3D MAGNETIC MODEL OF THE EARTH CRUST OF THE EASTERN EUROPEAN CRATON WITH THE ACCOUNT OF THE EARTH SPHERICITY AND ITS TECTONIC INTERPRETATION

The geomagnetic field is widely used to obtain information on the deep structure and development of the Earth’s lithosphere, small-scale forecasting of minerals, and the solution of a number of environmental problems. The most significant results are obtained due to the development of 2D, 3D and 4D magnetic models of the Earth’s crust (lithosphere) in which the spatial and spatiotemporal distribution of magnetic sources is reflected. The reliability of the spatiotemporal distribution (location) of magnetic sources and the magnitudes of their magnetization depends on the adequacy of taking into account the geometry of objects and the inhomogeneity of the Earth’s main magnetic field. In this regard, for the East European Craton for the first time its regional 3D magnetic model for a spherical Earth is developed. To develop the model, we used digital data WDMAM at a height of 5 km, a priori data on the depths of the surface of the crystalline basement and Moho, the temperature distribution, as well as the results of other geological and geophysical researches. According to S.V. Bogdanova, the Eastern European Craton was formed due to the saturation of three segments (Fennoscandia, Volgo-Uralia and Sarmatia) in a time interval of 2,1–1,8 Ga. At the Phanerozoic stage of development, the modern borders of the craton were formed. It is established that a non-uniform distribution of magnetic sources and magnitudes of their magnetization is observed on the boundaries of the craton. The maximum concentration of magnetic sources is characteristic for the edge parts of the craton. The southwestern boundary of the craton is marked by magnetic sources with a magnetization of (1,0–3,0) A/m at depths of (10–18÷38–44) km. Stretching of the sources is consistent with the stretch of the Trans-European sutural zone and the Baltic-Transnistrarian zone of pericratonic troughs (subsidence). The stretching of magnetic sources in the southeast of the craton within Fennoscandia and the Volgo-Uralia is coordinated with the strike of the Phanerozoic structures of the Ural and Timan. Magnetic sources lie in the interval (10–18÷38–44) km and have a magnetization of (0,7–4,0) A/m. Magnetic sources of the northern (within Fennoscandia) and southern (within Sarmatia) parts of the craton have an end joint with its boundary. The zones of articulation of the EEC segments are also distinguished by sources of regional magnetic anomalies. Magnetic sources of the Central-Russian rift system divide the magnetic crust of the Volgo-Uralia and the weak magnetic crust of Fennoscandia, and the sources of the Volyn-Orsha rift system are Fennoscandia and Sarmatia. Magnetic sources of the Pachelma rift zone are separated by Sarmatia and Volgo-Uralia. We note that approximately the same strike has magnetic anomalies of the Kursk-Bryansk band with maximal values of the magnetization of their sources within the limits of the craton (>10,0 A/m). According to the concept of tectonics of lithospheric plates, the magnetic inhomogeneity of the zones of saturation of the segments of the craton and its outer boundaries can be considered as sources of subduction type, which arose at the stage of their formation. In the Riphean and Phanerozoic stages of the development of the lithosphere within the zones of saturation of the segments of the craton and its outer boundaries, magnetic sources of rift nature were formed. Magnetic sources of subduction-reduction and rifting types are characterized by a corresponding metallogenic specialization, therefore the developed model can be used both for tectonic constructions and for small-scale forecasting of minerals.

Keywords: East European Craton, 3D magnetic model.

Introduction. The development of three-dimensional magnetic models of the Earth's lithosphere is an integral component to reveal a sources allocation through its section, as well as geological coordination of the results of surface, aerial, stratospheric and satellite magnetic surveys. To obtain the real sources shape and the values of their magnetization from the results of magnetic modeling for large areas, it is necessary to take into account the sphericity of the Earth. In this paper, the task was to develop three-dimensional magnetic model of the territory of the East European Craton (EEC) taking into account the sphericity of the Earth in order to clarify the Earth's crust deep structure.

Data and methods. To date, small-scale magnetic models and magnetization distribution patterns in the lithosphere of EEC have been developed [8, 13, 14, 17, etc.]. For a number of DSS profiles within the Craton as well as its individual parts, magnetic models in the 2- or 3-dimensional variant are constructed in the Cartesian coordinate system [9, 18, 20 et al.].

Within a reasonable compromise between the size of the territory and the detailed studies for the EEC, a scale model of 1 : 5 000 000 was developed, with the detailing of its south-western part.

To create the initial approximation of the three-dimensional magnetic model of the Earth’s crust of the East European Craton, the following data were used: World Digital Magnetic Anomaly Map (WDMAM) at an altitude of 5 km, heat flow distribution data; temperature at the Moho boundary; scheme of distribution of the foundation surface, Moho, as well as other geological and geophysical data [7, 13, 19, 21, 22, 24, 25].

As shown by the experience of previous studies on the construction of the scheme of the deep structure of the EEC [8, 13, 14, 17, etc.], in the anomalous magnetic field there is a regional component, the sources of which belong to the lower floor of the Earth’s crust. An anomalous magnetic field map [15] was constructed for the analysis of an anomalous magnetic field and the development of a magnetic model of the Earth’s crust of the territory of the EEC, using a digital array of WDMAM [25]. Taking into account the scale of the map, one can take an abnormal magnetic field ΔB for the first approximation of its regional component $\Delta B_{reg}$, naturally complicated by high-intensity anomalies of local character. An anomaly of the magnetic field was obtained by averaging the original field with a pallet (window) 50x50 km (for the Kursk magnetic anomaly region -100x100 km). These anomalies are considered as regional and they were used for magnetic modeling. For the territory of Ukraine, a map of the anomalous field $\Delta B_{o}$ of 1 : 500,000 scale was used as a basis [5, 10]. As for the EEC area, the regional
component was obtained by averaging the data with a window 50x50 km. Thus, 94 regional magnetic anomalies (RMAs) are allocated within the EEC, the sources of which in the model are represented by one and several magnetic blocks.

The magnetically active layer of the Earth's crust extends to the depths where the Curie temperature of magnetite 580 °C, the main magnetic mineral of the crystalline part of the Earth's crust, is reached. Given the "cold" regime of the lithosphere for a large part of the territory of the EEC [21], the lower limit of this layer may be Moho surface, as a petrological boundary. The upper edge of deep sources in most cases refers to the roof of the doreite layer of the Earth's crust. For the territory of the craton, the depth to this boundary is (8–15) km. Exceptions are the Dnieper-Donetsk avlakogen and the Caspian depression, where the depth of immersion of the crystalline basement reaches 20 km.

The direction of the total magnetization vector as a result of its equilibrium state in the deep parts of the crust corresponds to the direction of the total geomagnetic field strength vector.

Consideration of the spatial inhomogeneity of the main (normal) magnetic field of the Earth B_{IGRF} and the relationship between the components of the induction vector for different parts of the investigated region are important when developing magnetic models of large regions [15]. As shown in [15] for the area of research in the 2005 epoch, the modulus of induction of the main magnetic field varies within the limits of 45000–57400 nanotesla, and the declination and inclination angle is $D_{IGRF} = 1^\circ \pm 19^\circ$ and $I_{IGRF} = 62^\circ \pm 79^\circ$ respectively. Naturally, ignoring this can lead to errors both in estimating the magnetization of the sources of the Earth's crust and in their spatial position. The possibility of taking this feature into account is realized in software and algorithmic support of the solution of the direct magnetoproSpectoring problem for a spherical Earth [4, 6].

Results and discussion. The East European craton has an area of 6.7 square km, including the shelves. Within the EEC, the Precambrian crystalline crust is represented in the Baltic and Ukrainian shields, as well as in certain areas of Belarus and the Voronezh crystal massif. The rest of the craton is covered with Late Proterozoic and Phanerozoic sedimentary cover.

The craton consists of three segments: Fennoscandia, Volgo-Uralia and Sarmatia, which differ in tectonic regime and age of the crust, which have united in the interval of 2,1–1.9 Ga. The processes of activation of the craton were reduced to the formation of Riphean rifts in the zones of suturation of segments and its marginal parts [22, 27].

The Fennoscandian segment occupies the northern, northwestern part of the craton. Eastern Fennoscandia, like the Volgo-Uralia, is characterized by the crustal age of 3,8–2.6 Ga, the western part of the segment has a paleoproterozoic crust of 1,95–1,65 Ga. The thickness of the Earth's crust segment is from 30 km to 58 km.

Along the northeastern border, the Riphean and Vendian Timan strata were thrust over Fennoscandia. This is well emphasized by the sources located along the boundary, which differ sharply from their mosaic character in the inner part of the segment (see Fig. 1). Marginal sources with a magnetization of (0,5+1,5) A/m are confined to the elevation of M-surface up to 34 km [24]. It should be noted the south-west fall of the lateral faces of the sources.

Approximately the same ratio of magnetic sources is typical for the northwestern boundary of the segment, hidden under the overturned caledonides of northern Scandinavia. Magnetic sources have magnetization mainly from 1,0 A/m to 2,5 A/m and are located at depths from 10–12 km to 42–44 km.

The south-western boundary of the segment is traced along the line of the Trans-European suture zone. It delineates the ancient EEC and the Epipaleozoic West European platform. According to seismic data, the boundary is reflected by the vertical displacement of the M section by about 10 km, and the thickness of the sedimentary layer increased to (10–12) km [23]. In the magnetic model, the boundary is represented by a chain of the sources along it with a magnetization of 1–3 A/m and the depths from (10–18) km to 46 km. In accordance with [17], this area is associated with the Baltic-Transnistrian zone of pericratonic subsidesences.

Along 30°–31° east longitude magnetic sources form the Pecheneg-Ladoga belt of the submeridional direction, considered as a suture zone of repeated activation [16]. Within the zone, sources with a magnetization of 0,9–2,1 A/m are located at depths of 8–10 km + 40–42 km.

The Volgo-Ural segment is represented mainly by the Archean crust, which is completely buried under the Phanerozoic sedimentary cover. However, under it there are numerous Meso-Neoproterozoic avlakogenes and basins, filled with sedimentary rocks with a thickness of (2–10) km. The average thickness of the Earth's crust is about 40 km. In the magnetic model, its central part is characterized by an unordered mosaic nature of sources distribution with location depths from 10–18 km to 38–44 km and the magnetization of 0,7–1,5 A/m. These sources can, presumably, be connected with the system of stable Archean dome-like structures (Fig. 1) [1], whereas linear ones belong to the mobile belts of the Paleoproterozoic [22].

In the east, the Volgo-Ural segment is limited by the hercinides of the Urals, which are thrust to the craton. In this part of the segment there are strong magnetic sources (up to 4,0 A/m), the strike of which partially corresponds to the strike of its boundary. Further to the southeast, a zone of magnetic bodies also confined to the edge of the segment is clearly distinguished.

The Sarmatian segment is characterized by an average crustal thickness of 48 km and a strongly magnetized lithosphere [17].

The magnetization of the lower part of the crust, as it has been shown by the results of modeling, is much higher in comparison with the sources of the Volgo-Uralia and Fennoscandia. The spatial orientation of sources within Sarmatia varies in different ways with the extent of both the boundaries of the craton and the large tectonic units of the segment. The south-western, north-western and northeastern boundaries of the segment are characterized by magnetic sources of consonant strike. For the southern edge of the craton, the end joint of magnetic bodies with its boundary is characteristic. High values of magnetization are sources of Liviv (3,2 A/m), Odessa (3,5 A/m) and West Ingulets (3,6 A/m) RMA. Especially it is worth to note Kursk RMA with the source magnetization up to 10,0 A/m.
The magnetic sources junction areas. The East European craton is characterized by rifts and aulacogens underlying the platform sedimentary depressions. As a rule, meso-Neoproterozoic rifts and aulacogens are associated with the system of Paleoproterozoic sutures that appeared at the stage of craton formation from individual segments (Fig. 2). This group includes Pachelma and Central-Russian aulacogens, as well as the Volyn-Orsha Paleorift. A number of Neoproterozoic rifts are confined to passive continental margins. The Phanerozoic Pripyat-Dnieper-Donets rift and the Oslo graben are sharply discordant with respect to the ancient structures of the craton.
Within the East European craton, the three Riphean trascratonic rift systems will inherit zones of the Paleoproterozoic articulations of the Fennoscandian, Volgo-Ural and Sarmatian segments of the continental crust. Dynamically these systems represent different types of Paleoproterozoic tectonic events. The suture zone of the Pachelma aulacogene was created by thrusting the Volgo-Uralia onto Sarmatia, the Volyn-Orsha zone of articulation – by pushing the Paleoproterozoic crust of Fennoscandia under Sarmatia and the Central Russian suturation zone, probably formed by the collision of the Volgo-Uralia and the Archaean part of Fennoscandia. Rifting within the age is usually accompanied by mafic magmatism.

The Central Russian rift system divides higher magnetic crust of the Volgo-Uralia and weakly magnetic one of Sarmatia [22]. It should be noted that geotranssect “EUROBRIDGE” (fig. 2).

Conclusion. According to [11, 26] the tectonotypes of deep sources are subduction-obducted and rift zones of the Earth’s crust, as well as zones of transcrustal faults. In accordance with discussed above, the sources of the edge parts of the EEC can be considered as sources of subduction-obducted type that originated in the Riphean-Vendian and later stages of the formation of rifts and transcrustal faults are associated. These can be considered the Central Russian and Volyn-Orsha, Pachelma inter-segment rift systems, as well as intra-segment rifts, such as Pripyat-Dnieper-Donets in Sarmatia, Kaltasinsky in the Volgo-Uralia as well as a suture zone of multiple activation within Fennoscandia.

**Fig. 2. Magnetic inhomogeneity of the Earth's crust of the junction zone between Fennoscandia and Sarmatia for the EUROBRIDGE transect (Seismic-geological section for [23]):**

1. sedimentary cover; 2 – upper crust; 3 – middle crust; 4 – lower crust; 5 – uppermost mantle; 6 – Moho boundary; 7 – mantle reflector or zone of high-velocity gradient; 8 – Faults; 9 – mean magnetization of the crust (A/m)

The characteristic features of the Central Russian and Pachelm rift systems are the presence of positive linear magnetic anomalies, clear boundaries of rifts and increased heat flux. On the contrary, the rifts and grabens of the Volyn-Orsha aulacogene are less developed and have no clearly defined external boundaries with the host environment, and are characterized by a relatively low heat flux [2].


References


3D МАГНИТНАЯ МОДЕЛЬ ЗЕМНОЙ КОРЫ СХИДНОЕВРОПЕЙСКОГО КРАТОНА

С УЧЕТОМ СФЕРИЧНОСТИ ЗЕМЛИ И ЕЕ ТЕКТОНИЧЕСКАЯ ИНТЕРПРЕТАЦИЯ

Геомагнитное поле широко применяется для получения информации о глубинном строении и развитии литосферы Земли, мелко- масштабного прогнозирования коры, а также виртуализации низких экологических заданий. Наиболее важные результаты отмечены за счет разработки 2D, 3D и 4D магнитных моделей земной коры (литосферы), в которых отражаются пространственное и пространственно-временное распределение магнитных источников. Построение пространственно-временного распределения (рассмотрение) магнитных источников и величин их намагниченности зависит от адвекции объектов и неоднородности глобального магнитного поля Земли. В связи с этим для Восточноевропейского кратона впервые разработан его региональная 3D магнитная модель для сферической Земли. Для разработки модели использованы цифровые данные WDMAM на высоте 5 м, априорные данные о залегании поверхности и размещении фундамента и модели, распределение температуры, а также результаты других геохимических исследований. Согласно С.В. Бакаржиевой, Восточноевропейский кратон сформировался за счет сочленения трех сегментов (Фенноскандии, Волго-Ураль и Сарматии) во временной интервале 2,1–1,8 млрд лет. На фанерозойском этапе развития были сформированы его границы. Установлено, что в пределах кратона наблюдается неравномерное распределение магнитных источников и величин их намагниченности. Максимальная концентрация магнитных источников характерна для его краевых частей. Юго-западная граница кратона отмечается магнитными источниками с намагниченностью 1,0–3,0 А/м на глубинах 10–1846 м. Пространство источников согласуется с простиранием Трансевропейской супервулканической зоны в Восточноевропейском сегменте, включенного в супервулканическую зону Сарматии. Наиболее интересным является восточная зона сюпитного сочленения земной коры, где наблюдается плотное поселение магнитных источников с намагниченностью 0,7–4,0 А/м. Магнитные источники с практически равномерным распределением характерны для конкретных отрезков земной коры, в пределах которой наблюдается устойчивое значение магнитной силы. Эти магнитные источники могут использоваться для различных целей, включая геодинамическую интерпретацию. Ключевые слова: Восточноевропейский кратон, 3D магнитная модель.