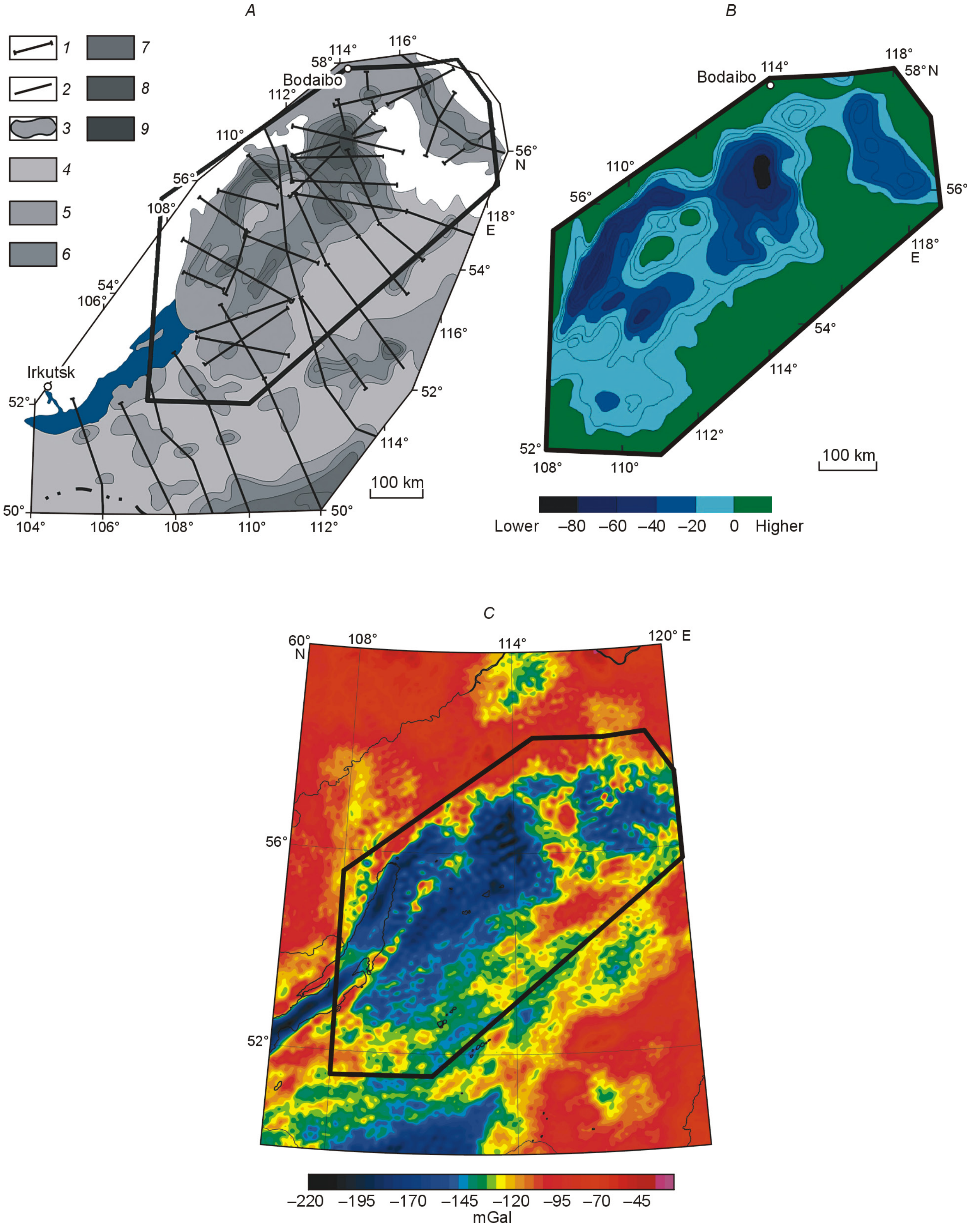

Fig. 3. Contour line map of intrusion thickness (*A*); map of decompensated gravity anomalies (contour lines at every 10 mGal) imaging the Angara–Vitim batholith (*B*); and map of Bouguer gravity anomalies based on satellite altimetry (*C*). Scale of gravity anomalies (Turutanov, 2011). *1*, interpretation transects; *2*, contour lines of intrusion thickness; *3*, continuous fields of Late Paleozoic granites beneath country rocks; *4*–*9*, fields of intrusions with different thicknesses: 0–2 km (*4*), 2–5 km (*5*), 5–10 km (*6*), 10–20 km (*7*), 20–25 km (*8*), >25 km (*9*). Note that the contours of Bouguer anomalies in *C* fit those of the pluton.

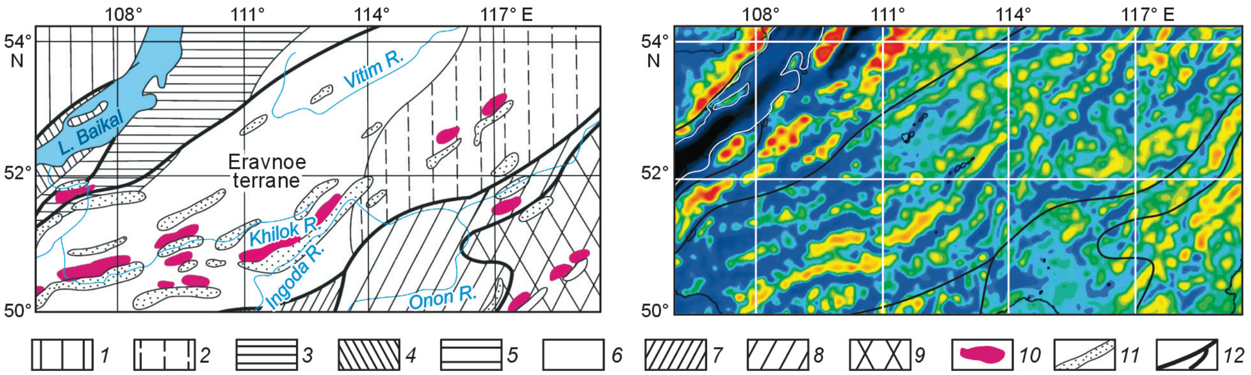

Fig. 4. Tectonic framework of the southern periphery of the Siberian craton (Mazukabzov et al., 2010) and map of free-air gravity anomalies (Andersen and Knudsen, 2016), compared. *1*, Siberian craton; *2*, Stanovik zone (fragment of a cratonic terrane reworked in the Early Cretaceous); *3*–*6*, structures of Transbaikalia (Paleozoic continental margin of Siberia): Vendian–Cambrian island arc terranes upon a pre-Vendian base (*3*), Vendian–Cambrian back-arc basin (*4*), Vendian–Cambrian island arc terranes with juvenile crust (*5*), Cambrian–Silurian island arc terranes and back-arc basins (*6*); *7*, *8*, island-arc (7) and sea-margin (8) structures of the Mongolia–Okhotsk ocean; *9*, Argun microcontinent with Precambrian crust; *10*, metamorphic core complexes; *11*, Early Cretaceous basins; *12*, main faults.

Hangayn province. The asthenospheric upwarps within the province are clearly pronounced against generally shallow asthenosphere reaching a depth of 100 km (Zorin et al., 1989). There are three offshoots from the main province that form isolated basaltic fields of Vitim and Udokan (Baikal branch) and the less distinct Hentiyn and South Gobi branches.

The oldest Cenozoic basalts (~30 Ma) occur in the South Hangayn and South Gobi fields while the youngest eruptions are known from the East Sayan and Udokan areas

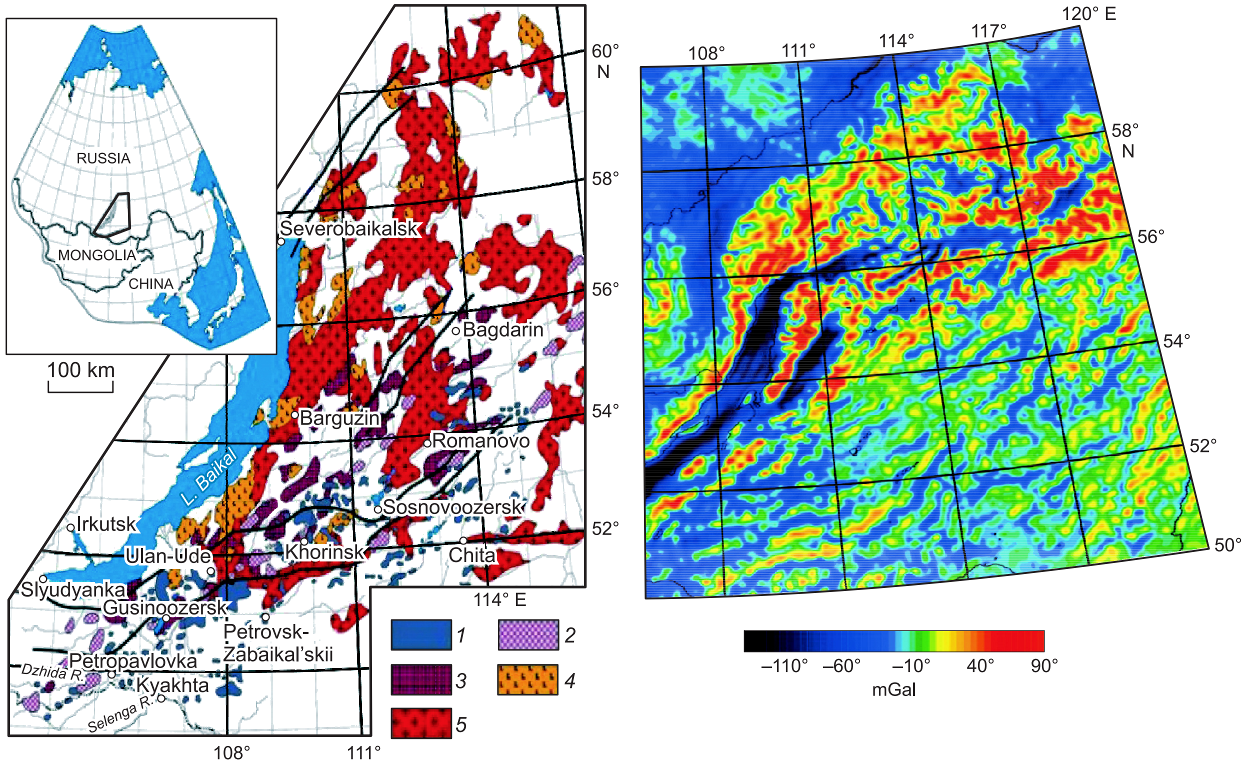

Fig. 5. Locations of granitoids in the Late Paleozoic Western Transbaikalian igneous province (Tsygankov, 2014) and map of free-air gravity anomalies (Andersen and Knudsen, 2016). *1*, alkali-feldspar and alkaline granites and syenites of the Mongolia–Transbaikalia volcanoplutonic belt: Early (280–273 Ma) and Late (230–210 Ma) Kunalei complexes; *2*, shoshonite intrusive series (monzonite-quartz syenite with synplutonic mafic rocks, Lower Selenga complex, 285–278 Ma); *3*, transitional rocks from high-K calc-alkaline to subalkaine granites and quartz syenites with synplutonic mafic rocks (Zaza complex, 305–285 Ma); *4*, high-K calc-alkaline quartz monzonites, quartz syenites, and gabbro (Chivyrkui complex, 305–285 Ma); *5*, calc-alkaline Barguzin complex (Angara–Vitim batholith, 330–310 Ma).

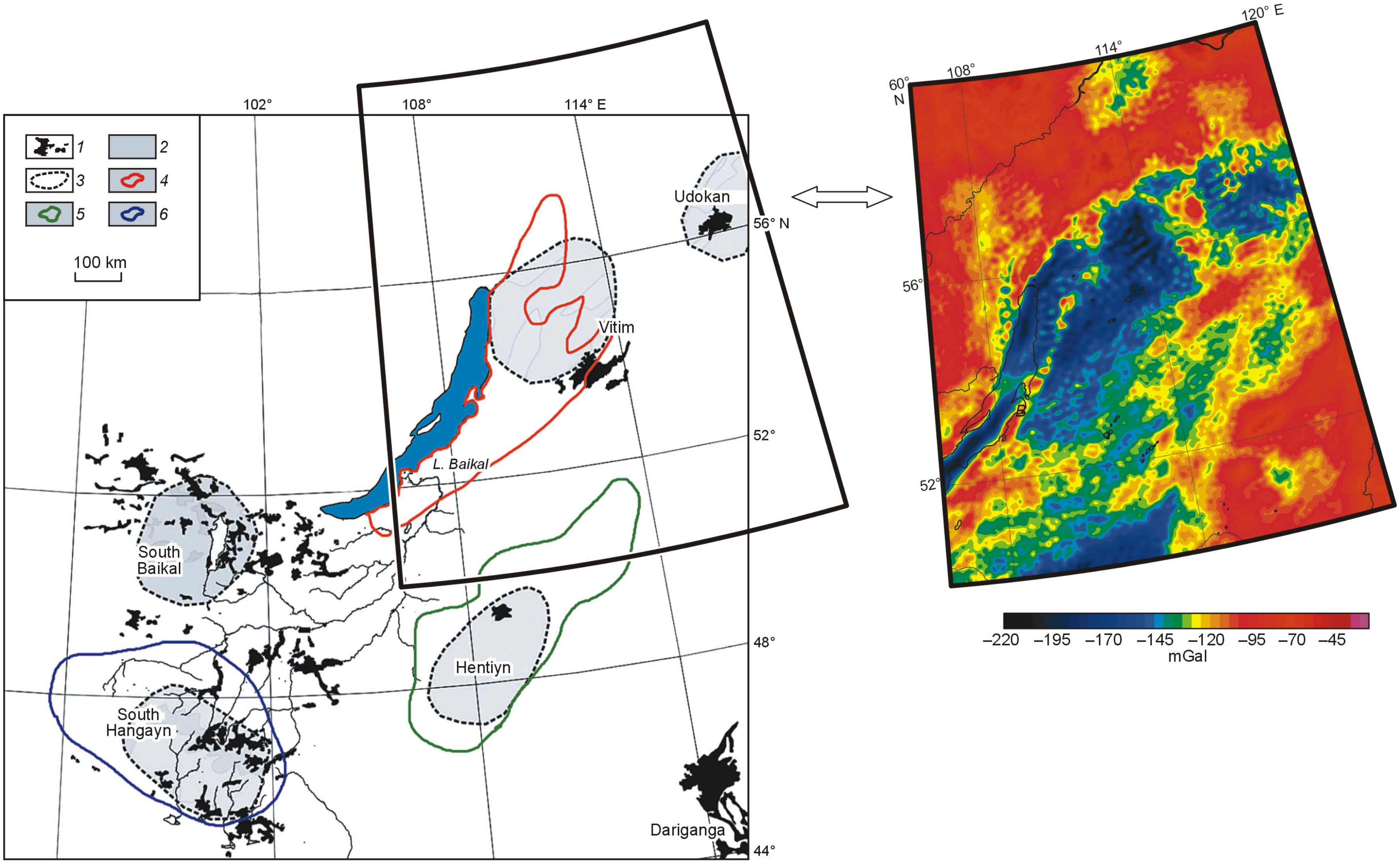

Fig. 6. Bouguer gravity anomalies, compared with plume anomalies and areas of magmatism. *1*, Late Cenozoic basaltic lava fields (Yarmolyuk et al., 1999, 2013); *2*, asthenosphere shallower than 100 km (Zorin et al., 1989); *3*, asthenospheric upwarps rising above 50 km (projections of mantle plumes), after Zorin et al. (1989); *4*, contour of Late Paleozoic Angara–Vitim batholith; *5*, contour of Early Mesozoic Hentiyn batholith; *6*, contour of Late Paleozoic Hangayn batholith.

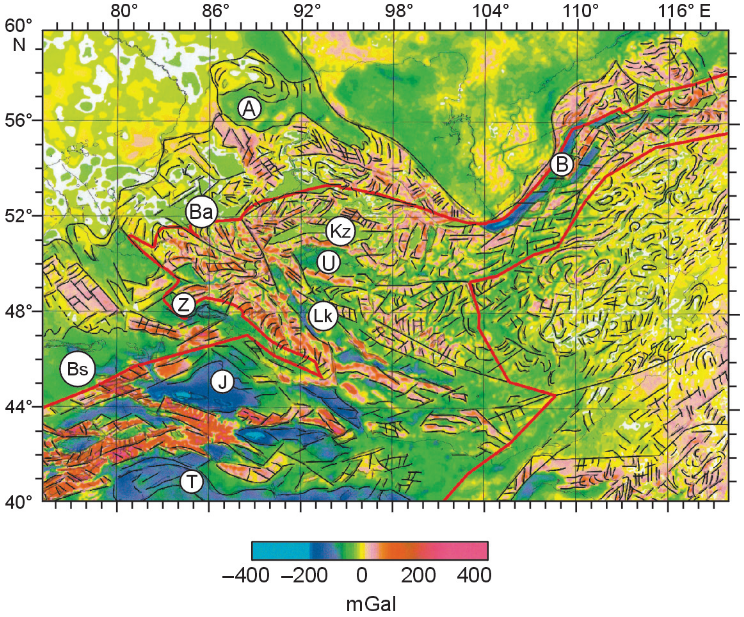

Fig. 7. Map of free-air gravity anomalies (a fragment) for Southern Siberia, Tien Shan, and Mongolia, compiled with reference to database from (Andersen and Kundsen, 2014), with structural elements according to (Dobretsov et al., 2013, 2016). See text for explanation. Abbreviations stand for basin names: T, Tarim; J, Jonggar; Bs, Balkhash; Z, Zaisan; Lk, Lake; U, Ubsunuur; Kz, Kyzyl; Ba, Barnaul; A, Achinsk; B, Baikal.

(Yarmolyuk et al., 1995; Rasskazov et al., 1997, 2000). According to one model, volcanism associated with the Mongolian superplume propagated from the southern Gobi to the Hangayn mountains, then northwestward, into the East Sayan, and on northeastward off Lake Hövsgöl toward the Udokan field (Yarmolyuk et al., 1995; Dobretsov et al., 1996). This model, however, has never been developed in detail. Another possibility is that the Mongolian superplume splits at the lower–upper mantle boundary into several smaller plumes (see their projections in Fig. 6), as it was suggested by Dobretsov (2003, 2011b).

Note that the fields of basaltic volcanism formed quite synchronously with mantle anomalies, in the Late Cenozoic, as plume heads impinged on the crust base, and they may be inherited from the far older Angara–Vitim (300–230 Ma) and Hentiyn (250–220 Ma) batholiths.

Cenozoic magmatism in the Hövsgöl–Baikal zone is obviously of plume origin and occurs mainly as Neogene and Quaternary alkaline and subalkaline basalts (Melyakhovetsky et al., 1986; Yarmolyuk et al., 1995, 2013; Litasov et al., 1999, 2000; Rasskazov et al., 1997, 2000; Dobretsov et al., 2001). The basaltic fields of the Vitim plateau, South Baikal, South Hangayn, and Udokan areas (Figs. 5, 6) coincide with the Hövsgöl–Baikal rift system only on its flanks (Hövsgöl, Tunka, and Kodar–Udokan areas). The rift zone is amagmatic over ~75% of its territory, though being characterized by uneven surface topography, high seismicity, and a contrasting gravity pattern. Thus, basaltic plume magmatism hardly can be responsible for Cenozoic tectonic activity and crust transformation in the >1500 km long and 100–300 km wide rift system.

More than 50 % of the orogenic province (or even more, counting a part of the Siberian craton territory) have been off the influence of Cenozoic lithospheric tectonism (Figs. 1 and 4), but gravity anomalies in Transbaikalia correlate well with Mesozoic geodynamic complexes. The latter are most often elongate zones (Figs. 4, 7), with Mesozoic sediments on the margins and older rocks (including Paleozoic granites or Jurassic–Cretaceous metamorphic core complexes) in the center or, asymmetrically, on one side (Sklyarov et al., 1997; Mazukabzov et al., 2011). Thirteen metamorphic core complexes shown in Fig. 4 remain unaffected by Cenozoic tectonic activity in the Eravnoe, Aga, and Argun zones; only the Selenga complex lies within the zone of Cenozoic tectonism. Metamorphic cores are prominent in the gravity field as oval-shaped or linear gravity highs up to 50 mGal surrounded by lows of the same magnitude which mark basins filled with Mesozoic sediments. The anomalies reach 150–200 km long and 15–20 km wide (Fig. 4).

Structural, petrological, and geochronological data show that a large part of metamorphic core complexes in Transbaikalia (Sklyarov et al., 1997; Mazukabzov et al., 2011) formed in a setting of extension associated with collapse of the Late Mesozoic Mongolia–Okhotsk orogen. Increase in heat flux and plasticity in the lower crust due to crust thickening caused orogen instability, with the ensuing regional extension and decollement in the middle crust. The extension and related crust thinning were accompanied by isostatic uplift and exhumation of middle crust material, with formation of metamorphic core complexes. The complexes consist of a granite or gneiss-granite core surrounded by zones of stress metamorphism (blastomylonites and mylonites) and listric faults; the latter zone is composed of Mesozoic and Late Paleozoic volcanic-sedimentary rocks subject to brittle deformation. The metamorphic cores formed by simple shear along regional detachment faults deepening southeastward; tectonic material transport and extension followed the same NW to SE direction. The activity maintained the formation of listric faults and rift basins. The complexes were exhumed at 112–123 Ma, while metamorphism acted at 140–130 Ma.

Most of Mesozoic basins contain Middle–Late Triassic volcanic-sedimentary rocks of the Chernyi Yar Formation which make up elongate NE-striking zones in volcanic-tectonic structures. The lower part of the 700 to 1500 m thick formation consists of sediments varying in size from conglomerate to silt while the upper part is mainly volcanic (trachybasalt to basaltic trachysndesite and trachyrhyodacite). Triassic volcanics are discordantly overlain by Jurassic volcanic-sedimentary rocks which include several formations deposited in a continental setting within graben-like basins. The total sediment thickness reaches 2500 m. The Early–Middle Jurassic deposition was accompanied by outpourings of felsic and alkaline mafic lavas. In the latest Middle Jurassic, conditions in some basins became favorable for coal deposition (Tugnui Formation coal-bearing sediments).

Numerous Late Mesozoic basins in the Khilok zone are rifts reaching widths of 20–25 km, with up to 2 km thick Late Jurassic–Early Cretaceous clastic sediments (sandstone, siltstone, mudstone, and brown coal intercalations) and rare trachybasalt layers (Gordienko et al., 1999; Mazukabzov et al., 2011). Some basin sections have black shale with abundant marine fauna (“fish shale”) at the base, which likely deposited when freshened sea waters penetrated inward the continent along a system of Cretaceous basins (Nesov and Starkov, 1992).

Thus, the metamorphic core complexes and the Mesozoic basins show up clearly in the map of gravity anomalies (Fig. 4). Most of the revealed meatorphic cores in Transbaikalia coincide with elongate gravity highs and border lows corresponding to half-ramps with Mesozoic sediments. Some mismatch, especially in the northeastern Stanovik and in the Argun zone, may be a consequence of poor survey coverage or variations in the erosion base level or gravity equilibration after the Mesosoic.

MESOZOIC AND LATE CENOZOIC TECTONISM AND MAGMATISM: RECORD IN THE GRAVITY FIELD

Activity along the Central Asian orogenic belt led to the formation of the Mesozoic Mongolia-Okhotsk orogen and the Cenozoic Baikal rift system. The latter was, possibly, a far-field response to the India–Eurasia collision (Zonenshain et al., 1990; Dobretsov et al., 1995, 1996, 2016, 2017; De Grave et al., 2004, 2006, 2007a,b,c, 2008, 2011a,b, 2012, 2013; Buslov et al., 2007, 2008; Glorie et al., 2010, 2011, 2012a,b; Buslov, 2012; Delvaux et al., 2013; De Pelsmaeker et al., 2015), which produced the modern mountain systems of Central Asia and sedimentary basins, shear and thrust zones, and rifts. Both pre-Cenozoic and Cenozoic structures are prominent in the map of free-air gravity anomalies (Fig. 7) (Dobretsov et al., 2013, 2016).

The gravity field images various types of deformation patterns resulting from events of different ages. See, for instance, a zone of Cenozoic deformation extending from the Tarim basin (T) as far as Lake Baikal (B) and adjacent rift basins (Fig. 7). The basins and ranges typically have rhom-

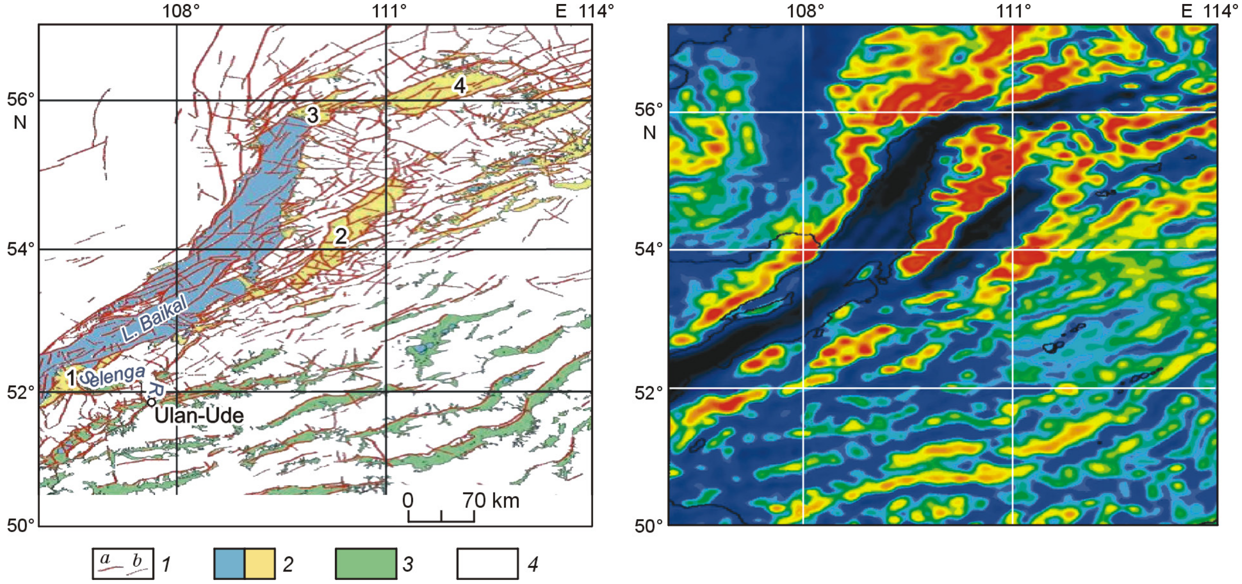

Fig. 8. Digital map (Lunina et al., 2010; Lunina, 2012, 2016) of active faults of Pribaikalia and Transbaikalia (left) and free-air gravity anomalies (right), compared. *1*, observed (*a*) and inferred (*b*) faults; 2, Cenozoic basins of the Baikal rift system; *3*, Mesozoic basins; *4*, Siberian craton: basement and sediments. Roman numerals stand for Cenozoic basins: 1, South Baikal, 2, Barguzin, 3, North Baikal, 4, Muya.

bic contours, and some consist of smaller rhombic structures. The gravity field is highly contrasting, with anomalies ranging from –300 to +300 mGal in the Tien Shan and its surroundings and from –250 to +200 mGal around Lake Baikal (Fig. 4). Oval-shaped and curved features off the zone of Cenozoic deformation correspond to Paleozoic–Mesozoic fold-thrust belts and related strike-slip faults (Buslov et al., 2003, 2004, 2009; Buslov, 2011). The gravity pattern within the Siberian craton and the West Siberian plate is diffused and images shallow subsidence and low uplift of the basement.

The pattern of free-air gravity anomalies compared in Fig. 8 with a digital map of Late Cenozoic active faults and Cenozoic and Mesozoic basins in the Pribaikalian and Transbaikalian areas (Lunina, 2012) provides a clear image of the Siberian craton periphery: the flanking orogen and a heavily faulted and folded transition zone.

There are more than 1300 faults consisting of 1800 segments in the Western Baikal area (Fig. 8): about 800 observed and 800 inferred faults (Lunina et al., 2010; Lunina, 2012, 2016). As shown by maps in Fig. 8, the zone of Cenozoic tectonic activity is distinctly delineated by a belt of large earthquakes and gravity contrasts between –110 to –120 mGal in basins and +90 to +100 mGal in ranges, as well as a system of rift basins with Cenozoic or locally Mesozoic sediments. The Baikal rift system itself is a collage of small (10–20 km) rectangular or rhomb-shaped blocks (Fig. 8). The square or thaw-tooth basin borders (gravity lows) are more prominent than the mountains, though small rhombs are well detectable northeast of Lake Baikal. The rectangular-rhombic pattern disappears in the Eravnoye, Stanovik, Hentiyn, and Argun zones south of the lake, while the gravity lows (basins) become curved, meandering, or semicircular being controlled by the pattern of Mesozoic (mostly Cretaceous) basins with a half-ramp geometry in the northwest.

DISCUSSION AND CONCLUSIONS

The use of open spaceborne gravity data for both onshore (Dobretsov et al., 2016, 2017) and offshore territories (Dobretsov and Vasilevsky, 2018) allows us to discuss several debatable issues: (1) origin of geodynamic complexes and structures in Transbaikalia, their linkage to plumes, and record in geophysical fields depending on age and deformation style; (2) footprints of Mesozoic and Late Cenozoic tectonic events in the gravity field.

The tectonic setting of Late Paleozoic magmatism in Transbaikalia, which produced the Baikal–Vitim batholith, remains open to discussions. The choice is mainly among the models of an active continental margin (Rytsk et al., 1998; Mazukabzov et al., 2010; Metelkin et al., 2012; Donskaya et al., 2013); plume activity (Yarmolyuk et al., 1997); a postcollisional setting (Tsygankov et al., 2010; Litvinovsky et al., 2011); and crust delamination in a collisional orogen (Gordienko et al., 2003). Each model has its strong and weak points ((Tsygankov, 2014) and the considerations above). In addition to lithology and chemistry, the origin of igneous bodies can be inferred from their geometry and size, as well as their position with respect to the plume, subduction, or mixed magma source.

A high-resolution tomographic model of the subsurface beneath the Klyuchevskoy group of volcanoes in the Pacific margin (Dobretsov et al., 2012) images a large magma reservoir (a conduit or an intermediate chamber) with very low seismic velocities at the crust–mantle boundary, while the material comes to this reservoir from the boundary between a mantle wedge and a slab. Two levels detectable within the crust apparently correspond to oval-shaped intermediate reservoirs (10–12 km in diameter) at depths 12–15 and 0–5 km.

As we wrote in the beginning, a wealth of geological and geophysical data has been collected to constrain the geometry and size of the Angara–Vitim batholith (Turutanov, 2011) which differ from those of magma sources within the present active margin. Interpretation of gravity, magnetic, and seismic (including DSS) data shows that all large and some smaller granitic intrusions within the strip of gravity lows merge at depths into a single sheet-like body about 750 km long, up to 250 km wide, and 2 to 30 km thick (average thickness being 8–10 km). The most widespread Middle–Late Carboniferous rocks of the Barguzin complex are poorly pronounced in the free-air gravity field (Fig. 5), and only the youngest Kunalei intrusions (230–210 Ma) preserve their round or semicircular shapes and often coincide with Mesozoic metamorphic core complexes. In general, the fields of the Kunalei syenites and granosyenites make up the periphery of the Angara–Vitim batholith and may have no relation to the latter but be rather an independent structure similar to the Uda–Vitim rift zone (Yarmolyuk et al., 1997, 1999, 2013). The location of the Barguzin granitoids fits the zone of plume-related Vitim anomaly (Fig. 5): the Barguzin main body has a circular shape while its oval-shaped end coincides with the central and outer parts of a Bouguer gravity anomaly (Fig. 4, black and blue colors, –150 to –200 mGal), which together form a strip, about 1000 km long and 200–250 km wide. The oval features may be asthenospheric upwarps or projections of mantle plumes that occur 45–50 km below the crust base (Zorin et al., 1989). In general, Bouguer anomalies (Fig. 6) match large structures in the lithospheric mantle or along the crust boundary produced mainly by the effect of Late Cenozoic plumes. The basaltic fields formed almost synchronously with mantle structures in the late Cenozoic, likely, from the same source (a plume head approaching the crust base), and may be inherited from the much older Barguzin complex (300–230 Ma).

Metamorphic core complexes and Mesozoic basins show up clearly in the map of free-air gravity anomalies (Fig. 4). Most of the detected Mesozoic metamorphic cores match the oval-shaped gravity highs and border lows of similar shapes corresponding to half-ramp basins filled with Mesozoic sediments.

The pattern of gravity anomalies corresponding to a tectonic framework produced by deformation events of different ages, which was revealed for the Central Asian orogenic belt in general (Dobretsov et al., 2013, 2016), is prominent in Transbaikalia as well. The Baikal rift system (Figs. 7, 8) is a collage of small (10–20 km) rectangular or rhomb-shaped blocks. The rectangular or thaw-tooth basin borders (gravity lows) are more prominent than the mountains, though small rhombs are well detectable northeast of Lake Baikal. The gravity lows (basins) south of the lake become curved, meandering, or semicircular being controlled by the pattern of Mesozoic (mostly Cretaceous) basins with half-ramp geometry of their northwestern side (Fig. 8).

Thus, the free-air gravity pattern reveals the key feature of the region (Figs. 7, 8): a sharp boundary of the zone of Cenozoic tectonism marked by gravity contrasts between –110 to –120 mGal in basins and +90 to +100 mGal in ranges, as well as by a system of rift basins filled with Cenozoic or locally Mesozoic sediments, which jointly produce a rectangular-rhombic pattern of the Baikal rift zone common to the whole Central Asian orogen (Dobretsov et al., 2013, 2016).

The study was carried out as part of the government assignment to the A.A. Trofimuk Institute of Petroleum Geology and Geophysics and to the V.S. Sobolev Institute of Geology and Mineralogy, both in Novosibirsk, as well as part of Integration Project No. 34 of the Siberian Branch of the Russian Academy of Sciences, and grant No. 1705-00833 from the Russian Foundation for the Basic Research. Additional support came from the government of the Russian Federation, grant No. 14.Y26.31.0029.

REFERENCES

Andersen, O.B., Knudsen, P., 2006. Deriving the DTU15 Global high resolution marine gravity field from satellite altimetry, in: ESA Living Planet Simp., 9–13 May, 2016, Pap. 1558. Praque.

Alakshin, A.M., Lysak, S.V., Pismenny, B.M., Pospeev, A.V., Pospeeva, E.V., 1991. Deep structure and geodynamics of the Sayan–Baikal mountain province and adjacent areas of East Siberia, in: Deep Structure of the USSR Territory [in Russian]. Nauka, Moscow, pp. 88–105.

Bonvalot, S., Balmino, G., Briais, A., Kuhn, M., Peyrette, A., Vales, N., Biancale, R., Gabalda, G., Reinquin, F., Sarrailh, M., 2012. World Gravity Map. Commission for the Geological Map of the World. Eds. BGI-CGMW-CNES-IRD, Paris.

Bulgatov, A.N., 1988. Geological-geophysical model of upper crust in Northern Transbaikal. Geologiya i Geofizika (Soviet Geology and Geophysics) 29 (9), 62–67 (54–58).

Bulgatov, A.N., 2015. Late Riphean and Vendian–Paleozoic Geodynamics of the Baikal Mountain Province [in Russian]. Geo Publishers, Novosibirsk.

Buslov, M.M., 2011. Tectonics and geodynamics of the Central Asian Foldbelt: the role of Late Paleozoic large-amplitude strike-slip faults. Russian Geology and Geophysics (Geologiya i Geofizika) 52 (1), 52–71 (66–90).

Buslov, M.M., 2012. Geodynamic nature of the Baikal Rift Zone and its sedimentary filling in the Cretaceous–Cenozoic: the effect of the far-range impact of the Mongolo-Okhotsk and Indo-Eurasian collisions. Russian Geology and Geophysics (Geologiya i Geofizika) 53 (9), 955–965 (1245–1255).

Buslov, M.M., Watanabe, T., Smirnova, L.V., Fujiwara, I., Iwata, K., de Grave, I., Semakov, N.N., Travin, A.V., Kir'yanova, A.P., Kokh, D.A., 2003. Role of strike-slip faulting in Late Paleozoic–Early Mesozoic tectonics and geodynamics of the Altai–Sayan and East Kazakhstan regions. Geologiya i Geofizika (Russian Geology and Geophysics) 44 (1–2), 49–75 (47–71).

Buslov, M.M., Watanabe, T., Fujiwara, Y., Iwata, K., Smirnova, L.V., Saphonova, I.Yu., Semakov, N.N., Kiryanova, A.P., 2004. Late Paleozoic faults of the Altai region, Central Asia: tectonic pattern and model of formation. J. Asian Earth Sci. 23 (5), 655–671.

Buslov, M.M, De Grave, J., Bataleva, E.A., Batalev, V.Yu., 2007. Cenozoic tectonic and geodynamic evolution of the Kyrgyz Tien Shan Mountains: A review of geological, thermochronological and geophysical data. J. Asian Earth Sci. 29 (2–3), 205–214.

Buslov, M.M., Kokh, D.A., De Grave, J., 2008. Mesozoic–Cenozoic tectonics and geodynamics of the Altai, Tien Shan, and Northern Kazakhstan, from apatite fission-track data. Russian Geology and Geophysics (Geologiya i Geofizika) 49 (9), 648–654 (862–870).

Buslov, M.M., Ryabinin, A.B., Zhimulev, F.I., Travin, A.V., 2009. Manifestations of the Late Carboniferous and Early Permian stages of formation of nappe-fold structures in the southern framework of the Siberian platform (East Sayany, South Siberia). Dokl. Earth Sci. 428: 1105. DOI: 10.1134/S1028334X09070149.

Buslov, M.M., Geng, H., Travin, A.V., Otgonbaatar, D., Kulikova, A.V., Ming, Ch., Stijn, G., Semakov, N.N., Rubanova, E.S., Abildaeva, M.A., Voitishek, E.E., Trofimova, D.A., 2013. Tectonics and geodynamics of Gorny Altai and adjacent structures of the Altai–Sayan folded area. Russian Geology and Geophysics (Geologiya i Geofizika) 54 (10), 1250–1271 (1600–1627).

Burmakina, G.N., Tsygankov, A.A., 2013. Mafic microgranular enclaves in Late Paleozoic granitoids in the Burgasy quartz syenite massif, western Transbaikalia: Composition and petrogenesis. Petrology 21 (3), 280–303.

De Grave, J., Buslov, M.M., Van den Haute, P., 2004. Intercontinental deformation in Central Asia: distant effects of India–Eurasia convergence revealed by apatite fission-track thermochronology. Himalayan J. Sci. 2 (4) (Spec. Issue), 121–122.

De Grave, J., Buslov, M., Van den Haute, P., Metcalf, J., Batalev, V., 2006. From Palaeozoic Eurasian assembly to ongoing Indian indentation: multi-chronometry of the northern Kyrgyz Tien Shan batholith. J. Asian Earth Sci. 26(2), 133.

De Grave, J., Buslov, M., Van den Haute, P., 2007a. Distant effects of India–Eurasia convergence and Mesozoic intracontinental deformation in Central Asia: Constraints from apatite fission-track thermochronology. J. Asian Earth Sci. 29 (2–3), 188–204.

De Grave, J., Buslov, M.M., Van den Haute, P., Dehandschutter, B., 2007b. Meso-Cenozoic evolution of mountain range – intramontane basin systems in the southern Siberian Altai mountains by apatite fission track thermochronology. J. Asian Earth Sci. 29, 2–9.

De Grave, J., Buslov, M.M., Van den Haute, P., Dehandschutter, B., Delvaux, D., 2007c. Meso-Cenozoic evolution of Mountain Range—intramontane basin systems in the Southern Siberian Altai Mountains by apatite fission-track thermochronology, in: Thrust Belts and Foreland Basins: from Fold Kinematics Hydrocarbon Systems. Springer, Berlin, Chapter 24, pp. 457–470.

De Grave, J., Van den Haute, P., Buslov, M.M., Dehandschutter, B., Glorie, S., 2008. Apatite fission-track thermochronology applied to the Chulysman Plateau, Siberian Altai Region. Radiat. Meas. 43 (1), 38–42.

De Grave, J., Glorie, S., Buslov, M.M., Izmer, A., Fournier-Carrie, A., Batalev, V.Yu., Vanhaecke, F., Elburg, M., Van den Haute, P., 2011a. The thermo-tectonic history of the Song-Kul plateau, Kyrgyz Tien Shan: Constraints by apatite and titanite thermochronometry and zircon U/Pb dating. Gondwana Res. 20 (4), 745–763.

De Grave, J., Glorie, S., Zhimulev, F.I., Buslov, M.M., Elburg, M., Vanhaecke, F., Van den Haute, P., 2011b. Emplacement and exhumation of the Kuznetsk-Alatau basement (Siberia): implications for the tectonic evolution of the Central Asian Orogenic Belt and sediment supply to the Kuznetsk, Minusa and West Siberian Basins. Terra Nova 23, 248–256.

De Grave, J., Glorie, S., Ryabinin, A., Zhimulev, F.I., Buslov, M.M., Izmer, A., Elburg, M.A., Vanhaecke, F., 2012. Late Palaeozoic and Meso-Cenozoic tectonic evolution of the southern Kyrgyz Tien Shan: Constraints from multi-method thermochronology in the Trans-Alai, Turkestan-Alai segment and the southeastern Ferghana Basin. J. Asian Earth Sci. 44, 149–168.

De Grave, J., Glorie, S., Buslov, M.M., Stockli, D.F., McWilliams, M.O., Batalev, V.Y., Van den Haute P., 2013. Thermo-tectonic history of the Issyk-Kul basement (Kyrgyz Northern Tien Shan, Central Asia). Gondwana Res. 23, 998–1020.

De Pelsmaeker, E., Glorie, S., Buslov, M.M., Zhimulev, F.I., Poujol, M., Korobkin, V.V., Vanhaecke, F., Vetrov, E.V., De Grave, J., 2015. Late-Paleozoic emplacement and Meso-Cenozoic reactivation of the southern Kazakhstan granitoid basement. Tectonophysics 622, 416–433.

Delvaux, D., Cloetingh, S., Beekman, F., Sokoutis, D., Burov, E., Buslov, M.M., Abdrakhmatov, K.E., 2013. Basin evolution in a folding lithosphere: Altai-Sayan and Tien Shan belts in Central Asia. Tectonophysics 602, 194–222.

Didenko, A.N., Efimov, A.S., Nelyubov, P.A., Sal'nikov, A.S., Starosel'tsev, V.S., Shevchenko, B.F., Goroshko, M.V., Gur'yanov, V.A., Zamozhnyaya, N.G., 2013. Structure and evolution of the Earth's crust in the region of junction of the Central Asian Fold Belt and the Siberian Platform: Skovorodino–Tommot profile. Russian Geology and Geophysics (Geologiya i Geofizika) 54 (10), 1236–1249 (1583–1599).

Dobretsov, N.L., 2003. Mantle plumes and their role in the formation of anorogenic granitoids. Geologiya i Geofizika (Russian Geology and Geophysics) 44 (12), 1243–1261 (1199–1218).

Dobretsov, N.L., 2011a. Fundamentals of Tectonics and Geodynamics [in Russian]. Novosibirsk. Gos. Univ., Novosibirsk.

Dobretsov, N.L., 2011b. Early Paleozoic tectonics and geodynamics of Central Asia: role of mantle plumes. Russian Geology and Geophysics (Geologiya i Geofizika). Russian Geology and Geophysics (Geologiya i Geofizika) 52 (12), 1539–1552 (1957–1973).

Dobretsov, N.L., Buslov, M.M., 2007. Late Cambrian-Ordovician tectonics and geodynamics of Central Asia. Russian Geology and Geophysics (Geologiya i Geofizika) 48 (1), 71–83 (93–108).

Dobretsov, N.L., Buslov, M.M., 2011. Problems of geodynamics, tectonics, and metallogeny of orogens. Russian Geology and Geophysics (Geologiya i Geofizika) 52 (12), 1505–1515 (1911–1926).

Dobretsov, N.L., Vasilevsky, A.N., 2018. Gravuty field, surface topography, and volcanic complexes of Kamchatka and its junction with the Aleutian arc. Russian Geology and Geophysics (Geologiya i Geofizika) 59 (7), 780–802 (970–997).

Dobretsov, N.L., Berzin, N.A., Buslov, M.M., Ermikov, V.D., 1995. General aspects of the evolution of the Altai region and the interrelationships between its basement pattern and the neotectonic structural development. Geologiya i Geofizika (Russian Geology and Geophysics) 36 (10), 5–19 (3–15).

Dobretsov, N.L., Buslov, M.M., Delvaux, D., Berzin, N.A., Ermikov, V.D., 1996. Meso- and Cenozoic tectonics of the Central Asian mountain belt: effects of lithospheric plate interaction and mantle plumes. Int. Geol. Rev. 38, 430–466.

Dobretsov, N.L., Kirdyashkin, A.G., Kirdyashkin, A.A., 2001. Deep-Seated Geodynamics, second edition [in Russian]. Izd. SO RAN, filial Geo, Novosibirsk.

Dobretsov, N.L., Koulakov, I.Yu., Litasov, Yu.D., 2012. Migration paths of magma and fluids and lava compositions in Kamchatka. Russian Geology and Geophysics (Geologiya i Geofizika) 53 (12), 1253–1275 (1633–1661).

Dobretsov, N.L., Buslov, M.M., De Grave, J., Sklyarov, E.V., 2013. Interplay of magmatism, sedimentation, and collision processes in the Siberian craton and the flanking orogens. Russian Geology and Geophysics (Geologiya i Geofizika) 54 (10), 1135–1149 (1451–1471).

Dobretsov, N.L., Buslov, M.M., Vasilevsky, A.N., Vetrov, E.V., Nevedrova, N.N., 2016. Cenozoic history of topography in southeastern Gorny Altai: thermochronology, resistivity and gravity records. Russian Geology and Geophysics (Geologiya i Geofizika) 57 (11), 1525–1534 (1937–1948).

Dobretsov, N.L., Buslov, M.M., Rubanova, E.S., Vasilevsky, A.N., Kulikova, A.V., Bataleva, E.A., 2017. Middle–Late Paleozoic geodynamic complexes and structure of Gorny Altai and their record in gravity data. Russian Geology and Geophysics (Geologiya i Geofizika) 58 (11), 1277–1288 (1617–1632).

Donskaya, T.V., Gladkochub, D.P., Mazukabzov, A.M., Ivanov, A.V., 2013. Late Paleozoic–Mesozoic subduction-related magmatism at the southern margin of the Siberian continent and the 150 million-year history of the Mongol-Okhotsk Ocean. J. Asian Earth Sci. 62, 79–97.

Förste, C., Bruinsma, S.L., Abrikosov, O., Lemoine, J.-M., Schaller, T., Götze, H.-J., Ebbing, J., Marty, J.C., Flechtner, F., Balmino, G., Biancale, R., 2014. EIGEN-6C4 The latest combined global gravity field model including GOCE data up to degree and order 2190 of GFZ Potsdam and GRGS Toulouse. Proc. 5th GOCE User Workshop, Paris, 25–28 November, 2014.

Glebovitsky, V.A., Nikitina, L.P., Saltykova, A.K., Pushkarev, Yu.D., Ovchinnikov, N.O., Babushkina, M.S., Ashchepkov, I.V., 2007. Thermal and chemical heterogeneity of the upper mantle beneath the Baikal-Mongolia region. Petrology 15 (1), 58–89.

Glorie, S., De Grave, J., Buslov, M.M., Elburg, M.A., Stockli, D.F., Gerdes, A., Van den Haute, P., 2010. Multi-method chronometric constraints on the evolution of the Northern Kyrgyz Tien Shan granitoids (Central Asian Orogenic Belt): from emplacement to exhumation. J. Asian Earth Sci. 38, 131–146.

Glorie, S., De Grave, J., Buslov, M.M., Zhimulev, F.I., Stockli, D.F., Batalev, V.Yu., Izmer, A., Van den Haute, P., Vanhaecke, F., Elburg, M.A., 2011. Tectonic history of the Kyrgyz South Tien Shan (Atbashi-Inylchek) suture zone: the role of inherited structures during deformation-propagation. Tectonics 30 (6), TC6016.

Glorie, S., De Grave, J., Buslov, M.M., Zhimulev, F.I., Elburg, M.A., Van den Haute, P., 2012a. Structural control on Meso-Cenozoic tectonic reactivation and denudation in the Siberian Altai: Insights from multi-method thermochronometry. Tectonophysics 544–545, 75–92.

Glorie, S., De Grave, J., Delvaux, D., Buslov, M.M., Zhimulev, F.I., Van den Haute, P. 2012b. Tectonic history of the Irtysh shear zone (NE Kazakhstan): New constraints from zircon U/Pb dating, apatite fission track dating and paleostress analysis. J. Asian Earth Sci. 45, 138–149.

Gordienko, I.V., Metelkin, D.V., 2016. The evolution of the subduction zone magmatism on the Neoproterozoic and Early Paleozoic active margins of the Paleoasian Ocean. Russian Geology and Geophysics (Geologiya i Geofizika) 57 (1), 69–81 (91–108).

Gordienko, I.V., Bayanov, V.D., Klimuk, B.C., Ponomarchuk, V.A., Travin, A.V., 1999. The composition and ^{39}Ar/^{40}Ar age of volcanogenic rocks of the Chikoi-Khilok rift valley in Transbaikalia. Geologiya i Geofizika (Russian Geology and Geophysics) 40 (4), 583–591 (566–575).

Gordienko I.V., Kiselev A.I., Lashkevich V.V., 2003. Lithospheric delamination and related magmatism in fold areas (folded periphery of the southern Siberian craton), in: Rundkvist, D.V. (Ed.), Problems of Global Geodynamics. Proc. Theoretical Workshop, OGGGGN RAN, 2000–2001 [in Russian]. GEOS, Moscow, pp. 185–199.

Litasov, K.D., Dobretsov, N.L., Sobolev, A.V., 1999. Melt percolation and reaction in the upper mantle: evidence from peridotite xenoliths of the Vitim and Udokan volcanic fields of Transbaical'e. Dokl. Akad. Nauk 368 (4), 525–529.

Litasov, K.D., Liitasov, Yu.D., Mekhonoshin, A.S., Mal'kovets, V.G., 2000. Geochemistry of clinopyroxenes and petrogenesis of mantle xenoliths from Pliocene basanites of the Dzhilinda River (Vitim volcanic field). Geologiya i Geofizika (Russian Geology and Geophysics) 41 (11), 1557–1574 (1502–1519).

Litvinovsky, B.A., Zanvilevich, A.N., Alakshin, A.M., Podladchikov, Yu.Yu., 1993. Angara–Vitim Batholith: The Largest Granitoid Pluton [in Russian]. OIGGM SO RAN, Novosibirsk.

Litvinovsky, B.A., Yarmolyuk, V.V., Vorontsov, A.A., Zhuravlev, D.Z., Posokhov, V.F., Sandimirova, G.P., Kuzmin, D.V., 2001. Late Triassic stage of formation of the Mongolo-Transbaikalian alkaline-granitoid province: data of isotope-geochemical studies. Geologiya i Geofizika (Russian Geology and Geophysics) 42 (3), 445–455 (433–444).

Litvinovsky, B.A., Tsygankov, A.A., Jahn, B.M., Katzin, Y., Be'eri-Shlevin, Y., 2011. Origin and evolution of overlapping calc-alkaline and alkaline magmas: The Late Palaeozoic post-collisional igneous province of Transbaikalia (Russia). Lithos 125 (3–4), 845–874.

Lunina, O.V., 2012. Late Cenozoic Fault Tectonics of the Western Baikal Region. Author's Abstract, DrSci Thesis [in Russian]. Moscow.

Lunina, O.V., 2016. The Digital Map of the Pliocene–Quaternary Crustal Faults in the Southern East Siberia and the Adjacent Northern Mongolia. Geodin. Tectonophys. 7 (3), 407–434.

Lunina, O.V., Gladkov, A.S., Sherstyankin, P.P., 2010. A new electronic map of active faults for southeastern Siberia. Dokl. Earth Sci. 433 (2), 1016–1021.

Mazukabzov, A.M., Donskaya, T.V., Gladkochub, D.P., Paderin, I.P., 2010. The Late Paleozoic geodynamics of the West Transbaikalian segment of the Central-Asian fold belt. Russian Geology and Geophysics (Geologiya i Geofizika) 51 (5), 482–491 (615–628).

Mazukabzov, A.M., Sklyarov, E.V., Donskaya, T.V., Gladkochub, D.P., Fedorovsky, V.S., 2011. Metamorphic core complexes of the Transbaikalia: review. Geodyn. Tectonophys. 2 (2), 95–125.

Melyakhovetsky, A.A., Ashchepkov, I.V., Dobretsov, N.L., 1986. Amphibole- and phlogopite-bearing mantle xenoliths and congenetic inclusions of the Bortoi volcanics (Baikal rift zone). Dokl. AN SSSR 286 (5), 1215–1219.

Metelkin, D.V., Vernikovsky, V.A., Kazansky, A.Yu., 2012. Tectonic evolution of the Siberian paleocontinent from the Neoproterozoic to the Late Mesozoic paleomagnetic record and reconstructions. Russian Geology and Geophysics (Geologiya i Geofizika) 53 (7), 675–688 (883–899).

Nesov, L.A., Starkov, A.I., 1992. Cretaceous vertebrates from the Gusinoe-Lake Basin in Transbaikalia and their contribution into age determination and reconstruction of deposition environment. Geologiya i Geofizika (Russian Geology and Geophysics) 33 (6), 10–18 (9–16).

Parfenov, L.M., Bulgatov, A.N., Gordienko, I.V., 1996. Terranes and formation of orogens in Transbaikalia. Tikhookeanskaya Geologiya 15 (4), 3–15.

Parfenov, L.M., Popeko, L.I., Tomurtogoo, O., 1999. Tectonics of the Mongolia-Okhotsk orogen. Tikhookeanskaya Geologiya 18 (5), 24–43.

Parfenov, L.M., Berzin, N.A., Khanchuk, A.I., Badarch, G., Belichenko, V.G., Bulgatov, A.N., Dril, S.I., Kirillova, G.L., Kuzmin, M.I., Nockleberg, W., Prokopiev, A.V., Timofeev, V.F., Tomurtogoo, O., Yan, X., 2003. Formation model for orogens in Central and Eastern Asia. Tikhookeanskaya Geologiya 22 (6), 7–41.

Pavlis, N.K., Factor, J.K., Holmes, S.A., 2007. Terrain-related gravimetric quantities computed for the next EGM, in: Gravity Field of the Earth, Proc. 1st Int. Symposium of the International Gravity Field Service, Harita Dergisi. Spec. Issue 18, 1B, Istanbul, Turkey, 318–323.

Rasskazov, S.V., Boven, A., Andre, L., Legeos, D.P., Ivanov, A.V., Punzalan, L., 1997. History of magmatism in the northeastern Baikal rift system. Petrologiya 5 (2), 101–120.

Rasskazov, S.V., Logachev, N.A., Brandt, I.S., Brandt, S.B., Ivanov, A.V., 2000. Late Cenozoic Geochronology and Geodynamics: Southern Siberia—Southern and Eastern Asia [in Russian]. Nauka, Novosibirsk.

Rytsk, E.Yu., Neimark, L.A., Amelin, Yu.V., 1998. Age and tectonic settings of Paleozoic granitoids of the northern Baikal fold area. Geotektonika 5, 46–60.

Sklyarov, E.V., Mazukabzov, A.M., Melnikov, A.I., 1997. Cordilleran-Type Metamorphic Core Complexes [in Russian]. OIGGM, Novosibirsk.

Tsygankov, A.A., 2014. Late Paleozoic granitoids in western Transbaikalia: sequence of formation, sources of magma, and geodynamics. Russian Geology and Geophysics (Geologiya i Geofizika) 55 (2), 153–176 (197–227).

Tsygankov, A.A., Matukov, D.I., Bepezhnaya, N.G., Larionov, A.N., Posokhov, V.F., Tsyrenov, B.S., Khromov, A.A., Sergeev S.A., 2007. Late Paleozoic granitoids of western Transbaikalia: magma sources and stages of formation. Russian Geology and Geophysics (Geologiya i Geofizika) 48 (1), 120–140 (156–180).

Tsygankov, A.A., Litvinovsky, B.A., Jahn, B.M., Reikov, M., Liu, D.I., Larionov, A.N., Presnyaiakov, S.L., Lepekhina, E.N., Sergeev, S.A., 2010. Sequence of magmatic events in the Late Paleozoic of Transbaikalia (U–Pb isotope data). Russian Geology and Geophysics (Geologiya i Geofizika) 51 (9), 972–997 (1249–1276).

Tsygankov, A.A., Khubanov, V.B., Travin, A.V., Lepekhina, E.N., Burmakina, G.N., Antsiferova, T.N., Udoratina, O.V., 2016. Late Paleozoic gabbroids of western Transbaikalia: U–Pb and Ar–Ar isotopic ages, composition, and petrogenesis. Russian Geology and Geophysics (Geologiya i Geofizika) 57 (5), 790–808 (1005–1027).

Turutanov, E.Kh., 2011. The Angara-Vitim batholite: Data on morphology and sizes based on gravimetric data. Dokl. Earth Sci. 440 (6), 1464–1466.

Vitte, L.V., Vasilevsky, A.N., 2013. Geologic nature of regional magnetic and gravity anomalies in the Mongol-Transbaikalian province of the Central Asian Fold Belt. Russian Geology and Geophysics (Geologiya i Geofizika) 54 (12), 1442–1449 (1851–1860).

Vitte, L.V., Vasilevsky, A.N., Pavlov, E.V., 2009. Regional magnetic and gravity anomalies in the Siberian craton and their geological causes. Geofizicheskii Zhurnal 31 (6), 1–40.

Yarmolyuk, V.V., Kovalenko, V.I., 2003. Deep geodynamics and mantle plumes: their role in the formation of the Central Asian fold belt. Petrology 11 (6), 504–531.

Yarmolyuk, V.V., Kovalenko, V.I., Ivanov, V.G., 1995. The Central Asian Late Mesozoic-Cenozoic within-plate volcanic province: a projection of a mantle hot field. Geotektonika, No. 5, 41–67.

Yarmolyuk, V.V., Budnikov, S.V., Kovalenko, V.I., Antipin, V.S., Goreglyad, A.V., Salnikova, E.B., Kotov, A.B., Kozakov, I.A., Kovach, V.P., YaIakovleva, Z.S., Berezhnaya, N.G., 1997. Geochronology and geodynamics of the Angara-Vitim batholith. Petrologiya 5 (5), 451–466.

Yarmolyuk, V.V., Kovalenko, V.I., Kovach, V.P., Budnikov, S.V., Kozakov, I.K., Kotov, A.B., Salnikova, E.B., 1999. The Nd isotope systematics of crustal magmatic protoliths in Western Transbaikalia and a problem of Riphean crust growth in Central Asia. Geotektonika, No. 4, 3–20.

Yarmolyuk, V.V., Litvinovsky, B.A., Kovalenko, V.I., Borminjan, Zanvilevich. A.N., Vorontsov, A.A., Zhuravlev, D.Z., Posokhov, V.F., Kuzmin, D.V., Sandimirova, G.P., 2001. Permian and Triassic history and sources of alkaline-granitoid magmatism in the North Mongolian-Transbaikalian rift belt. Petrologiya 9 (4), 350–380.

Yarmolyuk, V.V., Kovalenko, V.I., Kovach, V.P., Kozakov, I.K., Kotov, A.B., Sal'nikova, E.B., 2003. Geodynamics of caledonides in the Central Asian foldbelt. Dokl. Earth Sci. 389 (3), 311–316.

Yarmolyuk, V.V., Kovalenko, V.I., Sal'nikova, E.B., Kovach, V.P., Kozlovsky, A.M., Kotov, A.B., Lebedev, V.I., 2008. Geochronology of igneous rocks and formation of the Late Paleozoic south Mongolian active margin of the Siberian continent. Stratigr. Geol. Korr. 16 (2), 162–181.

Yarmolyuk, V.V., Kuzmin, M.I., Vorontsov, A.A., 2013.West Pacific-type convergent boundaries and their role in the formation of the Central Asian Fold Belt. Russian Geology and Geophysics (Geologiya i Geofizika) 54 (12), 1427–1441 (1831–1850).

Zonenshain, L.P., Kuzmin, M.I., Natapov, L.M., 1990. Geology of the USSR: A Plate Tectonic Synthesis. Geodyn. Ser. 21, Page, B.M. (Ed.). AGU, Washington.

Zorin, Yu.A., Turutanov, E.Kh., 2004. Regional isostatic gravity anomalies and mantle plumes in southern East Siberia (Russia) and Central Mongolia. Geologiya i Geofizika (Russian Geology and Geophysics 45 (10), 1248–1258 (1200–1210).

Zorin, Yu.A., Pis'mennyi, B.M., Novoselova, M.R., Turutanov, E.Kh., 1985. Decompensation gravity anomalies. Geologiya i Geofizika (Soviet Geology and Geophysics) 26 (8), 104–108 (92–96).

Zorin, Yu.A., Balk, T.V., Novoselova, M.R., Turutanov, E.Kh., 1988. Lithospheric thickness beneath the Mongolia-Siberia mountain province and its surroundings. Izv. AN SSSR, Fizika Zemli, No. 7, 33–42.

Zorin, Yu.A., Kozhevnikov, V.M., Novoselova, M.R., Turutanov, E.Kh., 1989. Thickness of the litosphere beneath the Baikal rift zone and adjacent regions. Tectonophysics 168, 327–337.

Zorin, Yu.A., Belichenko, V.G., Turutanov, E.Kh., Mazukabzov, A.M., Sklyarov, E.V., Mordvinova, V.V., 1995. The East Siberia transect. Int. Geol. Rev. 37 (2), 154–175.

Editorial responsibility: E.V. Sklyarov