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Magnetic model and heterogeneity of the crystalline crust of the southwestern boundary of the East European Craton

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The paper presents 3D magnetic modeling of the crystalline crust in the Teissere-Tornquist line (TTL) area and its northwestern branching into the Sorgenfrei and Thor-Tornquist zones. The anomalous magnetic field was analyzed based on ground, airborne, and satellite surveys. The boundaries of the East European Craton segments follow the structure of the TTL, in which we have identified two branches of different strikes; they form a triple articulation with the Fennoscandia-Sarmatia suture zone.The TTL segmentation corresponds to the distribution of magnetic sources along the TTL.

Key words: 3Dmagnetic modelling, magnetic field, Teisseyre-Tornquistline, East European Craton.

Introduction. As presented in numerous publications, the characterisation of the margins and the type of articulation of the East European Craton (EEC) with the surrounding regions leaves several controversial issues. The southwestern boundary of the EEC has been studied by geological and geophysical methods for more than 100 years and is usually associated with the Teisseyre-Tornquist Line (TTL). However, causal connection between the heterogeneities of different lithospheric layers and the history of its development remain a problem. This also applies to the deep magnetic heterogeneities of the crystalline crust, their nature, and their connection with the structure of the crust and mantle.

The object of study is the crystalline crust in the vicinity of the TTL, which separates the three-layer-thick high-velocity crust of the EEC from the thin crust of the West European Platform. A 3D magnetic model of the EEC at 1:5 000 000, built with a spherical Earth in mind [Orlyuk et al., 2017], provides an idea of the distribution and types of deep magnetic

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sources but requires further detailed modelling in the craton margins.

The research aims to detail the magnetic model of the crystalline crust of the southwestern marginal part of the EEC and to establish a connection with its structure.

The methodology consists of qualitative and quantitative description of the geomagnetic field based on the ground, airborne, and satellite surveys, assessment of the crust magnetization by three-dimensional modelling taking into account a priori seismic data along the DSS profiles, and analyzing the relationship between deep magnetic sources and the crustal structure features.

Results. The 3D magnetic model of the TTL crystalline crust and its northwestern branching into the Sorgenfrei (STZ) and Thor-Tornqvist (Thor-TZ) zones is shown in Fig. 1. The upper limits of local sources are attributed to the surface of the crystalline basement, and the lower ones, to the roof of the middle crust. The deep magnetic sources are limited to the roof of the middle crust (V_P=6.3 km/s) and the Mohodiscontinuity or to the depth of the Curie isotherm of the magnetite.

The model was based on the scheme of the main tectonic elements based on published materials such as [Grad et al., 2002, etc.] and the identification of the transition zone of the EEC crust to Avalonia and Variscids, underlain by the thinned lower crust of the EEC. The main lineament of the TTL[1] region separates the EEC and its segments — Fennoscandia (FSc) and Sarmatia (Sm) with their suture zone (FSS) — from the structure of the Western European Platform (WEP), including the Variscids and the Carpathians. We believe theTTL has two branches: a northwest branch along FSc with a strike of 305° and a southeast branch along Sm (330°). Combined with the FSS, they form a triple joint. The TTL is a complex system with faults adjacent and subparallel to it, which generally corresponds to a right strike. The system of associated faults of the southeastern branch is bounded on the eastern side by the meridional Ukrainian-Baltic activation zone (Uk-BZ).

[1] Here and after, we refer to its position in the crystalline crust.

The area is composed of two main types of crystalline crust: the high-velocity three-layer crust of the EEC and the low-velocity two-layer crust of the WEP. A third type, the 'transitional' crust, can be traced southwest of the TTL and is developed at the contact of the EEC with East Avalonia; to the southeast, it can be traced along the boundary with the FSc with a decrease in thickness to the FSS. Along the Sm it is fixed to the RomUkrSeis profile.

The nature of the faults associated with the TTL and with the 'transitional' crustal type area indicates different geodynamic regimes of formation of the northwestern and southeastern branches of the TTL. Their different ages of activation are also indicated by the distribution of the Vendian Volyn volcanic of Sarmatia and Neoproterozoic volcanic of the Trans-Scandinavian Volcanic Belt (TIB1) of Fennoscandia along the TTL (see Fig. 1).

The described branches of the TTL correspond to the stages of the EEC collision: in the late Ordovician — with the microcontinentAvalonia, in the Late Cretaceous—Early Permian — with the rest of the European Hercynianterranes [Gintov et al., 2022].

In the northwest, the northwestern TTL branch is divided into the Thor-TZ and STZ along the possible southern extension of the submeridional Svecon-Norwegian Front (SNF). The crustal boundary of the EEC is the Thor-TZ zone separating the three-layer high-velocity craton crust from the low-velocity thin crust of Avalonia.

The magnetic model of the region was preceded by an analysis of the anomalous magnetic field at high altitudes (Fig. 2). As is well known, many authors associate the TTL is associated by many authors with a zone of increased gradient of the ground magnetic field. Such a zone can be traced in the field at an altitude of 100 km within the same limits as in the ground field. The most intense anomalies at this height are observed southeast of the SNF within Fennoscandia. Further to the southeast, the combined effect of anomalies above the Lviv Trough and anomalies accompanying the TTL persists. In the Magsat satellite field, the maximum of the positive anomaly and the field at an altitude of 100 km cor-

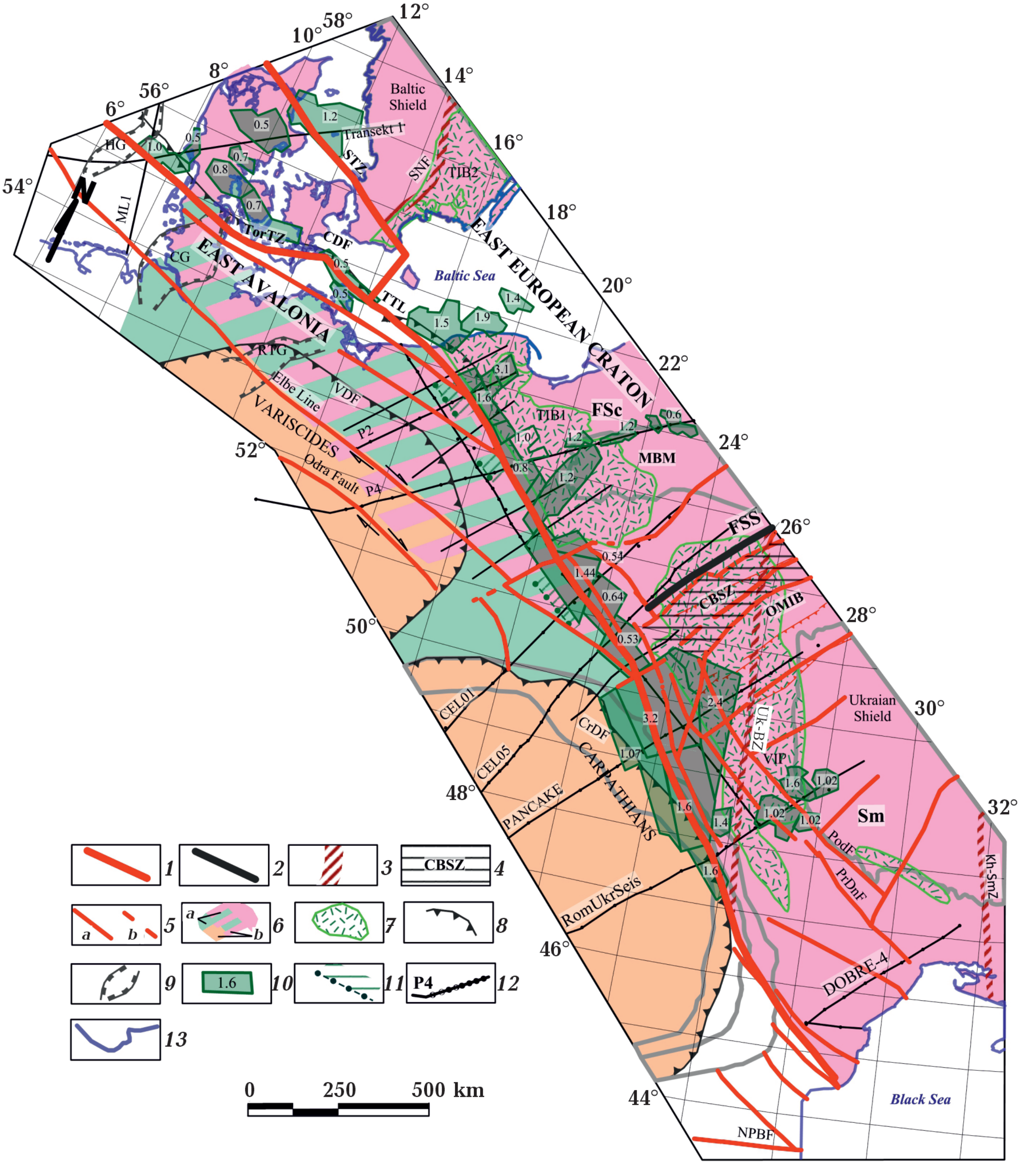

Fig. 1. 3D magnetic model of the crust and a scheme of the main tectonic elements of the EEC's southwestern edge and its surroundings: *1* — position on the crystalline basement of the Teisseyre-Tornquist line (TTL), Sorgenfrei-Tornquist (STZ) and Thor-Tornquist (ThorTZ) zones; *2* — Fennoscandia-Sarmatia suture (FSS) (a) and their possible extension (b); *3* — transregional activation zones: Ukrainian-Baltic (Uk-BZ), Kherson-Smolensk (Kh-SmZ) and Sveconorwegian Front (SNF); *4* — Central Belarusian Suture zone (CBSZ); *5* — main faults (*a*) and their possible extension (*b*); *6* — Avalonia crust underlain by high-velocity EEC crust (*a*), Variscide crust underlain by lower EEC crust (*b*); *7* — volcanic provinces (VIP, TIB1, TIB2); *8* — deformation fronts: Caledonian (CDF), Variscide (VDF), Carpathian (CrDF); *9* — graben boundaries; *10* — magnetic sources, magnetization values, A/m; *11* — projection of the lower boundary of magnetic sources to the Earth's surface; *12* — seismic profiles; *13* — coastline.

respond to the FSc part southeast of SNF and the central part of TIB1. The zone of increased gradient is traced in the satellite field along the TTL to the FSS zone. The anomaly above the LvivTrough is not reflected in the satellite field, indicating a source's core nature. The transition from the southwestern boundary of the craton to its southern boundary in the fields at high altitudes is marked by a latitudinal regional minimum. Fig. 2 also shows the field of the total gradient modulus of the anomalous magnetic field according to [Milano et al., 2019]. The absence of anomalies of the total field gradient within the WEP once again confirms its crust's weak magnetization. Large tectonic zones are clearly visible in the gradient field: Uk-BZ, FSS, and SNF and its possible southern extension, which indicates their deep origin.

This segmentation of the TTL corresponds to the distribution of magnetic sources along it. From the northeast, the northwestern branch of the TTL is almost continuously accompanied by deep magnetic sources up to the FSc boundary. The northeast-trending heterogeneities of the craton Precambrian basement are at the perpendicular junction with them, indicating their different ages.In the domain bounded by the Thor-TZ and STZ, deep magnetic sources are traced sporadicallyalong both of these zones. In the southeastern branch of the TTL, the distribution of deep magnetic anomalies is different. The sources associated with the TTL are associated with

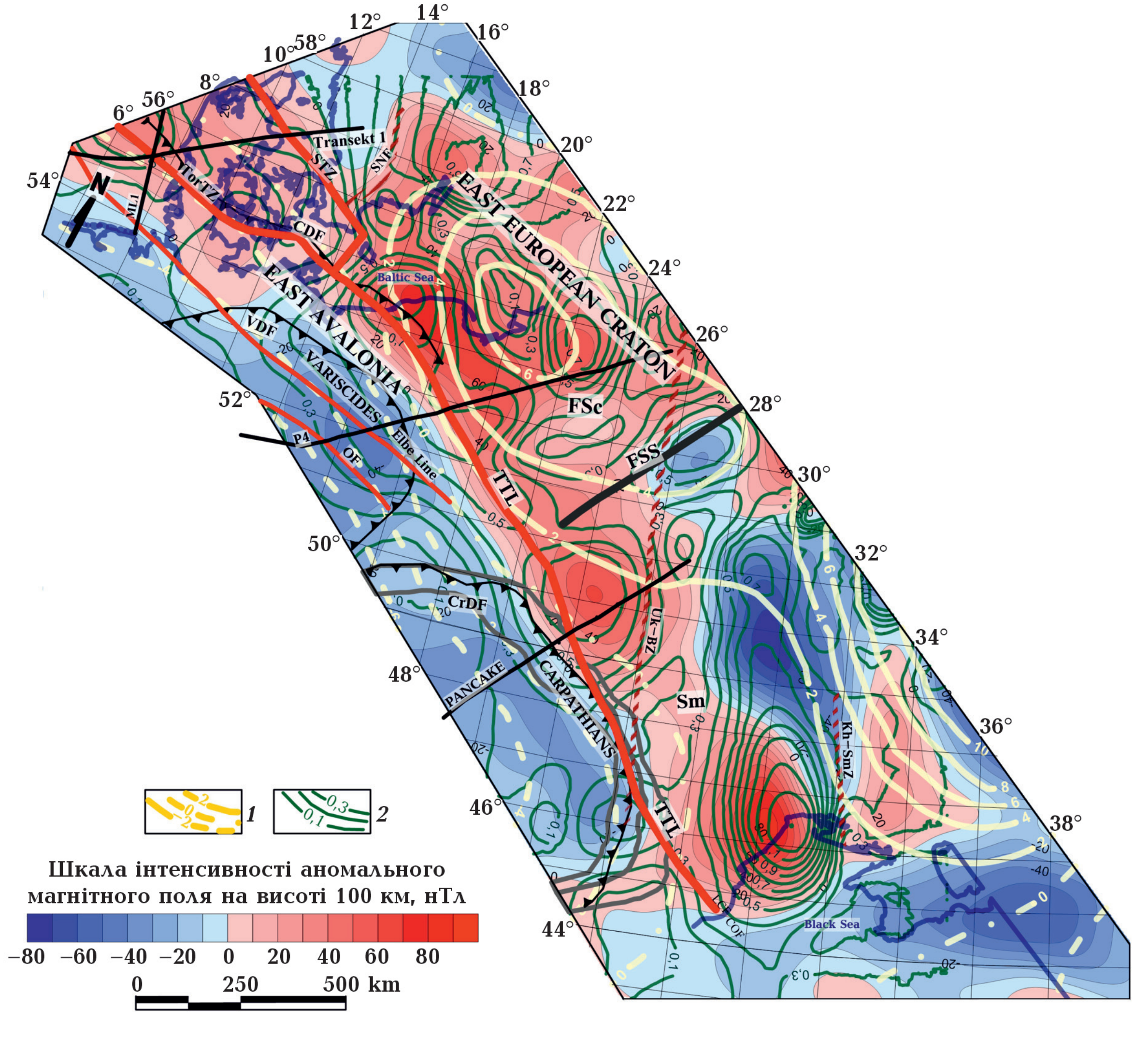

Fig. 2. Anomalous magnetic field at an altitude of 100 km, intensity scheme of the full gradient of the anomalous magnetic field, Magsat satellite field (for other symbols, see Fig. 1): *1* — Magsat anomalous magnetic field isodynes, nT; *2* —intensity isolines of the total anomalous magnetic field gradient, nT km^{-1}.

the Subcarpathian Trough to the southwest of the TTL and are attributed to the upper and middle crust. A complex deep source in the form of a northwest-trending body is articulated with the source directly below the Lviv Trough and borders the meridional magnetic source to the west of the Uk-BZ. This zone delimits a series of deep sources associated with the TTL to the southeast.

The magnetization of the deep sources estimated from the three-dimensional modelling is 0.5—3.2 A/m. This model should be considered one of the options since the modelling assumes strict limitations on the depths of the upper crustal and deep sources. It is important to emphasize that the main epochs of crustal extension are accompanied by magmatic activity, including mafic activity. Magnetic sources can be indicators of crustal extension regimes. A number of authors have noted a Neoproterozoic extension regime along the TTZ, which contributes to the intrusion of the basement-ultrabasement rocks. The absence of deep magnetic sources along the TTL southeast of the Uk-BZ is a consequence of the predominance of compression modes in the formation and development of the TTZ.

Conclusions. The results of the magnetic modelling of the TTZ region and the analysis of the anomalous magnetic field at high altitudes, including satellite imagery, allow us to draw the following conclusions: 1) The magnetization intensity of the deep sources (0.5—3.2 A/m) corresponds to their mafic-ultramafic composition; 2) Along the southwestern boundary of the FSc, the associated TTL sources are recorded almost continuously, have a perpendicular junction with the sources of the EEC itself and are dated as younger; 3) The Sm boundary is accompanied by deep bodies only in the Lviv Trough area, and no deep sources are detected southeast of the Ur-BZ; 4) The boundaries of the EEC segments follow the TTL structure, in which we have identified two branches of different strikes. They form a triple articulation with the FSS; 5) Magnetic sources confined to extension zones characterize different modes of development of different branches of the TTL. In general, the TTL fault system corresponds to a large-scale right-lateral displacement; 6) In the Earth's crustal structure, a transitional crustal type from the EEC to the WEP crust is distinguished, underlain by the lower EEC crust.

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Магнітна модель та неоднорідність кристалічної кори південно-західної границі Східноєвропейського кратону

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Представлено результати 3D магнітного моделювання кристалічної кори району лінії Тейссейре—Торнквіста (TTL) та її північно-західного розгалуження на зони Соргенфрей та Тор-Торнквіст. Виконано аналіз аномального магнітного поля за результатами наземних, аеро- та супутникових зйомок. Границі сегментів Східноєвропейського кратону підпорядковуються будові TTL, у складі якої виділено дві гілки різного простягання, вони складають потрійне зчленування з шовною зоною Фенноскандія-Сарматія. Сегментація TTL відповідає особливостям розподілу магнітних джерел уздовж TTL.

Ключові слова: 3D магнітне моделювання, магнітне поле, лінія Тейссейре—Торнквіста, Східноєвропейський кратон.