Preliminary investigation of the crustal structure of the Middle Urals by geomagnetic methods, based on the global model EMAG2

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SUMMARY

The EMAG2 database of lithospheric magnetic anomalies was used to construct a magnetic model of the earth's crust within the Middle Urals and adjacent margins of the East European platform and the West Siberian plate on an area 800x500 km. The vertical component of the magnetic anomalies has been identified by an approximation method using the class of singular sources - magnetized rods. The data obtained make it possible to apply computational methods for harmonic functions. Studies of the structural features of the magnetic field have been carried out. Computer programs were used in which parallel computations were implemented. Anomalies from the granite and basalt layers of the earth's crust were separated, for which the surfaces of magnetized sources were constructed using the method of local corrections. Within the granite layer, the magnetic model is built for a magnetization of 3 A/m. The sources of regional anomalies in the western part of the territory within the margin of the East European platform and the western slope of the Middle Urals have a high magnetization of about 6 A/m.
Introduction

The global databases, which represent anomalous magnetic field on the Earth's surface, provide ample opportunities for modeling heterogeneities in the lithosphere's structure (Muravyev, 2015). Work on the first global model, the World Digital Magnetic Anomaly Map (WDMAM), was started by the International Association for Geomagnetism and Aeronomy (IAGA) and the Commission for the Geological World Map (CWG) in 2007. The second version of this database is now available (Dyment et al., 2018). All available data of ground, marine, airborne and satellite surveys of the earth's magnetic field anomalies were integrated to build a global map. One of the results of this work was another model – EMAG2, which has a resolution of 2 arc minutes and a reference to an altitude of 4 km above the geoid (Meyer et al., 2017). In order to study the lithosphere's structure of the Middle Urals and adjacent territories of the East European platform and West Siberian plates, the EMAG2 version 3 data were used to construct a magnetic model of the earth's crust (Figure 1). The initial data set was prepared with a spatial step of 1 km within the study area (56º-60º N and 54º-66º E) in a conventional coordinate system in the Gauss-Kruger projection (Muravyev, Byzov, 2015).

Figure 1 Middle Urals: lithospheric anomalies $\Delta B_a$ model EMAG2 and main tectonic structures (left); singular sources obtained as a result of approximation $\Delta B_a$ and vertical component $B_z$ (right). $a$ - the boundary of the study area; $b$ - boundaries of tectonic structures; $c$ - singular sources - rods. Tectonic structures: 1 - East European platform; 2 - Urals; 3 - West Siberian plate

Approximation method

Anomalies of the absolute value of geomagnetic induction $\Delta B_a$ cannot be represented as harmonic functions, since they do not satisfy the Laplace equation. For the correct application of methods for finding sources of anomalies, isolating anomalies from various layers of the earth's crust, it is necessary to determine $B_z$ - the vertical component of magnetic anomalies, and also make a reduction to the pole, that is, calculate $B_v$ with vertical magnetization of sources. We applied the method of approximating the anomalies of the magnetic induction modulus by the fields of singular sources (Byzov et al., 2017). The existing grid of values $\Delta B_a$ we approximated by anomalies from of system of rods uniformly magnetized along their axis. The software PodborSterj2015 (Byzov et al., 2016a) was used, which implements parallel computations on a high-performance computing cluster based on NVidia graphics accelerators. The dimension of the initial data grid was 501 × 801 (401301 points). Magnetic induction anomalies $\Delta B_a$ were approximated by a set of singular sources, which consisted of 337 rods. In this case, 2359 optimized parameters (coordinates of the ends of the rods and their magnetization) were determined, and the approximation error was less than 3%. Table shows the extreme values of the intensity of the initial magnetic anomalies and the values of the model anomalies, calculated as a result of the approximation, as well as the values of the vertical components ($B_n$, $B_p$, $B_z$) and the mean square deviation (RMSD).
### Table

<table>
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<tr>
<th>Data (nT)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>RMSD</th>
</tr>
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<td>929</td>
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<td>184</td>
</tr>
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<td>13</td>
<td>182</td>
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<td>134</td>
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<td>Component $B_y$</td>
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<tr>
<td>Component $B_z$</td>
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<td>9508</td>
<td>15</td>
<td>185</td>
</tr>
</tbody>
</table>

### Separation of anomalies from the layers of the earth's crust

To separate the anomaly from sources in different layers of the earth's crust, we used a technique based on up-and-down recalculations (Martyshko et al., 2014, 2016). The problem was solved in several stages. At the first stage, the $B_z$ data were numerically recalculated up to the height $H$. In such calculations, anomalies from local sources located in the layer from 0 to depth $H$ practically disappear. In order to finally get rid of the influence of sources in the upper layer, the upward recalculated data analytically continued downward to the depth $H$. Since the field recalculation to down problem belongs to the class of ill-posed problems, then the calculations were performed using regularization method (Martyshko et al., 2016). At the next stage, the data was recalculated upward again to the level of the day surface $h = 0$. The resulting transformed data can be considered as anomalies from sources located below the boundary $H$. After calculating the difference between the observed and transformed data, we obtain anomalies from local sources located in the upper layer. By calculating for different values of the height $H$ (or depth), anomalies from sources located in different horizontal layers can be obtained. The calculations were performed using the GridCalc software package (Byzov et al., 2016b), on a computing cluster based on NVidia graphics accelerators. For the study area, anomalies from sources in various layers of the earth's crust were calculated. Since the initial data are set at an altitude of 4 km, therefore, there are practically no magnetic anomalies from sources in the upper layer of the earth's crust to a depth of 4 km (Figure 2a.). For the granite layer, we calculated the anomalies using transformations for heights of 4 and 20 km. And for the basalt layer - as the difference for heights of 20 and 50 km. Maps of these anomalies are shown in Figure 2b.

![Figure 2](image)

**Figure 2** Magnetic anomalies from sources in granite (a) and basalt (b) layers

### Magnetized sources modeling results

We applied the method of local corrections to determine the boundaries of magnetic anomalies sources. This method allows solving the inverse magnetic problem for a layered model and geometry determination of the contact surface between two layers with different magnetic properties. The integral equation solution is necessary to find points on the source surface. The method is described in
detail in (Martyshko et al., 2016; Fedorova and Roublev, 2019) and has been successfully used for both near-surface and deep sources (Fedorova et al., 2013, 2017; Fedorova and Roublev, 2019; Martyshko et al., 2018).

In the granite layer, the source models are built for a magnetization of 3 A/m (Figure 3a). Within the East European Platform, magnetized sources form linear belts 100-200 km long, the strike of the belts varies from sublatitudinal to submeridional, which indicates a long and complex history of the formation of the basement of the ancient platform. Within the Urals, linear belts stretch across the entire study area in the north-south direction (more than 500 km). In Western Siberia, linear belts also stretch in the north-south direction, but they are located deeper than under the Ural Orogen. The basalt layer surface models were calculated for magnetization values: 3, 4, 5 and 6 A/m and an average boundary depth of 20 km. In the western part of the territory, within the margin of the East European Platform and the Western slope of the Middle Urals, for magnetization of 3, 4, and 5 A/m, the model surfaces rise too high to 9 km, 11 km, and 13 km, respectively. Therefore, we have chosen a model with a magnetization of 6 A/m (Figure 3b), which better corresponds to seismic results. On the Sverdlovsk DSS profile, it was found that the basalt layer rises up to 15 km (Druzhinin et al., 1976, 2014). These results clarify deep faults locations in the upper crust of the Middle Urals and their relationship with deep basic belts protruding above the basalt layer of the earth's crust.

![Figure 3](image.png)

**Figure 3** Surfaces of magnetized sources in granite (a) and basalt (b) layers of the earth's crust

**Conclusions**

Studies of the structural features of the magnetic field of the Middle Urals on an 800×500 km area, based on the global database of lithospheric magnetic anomalies EMAG2, have been carried out. The vertical component of the magnetic anomalies has been identified by an approximation method using the class of singular sources – magnetized rods. The data obtained make it possible to apply computational methods for harmonic functions.

Transformations were carried out to different heights and anomalies from sources in the granite and basalt layers of the earth's crust were identified. Computer programs were used in which parallel computations were implemented. Source models were calculated for various values of magnetization using the method of local corrections. It was found that the sources of regional anomalies in the western part of the territory within the margin of the East European platform and the western slope of the Middle Urals have a high magnetization of about 6 A/m. Within the granite layer, the magnetic model is built for a magnetization of 3 A/m. For further research and construction of a model of the upper layer (from the earth's surface to a depth of 4 km), it is necessary to use more detailed maps based on aeromagnetic data from the Ural region (Chursin et al., 2008).

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References


