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GEOPHYSICS

Cenozoic Plume in the Upper Amur Area*

A. M. Petrishchevsky[1] and Corresponding Member of the RAS A. I. Khanchuk[2]

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In the Russian Upper Amur Area and adjacent regions of southern Yakutia, Archean and Proterozoic metamorphic complexes intruded by Jurassic Stanovoi granitoids are most widespread. Cenozoic formations represented by low-depth volcanosedimentary deposits within overlying basins compose less than 10% of the area of this region [3]. According to the conclusions of most researchers [2, 3, 14], the origin and modern geodynamics of Cenozoic structures are related here with the eastern extension of the Baikal rift system, which predetermines the linear (sublatitudinal) character of Cenozoic deformations of the crust and upper mantle in the Upper Amur area. New data obtained by the authors during the study of the spatial distributions of tectonosphere density heterogeneities up to depths of 100 km indicate that the deep structures of the Aldan Shield and adjacent Stanovoi fold–thrust system sharply differ from structures of the Baikal–Vitim superterrane and Baikal rift system and that they are characterized by a completely different concentric-zonal type of Cenozoic geodynamic activity.

We found the attributes of the central type of tectonomagmatic structure between upper reaches of the Olekma, Amur, Aldan, and Zeya rivers in the course of study of the spatial distributions of density gradients (μ_z) in the crust and upper mantle, which were obtained as a result of the non-a priori formalized procedure by the algorithm [8, 9]:

$$\mu_z = \frac{V_{zm} Z_0}{4\pi K (Z_0 - H_c)^2}, \qquad (1)$$

where V_{zm} is the amplitude of the quasi-symmetric gravity disturbance measured relative to the linear background, tangent to bend points ($V_{zx} = 0$) of the Bouguer anomalies plot at the flanks of this disturbance; Z_0 is the center of the volumetric source depth and the equivalent spherical source of gravity anomaly unequivocally determined on the basis of its shape without data on the density or size of the source; $H_c = Z_0 - R$ is the depth of the "condensation" (or "sweeping") surface of the volumetric source mass on a surface of the equivalent sphere; R is the radius of the equivalent sphere; and K is the gravity constant ($6.673 \cdot 10^{-11}$ m^3/kg s^2).

The physical sense of the parameter μ_z signifies a vertical gradient of the superficial density of a spherical source (a plane source at the infinitesimal size of an elementary cell) of gravity anomalies in points of the space: $\mu_z(x, y, H_c)$.

At the first stage of the procedure, as a result of the processing and multitudinous automatic interpretation of Bouguer anomaly plots (step of the field-points 12.5 km) on parallel meridional and equidistant (spacing 50 km) profiles, the massif of meanings (Z_0, V_{zm} (x, y)) was formed. At the second stage, with the help of algorithm (1), in extreme points of elementary gravity anomalies, we calculated meanings (μ_z for the crust and upper mantle layers contained in the depth intervals 2–10, 7–15, 12–20, 17–30, 27–40, 33–50, 42–60, 52–70, 62–80, 72–90, 77–100, 82–120, and 102–150 km from the geoid surface, on the corresponding surfaces H_c = 0, 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, 70, 80, and 100 km. As characteristic meanings of the superficial density gradients for each layer, we accepted the values of the density gradients of equivalent spherical sources contained inside a layer and tangent to its surface. The condensation surface (H_c) of volumetric sources for each layer is always located at 2 km above the layer surface, due to which the function (1) has no breaks in points $H_c = Z_0$. The models (Figs. 1A–1C) are constructed on the basis of 380 isolated determinations (V_{zm} and Z_0) in points of maximums and minimums of quasi-symmetric Bouguer anomalies. The results of calculations were transposed in units of the 3D matrix (100 × 100 × 10 km) used for the construction of map-sections (Figs. 1A, 1B) and the vertical section (Fig. 1C) of the μ_z parameter. The 3D model ($\mu_z(x, y, H_c)$) obtained in this way represents a tomographic reflection of the density heterogeneity (contrast) of the tectonosphere.

Analysis of the 3D model $\mu_z(x, y, H_c)$ in the upper crustal layer of the Upper Amur area and adjacent

* The article was translated by the authors.

[1] *Institute of Complex Analysis of Regional Problems, Far East Division, Russian Academy of Sciences, Birobidzhan, Russia; e-mail: petris@stl.ru*

[2] *Far East Geological Institute, Far East Divison, Russian Academy of Sciences, pr. Stoletiya Vladivostoka 159, Vladivostok, 660022 Russia; e-mail: khanchuk@fegi.ru*

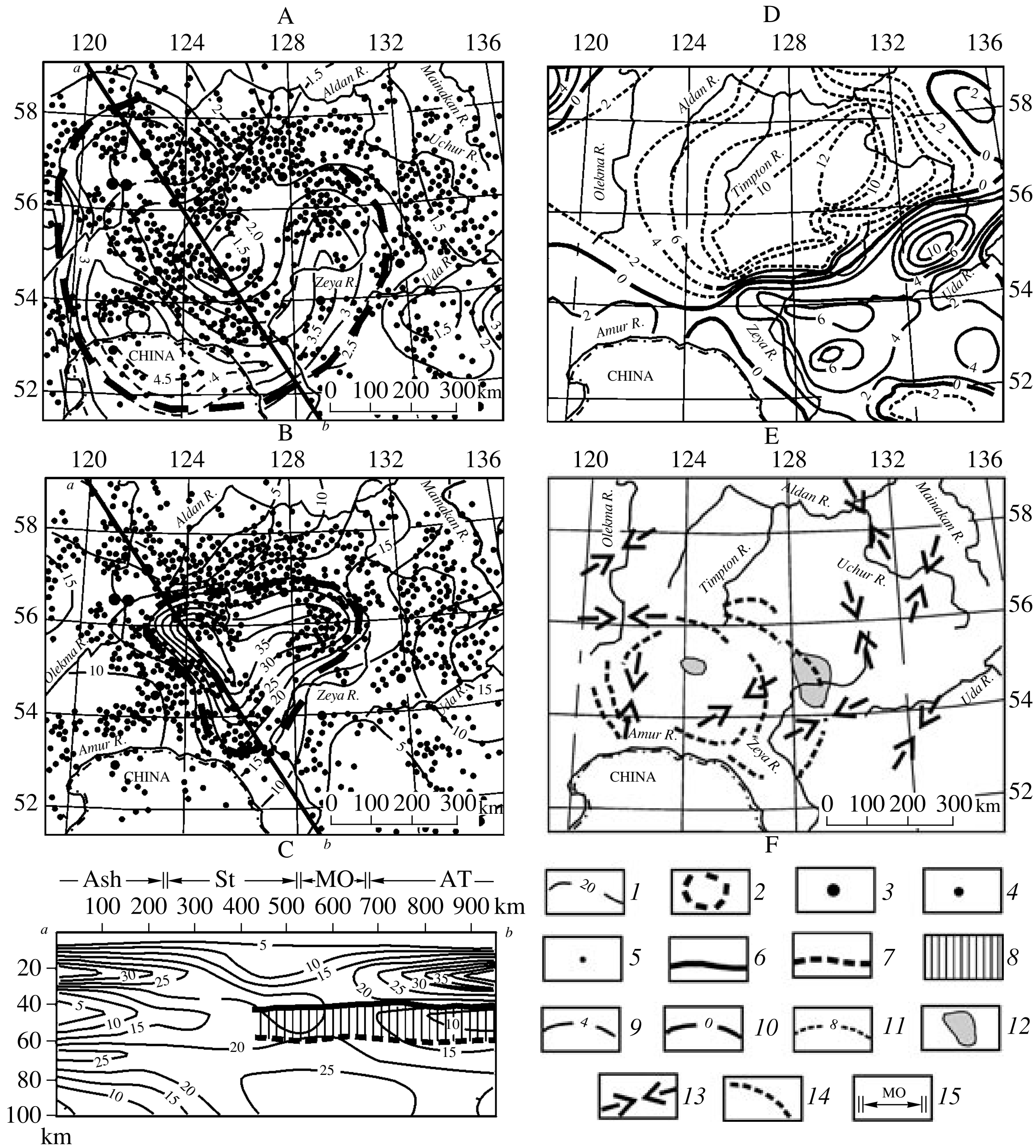

Fig. 1. Structure and dynamics of the Aldan–Zeya Plume. (A, B) Map-sections of the 3D density gradient model at a depth of 5 and 35 km, respectively; (C) vertical section of the tectonosphere density gradients on the northern flank of the Tynda–Zeya–Obluch'e seismic profile; (D) map of modern vertical movements in the Earth's surface; (E) scheme of the vectors of mechanical pressures and axes of arc-shaped magnetic anomalies. (*1*) Isolines of the *z* parameter (10^{-2} kg m^2/km); (*2*) contours of the Aldan–Zeya Plume in horizontal sections; (*3*–*5*) centers of earthquakes [14] with magnitudes: (*3*) >6, (*4*) 4–6, (*5*) <4; (*6*–*7*) wave velocity heterogeneities [1] on section B, including the Moho (*6*); (*8*) the layer with decreased wave velocity in the upper mantle [1]; (*9*–*11*) the speed of modern vertical movements of the Earth's surface, mm/yr [5]: (*9*) uplift, (*10*) zero isoline, (*11*) subsidence; (*12*) heat flow anomalies with intensity more than 50 mW/m^2 [2]; (13) vectors of compressing pressures caused by strong earthquakes [6, 12]; (*14*) axes of arc-shaped magnetic minimums [2]; (*15*) boundaries of structural elements and their abbreviations on section B: (Ash) Aldan Shield, (St) Stanovoi fold–thrust system, (MO) Mongol–Okhotsk suture, (AT) Amur superterrane.

regions of southern Yakutia at depths of 5 to 20 km revealed a concentric-zonal distribution of the density gradient maximums relative to a minimum at the center (Fig. 1A) that is typical for geophysical (magnetic, geoelectric, airborne gamma-spectrometric, and others) anomalies above tectonomagmatic structures of the central type, in particular, plumes [10]. In the crust section of the Upper Amur area (Fig. 1B), maximums of the μ_z parameter correspond to plates of intensely metamorphosed crystal complexes of the Aldan–Stanovoi and Amur terranes, whose density properties and, consequently, rigidity are decreased above the center of the structure. Support of the layer with low values of the density gradient (at a depth interval of 30–60 km from a surface) by the decreased wave velocity [1, 4] and electrical resistance [11] allows one to assume that crystal plates of the Archean–Proterozoic crust occur here on a rather less viscous subcrustal layer of the upper mantle, whose substance is in a "critical" phase condition (high contents of free fluids or the partial melting). There is no doubt that the existence of a plastic layer in the crust base provided, and continues to provide, an opportunity for large-scale horizontal movements of the tectonic complexes that have been established in this area by geological survey [7, 13]. The deep map-section of the structure (Fig. 1B) is characterized by an isometric maximum of the density gradient (μ_z), which corresponds to the lowered crustal block (Fig. 1B) at the structure center.

The density heterogeneity distribution in the crust and upper mantle of the Upper Amur area (Figs. 1A–1C) is accompanied by a complex of attributes that make it possible to relate the Aldan–Zeya structure of the central type to the lithosphere plume with an inversional (collapsed) roof, whose structural features are reflected in the modern geodynamics of the region. The spatial distribution of the crustal earthquakes in the Upper Amur area [14] is characterized by a confinement of their major part to flanks of the Aldan–Zeya plume (Figs. 1A, 1B), but the central (inversional) part of the structure is less seismic. This is caused by the peripheral location of rigid crystal plates interacting tectonically above the layer of increased viscosity. The vectors of the mechanical pressures of compression measured in a field of strong earthquakes of the Upper Amur area [6, 12] are oriented tangent to the plume contour (Fig. 1E). This constitutes an additional attribute related to the lessor viscosity of the central part of the plume. The subsiding structure center inferred from the distribution of the density gradients (Fig. 1C) coincides with the direction of modern vertical movements of the Earth's surface (Fig. 1D), which have been established as a result of repeated altitude measurements [5]. This fact testifies to the modern geodynamic activity of the Aldan–Zeya Plume. The crystallization of the central (trunk-like) deep part of the plume, which is responsible for the transportation of Cenozoic volcanic melts to the upper crust horizons, has probably not been completed. This is indicated by the intense heat flow anomalies (Fig. 1E) and by the presence of Pliocene–Quaternary alkaline basalt in the volcanosedimentary cover [3]. In the southeastern part of the plume, one can see the arc-shaped negative magnetic anomalies (Fig. 1E) that are typical of volcanotectonic structures of the central type. Anomalies above the domes correspond to fault or injection (magmatic) fractures. Such fractures quite often are conductors of the most recent fluid components of paleomagmatic chambers, the crystallization of which is terminated by the formation of dikes and ore fields on flanks of structures. The ring zone of magnetic anomalies with a maximum of heat flow anomaly in the concenter (Fig. 1E) can be caused by the Cenozoic peripheral crustal magmatic chamber, the center of which is displaced 100–120 km to the southwest from the plume center (Fig. 1B). The listed plume characteristics should be supplemented with an expression of the southern half of the structure in the Earth's surface relief.

The data considered indicate that the Upper Amur area of the deep tectonomagmatic structure incorporates the Cenozoic lithosphere plume, the central part of which is located between upper reaches of the Aldan and Zeya rivers. The Cenozoic age of the plume is suggested by the following attributes: (1) the connection of concentric deep structures of the crust with a field of seismicity of the region and with vectors of modern tectonic pressures; (2) intense heat flow anomalies above the structure center; (3) intense downwarping of the Earth's surface above the plume center corresponding to a downwarping of the density gradient isolines and the decrease of this parameter in the lower crust and subcrustal layers; (4) the presence of Pliocene–Quaternary alkaline basalts (typical indicator of the Cenozoic plumes) in the volcanosedimentary cover; and (5) the reflection of the structure in a modern relief of the Earth's surface.

The structure described is accompanied by nine geospheric attributes, including geophysical, geological, geomorphological, and geodynamic characteristics of a geosphere. An exact conformity of spatial distributions of the listed parameters (Figs. 1A–1E) is not always explained by various grids of their determination (a rare network of the heat flow and repeated altitude measurements) or by the differently directed horizontal movements of tectonic plates [7, 13] above a layer of the decreased viscosity beneath the crust base. These discrepancies grow toward flanks of the structure. However, the concenter of all geospheric anomalies is packed into a square defined at 124°–128° E and 54°–56° N.

The detection and 3D modeling of the deep tectonomagmatic structure of the central type in the Upper Amur area provides a key for understanding the interrelation between the static lithostructural characteristics of the crust and upper mantle and the Cenozoic activated and modern geodynamic processes in this region. They also promote target-directed searches for new endogenous ore deposits.

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