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Numerical Modeling of the Sources of Magnetic Anomalies in the South Urals Earth's Crust[1]

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Abstract—Using new computer technologies for the northern part of the South Urals, the structural features of the anomalous magnetic field have been studied, magnetic anomalies from different layers of the Earth's crust have been identified, and corresponding volume models of the sources of anomalies (the boundaries of basite–ultrabasite massifs, deep-seated belts, and basalt layer) have been constructed. The new data on the structure of the South Urals Earth's crust make it possible to clarify the position of deep faults and their connection with deep-seated basite–ultrabasite belts. Deep-seated root blocks have been identified for large hyperbasite massifs. Within the Taratash anticlinorium, the constructed models of the sources of magnetic anomalies allow us to conclude that the oldest Taratash complex in the Urals is an elevated part of the deep-seated basite–ultrabasite belt of the East European Platform.

Keywords: Earth's crust, magnetic anomaly, modeling, basite–ultrabasite massifs, South Urals

INTRODUCTION

The development of geophysical methods for modeling the sources of gravitational and magnetic fields for large data arrays allows us to move from studying the deep structure of the lithosphere along DSS profiles to 3D models. In this paper, we interpreted the magnetic field based on new computer technologies, constructed 3D sources of anomalies, and obtained new results on the structure of the Earth's crust in the northern part of the South Urals. The study area includes the folded area of the Urals and adjacent structures of the East European Platform (Fig. 1). The tectonic scheme in Fig. 1 and the names of the deep faults are given in accordance with the data of the third generation N-40 and N-41 geological maps (State…, 2013a,b). The deep structure of a number of geological complexes of this area and the history of their formation are debatable to this day.

Within the northern part of the Bashkiriya megaanticlinorium, composed of a thick complex of almost nonmetamorphosed terrigenous-carbonate sediments of Riphean and Vendian, in the Taratash anticlinorium, the most ancient metamorphic rocks in the Urals crop out. According to current estimates, the age of the substrate reaches 3500 Ma (Krasnobaev et al., 2011; Stepanov and Ronkin, 2016). The length of the Taratash anticlinorium is 40–45 km and its width reaches 12–15 km. By the set of rocks and features of the earliest granulite metamorphism (about 2700 Ma), the Taratash complex is close to the oldest granulite formations of the East European and Siberian Platforms. Therefore, many researchers believe that the complex is a protrusion of the pre-Riphean basement of the Russian Platform (Garan, 1969; Sobolev, 1969; Lennykh et al., 1978; Milanovskii, 1989; and etc.).

Seismic studies in this region were carried out along the latitudinal direction by the method of reflected waves (MFV) on the Taratash profile to a depth of 12 km (Necheukhin et al., 1986) and to a depth of 70 km on the DSS profile of the same name (Druzhinin et al., 1990), and also on the meridional Nizhnyaya Tura–Orsk DSS profile (Druzhinin et al., 1985). The main seismic boundaries of the Earth's crust are constructed on the deep section of the Taratash DSS profile (Druzhinin et al., 1990): K_1, surfaces of the crystalline basement; M, upper mantle. Intermediate boundaries in the crust were determined: K_{01}, the second seismic structure floor (or the ancient basement); K_2, the third seismic structure floor (protofoundation or basalt layer); KM, the transition zone between the crust and the mantle. The thickness of the sediment cover in the western part of the profile reaches 5 km with small fluctuations in certain places from 4 to 8 km. The K_{01} boundary is located at depths of 8–13 km, an average of 4–5 km deeper than was thought before conducting seismic surveys. The K_2 surface is located at depths from 14 to 30 km, the average depth is 18–20 km, and rises up to 14 km occur in the Central Urals and Eastern Urals uplifts. In the western part of the profile, under the structures of the East European Platform, the depth to the upper mantle varies from 35 to 40 km, slowly increasing to 45 km under the Western Urals folding zone and the Central Urals uplift.

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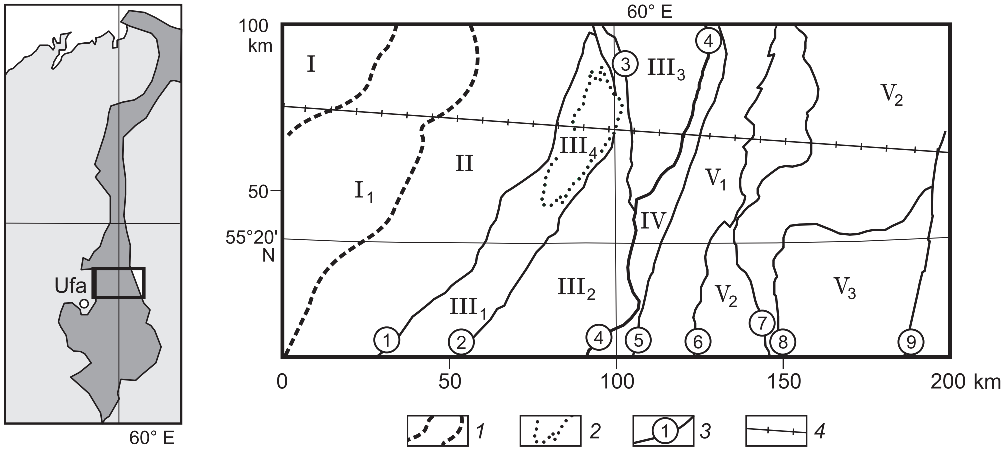

Fig. 1. Tectonic scheme of the South Urals. *1*, boundaries of the Ural foreland basin; *2*, contours of Taratash anticlinorium; *3*, deep faults and their numbers; *4*, Taratash profile. Tectonic structures: I, East European Platform (Russian plate), I_1, Urals marginal trough; II, Western Urals megamonoclinorium; III, Central Urals megaanticlinorium (III_1, Zilair synclinorium, III_2, Bashkiriya anticlinorium, III_3, Ufalei anticlinorium), III_4, Taratash anticlinorium; IV, Tagil–Magnitogorsk megasynclinorium; V, Eastern Urals megaanticlinorium (V_1, Sysert'–Ilmenskie Gory anticlinorium, V_2, Alapaevsk–Sukhtelinskii synclinorium, V_3, Chelyabinsk–Suunduk anticlinorium). Faults: 1, Taratash–Kuragai (Zilmerdak); 2, Karatash–Zyuratkul'; 3, Ufa (Western Ufalei); 4, Main Urals; 5, Miass; 6, Murzinka; 7, Argayash; 8, Ilmenskie Gory; 9, Chelyabinsk–Alapaevsk.

Then, under the Magnitogorsk trough and the East Urals uplift, the base of the Earth's crust abruptly sinks to 60–65 km and rises to 45–50 km in the Eastern Urals trough. Numerous faults modify the seismic section, both in the upper crust and deeper, intersecting the entire crust and even the upper mantle to a depth of 70–80 km.

As a result of complex geological and geophysical studies, the authors (Druzhinin et al., 1990) concluded that the East European Platform boundary passes west of the Taratash complex along the Yamantau zone of deep faults separating the East European Platform and the West Siberian plate, while "the Taratash complex may be an elevated structure of the eastern platform (Siberian), and not East European Platform. ... At great depths beneath are the megacomplexes of the eastern margin of the East European Platform, which extend 30–40 km east of the western border of the Taratash complex along the upper structures".

The well, drilled in the core of the Taratash anticline 5 km from the western edge, under the gneisses and migmatites of the lower Precambrian, entered the Devonian rocks at a depth of 1000 m. However, the well, drilled 15 km from the western edge of the anticlinorium, did not come out from the Riphean to a depth of 5 km (Milanovskii, 1989). A number of authors (Kamaletdinov, 1974; Kazantseva et al., 1986) believe that the anticlinorium has a scaly integumentary nature. In the central part, the Taratash anticlinal structure is located in a tectonic sheet with a horizontal amplitude of at least 20 km, the frontal part of which stands out as the Suliinsk overthrust. However, not all researchers agree with such conclusions and large horizontal shifts. According to the results of seismic surveys of the MFV, the amplitude of the displacement of the upper part of the Taratash protrusion is estimated at 1–4 km (Necheukhin et al., 1986). Similar conclusions that the amplitude of horizontal displacements in the upper crust does not exceed several kilometers are given in (Druzhinin et al., 1990). In addition, the authors of this article emphasize that "the connection of the deposits of the actual East European Platform cover with the folded complexes of the western Urals and the deposits of the Central Urals uplift occurred not as a nappe, but in a series of overthrusts and steep uplifts with a total vertical amplitude of about 8 km."

The Urals region is one of the orogens most abundant in basite-ultrabasite massifs. The massifs are mainly concentrated in linearly elongated belts and are confined to deep faults stretching hundreds and even thousands of kilometers. In the South Urals, seven large hyperbasite belts have been identified, located along the structural-formational zones (Kazantseva, 2013). The bodies associated with the deep faults, as a rule, have steep angles of incidence, some of such bodies are traced to great depths by geophysical data. A number of hyperbasite massifs have small angles of incidence and a flat shape, which, apparently, is a consequence of their thrust nature and the detachment of these arrays from the root blocks. Such formations in the South Urals include the large Kraka massifs, and their allochthonous nature has been established both by geological (Kazantseva, 2009) and geophysical data (Fedorova and Ivanov, 2000).

As is known, various methods for interpreting gravitational and magnetic anomalies, mainly in a two-dimensional version, were widely used to determine the boundaries of arrays and the angles of incidence of faults. In our work, three-dimensional methods of interpretation of magnetic anomalies were applied. At the first stage, the structural features of the anomalous magnetic field were studied, and anomalies from different layers of the Earth's crust were distributed. This procedure allows one to determine at what depth the sources of anomalies are located, to analyze the distribution of sources, and, therefore, it is possible to establish a connection of objects in the upper crust with deep blocks. Then, at the second stage, the inverse problem of magnetometry is solved for separated anomalies. As a result, the surfaces of magnetic sources in different layers of the Earth's crust are determined.

TECHNIQUE AND RESULTS OF SEPARATION OF ANOMALIES FROM SOURCES IN DIFFERENT LAYERS OF THE EARTH CRUST

The anomalous magnetic field has an integral character and contains components from all sources located in the upper lithosphere. To isolate anomalies from sources in different layers of the Earth's crust, a technique was used based on recalculation of the field in up and down (Martyshko et al., 2016). As a rule, in open areas, anomalies from near-surface blocks make the largest contribution. The intensity of the anomalies decreases significantly with distance from local sources. With increasing distance R from the source, the magnetic field decays according to the law—$1/R^3$. If sources near the surface create magnetic anomalies 200–1000 nTl, then at an altitude of 5 km the intensity of the anomalies will be less than 1–8 nT, i.e., in magnitude it becomes comparable to the error of observations.

The problem of extracting the effect from local sources located in a horizontal layer from the Earth's surface to a certain depth H was solved in several stages. At the first stage, the observed magnetic field was recalculated up to the height H using the numerical method. In order to finally get rid of the influence of sources in the upper layer, the field recalculated up analytically continued down to the depth H. Since the problem of recalculation of the downfield belongs to the class of incorrectly posed problems, then in the calculations we used a method with the application of regularization. At the next stage, the field was recalculated up to the level of the day surface $h = 0$. The resulting transformed field can be viewed as a field from sources located below the H border. After calculating the difference between the observed and transformed fields, we obtain anomalies from local sources located in the upper layer. Using calculations for different heights of H, anomalies can be obtained from sources located in different horizontal layers.

When studying large areas, one has to set up large amounts of data, which leads to a significant investment of time when computing on single-processor computers. The use of parallel algorithms for multiprocessor computing systems significantly reduces computation time. A new computer technology has been created and it is based on parallel computing. A description of the mathematical apparatus and parallel computing algorithms on the Uranus supercomputer is given in (Martyshko et al., 2012, 2014). The results of applying this technology for the Eurasian Circumpolar Sector were published in (Fedorova et al., 2015; Martyshko et al., 2015). The algorithm is also implemented on the NVidia graphics processor in the "Calculations of analytical continuation of potential GRIDCALC fields" program (Byzov et al., 2016a).

The computer technology developed has been applied to study the structure of the anomalous magnetic field on an area of 200 × 100 km in the South Urals (Fig. 1). Digital maps of the Urals region were used (Chursin et al., 2008). Using transformations for recalculation heights $H = 2$ and 5 km, anomalies from the magnetized massifs in the upper layers of the Earth's crust are identified. For magnetic field sources located in deeper layers, the calculations were performed for $H = 10$ and 20 km. The magnetic field calculated for $H = 20$ km consists of long-wave regional anomalies, which correspond to the integral distribution of magnetization in the lower layers of the cortex. A map of the anomalous magnetic field and maps of the separated anomalies are shown in Fig. 2.

Maps of separated anomalies allow us to trace the connection of subsurface massifs with deep structures. In the western Urals, within the Taratash anticlinorium, magnetic anomalies are present on all maps (Fig. 2*b–f*). Sources of anomalies can be both ancient Archean–Proterozoic metabasites, and younger magmatic formations, which were revealed during geological surveys. In the upper layer, magnetic anomalies can be created by iron ore deposits. High-intensity anomalies of up to 30,000 nT have been detected above ground ore bodies (Dymkin, 1984). Since the thickness of the ore layers is small and the anomalies are relatively small, the intensity of the anomalies rapidly decreases with height, and according to aeromagnetic survey data at an altitude of 70–100 m, the anomalous ΔT_a field does not exceed 1200 nT.

Note that local anomalies from the near-surface layer can be traced beyond the boundaries of the Taratash anticlinorium in the southwestern direction (Fig. 2*b*), and, therefore, the complex extends another 5–10 km under sedimentary covers. This conclusion is also confirmed by the morphology of the positive anomaly for the layer from 5 to 10 km (Fig. 2*d*). On the map of magnetic anomalies from a layer of 10–20 km (Fig. 2*e*) a linear anomaly is clearly distinguished, which extends from the Taratash anticlinorium in a westerly direction to the Ural marginal depression of the East European Platform. In this part of the study area, the southern flank of the regional magnetic anomaly is also elongated in a westerly direction (Fig. 2*e*). The epicenter of the anomaly is located within the Taratash complex, therefore in the future we will call this regional anomaly Taratash. The distribution of anomalous fields on all maps seems to indicate that the Taratash anticlinorium is composed of deeper blocks of the East European Platform brought to the surface.

In the central and eastern parts of the studied territory of the South Urals, chains of local anomalies forming linear belts associated with deep faults clearly appear on the map for the upper layer (Fig. 2*b*). In our work, the position of faults and their names are given in accordance with the data of geological maps of N-40 and N-41 of the third generation (State..., 2013a,b).

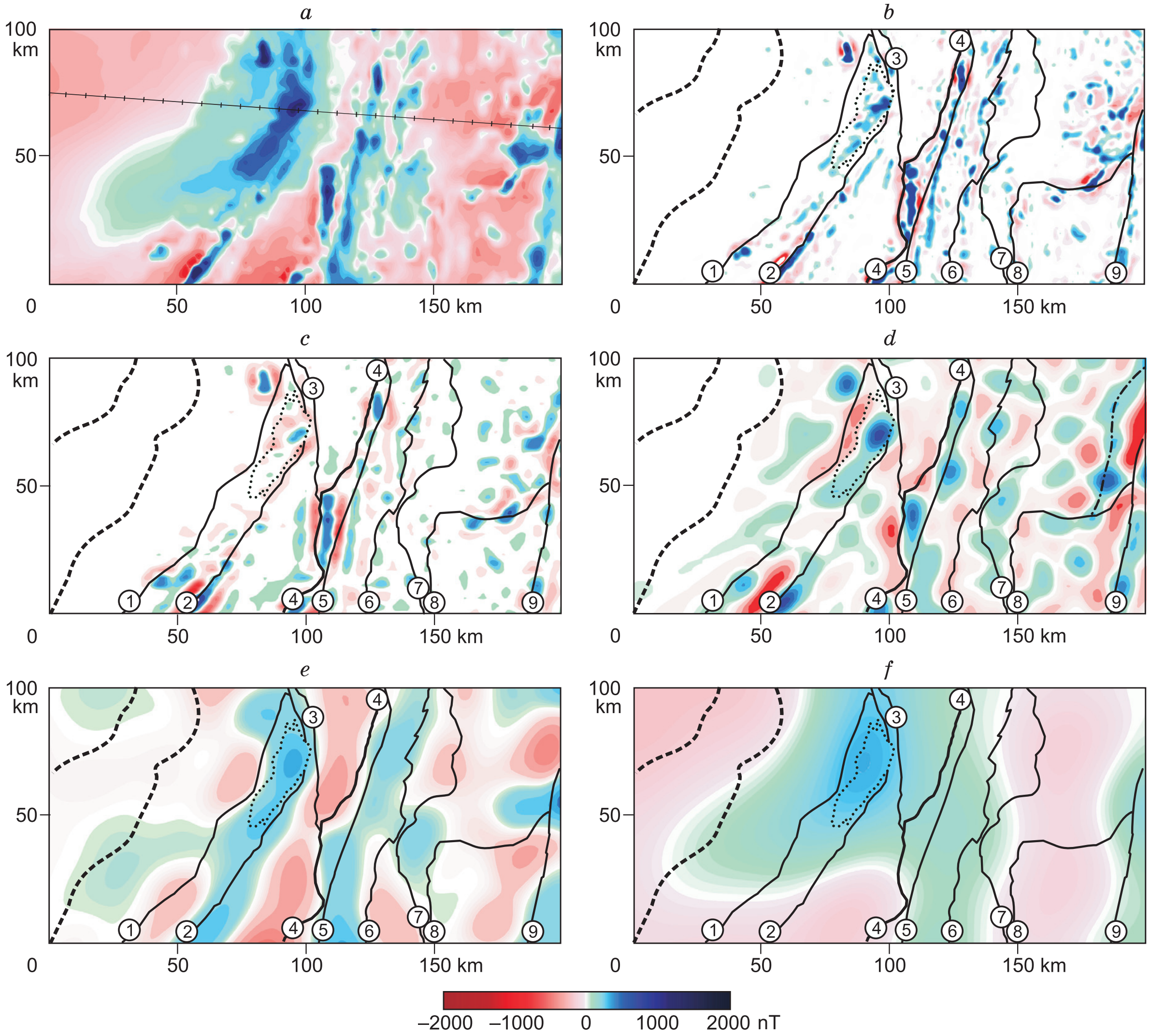

Fig. 2. Maps of the anomalous magnetic field (*a*) and detected anomalies from the layers of the Earth's crust for depths of 0–2 km (*b*), 2–5 km (*c*), 5–10 km (d) and 10–20 km (*e*) and regional anomalies (*f*). The position of the Taratash profile of the DSS is shown by a solid line on the map (*a*). The dash-dotted line shows an extended linear anomaly created by ultrabasite belt, the upper edges of which are deeper than 5 km. Other designations same as Fig. 1.

The most intense local anomalies (from 400 to 2500 nT) were created by large massifs brought to the surface and, as a rule, consisting of basite-ultrabasite rocks (dolerites, gabbros, serpentinized harzburgites, dunites, pyroxenites, etc.). Blocks of magnetized rocks not brought to the surface create less intense anomalies. The position of the massifs located deeper than 2 km can be traced on maps (Fig. 2*c*, *d*). Anomalies from a large number of basite-ultrabasite massifs are clearly traced to a depth of 5 km and, possibly, are associated with extended zones of hyperbasites in the deeper layers of the Earth's crust (Fig. 2*d*, *e*). The anomalies from deep-seated sources within the Karatash–Zyuratkul', Main Urals, Miass and Chelyabinsk–Alapaevsk faults are most clearly manifested. In addition, in the northeastern part of the tablet, an extended linear anomaly was discovered, apparently created by an ultrabasic belt, the upper edges of which are located deeper than 5 km.

In the regional field, in addition to the Taratash anomaly east of the Main Ural Fault, a positive anomaly is observed with an intensity up to 140 nT (Fig. 2*f*). The anomaly is extended in the direction from south to north, its epicentral part is between the Miass and Murzinka faults over the structures of the Eastern Ural uplift. In the central part of the area, its western flank is superimposed on the Taratash anomaly.

METHOD OF SOLUTION OF THE INVERSE PROBLEM OF MAGNETOMETRY

For the three-dimensional interpretation of magnetic field anomalies, we used a modified method of local corrections (Martyshko et al., 2010, 2016). The method is developed to solve the inverse problem of magnetometry for a layered model and allows determining the geometry of the contact surface between two layers for given values of uniform vertical magnetization in the layers and the average depth to the second layer.

The vertical component of the magnetic field $Z(x, y)$ at the point (x, y) on the surface of the Earth is calculated by the formula:

$$Z(x,y) = \Delta I \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\left(\frac{z(x,y)}{\left((x-x')+(y-y')^2+z^2(x,y)\right)^{3/2}} - \right.$$

$$\left. - \frac{H}{\left((x-x')^2+(y-y')^2+H^2\right)^{3/2}}\right)dx\,dy\,, \qquad (1)$$

where $z(x, y)$ is the equation of the surface S separating the upper and lower layers; $\Delta I = I_2 - I_1$, the magnetization jump at the boundary of the layers; H is the horizontal asymptote.

An iterative method for finding the boundary has been developed, based on the assumption that the change in the field value at some point has the greatest effect on the change in the part of the surface S nearest to a given point. At each step, an attempt is made to reduce the difference between the set and approximate field values at a given node by changing the value of the desired function in the same node. Earlier, this approach was proposed for the approximate solution of nonlinear inverse gravimetric problems (Prutkin, 1986).

Discretization of equation (1) leads to the following system of nonlinear equations:

$$c\sum_i\sum_j K_{i_0 j_0}(z_{ij}) = U_{i_0 j_0}\,,$$

where c is the weight coefficient of the cubature formula, $U_{i_0 j_0} = \Delta Z(x_{i_0}, y_{j_0}, 0)$ is the left side of equation (1), $z_{ij} = z(x_i, y_i)$, $K_{i_0 j_0}(z_{ij}) = K(x_{i_0}, y_{j_0}, x_i, y_j, z_{ij})$ is the integrand in (1).

To find the values z_{ij}^{n+1} of the unknown function $z(x, y)$ at $n+1$ iterations, an iterative formula is used:

$$\left(z_{ij}^{n+1}\right)^2 = \frac{\left(z_{ij}^{n}\right)^2}{1+\alpha(z_{ij}^{n})^2\cdot(U_{ij}-U_{ij}^{n})}\,,$$

where α is the regularization parameter, $\{z_{i,j}^{n}\}$ $z(x, y)$ are the values, n is the iteration number.

The proposed method does not use nonlinear minimization, which makes it possible to significantly reduce the computation time and quickly solve three-dimensional problems (Martyshko et al., 2016). The original field, set on a grid of 100 × 100 points, is restored with a relatively low error (less than 1 percent) in 100–300 iterations and the calculation process takes several minutes.

In order to calculate the values of the component Z_V with the vertical magnetization of the sources, a method of reducing the data ΔT_a to the pole was used and an approximation method was developed (Muravyev et al., 2016). In this method, a class of singular sources, rods uniformly magnetized over the normal field of the Earth, is used as model sources. The algorithm is implemented using parallel computing technology on an NVidia GPU in the program "Selection of a magnetic field by a set of rods PodborSterj2015" (Byzov et al., 2016b). The method allows high-precision approximation of complex magnetic anomalies.

Using the solution of the direct problem for the singular sources found, it is easy to calculate the values of Z_V for the vertical direction of the magnetization vector. For anomalies, the intensity of which varies from –1000 to 3000 nT, the error of the obtained values is estimated as ±20 nT. Note that in order to find the geometry of the volume sources of the magnetic field, the conversion to the pole can significantly reduce the computational process for solving the inverse problem. With the magnetization directed along the modern geomagnetic field, these sources will correspond to induction anomalies ΔT_a.

MODELS OF SOURCES OF MAGNETIC ANOMALIES

The magnetization of the layers of the Earth's crust. The main carriers of magnetization in the Earth's crust are titanomagnetite minerals and, above all, magnetite. Sedimentary rocks contain an insignificant amount of magnetic minerals and do not create noticeable magnetic anomalies. In the upper crystalline layer of the Earth's crust, blocks with significant magnetization are distinguished, but the average magnetization of the granite layer is low, it is estimated not to exceed 0.3 A/m (Krutikhovskaya et al., 1982). Basaltic rocks are characterized by high magnetization values of 2–6 A/m, and according to the simulation results of the northern segment of the Urals region, the average magnetization of this layer is 3 A/m (Fedorova et al., 2013, 2017b).

The upper mantle has low magnetic properties (Pecherskii et al., 2006). Therefore, the lower limit of the magnetoactive layer of the lithosphere can be the Moho boundary, or the depth in the lower crust, where the temperature exceeds 580 °C—the magnetite Curie temperature. As a result of studying the anomalous magnetic field of the Urals folded system, it was not possible to isolate the anomalies that could correspond to a sharp change in the relief of the Moho boundary. Most likely, this is due to the fact that the lower part of the basalt layer and the transition zone between the crust and the mantle have a low magnetization. Statistical studies of the relationship between regional magnetic anomalies and seismic boundaries, as well as the thickness of the consolidated crust or lower high-velocity layer of the Earth's crust revealed a direct relationship only with the surface of the basalt layer (Fedorova et al., 2017a).

Geothermal studies in deep and ultradeep wells showed a fundamentally new result of the temperature gradient changes at depth as the main indicator of the thermodynamic regime of the subsoil. The temperature rises much faster than previously thought from measurements in shallow wells. In the relatively cold crust of the ancient East European Platform, at a depth of 12 km, the temperature reached 220 °C instead of the expected 120–130 °C (Orlov and Laverov, 1998). A temperature of 90 °C was recorded at a depth of 5 km in the Urals well SG-4 (Shchapov, 2000). According to the results of measurements on young plates, temperature gradients are significantly higher than on the East European Platform, and at a depth of 7 km in Timano-Pechorskaya SG-5, Tyumenskaya SG-6 and En-Yakhinskaya SG-7, the temperature reaches 160, 200 and 210 °C, respectively (Mazur, 1996; Khakhaev et al., 2000). Therefore, it can be assumed that the Earth's interior is heated to a temperature of 580 °C at a depth of 30–35 km, and, therefore, the base of the magnetoactive layer is located significantly above the Moho boundary.

The magnetization of the massifs. For the rocks of the Urals massifs of basic and ultrabasic composition, magnetic susceptibility can reach $20,000 \times 10^{-5}$ SI, however, the average values do not exceed 6000×10^{-5} SI (Ryzhii, 1988). Information on residual magnetization measurements is very scarce. According to research results in wells up to 1000 m in the North Taratash area, it follows that rocks with high magnetic susceptibility ($2000–8000 \times 10^{-5}$ SI units) have predominantly induced magnetization (Beloglazova et al., 2017). Taking into account that the average value of the Koenigsberg factor of rocks is less than 1 (Ryzhii, 1988), it can be estimated that the residual magnetization does not exceed 2 A/m.

In order to estimate the magnetization in the upper crust of basite-hyperbasite massifs and other blocks, the magnetic anomalies were interpreted by the two-dimensional method (Tsirul'skii et al., 1980) along the Taratash profile. The boundaries of the magnetic blocks for different values of magnetization are calculated. The results made it possible to estimate that the integral magnetization of the massifs is 2–3 A/m. Given the results of interpretation on other Urals profiles of the DDS (Shapiro et al., 1997; Fedorova and Kolmogorova, 2013; Kolmogorova and Fedorova, 2015; etc.) to simulate the three-dimensional method, we set the magnetization of 3 A/m.

Interpretation results. An anomalous magnetic field contains quite a few intense anomalies created by small massifs brought to the surface of the Earth. They are clearly shown on the map for a layer from 0 to 2 km (Fig. 2*b*). To exclude minor anomalies, recalculations for $H = 1$ km were made. Anomalies from large massifs are clearly visible both in the 0–2 km layer and in the 2–5 km layer. Considering these data and the fact that the thickness of the sedimentary layer is 5 km, the value $H = 5$ km was chosen for the interpretation of local anomalies in the near-surface layer. The transformations of the anomalous magnetic field for $H = 5$ and 20 km were used to calculate the upper surfaces of sources lying deeper than 5 km, and the long-wave anomalies were used to construct the surface of the basalt layer. The lower boundary of the magnetic rocks in this layer is set at a depth of 30 km.

To solve the inverse problem, the magnetic field data from the layers were set on grids of 100×100 points. As a result of the iterative process, the geometry of the sources in each layer is determined, while the relative error of the deviation of the model and initial values is less than 1 percent. To control the compliance of the models obtained with the initial field, calculations were made for sources in all layers for magnetization directed along the modern geomagnetic field. Visually, the map of anomalies from model sources practically does not differ from the map of the initial field, the mean square error at all points is ±18 nT.

The results of modeling in the form of three-dimensional relief of the source boundaries are shown in Fig. 3. In the upper layer (Fig. 3*a*), the geometry of the magnetic sources is in good agreement with the geological mapping data of large basite-ultrabasite massifs. The constructed boundaries of the sources allow us to trace the continuation of known massifs to the depth and in the plan, their connection with extended belts. Also clearly visible are other massifs not brought to the surface, located within the upper 5 km. For example, in the southern part of the area in the vicinity of the Karatash–Zyuratkul' fault and the Kusa–Kopan' intrusive massifs associated with it, the model is clearly visible to the west and east of the fault, subparallel linearly elongated narrow belts, whose upper edges are located below 1.5–2 km (Fig. 3*a*).

The surfaces of deeper magnetized sources located in a layer from 5 to 20 km are shown in Fig. 3*b*. The powerful belt in this layer is located under the Kusa–Kopan' massifs, it is shifted to the east relative to the upper massifs and, probably, is the root unit not only for these intrusions, but also for the subparallel eastern belt. We will not describe in detail the ratio of all sources, since they are clearly visible in the figure.

The results allow not only to clarify the position of the hyperbasite belts and deep faults in the upper crust, but also to identify faults under sediments and granite massifs in the eastern part of the South Urals. One of such faults, associated with the belt of hyperbasites submerged below 5 km, we marked with a dash-dotted line (Fig. 3*b*). The connection of some sources with the rise of the basalt layer is clearly manifested (Fig. 3*c*).

In the Taratash anticlinorium, according to the simulation results, the surface of the basaltic crust rises to 14 km (Fig. 3*c*). In the granite layer within the Bashkir mega-anticlinorium, two arcuate belts are distinguished. One belt runs directly beneath the Taratash anticlinorium, and in the northern part it continues beyond the boundaries of the Karatash–Zyuratkul' and Ufa (Western Ufalei) faults. Possibly, the Ufalei gneiss-migmatite complex is also associated with it. The second belt is located to the west of the Taratash protrusion. The southern flanks of both belts extend in the direction of the Urals marginal depression in a

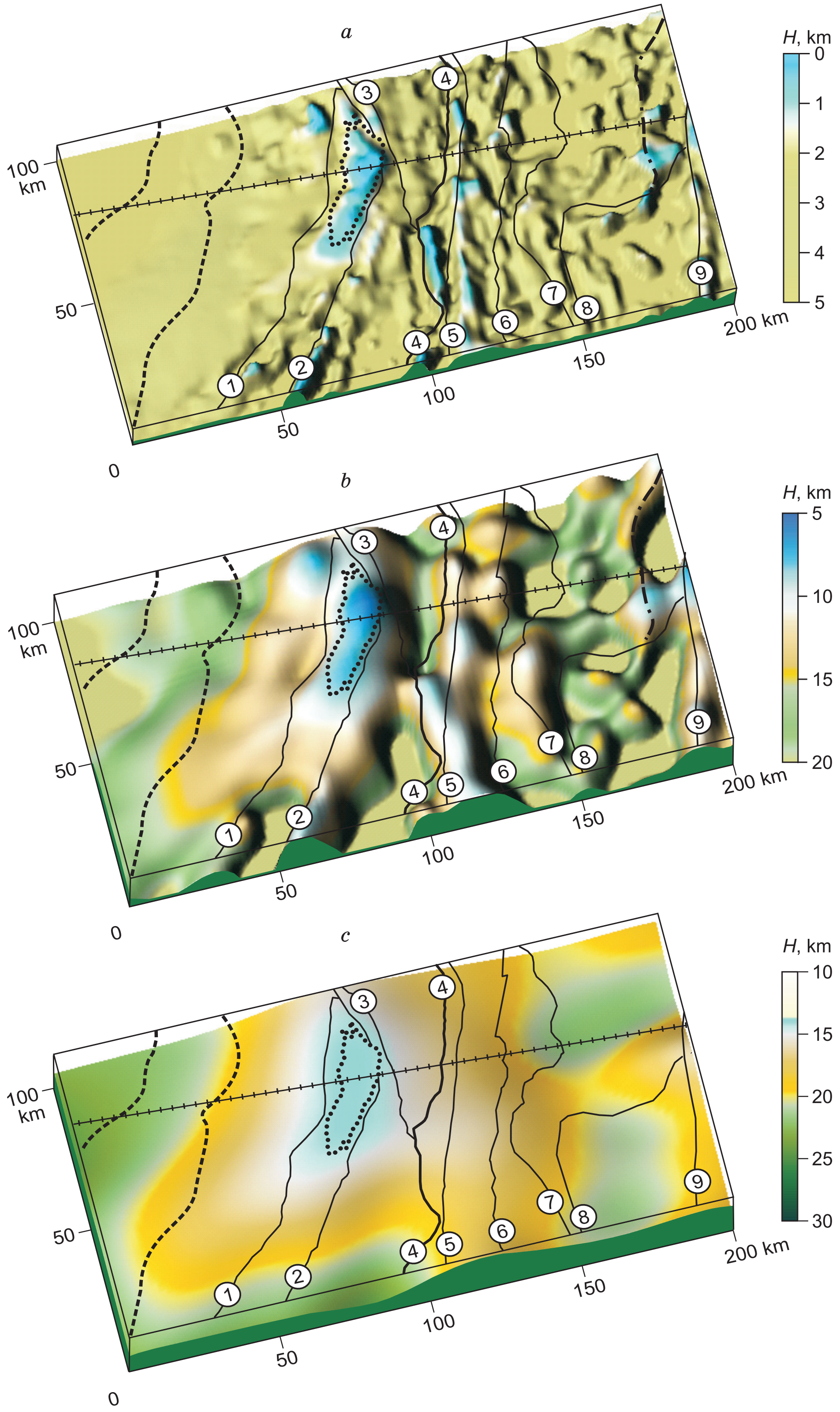

Fig. 3. Results of modeling of sources of magnetic anomalies: in the upper layer to a depth of 5 km (*a*), in a layer from 5 to 20 km (*b*) and the surface of the basalt layer (*c*). The dash-dotted line shows the extended ultrabasitic belt. Other designations in Fig. 1.

westerly direction, and their position is inconsistent with the location of the Taratash–Kuragai fault. In our opinion, this testifies to the earlier formation of belts within the East European Platform, prior to orogenic processes in the Urals. In the east of the Taratash protrusion, between the Zyuratkul' and Main Urals faults, there are no magnetic sources in the granite layer. As follows from the simulation results, in Taratash anticlinoria in the upper layer, the magnetic blocks are located directly above the rise of the basalt layer and the basite-ultrabasite belt protruding above it in the granite layer. Therefore, there were hardly any major horizontal movements from the east to the west of the upper complexes.

CONCLUSIONS

As a result of the use of modern computer technologies for the territory of the South Urals, the structural features of the anomalous magnetic field were studied, magnetic anomalies from different layers of the Earth's crust were identified and corresponding models of anomaly sources were constructed—basite-ultrabasite arrays, deep belts and basalt layers. These results make it possible to clarify the position of the deep faults in the upper crust of the South Urals and their connection with the deep basite-ultrabasite belts that project above the basalt layer of the Earth's crust.

An analysis of the distribution of sources of magnetic anomalies in the crustal layers within the Taratash anticlinorium and the constructed source models allow us to conclude that the oldest Taratash complex in the Urals is the upper part of the elevated basite-ultrabasite belt of the East European Platform and it is located above the rise of the basalt layer of the Earth's crust.

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