УДК 550.38.+551.243 DOI: https://doi.org/10.24028/gj.v45i4.286284

The geomagnetic field of the Ukrainian Carpathians and a 3D magnetic model of the Transcarpathian Depression

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Received 5 January 2023

The article presents the results of a qualitative and quantitative analysis of the geomagnetic field of the Ukrainian Carpathians and 3D magnetic modeling along the PANCAKE geotransect and Transcarpathian Depression, as well as a comparison of the obtained results with fault-block tectonics, deep structure, and distribution of a number of types of endogenous ore deposits and hydrocarbon accumulations.

It is shown that the overthrust northeastern part of the Carpathian arc lies on the magnetic crust, and the southwestern one — on its non-magnetic lower part, and between the Rava-Rus'ka and Krakovets and Pre-Carpathian faults, the Earth's crust is magnetized throughout.

For the territory of the Transcarpathian Depression, the regional and local components of the geomagnetic field were identified for the first time, geological and geophysical characteristics were provided, and their tectonic interpretation was proposed.

A three-dimensional magnetic model of the Transcarpathian Depression was created taking into account the magnetization of rocks according to measurements. A detailed magnetic model of the upper part of the crustal section of the Transcarpathian Depression was developed. The connection of magnetic sources with fault zones was analyzed; the results were compared with the deep structure and distribution of ore deposits and hydrocarbon accumulations.

The regional source with magnetism I=1.0 A/m is located within the Mukachevo Depression and is located at a depth of 6.0 km to 13 km. The local component of the geomagnetic field reflects the magnetic inhomogeneity of the Earth's crust in the upper 3—4 km of the section and mainly reflects the volcano-tectonic structures and dike formations of the Vyhorlat-Gutyn Ridge, the Chop-Berehove Uplift, and the Velika Dobron' Uplift. The maximum depths of magnetic sources (up to 3.5 km) and their magnetization (1.22 A/m) are characteristic of the structures of the Vyhorlat-Gutynsky Ridge, intermediate values of depths (2.0—3.0 km) and magnetization (up to 0.93 A/m) belong to the Chop-Berehove Uplift, and the minimum depths (up to 1.1 km) and magnetization (up to 0.7 A/m) are characteristic of the Velika Dobron' Uplift.

It is shown that the gas fields of Transcarpathia correspond to local positive magnetic anomalies and are localized above a deep magnetic source. Within the Berehove Uplift, positive anomalies and magnetic sources indicate andesiteporphyrite shafts and andesite domes of Sarmatian age associated with gold, gold-polymetallic and silver mineralization. A zone of antimony mineralization is associated with the Pannonian-Pontic volcanic struc-

Citation: *Orlyuk, M.I., Bakarzhieva, M.I., Marchenko, A.V., Shestopalova, O.E., & Drukarenko, V.V.* (2023). The geomagnetic field of the Ukrainian Carpathians and a 3D magnetic model of the Transcarpathian Depression. *Geofizicheskiy Zhurnal*, *45*(4), 20—42. https://doi.org/10.24028/gj.v45i4.286284.

tures along the southern foot of the Vyhorlat-Gutyn Ridge, and deposits and occurrences of bismuth and mercury correlate well with intrusive formations of the Dacian-Romanian age.

Key words: geomagnetic field, magnetic model, magnetic properties of rocks, volcano-tectonic structures, minerals, Carpathians, Transcarpathian Depression.

Introduction. To date, the Ukrainian Carpathians have been fairly well studied by geological and geophysical methods using model representations of various tectonic concepts regarding their deep structure, geodynamics of the lithosphere, and mineral predictions, and have been described in numerous publications [Subbotin, 1955; Ivaniuta, 1978; Vyalov et al., 1981; Pashkevich et al., 1985; Glushko, Kruglov, 1986; Sollogub et al., 1988; Lyashkevich et al., 1995; Kolodiy, 2004; Gordyenko et al., 2011; Zayats, 2013; Starostenko et al., 2013; Tretyak et al., 2015; Kutas, 2016; Hnylko, Hnylko, 2019; Janic et al., 2022 and many others]. Taking into account a number of works in which the characteristics of the geomagnetic field of the Ukrainian Carpathians in general is covered [Subbotin, 1955; Krutykhovska et al., 1973; Orlyuk, 1984; Tretyak et al., 2015] we will rather briefly dwell on the general characteristics of the geomagnetic field and magnetization of the Earth's crust in the Carpathian region as a whole and focus in more detail on the Transcarpathian Depression. It is also worth noting that for the Carpathian region, and especially for Transcarpathia, there are negligible amount of magnetometric studies that are mainly related to regional research.

According to the studies [Orlyuk, 1984; Pashkevich et al., 1985; Monchak, Anikeev, 2017; Orlyuk et al., 2021, 2022a–c] the structural elements of geomagnetic field are clearly reflected in geomagnetic field of Carpathian region. It's qualitative and quantitative analysis makes it possible to obtain information about the geological structure, geotectonic development, and forecasting of minerals, in particular, hydrocarbon deposits. The geomagnetic field can be briefly described by its analysis in the area of the PANCAKE profile [Orlyuk et al., 2022a,c]. A differentiated magnetic field with intensity from –250 to 400 nT is characteristic of the East European Craton (EEC) (Fig. 1). The intensity of the regional component has maximum value in the area of the Paleozoic Lviv and Pre-Carpathian Depression, and then the field gradually decreases to practically zero in the area of the Inner Carpathians [Orlyuk et al., 2022a,c]. The local component has a significant differentiation within the EEC ±(250—600 nT) and Transcarpathian Depression ±(50—350 nT), and within the Pre-Carpathian Depression and Folded Carpathians it has an intensity of tens of nanoTesla (see Fig. 2).

Research methodology. For the analysis of the geomagnetic field and the development of 2D and 3D magnetic models and petrological-tectonic interpretation, a standard technique was applied, which was consisted in the use of reliable initial data on magnetic maps ΔB_{a}, experimental data on magnetic susceptibility χ and residual magnetization J, as well as taking into account the results of geological and geophysical research.

For the territory of the Carpathian region a map of anomalous magnetic field 1:500 000 was used [Orlyuk et al., 2021]. The division of the field into regional and local components was performed by averaging it with a sell size of 40×40 km [Orlyuk et al., 2022a].

For Transcarpathia, for the purpose of qualitative and quantitative analysis of the geomagnetic field, as well as the selection of regional $(\Delta B)_{\mathrm{a,reg}}$ and local $(\Delta B)_{\mathrm{a,loc}}$ components, a map of the anomalous magnetic field with a scale of 1:200 000 was used [State..., 2003]. The regional component is obtained by averaging the initial field with a 20×20 km palette. The local component of the geomagnetic field was obtained as the difference between the anomalous component of the geomagnetic field and its regional component ($(\Delta B)_{\mathrm{a,loc}}=(\Delta B)_{\mathrm{a}}-(\Delta B)_{\mathrm{a,reg}}$).

The information about the rocks' composition, type, age and magnetic parameters was obtained from the previous studies [Mikhaylova et al., 1974; Glevasskaya, 1983; Prykhodko et al., 1985, 2019; State..., 2003].

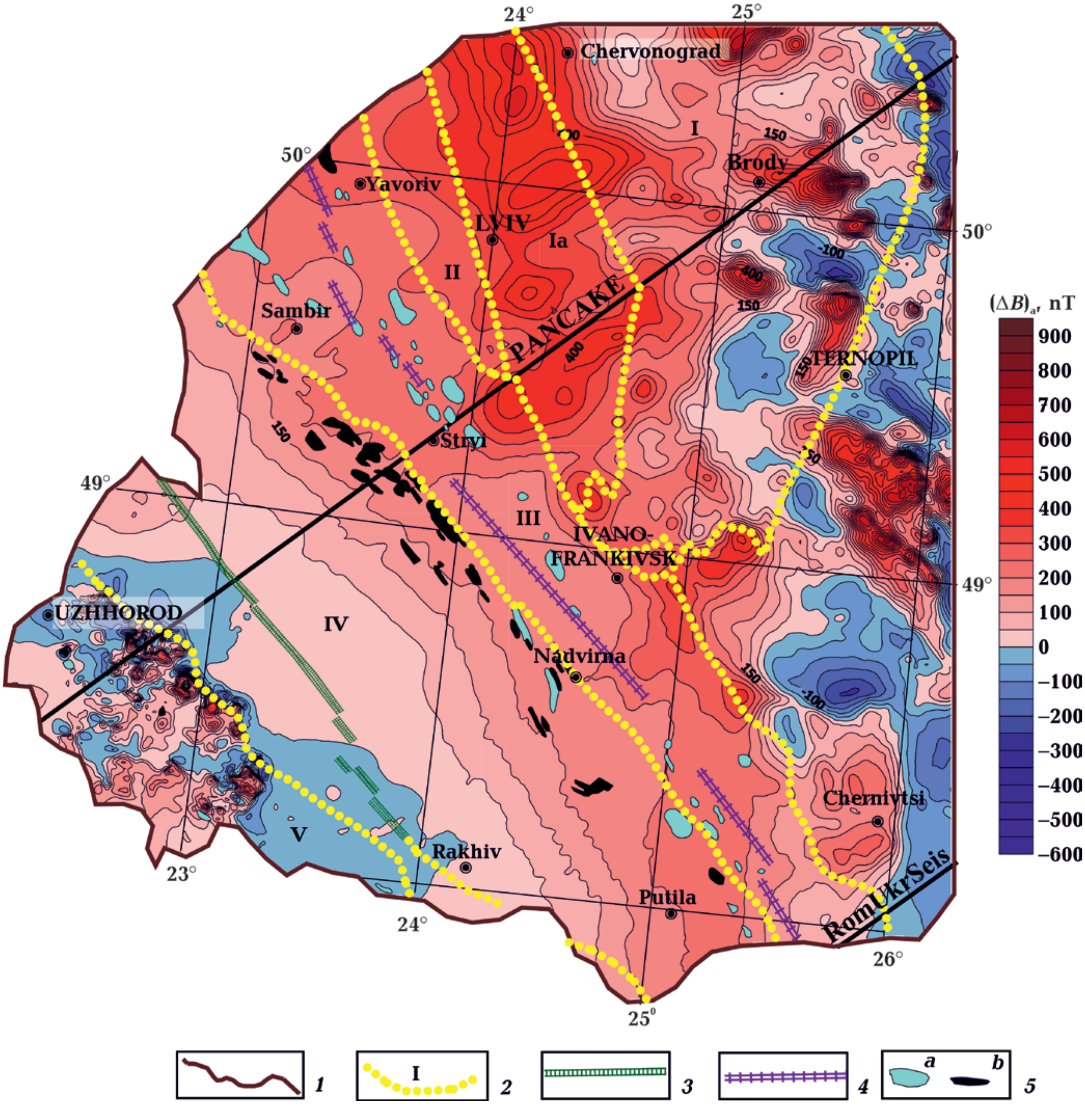

Fig. 1. Map of the anomalous magnetic field in comparison with the main structural elements and oil and gas potential of the western part of Ukraine (using the works [Glushko, Kruglov, 1986; Kutas et al., 1996; Ivaniuta, 1998; Murovska, 2019]): *1* — border of Ukraine, *2* — tectonic units, *3* — estimated boundary of Mesozoic-Paleozoic and Meso-Neoproterozoic basement, *4* — estimated boundary of Meso-Neoproterozoic and Archean(?)-Paleoproterozoic basement, *5* — deposits (*a* — gas and gas condensate, *b* — oil and oil condensate).

Tectonic units: I — slope of the East European Platform (Lviv Paleozoic Depression); Ia — Inner (Rostoch) zone of the Lviv Paleozoic Depression; II — Western European (Paleozoic) Platform (Rava-Rus'ka zone); III — Pre-Carpathian Depression; IV— zone of the Folded Carpathians; V — Transcarpathian Depression.

For an initial approximation for 3D modeling, the geomagnetic field's statistics analysis was investigated to estimate the parameters of magnetic sources and their spatial distribution using Surfer and the demo version of GSS Potent.

Algorithms and software of V.M. Zavoyskiy and I.M. Ivashchenko [Zavoyskiy, 1978; Kovalenko-Zavoyskiy, Ivashchenko, 2006] were used for magnetic modeling. In some cases, 2.5D magnetic modeling was applied along the profiles using demo version GSS

Potent algorithms and software (https://www.geoss.com.au/index.htm).

The magnetic model was developed according to the standard technique by solving the direct problem of magnetic exploration to clarify the geometric parameters of the sources and their magnetization [Orlyuk, 1984; Orlyuk et al., 2022a]. At the same time, the calculated field was compared with the regional and local ones, and their difference were used to adjust the magnetization parameters and the shape of the sources. Note that the total value of inductive and residual magnetization ($J=J_i+J_n$) was calculated for magnetic sources.

The aim of the study was to analyze the geomagnetic field, to develop the magnetic models of the deep and near-surface parts of the crust section and to interpretive obtained results. For this purpose in connection with the petrological and tectonic features of the structure and geodynamics of individual structural elements of the Transcarpathian Depression (TD), geological materials of the Uzhhorod group of sheets (scale 1:200 000) were used. The results of seismic study on the PANCAKE DSS profiles and Chop—Veliky Bychkiv, drilling results for individual wells, the depth of the crystalline foundation, etc. also were studied.

Magnetic model along the PANCAKE geotransect. In the works [Orlyuk, 1984; Kutas et al., 1996], magnetic models of the Earth's crust were created along geotraverse II which is located close to the PANCAKE profile. Several variants of magnetic models were developed, including those with a gradient distribution of rocks' magnetization which satisfied the regional features of the anomalous magnetic field. The magnetic model was created according to standard technique by solving the direct problem of magnetic exploration to clarify the geometric parameters of the sources and their magnetization [Orlyuk et al., 2021, 2022a,c]. The proposed magnetic model along the geotransect does not fundamentally differ from previously created models, namely: the crust of the marginal part of the East European Craton and the transition zone to the structures of Central Europe has increased magnetization. Deep magnetic sources are usually located in the middle and lower parts of the crust, and in the region of the maximum of the regional component, the upper limit is at a depth of about 10—15 km. According to the modeling the magnetic part of the crust at depths from 15—20 to 40—45 km with a magnetization of 1.5—2.0 A/m is traced to the Pre-Carpathian Fault, which is characterized by south-west dip and probably indirectly connected with perpendicular to it, deeper zones of displacement of rocks of the crust in the northeast direction. The source with a magnetization of 1—1.5 A/m (depth interval 20—45 km) is confined to the edge of the EEC. In the upper part of the crust section above this source at depths from 10—15 to 20 km, there is a magnetic body with a magnetization of 1.0—2.0 A/m which spatially coincides with a high-speed waveguide (with a speed of longitudinal waves of 6.10—6.20 km/s against a background of 6.23—6.27 km/s). The most submerged part of the sedimentary stratum of the Carpathian arc (its root) is approximately above the contact of the magnetic (in the northeast) and non-magnetic (in the southwest) parts of the consolidated crust. Further to the southwest, a weakly magnetized body in the middle crust stands out. This body spatially coincides with the Transcarpathian Depression.

In other words, in the area of the geotransect PANCAKE, the northeastern part of the Carpathian arc lies on the magnetic crust and the southwestern part on the non-magnetic one. The region with a magnetized crust is observed in the upper part of the section (between the Rava-Rus'ka, Krakovets and Pre-Carpathian Faults) (Fig. 2).

3D magnetic model of Transcarpathian Depression. Since the Transcarpathian region is an extremely interesting geological structure, in terms of geodynamics and by the presence of ore and mineral deposits, it is sufficiently well studied by geological and seismic methods [Lazarenko et al, 1963; Lazarenko, 1969; Chekunov et al., 1969; Podstrigach, Chekunov, 1978; Sollogub et al., 1978; Sollogub et al., 1988; Prykhodko et al., 2019]. However, the geomagnetic data are presented at limited quantity of works [Sub-

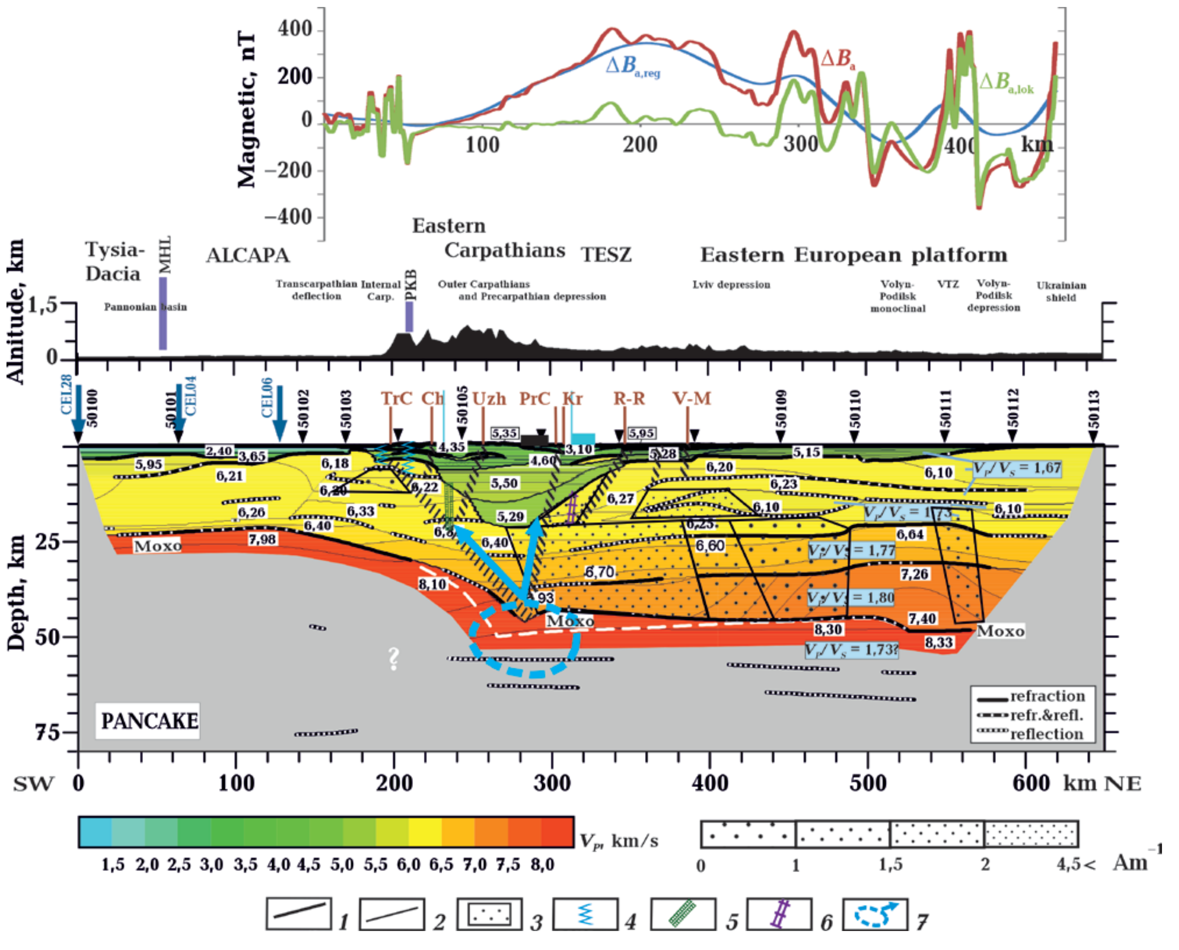

Fig. 2. Magnetic model of the Earth's crust along the PANCAKE profile (seismic model according to [Starostenko et al., 2022]: *1* — boundaries of reflection or refraction by P-waves; *2* — speed isolines, the values of which are given in km/s (white rectangles); *3* — magnetic sources; *4* — fluid-magmatic channels; *5* — predicted boundary of Meso-Neoproterozoic and Paleozoic crust; *6* — predicted boundary of the Archaean(?)-Paleoproterozoic and Meso-Neoproterozoic crusts; *7* — a potential source of hydrocarbons and ways of its entry into the crust. Black arrows show the explosion points. The positions of the tectonic units are indicated above. Rectangles on the profile: black — projections on the surface of generalized contours of oil and oil and gas deposits; blue — gas and gas condensate deposits; zones of the main faults are shown by hatching. TrC — Transcarpathia, Ch — Chornogolova, Uzh — Uzhok, PrC — Pre-Carpathia, Kr — Krakovets, R-R — Rava-Rus'ka, V-M — Velyko-Mostivske

botin, 1955; Khomenko, 1978; Anikeev et al., 2021; Orlyuk et al., 2021, 2022a–c]. First of all, we will briefly consider the current ideas about the geological and fault-block structure of the Transcarpathian Depression.

Geological and geophysical characteristics. The Transcarpathian Depression is characterized by a thin crust (about 25—30 km), dissected by faults into small blocks and by a powerful asthenosphere the roof of which is located at depths of 65—70 km [Nazarevych, Nazarevych, 2002]. According to seismic data, the crust is stratified and it is possible to conditionally highlight the roofs of «basalts» at a depth of about 16 km and «granites» at a depth of about 6 km. The depth of the Mesozoic-Paleozoic basement is about 2—3 km (up to 5 km in some areas). Above basement covering complex of terrigenous molasses (2.5—4 km thick) and Neogene, Pliocene, and Quaternary volcanics is observed. The most significant changes in the deep structure of the lithosphere relate to the Transcarpathian deep fault which limits the Alkapa terrain and is characterized by significant difference in the depth of the Mohorovychych surface (20—30 km), by different type of sedimentation during the Meso-Cenozoic and by multiphase volcanic formations and modern seismic activity [Podstrigach, Chekunov, 1978; Kutas et al., 1996; Mykyta, 2013; Maksymchuk et al., 2014; Prykhodko, Ponomaryova, 2018; Anikeev et al., 2021; Generalova, Pyrizhok, 2021 etc.].

In tectonic terms, the Transcarpathian Depression is a Neogene depression superimposed on the heterogeneous foundation of the inner Carpathians. Mesozoic magmatic formations are widespread in the basement, exposed by wells and form natural outcrops on the southern slope of the inner Carpathians. Cenozoic igneous formations was discovered by numerous wells and was outcropped in the area of Vyhorlat-Gutyn Ridge.

The formation of the depression was accompanied by the tectonic activation of the region, by the accumulation of molasse deposits formed due to the destruction of the Carpathian Mountains and magmatic activity, which was most intensively manifested in the Miocene—Pliocene. The Transcarpathian Depression has a block structure. The largest blocks correspond to the Chop-Mukachevo and Solotvyno Depressions, which are separated by the Oash deep fault (Fig. 3).

Petromagnetic characteristics of volcanic formations. Among the effusive formations of the TD, two volcanogenic formations are the most widespread: liparite-dacite with acidic composition and andesite-basalt with a medium-basic one.

According to the type of cover, volcanogenic formations are divided into subsequence and arc formations. Determination of the absolute age showed [Prykhodko, Ponomaryova, 2018] that acid volcanism (15.0—11.0 million years) preceded medium-basic volcanism (12.0—7.5 million years).

The main volcanic units of acidic magma are concentrated on the boundary of the TD with the Pannonian Middle Massif. Rocks are represented by ignimbrite-ash formations and acidic tuffs spreading over almost the entire territory of the depression. They form stratified horizons of varying thickness among chemogenic sedimentary rocks that filled numerous, often isolated basins of the eastern Paratethys in the Miocene. Formations of this type are attributed [Lazarenko et al., 1963; Lazarenko, 1969] to the initial stage of orogenesis and are synchronous for the entire region.

The earliest phases of acidic volcanism of the TD are attributed to the subsequence [Shtille, 1964] explosive type of fissure effusions. They are common in the zone of the Pre-Pannonian deep fault, which is traced along the Chop—Berehove—Baya Mare line by the uplift of the foundation. Volcanites form powerful effusive-pyroclastic strata composed of the liparit-dacite formation rocks, which are developed throughout the territory of the TD and correspond to the initial stage of orogenic volcanism.

Among the acidic volcanics, several phases can be distinguished, ranging in age from the Helvetian—Early Tortonian to the Middle Sarmatian. Liparit tuffs of the Novoselych suite are considered to be the oldest. Various volcanogenic formations of plagioliparitic and liparit-dacite composition of the early Sarmatian age are associated with the last phases of subsequence volcanism. These formations are well exposed within the Berehove area and consist of ignimbrite-ash formations and extrusive domes with short lava flows and belong to the Dorobratove Suite of Lower Sarmatian.

During decay time of volcanic activity of subsequential type and activation of block movements, plagioliparites domes (Mountain Ardov, Mountain Zolotista) were squeezed out within the boundaries of the Kosyno and Berehove regions which are connected to the already existing eruption paths of ignimbrite flows. Flows of liparites overlap with deposits of the Lukiv suite, within which acidic tuffs are known. Liparite tuffs are also known as part of the Almash Suite of the Middle Sarmatian period. The period of attenuation of subsequent volcanism is attributed to the Middle Sarmatian—Pliocene. The centers of eruptions are localized within the horst ring mapped around the middle Pannonian Massif (Chop—Berehove—Baya Mare structural-facies zone).

The rocks of the liparit formation form several raises within the Berehove Hills: Ko-

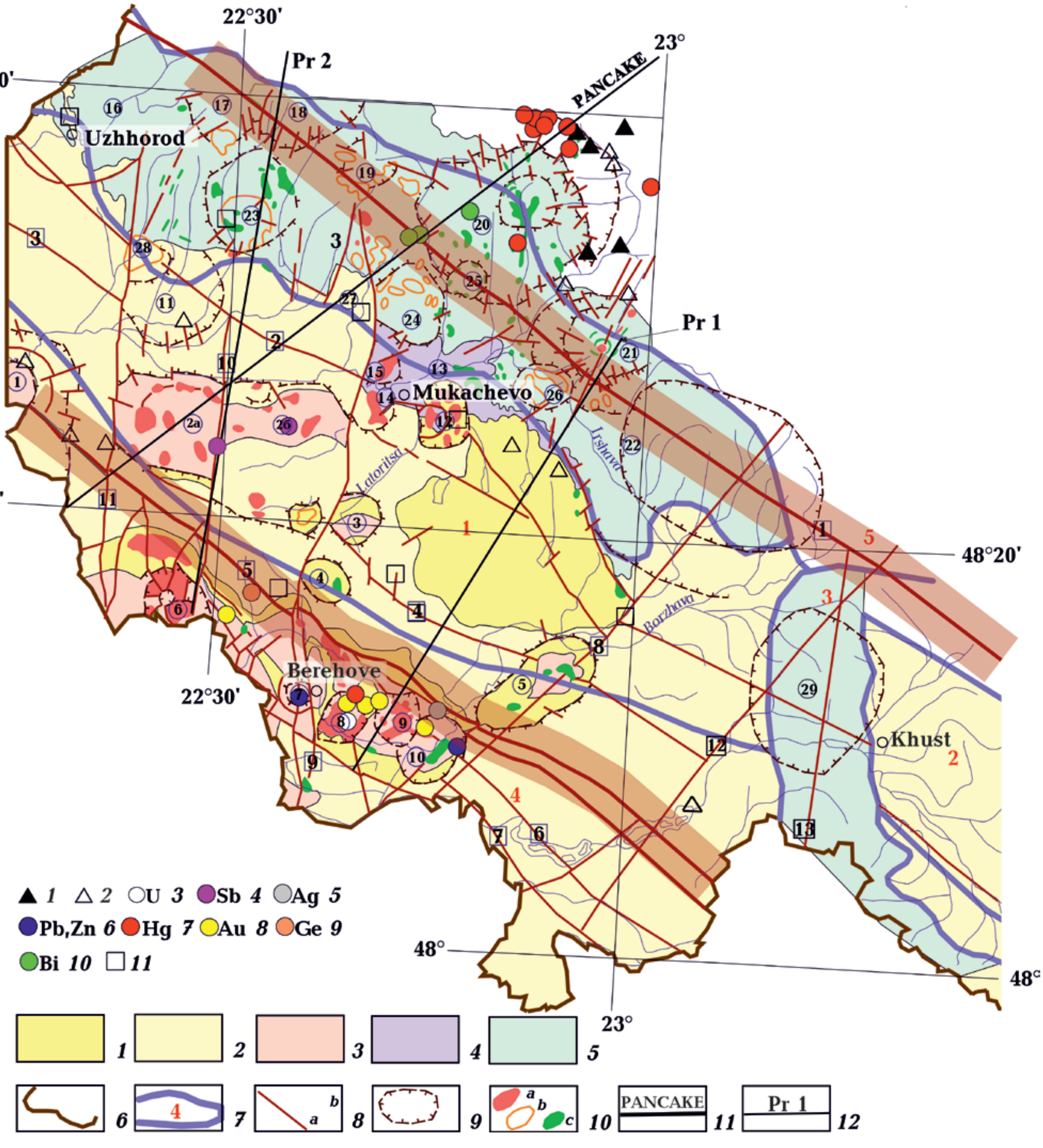

Fig. 3. Tectonic scheme of the Transcarpathian internal depression (using [Prykhodko et al., 1985; Matskiv et al., 1996]). Sedimentary complex: *1* — Sarmatian, *2* — Pannonian-Pliocene; *3—5 — Volcanogenic complexes include volcanic structures (numbers in circles)*: *3* — ***Sarmatian***: 1 — Chop, 2 — Velyka Dobron' (2a — Barkasove volcano, 2b — Goronda volcano), 3 — Drysyn, 4 — Chikosh-Goronda, 5 — Shalanky, 6 — Kosyno, 7 — Bucha, 8 — Zolotista, 9 — Kvasovo, 10 — Kalimen; *4* — ***Panon-Pontic***: 11 — Geyivtsi, 12 — Zhukivka (buried), 13 — Kuchava, 14 — Palanka, 15 — Lovachka; *5* — ***Dacian-Romanian***: 16 — Poprichnyi, 17 — Antalovets'ka 18 — Makovytsia, 19 — Khotar, 20 — Syniak, 21 — Dekhmaniv, 22 — Martynsky Kamin', 23 — Ostra, 24 — Zhornyna, 25 — Shkitena, 26 — Dilok , 27 — of Verkhnyi Koropets, 28 — Putka, 29 — Velykyi Sholles; *6* — border of Ukraine; *7* — *tectonic structures (numbers in rectangles in red)*: 1 — Chop-Mukachevo Basin, 2 — Solotvyno Basin, 3 — Vyhorlat-Gutyn Volcanic Ridge, 4 — Berehove Uplift Zone, 5 — Flysch Carpathians; *8a* — *main faults (numbers in squares)*: 1 — Transcarpathia, 2 — Gazhyn-Mukachevo, 3 — Stretava—Geyivtsi, 4 — of Remety, 5 — of Pre-Pannonia Ivanivtsy, 6 — Kalimen, 7 — of Gecha, 8 — of Irshava, 9 — of Mukachevo, 10 — of Rafainovo-VelykiLuchky, 11 — Gashpar, 12 — of Vynogradiv, 13 — of Oashand fault zones; *8b* — zones of faults; *9* — boundaries of volcanic structures; *10* — subintrusive, subvolcanic bodies, dykes of acidic (*a*), moderately acidic composition (*b*); medium-main composition (*c*); *11* — seismic profile of PANCAKE DSS; *12* — interpretive profiles. Mineral deposits and manifestations (filled and empty triangles, circles and squares): 1 — oil, 2 — gas, 3 — uranium, 4 — antimony, 5 — silver, 6 — lead, zinc, 7 — mercury, 8 — gold, 9 — germanium, 10 — bismuth, 11 — brown coal.

synske and Zastavnynske in the northwest; in the northeast — Ardov, Chepka, and Sharok domes. A large massif of liparites is known in the southeast of the district: Hayesh, Barna, and Pelikan Mountains. All liparites [Mikhaylova et al., 1974] are similar in composition. Rocks contain 70—75 % of SiO_2 and belong to liparites with some approximation to liparit-dacites. All varieties of rocks are almost of the same age and belong to the youngest formations of the Dorobratove Suite of the Lower Sarmatian. At the same time, according to paleomagnetic studies [Maleev, 1964], the East-Berehove liparites have normal magnetization (N), the West-Berehove and Kosin-Zastavne rocks are reversely magnetized (R). This fact should be interpreted as a non-synchronous formation of the western and eastern parts of the Berehove Uplift. According to [State...., 2003], these liparites belong to the Barkasove Sarmatian complex.

The most characteristic feature of medium-basic volcanism is the differentiation of source melts in peripheral foci or intermediate chambers, due to which the comagmatic series of basalt-liparite arose. They are represented in stratovolcanoes, monovolcanoes, domes and cinder cones. The rocks of the formation form two volcanic arcs: the northern one, known as the Vyhorlat-Gutyn Ridge (VGR) and the southern one, a chain of buried volcanoes in the middle and central parts of the TD [Lazarenko et al., 1963; Lazarenko, 1969 etc.].

The volcanic formations of the buried arc correspond to the characteristic features of the rocks of the andesite formation. Territorial convergence of volcanic mechanisms of andesite and liparite formations is observed within the Berehove Uplift. The structures are represented by the remains of eroded andesite volcanoes with thick horizons of coarse-clastic pyroclasts and lavas of the main and medium composition, domes of dacites and liparites, which according to [Maleev, 1964; Mikhaylova et al., 1974] belong to the Mukachevo suite. In the near border part of the Chop-Mukachevo Depression, lavas and tuffs are interlayered with sedimentary formations of the Ilnytsia Suite. The rocks form a single differentiated ridge, associated with a single magmatic source and the Uzhgorod-Mukachevo-Khustdeep fault, in connection with which they are classified as rocks of a single volcanic phase [Mikhaylova et al., 1974], whose outcrops are known within the Chop-Mukachevo Depression and Berehove Uplift. According to andesite-basalt and andesite stratovolcanoes are of late Tortonian—Early Sarmatian age (Chop, Goronda, Berehove block area), and dacites and andesite-dacites of the Velyka Dobron' area were formed in late Pannonian time. The destroyed lava-pyroclastic cones and monogenean volcanoes of the central and eastern parts of the buried ridge are late Pannonian-Levantine in age. According to [Mikhaylova et al., 1974], most of the studied rocks of the central part of the Chop-Mukachevo Depression (andesite-basalts (bores 252, 254)) and the town of Shalanky, two-pyroxene andesites of the monovolcano Drysyn Hill, dacites of Black Mountain and its northern slope have a normal (N) magnetization.

VGR is the largest volcanic structure of the andesite-basalt formation in the studied region. In its structure, three effusive-pyroclastic strata are distinguished [Mikhaylova et al., 1974]: Mukachevo, Gutyn and Buzhora, which correspond to the eruption products of various phases of Pliocene volcanism (Table). To the volcanogenic formations of the western part of the VGR are attributed the structures of the mountain ridge Poprichnyi on the right bank of the Uzh River and the large volcanic centers: of Antalovtsi, Makovytsia and Syniak between the Uzh and Latoritsa rivers. Volcanic formations are part of all three suites — Mukachevo, Gutyn and Buzhora, as well as there are the products of volcanism of an older phase, which is overlain by younger formations in most of the territory. According to paleomagnetic studies [Mikhaylova et al., 1974], most of rocks of all three complexes are characterized by normal (N) magnetization. At the same time, the largest number of outcrops with anomalous direction of vectors of natural residual magnetization (I_n) is found in this area. Anomalously magnetized rocks are characteristic of apical outcrops and exposed rock slopes and are probably remagnetized in the powerful electromagnetic fields of lightning discharges.

Large morphostructures of Borilov Dil and Velykyi Dil Mountains with the volcanoes Dekhmaniv, Buzhora etc., which actually belong to the VGR, as well as Gat and Dilok Ridges on the left bank of the Latoritsa River (Mukachevo district) can be distinguished in the confluence of the Latoritsa and Borzhava rivers. Normally (N) and reversely (R) magnetized rocks are present on the left bank of the Latoritsa River. R-rocks include dacites, andesite-basalts and their tuffs. N-rocks are represented by lava flows of andesite-basalts and andesites belonging to the Ilnytsia suite. Volcanites forming natural outcrops of the Borilov Dil Mountains with the tops of the Gombushka and Dekhmaniv Ridge are normally magnetized. The basalts from these peaks have the NR direction of magnetization, which may indicate remagnetization of the rocks of the western part of the VGR. Volcanogenic formations of Buzhora and Syniak are represented by andesite-basalts, coarse porphyry andesite-basalts, tuffs and lava breccias and are normally (N) magnetized rocks.

The southeastern part of the VGR is composed of andesite-basalt volcanism products of the VelykyiSholles and Oash ridges, which are separated from the northwestern part of the VGR by the regional Borzhavsky Fault. Andesit-basalts, liparites, dacites, and basalts were studied within the Velykyi Sholles ridge in sections crossing all complexes and suites of the ridge. The rocks are normally magnetized (N). They are characterized by a close direction of the I_n vectors, which almost coincides with the direction of the modern geomagnetic field vector within the region.

Within the Oash ridge, andesite-basalt magma differentials, regardless of their petrographic composition, are normally magnetized as in the Velykyi Sholles Ridge.

Hypabyssal intrusive formations of the Vyshkiv ore field and exposure of granodiorite-porphyries of the Oash Ridge are represented by varieties of gabbro-diabases, gabbro-porphyrites, diorite-porphyrites, quartz diorite-porphyrites, etc. All intrusive formations are normally magnetized. Most of them are characterized by high accuracy of I_n vectors, that concentrated close to the direction of modern geomagnetic field.

Thus, normally and reversely magnetized rocks of different petrographic composition and age were singled out in the section of the volcanogenic stratum. R-rocks are developed in the northeastern section of the VGR, where they make up the lower part of the section and within the Berehove-Baya Mare horst-anticline zone. Normally magnetized rocks occupy the southeastern part of the ridge, form the upper horizons of its section in the northwest of the Poprichnyi ridge, Antalovtsi and Makovytsia mountains, as well as in the Pelikan and Hayesh domes of the eastern margins of the Berehove Hills. Normally magnetized rocks are characterized by a cluster of vectors in north rhumbs with an average inclination hovering around 360° and an inclination close to 60°. This corresponds to the coordinates of the direction of the modern geomagnetic field within the research area (D=2° and I=62°). At the same time, in isolated outcrops of the lower effusive stratum, a decrease in the inclination angles to 40°—45° is noted, in the Syniak massif and within the Vyshkovo ore field, the most typical inclination angles are 70°—75°.

T a b l e . Magnetic characteristics of effusive formations of the Transcarpathian Depression

Rock type	Number of samples	Polarity	$I_{n\,\text{min–max/aver}}$, A/m	$X_{\text{min–max/aver}}$, 10^{-5} SI	$Q_{n\,\text{min–max/aver}}$
Velykyi Sholles Ridge					
Liparite lava breccia	8	N	1,3	400	9,86
Liparite	19	N	0,3–3,7 / 2	661–2350 / 1505	1,1–9,99 / 5,54

Rock type	Number of samples	Polarity	$I_{n\,\text{min–max/aver}}$, A/m	$X_{\text{min–max/aver}}$, 10^{-5} SI	$Q_{n\,\text{min–max/aver}}$
Dacite	18	N	0,75–1,3 / 1,025	398–2136 / 1267	1,54–5 / 3,27
Andesite-dacite	25	N	0,33–0,94 / 0,635	1228–1838 / 1533	1,3–1,98 / 1,64
Andesite	43	N	0,63–1,3 / 0,965	1212–2445 / 1829	0,96–3,27 / 2,11
Andesite-basalt	71	N	0,4–1,9 / 1,15	1650–2471 / 2061	0,42–2,07 / 1,24
Basalt	20	N	1,2–1,7 / 1,45	2040–2297 / 2169	1,33–2,24 / 1,78
Oash Ridge					
Andesite-basalt	10	N	0,35–2,4 / 1,375	1267–2907 / 2087	0,37–4,08 / 2,22
Basalt	57	N	0,5–2,7 / 1,6	950–3860 / 2405	0,4–6,38 / 3,39
Andesite	19	N	0,17–0,6 / 0,385	80–1276 / 678	0,34–2,15 / 1,24
Andesite-dacite	17	N	0,2–9,5 / 4,85	568–3102 / 1835	0,93–9 / 4,96
Andesite Two-pyroxene	26	N	0,7–1,9 / 1,3	1671–1732 / 1702	1,19–3,2 / 2,19
Dacite	14	N	0,5	1278	1,19
Liparite-dacite	37	N	0,1–5,3 / 2,7	328–1365 / 847	0,61–11,3 / 5,9
Poprichnyi Ridge					
Hypersthene andesite-basalt	13	R	0,4–1,9 / 1,15	958–1273 / 1116	0,98–6,12 / 1,47
Andesite	20	N	0,6	216	8,6
Dacite	14	R	0,02	19	1,91
Dacite	9	N	0,3	1428	0,61
Liparite	9	R	0,08	157	1,58
Liparite	9	A	0,03	45	1,65
Liparite-dacite	17	N	0,09	850	0,32
Syniak Ridge					
Two-pyroxene andesite-basalt	30	N	0,1–1,9 / 1	303–2212 / 1258	0,41–20,5 / 10,4
Liparite	19	N	2,4	450	12,7
Hypersthene andesite-basalt	11	N	0,9	975	2,8
Two-pyroxene andesite	66	N	0,11–1,6 / 0,86	230–866 / 548	0,84–12,1 / 6,47
Hypersthene Andesite	53	N	0,26–1,05 / 0,65	995–2001 / 1498	0,84–1,64 / 1,24
Plyshka Mountain					
Two-pyroxene andesite-basalt	68	N	0,1–37,5 / 18,8	230–4375 / 2303	1,16–40,2 / 20,7
Martynsky Kamin' Mountain					
Two-pyroxene andesite	81	N	1,2–59,8 / 30,5	614–4801 / 2707	4,5–304 / 154,3

Rock type	Number of samples	Polarity	$I_{n\,\text{min–max/aver}}$, A/m	$X_{\text{min–max/aver}}$, 10^{-5} SI	$Q_{n\,\text{min–max/aver}}$
Strypa Mountain					
Two-pyroxene andesite-basalt	29	R	0,4–1,2 / 0,8	566–1113 / 840	0,5–3,9 / 2,2
Antalovtsi Mountain					
Hypersthene andesite-basalt	16	N	68,7	5700	40
Hypersthene andesite-basalt	37	R	0,2–31,3 / 15,75	307–2200 / 1254	0,34–28,2 / 14,27
Hypersthene andesite	19	R	0,12–2,45 / 1,29	675–1305 / 990	0,62–9,55 / 5,08
Two-pyroxene andesite	21	N	0,05–0,3 / 0,175	485–532 / 508	0,36–5,3 / 2,83
Two-pyroxene andesite	9	R	0,3	470	1,91
Two-pyroxene andesite-basalt	19	R	0,2–0,26 / 0,23	342	2,28
Two-pyroxene andesite-basalt	22	N	1,9–3,8 / 2,85	303–826 / 565	15,6–20,5 / 18
Dacite	28	R	4,7–10,1 / 7,4	725–1883 / 1304	16,4–21,7 / 19
Makovytsia Mountain					
Two-pyroxene andesite-basalt	18	N	0,2–0,6 / 0,4	372–1830 / 1101	0,3–2,84 / 1,57
Hypersthene andesite-basalt	8	R	1,69	1558	3,4
Two-pyroxene andesite	11	R	0,73	691	6,97
Two-pyroxene andesite	37	N	0,4–8,5 / 4,45	432–1062 / 747	1,22–81,4 / 41,31
Buzhora Mountain					
Olivine Andesite-basalt	28	N	0,5	757	2,07
Basalt	213	N	0,35–1,69 / 1,02	478–2800 / 1639	1,16–5,85 / 3,5
Andesite-basalt	17	N	0,4	830	1,5
Coarse porphyry andesite	10	N	0,6	427	4,75
Borilov Dil Ridge					
Two-pyroxene andesite-basalt	71	N	0,08–3,4 / 1,74	82–2325 / 1203	1,3–13,5 / 7,4
Gat Ridge					
Two-pyroxene andesite-basalt	90	N	0,3–1,88 / 1,09	512–1762 / 1137	0,7–15 / 7,85
Coarse porphyry andesite-basalt	43	N	0,3–46,2 / 23,3	598–2466 / 1532	0,67–56 / 28,33
Berehove Hills					
Liparite	252	R	0,3–25,2 / 12,75	40–2673 / 1357	8,8–59,4 / 34,1

Rock type	Number of samples	Polarity	$I_{n\,\mathrm{min-max/aver}}$, A/m	$X_{\mathrm{min-max/aver}}$, 10^{-5} SI	$Q_{n\,\mathrm{min-max/aver}}$
Liparite	34	N	0,02–0,06 / 0,04	428	0,49–10 / 5,24
Shalanka Mountain					
Andesite	4	N	0,9	6062	0,4
Andesite-basalt	31	N	0,5–3,1 / 1,8	978–2371 / 1675	1,14–9,3 / 5,22
Chorna Mountain					
Andesite	25	N	0,36–2,5 / 1,43	1050–1333 / 1192	0,58–1,52 / 1,05
Andesite-basalt	17	N	0,5–1,1 / 0,8	1202–1288 / 1245	1,01–2,57 / 1,79
Basalt	82	N	0,4–1,1 / 0,75	1265–1770 / 1898	0,65–1,37 / 1
Dacite	45	N	0,2–0,9 / 0,55	908–2578 / 1743	0,56–1,7 / 1,13

The considered petrographic types of rocks (see Table 1) are present within all structural units of the region.

Geomagnetic field. Regional and local components can be distinguished in the composition of the geomagnetic field of the Transcarpathian Depression. The separation of the geomagnetic field for western Ukraine (according to a digital map of 1:500 000) is generally presented in the works [Orlyuk et al., 2021, 2022a,c] (Fig. 4).

As it shown in Fig. 4, the regional magnetic field is characterized by an insignificant intensity, up to 85 nT at the maximum where the volcano-tectonic structures of Zolotista, Kvasovo and Kalimen are located. The anomaly is slightly elongated in the north-northeast direction. In the northwest, the zero isoline of the anomaly has a sublatitudinal extension, and in the southeast, near the city of Khust, it has a submeridional extension. From a tectonic point of view, it is territorially refered to the Chop-Mukachevo Depression, partially covering part of the Vyhorlat-Gutyn Ridge in the north and east and the Berehove Hills in the south. The Solotvyno Depression is outside the boundaries of the regional anomaly.

The local magnetic field of the upper part of the crust (ΔB)$_{\mathbf{a,loc}}$, according to the technology of its acquisition, reflects the magnetic heterogeneity of the upper 2—4 km of the section of the Earth's crust.

A notable feature of the magnetic field is the concentration of elongated and oval-shaped magnetic anomalies within ring structures that correspond to the volcanic massifs of the same name. The intensity of magnetic anomalies within the Vyhorlat-Gutyn Ridge is 50—550 nT, the parallel Berehove Uplift is 50—300 nT, and in the area of the Velyka Dobron' Uplift it is 50—170 nT. Magnetic anomalies are localized along radial and arc ring faults of volcanic structures, more often distant from the edge of volcanoes (Syniak, Dekhmaniv and Martynsky Kamin' structure), or form its lateral part, less often above the central craters (Antalovtsi, Makovytskyi). Most volcanogenic structures and their individual elements are characterized by positive magnetic anomalies and associated minima. It should be noted that there are also negative anomalies that are probably of an independent nature (Geyivtsi, Putka, Makovytsia, Khotar).

Three-dimensional magnetic model. According to geological and petromagnetic studies, magnetic andesites and andesite-basalts are observed within the depression [Glevasskaya, 1983; State..., 2003]. The foundation of the Transcarpathian Depression consists of Paleozoic, Triassic and Jurassic metamorphic shales, upper Cretaceous marls and mudstones with sandstones and Paleogene sand-clay formations [Vyalov et al., 1965; Cheku-

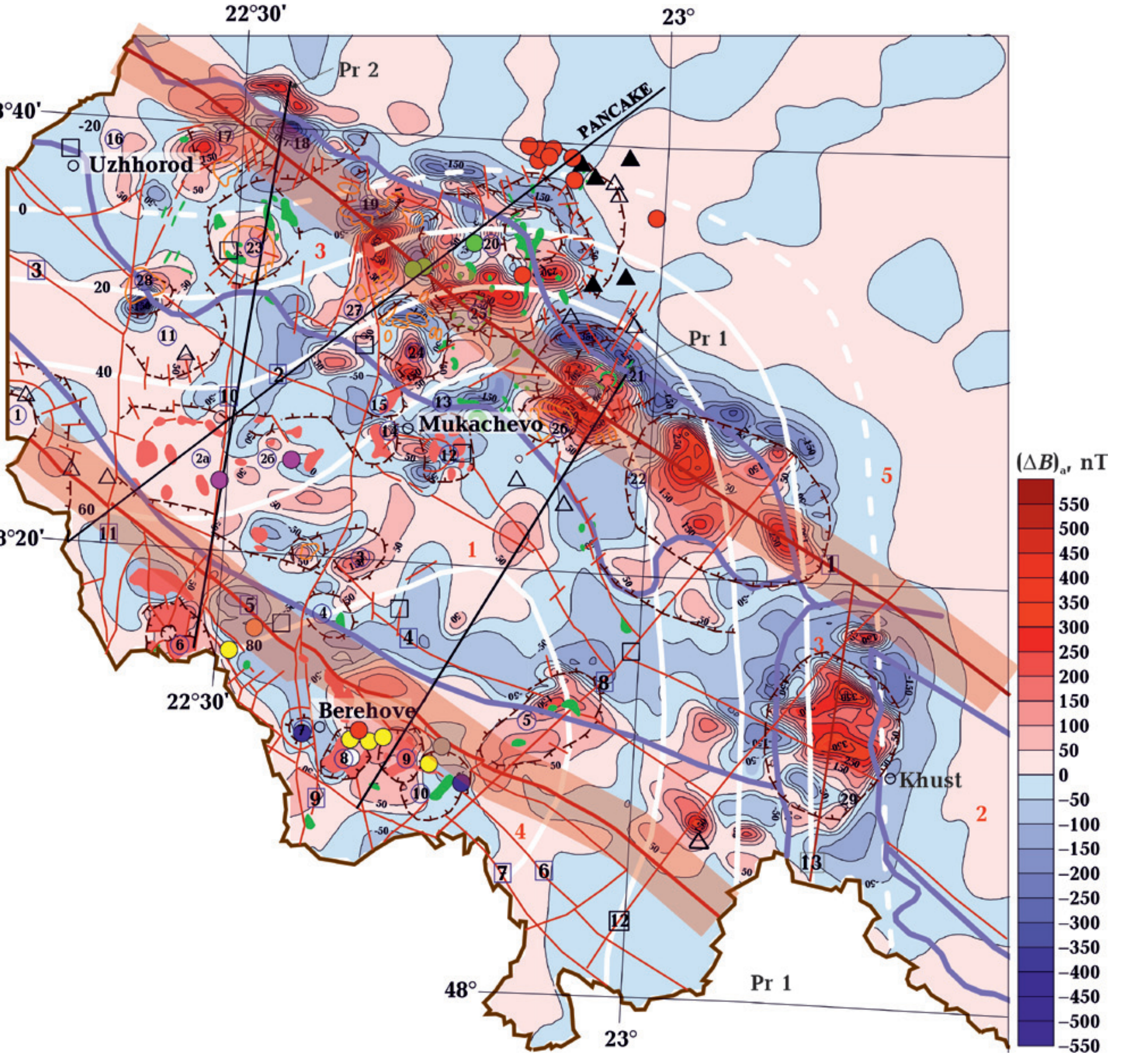

Fig. 4. Map of the regional $(\Delta B)_{a,reg}$ (white lines, dashed — zero) and local geomagnetic field of Transcarpathia in comparison with deposits and manifestations of hydrocarbon and metallic minerals. For the legend, see Fig. 1.

nov et al., 1969; State..., 2003; Prykhodko et al., 2019]. According to the geological sections of the upper part of the Earth's crust of Depression and to the interpretation of magnetic anomalies, their sources can be located at depths from the first meters to 3—3.5 km for the VGR regions and selectively the Berehove Uplift, in the Chop-Mukachevo and Solotvyno Depressions from the first hundreds of meters to 2—3 km.

The created magnetic model of the Transcarpathian Depression reflects the regional and local sources of the geomagnetic field (Fig. 5).

The regional class magnetic source is located at depths from 6.0 to 13 km and has a magnetization of 1.0 A/m (see Fig. 5, 6). In the section along the PANCAKE geotransect, the magnetic source is of trapezium-shape, the northeastern edge of which roughly coincides with the Transcarpathian Fault (see Fig. 2). In the southwest, the source goes beyond the territory of Ukraine. According to the model, the position of the upper margin of the northeastern edge of the source is in the zone of the Transcarpathian Fault starting from the point of intersection of the Transcarpathian and Irshava Faults, the eastern contact has a meridional extension (see Fig. 5). In the west and northwest, the contact of the body has a sublatitudinal strike, and within the intersection with the meridional Rafainovka-Velyki

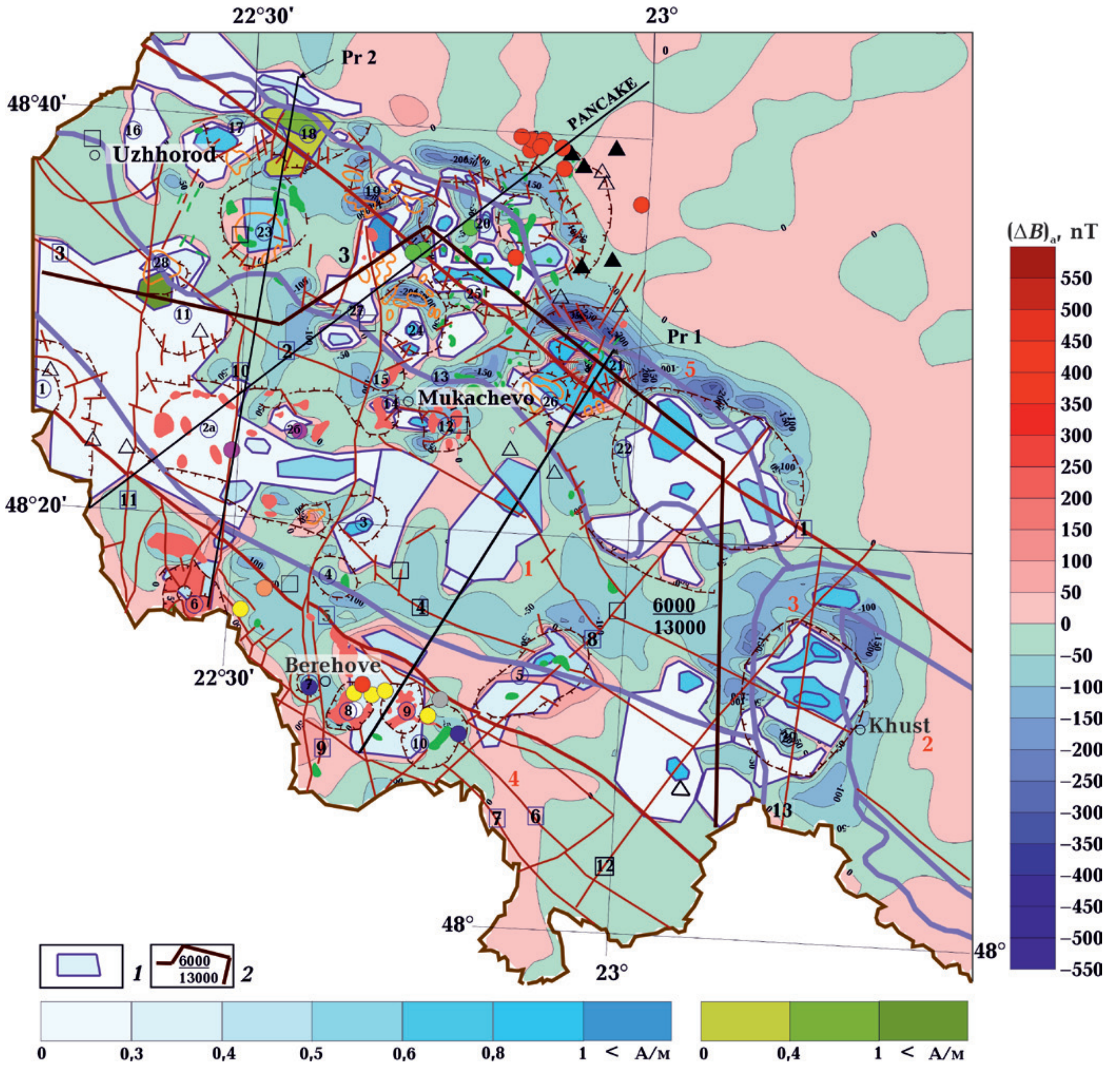

Fig. 5. Magnetic model of the Transcarpathian Depression. The first scale: magnetic sources were formed in the era of normal polarity, the second one — in the era of reverse polarity: *1* — projection on the daytime surface of magnetic sources of the uppermost part of the Earth's crust, *2* — projection on the daytime surface of a deep magnetic source. For other conventional signs, see Fig. 1.

Luchky Fault a northeast strike, according to the strike of the PANCAKE profile. Note that the position of the lateral limits of the magnetic source, according to the accuracy of the model construction, can vary laterally within 5—10 km, and should be taken into account when compiling a regional complex geological and geophysical model.

A magnetic model of the upper part of the section of the Earth's crust was created in more detail. To create it 68 sources of arbitrary shape were used, the horizontal distribution were shown by projections on the day surface (see Fig. 5), and the deep one — on sections along profiles 1 and 2 (see Fig. 6).

Magnetic sources with depths ranging from 200 to 1000 m and magnetization values of 0.4 A/m are localized within the Berehove Uplift in the zone of influence of the meridional Gashparsky Fault (Koson' structure). According to drilling data [State..., 2003], a thick layer (900—1100 m) of liparitic tuffs and

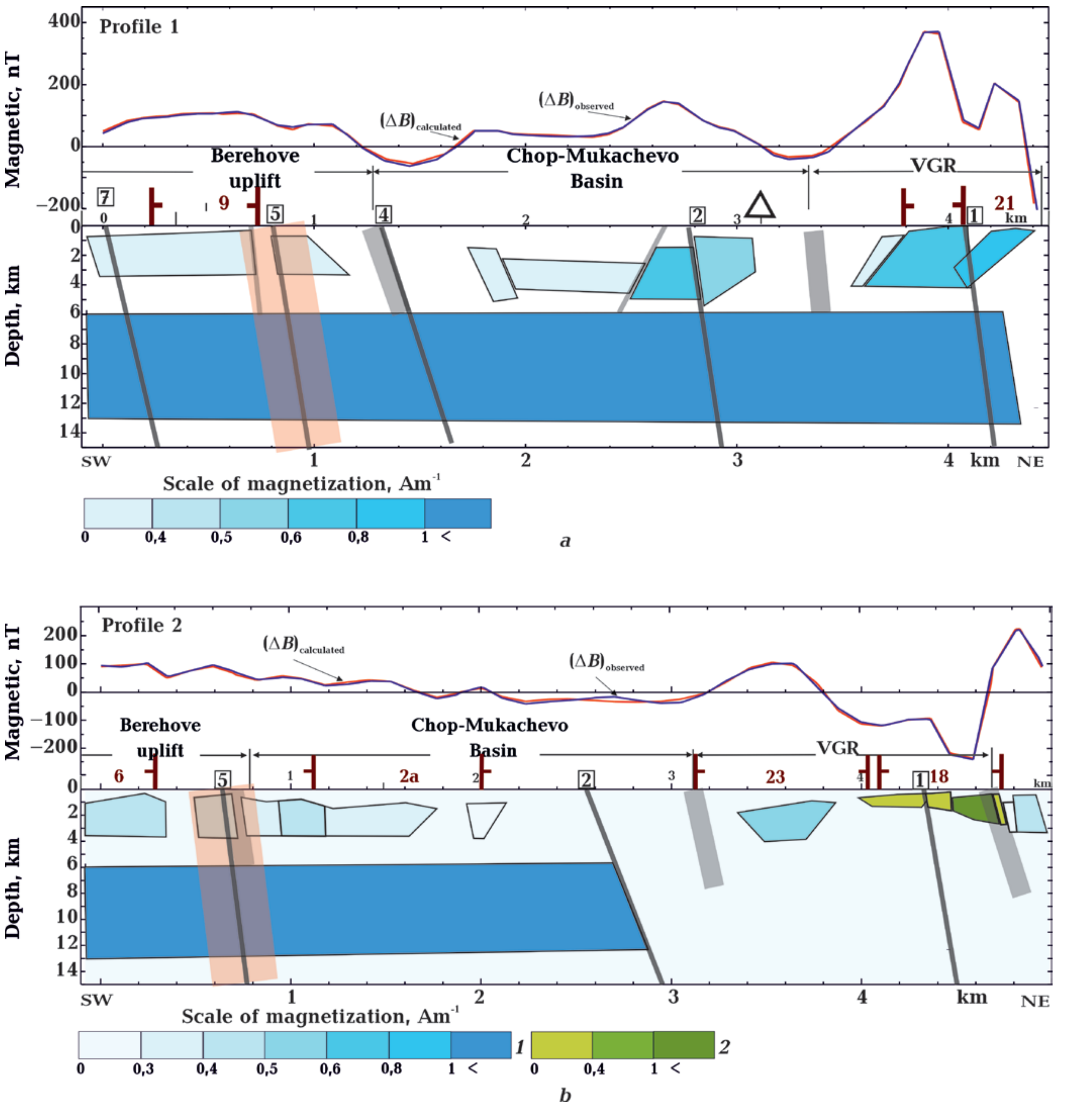

Fig. 6. Magnetic models along profiles 1(*a*) and 2(*b*). The models show one deep and several local sources, structural elements of the Transcarpathian Depression, faults and fault zones (numbers in rectangles), volcano-tectonic structures (numbers in circles) within profiles 1 and 2 shows the regional source (see Fig. 2), which lies in the depth range of 6—13 km and has a magnetization of 1 A/m.

xenotuffs with layers of terrigenous rocks is recorded in the lower part of the structures. The upper part of the Kvasovo and Kalimen calderas is composed of andesites and dacites.

In the magnetic field, they are distinguished by weakly magnetic anomalies (50—140 nT) of meridional extension with compression in the zone of influence of the Pre-Pannonian Fault. In the magnetic model, there are two sources that located in the depth interval of 500—3000 m and have a magnetization of 0.34—0.5 A/m.

The magnetic model of the area of the Shalanky caldera is manifested in the field by a northeast trending anomaly (with an intensity of 100—240 nT), according to the extension of the Irshava Fault, consists of three sources with depths of the upper edge of 10 m and the lower one of 1500 m. The source's magnetization in the southern part of anomaly is 0.36 A/m. In the north, the magnetic bodies are located in the zone of intersection of the Irshava and Remety Faults and have magnetizations of 0.44 and 0.6 A/m (see Fig. 5).

In the eastern part of the Chop-Mukachevo Depression, in the zone of influence of the Vynogradiv Fault, a northeast-trending anomaly stands out. Magnetic sources (3 sources) are located in the depth interval of 200—2000 m. The «background» source has a magnetization of 0.26 A/m, and the sources of the northern and southern parts have magnetizations of –0.69 and –0.93 A/m, respectively.

According to [State..., 2003], a layer of andesites, andesitic basalts and their tuffs with varying composition from leucocratic andesites (andesite-dacites) to almost basalts is recorded within the Velyka Dobron' Uplift at depths from 100—200 to 700—1100 m. In the magnetic field, the entire uplift zone is distinguished by a weak positive anomaly of mostly latitudinal extension. Eight sources are involved in the model. The «background» source has a magnetization of 0.16 A/m. In the central part of the uplift, two latitudinal bodies with magnetization values of 0.38 and 0.5 A/m are recorded (see Fig. 5, 6, *a*). Behind the Mukachevo Fault, the anomaly changes its extension from latitudinal to meridional. The magnetic sources corresponding to this anomaly have a magnetization of 0.37—0.7 A/m.

The volcanic structures of Syniak, Dekhmaniv, Khotar, Martynsky Kamin' and Dilok are represented by andesites, andesite-basalts and tuffs. Rocks do not go beyond caldera faults. In the magnetic field, the structures correspond to positive anomalies are concentrated within ring faults. All magnetic sources are in the depth interval from 10 to 3000—3500 m.

The Khotar volcanic structure in the northeast and in the south in the magnetic field corresponds to positive anomalies with an intensity of 180 and 50—500 nT, respectively. In the magnetic model, three sources are distinguished, their magnetization are 0.2, 0.34 and 1.04 A/m, respectively.

A number of anomalies with an intensity of 50—310 nT can be observed within the Syniak volcano, which clearly form a ring structure. The model uses ten magnetic sources with magnetization of 0.33—0.67 A/m.

Dekhmaniv and Dilok volcanoes form a complex ring structure, which in the magnetic field corresponds to three local maximums of the field. The anomaly in the south-southwest part has an intensity of 380 nT, in the north — 360 nT, and in the northeast — 260 nT. According to the model, these anomalies are caused by five bodies with a magnetization of 0.26—0.84 A/m.

The large ring structure of the Martynsky Kamin' is located in the zone of influence of the Transcarpathian and Irshava deep faults. Along the Transcarpathian Fault, local magnetic maxima with an intensity of 360 nT (west) and 320 nT (east) are distinguished, to which correspond the magnetic sources with magnetizations of 0.69 and 0.59 A/m, taking into account the background source –0.17 A/m. Magnetic sources with magnetization of 0.41 and 0.63 A/m explain the anomalies in the northern (170 nT) and southern (280 nT) parts of the structure.

In the «turn» zone of the VGR, the Velykyi Sholles volcanic structure is manifested by a positive magnetic anomaly of an almost isometric shape, with maxima of 200—390 nT. The magnetic model includes five bodies with depths ranging from 15 to 3000 m and having magnetization of 0.31—1.22 A/m.

Discussion. According to the geomagnetic field analysis and the modeling results, the Transcarpathian Depression is quite differentiated magnetically. First of all, it should be noted that the obtained regional magnetic anomaly and, accordingly, its deep source do not coincide with the Transcarpathian Depression in general, but are located only within the Chop-Mukachevo Depression. Only in the northeast, the contact of the magnetic body coincides with the Transcarpathian Fault, i.e., it has the Carpathian direction of extension. In the west, north-west and in the east, the contacts have an inconsistent position with the depression. This may indicate that the magnetic source itself reflects the heterogeneity of the Earth's crust, which was formed at the pre-Carpathian stage of its development, and the north-eastern contact of the magnetic source has a tectonic nature, which is related to the current seismicity of the Transcarpathian Fault [Maksymchuk et al., 2014]. Another possible interpretation is that the magnetic source is a slab of the local Pennin paleo-subduction zone [Generalova, Pyrizhok, 2021], the remnant of which is currently a suture zone. It is located on the border of the structures of the Outer and Inner Carpathians and is manifested as a compression zone in modern movements of the Earth's surface [Tretyak, Brusak, 2022]. Another important regularity can be considered the correspondence of the majority of local anomalies, which reflect volcano-tectonic structures, to the marginal parts of the regional magnetic anomaly. This is especially clearly visible on the example of magnetic anomalies of the VGR (Pennin zone) in the northeast and east of the region.

Taking into account the results of magnetic modeling, local sources have insignificant depths of the lower edge (the first kilometers up to a maximum of 5 km) and magnetization values (up to 1.0 A/m) of normal and reverse polarity. According to the above data, magnetic sources within the VGR at almost the same depths of occurrence differ significantly by their magnetic properties. Magnetic susceptibility is closely related to the amount of ferromagnetic minerals. It depends not so much on the iron content of the rock as on its distribution between silicates and oxides, on the ratio between ferrous and ferric oxide, and on the composition of ferromagnetic minerals. All these factors are closely related to the thermodynamic regime of the magnetic focus and the lava eruption conditions. These factors should be the subject of serious study.

Magnetic and mineralogical analysis confirmed the presence of paleomagnetic horizons of normal, reversed and intermediate polarity and also magnetic field inversions for the volcanic structures of the Transcarpathian Depression [Glevasskaya, 1983]. The heterogeneous structure of the Vyhorlat-Gutyn Ridge and the Berehove Uplift is shown. Both structures were formed during large epochs of geomagnetic polarity: the Uzhhorod reverse (15.2—12.3 million years) and the Transcarpathian normal (12.3—9.0 million years).

According to the results of the three-dimensional modeling, the volcano-tectonic structures of the Vyhorlat-Gutyn Ridge (Antalovtsi, Poprichnyi, Syniak, Dekhmaniv, Khotar, Martynsky Kamin', Dilok, Velykyi Sholles) are reflected in the magnetic model. The magnetization of the sources varies within J=0.17÷1.22 A/m, and the depth of their distribution is from the surface to the first tens or hundreds of meters up to 3000—3500 m.

In the area of the Chop-Berehove Uplift, there are magnetic sources with magnetization from J=0.26÷0.93 A/m and with a depth interval from 200—500 to 2000—3000 m, associated with Shalanky, Koson', Bucha, Zolotista, Kvasovo and Kalimen volcanic structures.

Geyivtsi, Zhukivska (buried), Kuchava, Palanka and Lovachka structures of the Velyka Dobron' Uplift are reflected by sources with lower magnetization J=0.16÷0.7 A/m and a depth interval from 100—200 to 700—1100 m.

In the magnetic model, there are also sources with reversed magnetization. They are inherent in the volcanic structure of Makovytsia and in the structures of the Velyka Dobron' Uplift.

In this regard, based on the results of magnetic modeling of the local geomagnetic field, sources formed in epochs of different polarity can be singled out. In Fig. 5, magnetic sources with vectors of normal and reversely magnetized rocks are depicted in different colors.

The calculated values of source magnetization based on the results of 3D-modeling are close to, or slightly smaller than, those obtained from experimental data for the rocks of the Transcarpathian Depression [Glevasskaya, 1983]. This is explained by the fact that when calculating the parameters of magnetic modeling, we use the weighted average value of magnetization for a layer of magnetic sources, and the experimental measurements refer to individual rock samples from outcrops and quarries.

Finally, let's briefly deal with questions of the possible connection with the magnetization of regional and local structures of the Earth's crust based on modeling with the distribution of several types of fossil minerals.

In this regard, it is worth noting that two small gas fields of Transcarpathia are located within the contour of the regional magnetic source. Directly in the upper part of the Earth's crust section they are confined to weakly magnetic and magnetic sources. The oil fields spread to the northeast of the Transcarpathian Fault, are located above the non-magnetic crust, outside the boundaries of the regional source.

It should be noted the links of silver-polymetal ore (Kelchey, Bucha, Kalimen) with subvolcanic and vent facies of the Sarmatian intrusive deposits. Gold ore mineralization was found at the boundaries of the Berehove ore field. This mineralization is refered to as vent facies of laparites in the remaining activation phase of Sarmatian volcanic structures [Prykhodko et al., 1985; Matskiv et al., 1996].

It is believed that ore concentrations of copper, molybdenum, and possibly gold may be associated with quartz diorite porphyrites and diorite porphyrites of Dacian-Romanian age, which are developed in the central part of the Syniak, Dekhmaniv and Ostra volcanic structures [Matskiv et al., 1996].

For this reason, it is worth paying attention to the long-lived meridional and northeastern faults, which play an important role in the formation of the structural plan of both volcanic and tectono-volcanic structures, as well as of the metallogeny of the Transcarpathian Depression, namely the localization of endogenous ore deposits and hydrocarbon accumulations.

Results. For the first time, a qualitative and quantitative analysis of the geomagnetic field was performed for the Transcarpathian Depression by dividing it into regional and local components, further magnetic modeling, as well as comparing the obtained results with fault-block tectonics, deep structure and distribution of several types of endogenous ore deposits and hydrocarbon accumulations.

1. The regional magnetic anomaly with an intensity of about 85 nT spatially coincides with the Chop-Mukachevo Depression. Anomaly is separated by the Transcarpathian fault, submeridional and northeast-trending faults.

2. The local component of the geomagnetic field reflects the magnetic heterogeneity of the Earth's crust in the upper 3—4 km of the section and mainly reflects volcano-tectonic structures and dike formations. The intensity of local magnetic anomalies within the Vyhorlat-Gutyns trand is 50—550 nT, the Berehove Uplift parallel to it is 50—300 nT, and in the area of the Velyka Dobron' Uplift it is 50—170 nT. It is worth noting that there are also negative anomalies, which probably have an independent nature (Geyivtsi, Putka, Makovytsia, Khotar).

3. For a reliable presentation of the magnetic model of the upper part of the crustal section, 68 sources were used. At the same time, in most cases, the volcano-tectonic structures of the Vyhorlat-Gutyn Ridge, the Chop-Berehove Uplift, and the Velyka Dobron' Uplift are reflected in the magnetic model. The maximum depths of magnetic sources (up to 3.5 km) and their magnetization (1.22 A/m) are characteristic for the structures of the Vyhorlat-Gutyn Ridge, intermediate values of depths (2.0—3.0 km) and magnetization (up to 0.93 A/m) belong to the Chop-Berehove Uplift, and the minimum depths (up to 1.1 km) and magnetization (up to 0.7 A/m) are typical for the Velyka Dobron' Uplift.

4. According to the simulation results, the regional source is located at depths from 6.0 km to 13 km and has a magnetization of 1.0 A/m. The northeastern edge of the source roughly coincides with the Transcarpathian Fault. The eastern contact has a meridional extension. In the west and northwest the contact of the body has a sublatitudinal and northeast extension, and in the southwest it extends beyond the territory of Ukraine.

5. Transcarpathian gas fields are tended to local positive magnetic anomalies and are localized above a deep magnetic source in places with the maximum thickness of Neogene

deposits. Within the Berehove Uplift, positive anomalies are intrinsic to andesite porphyrite shafts and andesite domes of Sarmatian age that are associated with gold, gold-polymetallic, and silver mineralization. A zone of antimony mineralization is associated with the Pannonian-Pontic volcanic structures along the southern foot of the Vyhorlat-Gutyn Belt, and deposits and occurrences of bismuth and mercury are closely associated with intrusive formations of Dacian-Romanian age.

Acknowledgement. Research was conducted by topics: III-3-23 Analysis of the geomagnetic field and magnetic models of lithospheric structures in connection with the solution of geological, geophysical and environmental problems; II-16-20 «Geodynamic development of the Ukrainian Carpathians and formation of mineral deposits based on the latest geological and geophysical data», part II «Geodynamic development of the lithosphere and formation of mineral deposits within the Ukrainian Carpathians». We express gratitude to G.M. Murovska for the useful remarks and requests that improved the article.

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Геомагнітне поле Українських Карпат та 3D магнітна модель Закарпатського прогину

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У статті викладено результати якісного та кількісного аналізу геомагнітного поля Українських Карпат і 3D магнітного моделювання вздовж геотрансекту PANCAKE та Закарпатського прогину. Отримані результати зіставлено з розломно-блоковою тектонікою, глибинною будовою та поширенням деяких видів ендогенних рудних родовищ і скупчень вуглеводнів. Показано, що насувна північно-східна частина Карпатської дуги залягає на магнітній корі, а південно-західна — на немагнітній нижній її частині. Між Рава-Руським, Краковецьким і Передкарпатським розломами земна кора намагнічена в усьому її розрізі. Для території Закарпатського прогину вперше виділено регіональну та локальну складові геомагнітного поля, подано геолого-геофізичну характеристику і запропоновано їх тектонічну інтерпретацію. Побудовано тривимірну магнітну модель цього прогину з урахуванням намагніченості гірських порід за експериментальними даними. Детально розроблено магнітну модель верхньої частини розрізу земної кори прогину. Проаналізовано зв'язок магнітних джерел з зонами розломів, отримані результати зіставлено з глибинною будовою та поширенням рудних родовищ і скупчень вуглеводнів.

Регіональне джерело з намагніченістю I =1,0 А/м знаходиться в межах Мукачівської западини і розташовано на глибині від 6,0 до 13 км. Локальна компонента геомагнітного поля відображає магнітну неоднорідність земної кори верхніх 3—4 км розрізу, а також переважно вулкано-тектонічні структури і дайкові утворення Вигорлат-Гутинського пасма, Чоп-Берегівського підняття та Великодобронського підняття. Максимальні глибини залягання магнітних джерел (до 3,5 км) та їх намагніченості (1,22 А/м) характерні для структур Вигорлат-Гутинського пасма, проміжні значення глибин (2,0—3,0 км) та намагніченості (до 0,93 А/м) стосуються Чоп-Берегівського підняття, а мінімальні глибини (до 1,1 км) та намагніченості (до 0,7 А/м) властиві Великодобронському підняттю.

Показано, що газові родовища Закарпаття приурочені до локальних додатних магнітних аномалій і локалізуються над глибинним магнітним джерелом. У межах Берегівського підняття за додатними аномаліями і магнітними джерелами виявлено штоки андезитових порфіритів і куполи андезитів сарматського віку, з якими пов'язане золоте, золото-поліметалеве і срібне зруденіння. До паннон-понтичних вулканоструктур уздовж південного підніжжя Вигорлат-Гутинської смуги тяжіє зона сурм'яного зруденіння, а з інтрузивними утвореннями дакій-румунського віку добре корелюють родовища та прояви вісмуту і ртуті.

Ключові слова: геомагнітне поле, магнітна модель, магнітні властивості порід, вулкано-тектонічні структури, корисні копалини, Карпати, Закарпатський прогин.