

Asthenosphere and Plates of Northeast Asia*

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In the territory of Northeast Asia north of latitude 56, the three largest lithospheric plates (Eurasian, North American, and Pacific) and some plates of second rank (Amur, Sea of Okhotsk, and Sea of Bering) [14] are conjugated and their space–time interrelations are the subject of heated discussions. Tectonists diagnose boundaries and kinematic characteristics of plates proceeding from analysis of the tectonostratigraphic, paleogeographic, magmatic, and structural attributes observed in a thin superficial layer of the crust [2, 8, 9, 13, 14]. Works of seismologists are based on the spatial distribution of centers of earthquakes and calculations of vectors of seismotectonic pressures in fields of strong seismic events [6, 14]. These systems of estimations do not always coincide during the characterization of spatial parameters and evolution of the lithospheric plates. In particular, the site of the modern boundary between the Eurasian (EAP) and North American (NAP) plates varies by more than 700 km in different estimations [3, 4, 8, 14].

The authors obtained new data on the tectonospheric structure up to a depth of 150 km as the result of the multiple formalized interpretation of gravity anomalies related to density inhomogeneities of the compaction class and spherical sources equivalent to them. Analysis of the 3D density gradient model allowed us to estimate the spatial parameters of asthenospheric lenses and large tectonic plates. Their comparison to the geological structure of superficial tectonic complexes essentially supplements and corrects representations about spatial relations and features of the evolution of lithospheric plates of North Asia.

In the absence of seismic and magnetotelluric data for most of the northeastern region of Russia and a

scarce network of heat flow measurements, the gravity anomalies here are the most representative source of information about the deep structure of the crust and upper mantle. However, using gravity modeling based on the block-layer approximation of geological space [15], we could reveal only the upper (Mesozoic, according to geochronologists) boundary of the asthenosphere in this region. The deep spatial parameters of the lithospheric plates in these models have not been diagnosed and investigated.

New opportunities for tectonic interpretation of gravity data in this region were revealed during analysis of spatial distributions of vertical gradients of the superficial density of spherical sources of gravity anomalies (μ_z) equivalent to density inhomogeneities of

a wide spatial range: $5 > \frac{\Delta H}{D} > 0.1$, where ΔH is the vertical thickness of an elementary geological body and D is its horizontal size along the cross section. Physical and mathematical substantiation and the construction technique of 3D models $\mu_z(x, y, z)$ are described in detail in [10, 11]. Comparison of the density gradient anomalies (μ_z) with distributions of the seismic wave velocity, electrical resistance, and thermophysical models of the crust and upper mantle suggested the following conclusion: this characteristic of the formalized geological space shows the degree of the rigidity of tectonic mediums. Maximums of the μ_z parameter correspond to metamorphic blocks and plates of the ancient continental crust and the lower layer of the lithosphere [11, 12]; minimums, to layers of lowered viscosity in the subcrustal layer of the upper mantle and asthenosphere [11].

The purpose of our communication is analysis of an objective (i.e., unrelated to the previous geological data and concepts) 3D model of the specialized geological space $\mu_z(x, y, z)$ used for diagnostics and spatial correlation of boundaries of the asthenosphere lenses and the lithospheric plates in northeastern Russia.

In sections of the Northeast Asian tectonosphere up to depths of 150 km from the geoid surface (Figs. 1c, 2b), one can clearly see sharp distinction of the density gradient distributions under the North Asia Craton (NAC) and the Kolyma–Omolon Superterrane (KOS). The

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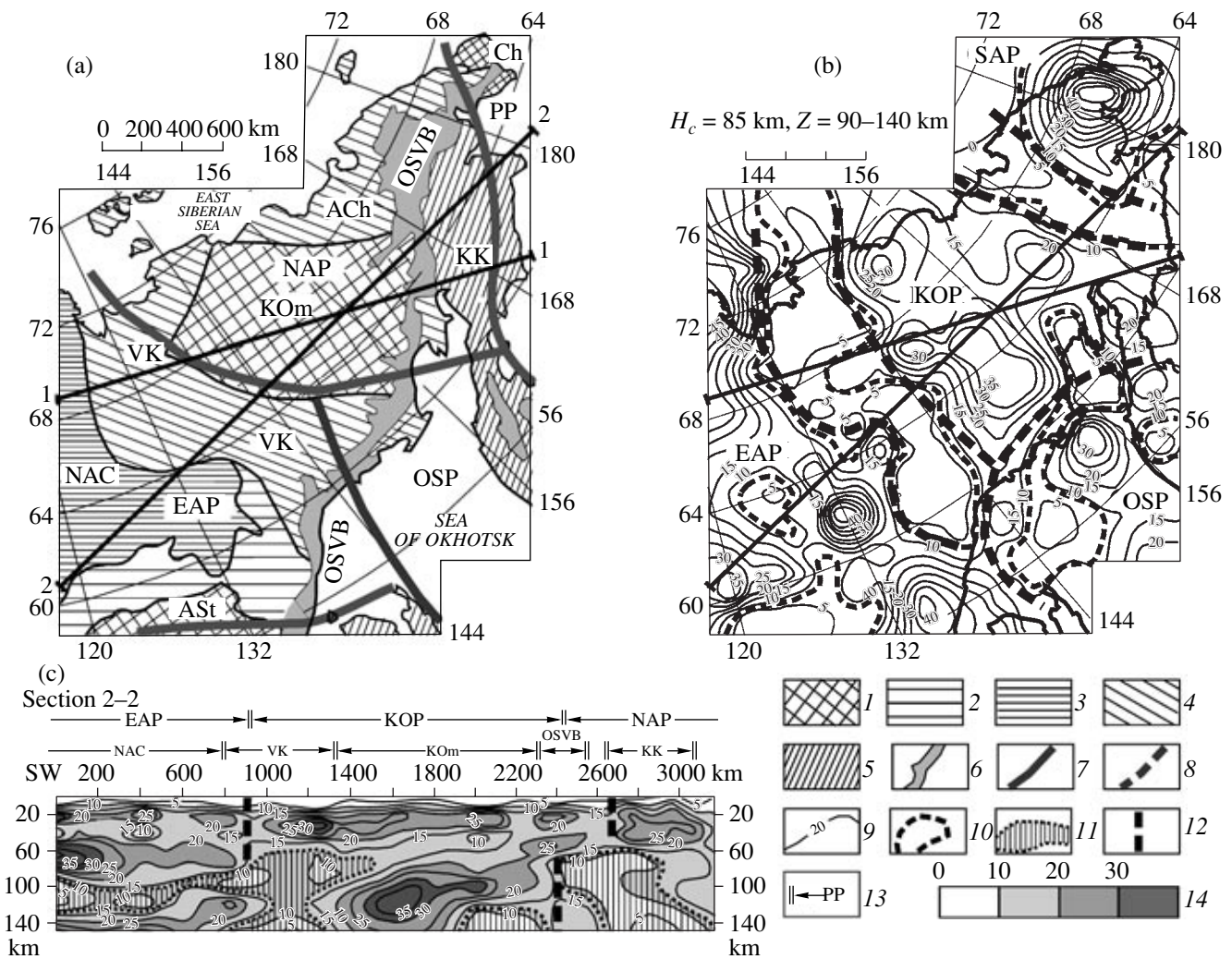


Fig. 1. Tectonic scheme of Northeastern Asia [3, 14] (a) and the map slice of density gradients of the upper mantle at depth $H_c = 85$ km (b) with Section 2-2 (c) (1) terranes with the Pre-Riparian continental crust; (2, 3) the plate cover of the North Asian Craton: (2) Paleozoic and Early Mesozoic, (3) Late Mesozoic; (4, 5) accretional-folded complexes: (4) Paleozoic and Early Mesozoic, (5) Late Mesozoic and Cenozoic; (6) Cretaceous–Paleogene volcanic belts; (7, 8) boundaries of lithospheric plates (7) in the upper crust layer [14] and (8) at deep levels; (9) isolines of μ_z parameter (10^{-2} kg/M²/km); (10, 11) asthenosphere lenses in the (10) plan and (11) sections; (12) deep faults, (13) boundaries of tectonic structures on sections and their designation; (14) painting scale of Sections (1 unit = 10^{-2} kg/M²/km). (H_c) the depth of a surface on which elementary density inhomogeneities of a layer included in the depth interval ($Z_1 - Z_2$) are condensed. Abbreviations of structural elements: plates: (EAP) Eurasian, (NAP) North American, (KOP) Kolyma–Omolon, (OSP) Sea of Okhotsk, (PP) Pacific; terranes with the crust of a continental type: (ASt) Aldan–Stanovoy, (KOm) Kolyma–Omolon, (Ch) Chukotsk; accretional folded-thrust systems: (VK) Verkhoyansk–Kolyma, (ACh) Anyui–Chukotsk, (KK) Koryak–Kamchatka; (OCVB) Okhotsk–Chukotka volcanic belt.

crust and upper mantle of the craton are characterized by a gently dipping six-layer section typical of areas with a prominent continental type of crust (Amur region, Northeastern Transbaikalia, northwestern coast of the Sea of Okhotsk [11]). Sections of the Kolyma–Omolon tectonospheric segment show two high-density-gradient layers with different morphological features. The first layer (depth interval 10–45 km) corresponds to the lower crust (crystalline) layer, while the second layer is separated from the first one by the lowered viscosity layer (zone of lower values of the μ_z parameter) and characterized by stepwise subsidence in

the direction from the North American Plate under the Kolyma–Omolon Superterrane (Fig. 1c). The lithospheric segment approximately fitting the site of the KOM is separated from adjacent segments by rises of a layer with low values of density gradients corresponding to the asthenospheric lenses (Figs. 1b, 1c). The observable distribution of density gradients allows us to assume that the lower inclined rigid tectonic slab in the section of the Kolyma–Omolon segment corresponds to the subducted North American Plate, whereas the upper one represents an independent tectonic element: the second-rank buffer Kolyma–Omolon Plate (KOP) is

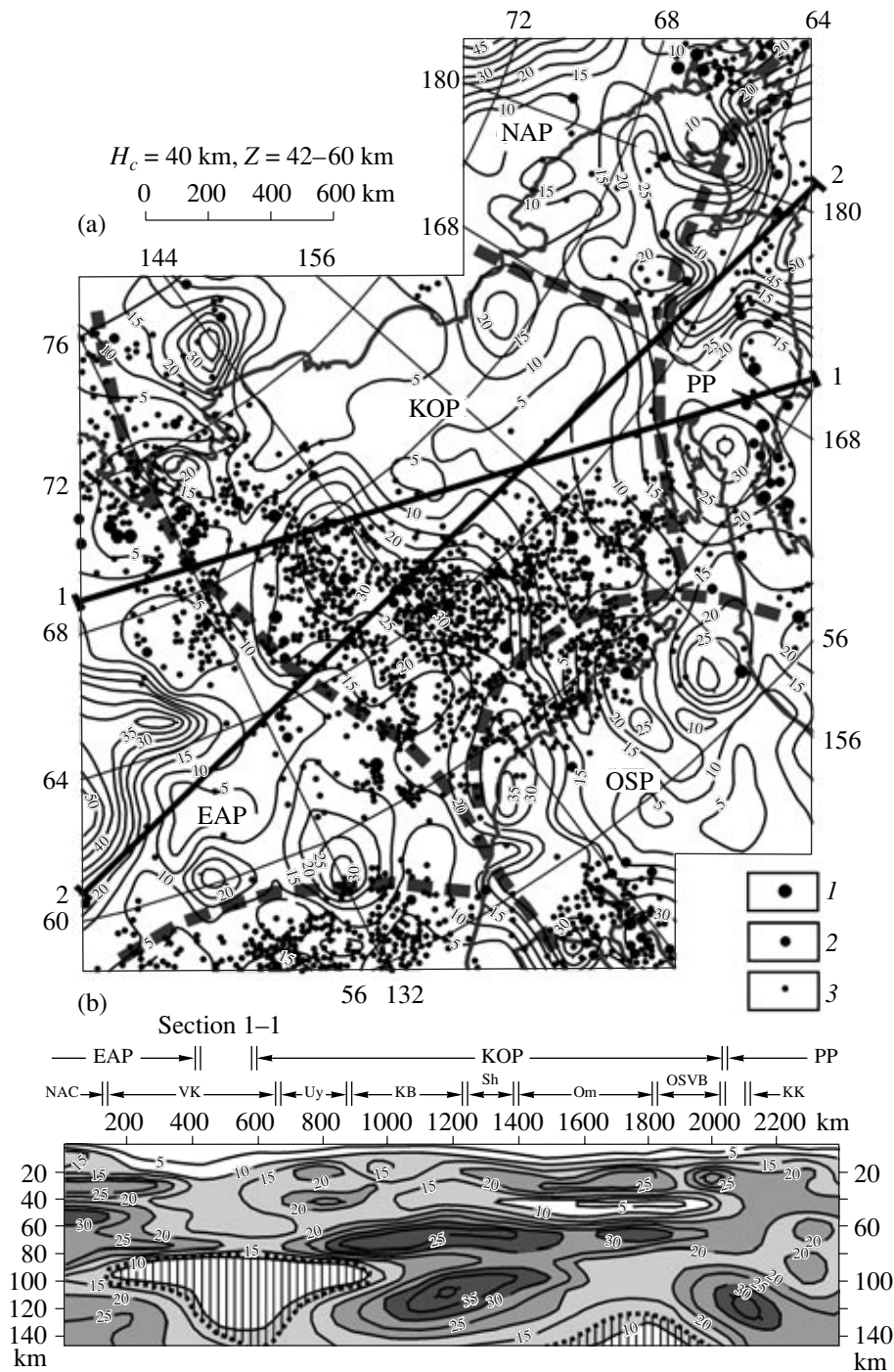


Fig. 2. Map slice of density gradients at the depth of $H_c = 40$ km (a) with the Section 1-1 (b). (1-3) centers of earthquakes [14] with magnitudes: (1) > 6 , (2) 4-6, (3) < 4 ; abbreviations of tectonic structures of third rank: terranes with the continental crust: (Uy) Uyandina, (Sh) Shamanikha, (Om) Omolon; (KB) Kolyma basin. Other designations are in Fig. 1.

similar to the Amur and Sea of Okhotsk plates. The tectonic isolation of the KOP emphasizes the peripheral arrangement of accretional and volcanic island-arc complexes close to similar complexes of Kamchatka and the Kurils on the southwestern, northeastern, and southern boundaries of this plate [1, 9, 13, 14]. Attributes of splitting of the North American litho-

sphere near the meridian 168° (Figs. 1c, 2b) are very similar to splitting of the Pacific upper mantle in the tectonospheric sections of the Sea of Okhotsk [11, Fig. 3]. The width of rigid plates at the base of the Kolyma-Omolon (25-35 km) and the Sea of Okhotsk (35-40 km) plates is also quite comparable. In the Pre-Late Mesozoic time, the Kolyma-Omolon Plate could have been

a part of the North American Plate [14] or Cula [13] Plate; as well as the Sea of Okhotsk Plate, a part of the Pacific [2].

In light of the data received (Figs. 1b, 1c, 2), the issue of the western superficial boundary of the NAP can be solved according to the assumption of L.M. Parfenov, who drew the boundary along ophiolites of the Southern Anyui zone [8]. However, other researchers also rightly consider that the southwestern boundary of the KOM (according to them, a part of the NAP) is buried under folded-thrusted complexes of the Verkhoyansk–Kolyma system [14]. This assumption is consistent with the morphological features of Section 1–1 in the eastern part of the North Asian Craton (Fig. 2b), which testify to directed and imbricated westward displacement of slabs of the upper crust (corresponding to μ_z -maximums) relative to the lower crustal and subcrustal ones. In connection with the inclined orientation of the North American Plate (Fig. 1c, 2b), the issue of its deep western boundary is meaningful only with reference to concrete slices of the tectonosphere. It is necessary to consider in the same aspect other boundaries of lithospheric plates on subcrustal (Fig. 2a) and near-asthenospheric (Fig. 1b) map slices.

In the subcrustal (lower crustal) map slice (Fig. 2a), the Kolyma–Omolon Plate (or microcontinent) is much larger than at the Earth's surface (Fig. 1a). In the southeast, it is contiguous with the Pacific Plate; in the south, with the Sea of Okhotsk Plate; and in west and southwest, with the Eurasian Plate, where its crystalline base (the layer with the maximum of the density gradients) is injected under folded-accretional and thrust complexes of the Verkhoyansk–Kolyma system (Section 2–2, Fig. 1c). According to the distribution of density gradients in the examined sections, like the western boundary of the North American Plate, this region was marked by splitting of the lithosphere into two rigid layers. Together with the overlapping folded–thrust complexes, the upper (lower crustal) layer was thrust over the North Asian Craton, whereas the lower (lithospheric) layer was underthrust. Such splitting was possible due to the presence of a layer of lowered viscosity (displayed by the minimum of density gradients) in the crust base (interval $x = 0–900$ km in Section 2–2, Fig. 1c). The area of the maximum of the μ_z parameter at the southern flank of the KOP covers the Okhotsk terrane and extends to the Sea of Okhotsk over a distance of up to 500 km from the coast (Fig. 2a). Observable horizontal displacements and changes of the axis orientations of μ_z maximums along the KOP–Sea of Okhotsk Plate boundary can be related to shear deformations. Their attributes are established here by geological observations [7].

The western and southern flanks of the Kolyma–Omolon Plate are seismically active in a zone 500–600 km wide (Fig. 2a). The kinematic analysis of fractures [14] and calculations of vectors of tectonic stresses accompanying strong earthquakes [5, 14] sug-

gest that pull-apart and oblique fault deformations prevailed here from the Paleocene to the present time [14, Fig. 1.16]. In the subcrustal slice of the upper mantle, the seismoactive zone (Chersky belt [14]) coincides with the zone of high-density gradients (Fig. 2a) extending across continental coasts over the East Siberian Sea and the Sea of Okhotsk. In the Sea of Okhotsk, it adjoins the Sakhalin belt of the crust–mantle seismicity. In the Arctic Ocean, it correlates with the seismic zone of the Hakkel mid-ocean ridge [6]. Such correlation indicates the superimposed character of the Chersky seismic belt, the spatial connection of which with deep boundaries of the different-aged lithospheric plates is rather indirect. The superficial position of earthquake centers (15–35, less often up to 55 km [14]) allows one to confidently correlate the Chersky belt with the western flank of the thin (25–35 km) rigid slab overlying the asthenosphere rise at the base of the Kolyma–Omolon Plate (Fig. 1c). Exhumation of the asthenosphere up to a depth of 60 km from the Earth's surface in the course of continental spreading provides here conditions for unloading of tectonic pressures anticipating seismic events in the crust and subcrustal layer of the mantle.

In the map slice of the near-asthenosphere upper mantle (Fig. 1b), the eastern boundary of the EAP is close to the boundary of the North Asian Craton (Fig. 1a), while the Kolyma–Omolon Plate is separated from the surrounding lithospheric segments by rises of the asthenospheric layer (minimums of the density gradient). As in the subcrustal map slice (Fig. 2a), lower lithospheric boundaries of the KOP are displaced (turned clockwise) relative to superficial contours of the Kolyma–Omolon Superterrane. The observed displacements are consistent with results of Mesozoic palinspastic reconstructions [9], according to which the initial (Late Jurassic) movement of the KOM occurred in the southwestern direction. After collision of its southwestern flank with the EAP, the direction of the superterrane motion changed to the northwest. In light of the models considered, it is plausible that this collision provoked the fanlike rotation of overlying tectonophysical layers relative to the lower ones from the southwest to the northeast (cf.: southwestern boundaries of the KOP on the schemes 1a, 1b, and 2a) at the southern flank. The model of level-by-level displacements of the KOP was possible owing to the Mesozoic granitoid magmatism in the middle crustal layer [14] and viscous layers at the base of the crust (Section 1–1, Fig. 2b) and the lithosphere (Section 2–2, Fig. 1c). This model is stacked into the shear system at the Early Cretaceous transform margin of Asia [7]. Along this system, NE- and N-oriented movements of tectonic masses adjacent to the continent prevailed in the superficial crustal layer of the continental margin.

The considered models supplement and correct the existing notions about spatial relations of the lithospheric plates and large terranes in Northeastern Russia. Since the models are based on the non-a priori for-

malized account procedures in a class of inverse gravity problems having internal (procedural) uniqueness of the decisions, they are an objective source of information. In the course of further research, these models can find application in study of debatable issues of the origin and evolution of superficial tectonic complexes, paleodynamic reconstructions, and metallogenic forecasts.

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