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Architecture of the upper crust along the WARR deep seismic profile SHIELD'21 across Ukraine based on seismic and geological data

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For the first time a seismic image of the East-European Craton upper crust between the Carpathians and the Dnieper-Donets Basin is presented, based on the finite-difference reflection/refraction migration processing of the SHIELD'21 deep profile results and its preliminary geological interpretation, taking into account available geophysical and geological data. The migration image shows a general domal shape of the top surface of the Archean to Palaeoproterozoic crystalline basement, which is devoid of sedimentary cover along the central part of the profile — at the Ukrainian Shield — and sloping to both sides, to the SW and NE below the sedimentary cover succession of the adjoining platform areas. The up-to-3—5-km-thick upper part of the portion of the East European Craton cross-cut by the profile is characterized by well-developed stratification and gentle folding at its flanks, while the central core is more homogeneous. High-angle faults are imaged mainly on the flanks of the Shield and dipping towards its center. The velocity model and migration image patterns agree with extensional tectonic structures identified on the terrain surface by fieldwork at the junction of the Podolian and Ros′ domains of the Ukrainian Shield. They allow the idea of a Palaeoproterozoic large-scale extension,

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providing a crustal heterogeneity that might have later impacted the Dnieper-Donets rift basin opening and evolution in Devonian time.

Key words: WARR seismic profile SHIELD'21, migration image, stress field, East European Craton, Volhyno-Podolian Homocline, Ukrainian Shield, Dnieper-Donets Basin.

Introduction. Carried out in 2021, the wide-angle reflection-refraction (WARR) SHIELD'21 deep seismic profile crosses the Archaean and Palaeoproterozoic crystalline complexes of the Ukrainian Shield and adjacent platform areas (for the profile location see [Starostenko et al., 2024]).The platform areas are represented by the Volhyno-Podolian Homocline (VPH) in the southwest (composed of Neoproterozoic to Cretaceous successions buried below the Neogene Carpathian Foredeep) and the Devonian to Cenozoic Dnieper-Donets Basin (DDB) in the northeast.

We present a seismic wave image of the upper crust (0—15 km deep) obtained by the finite-difference reflection/refraction migration method [Verpakhovska, 2021] applied to the SHIELD'21 data and its preliminary interpretation (Fig. 1). In addition, we have taken into account the results of previous [Mychak et al., 2022] and new (2024) geological study of the Precambrian complexes in the vicinity of the profile.

Results. The migration image in Fig. 1 (*c*, *d*) clearly displays the dome-like shape of the top surface of the East European Craton (EEC) with the Ukrainian Shield in its central segment.

The central core of EEC along the profile is practically devoid of a sedimentary cover, while its slopes are overlain by successions of deep sedimentary basins: the Carpath-

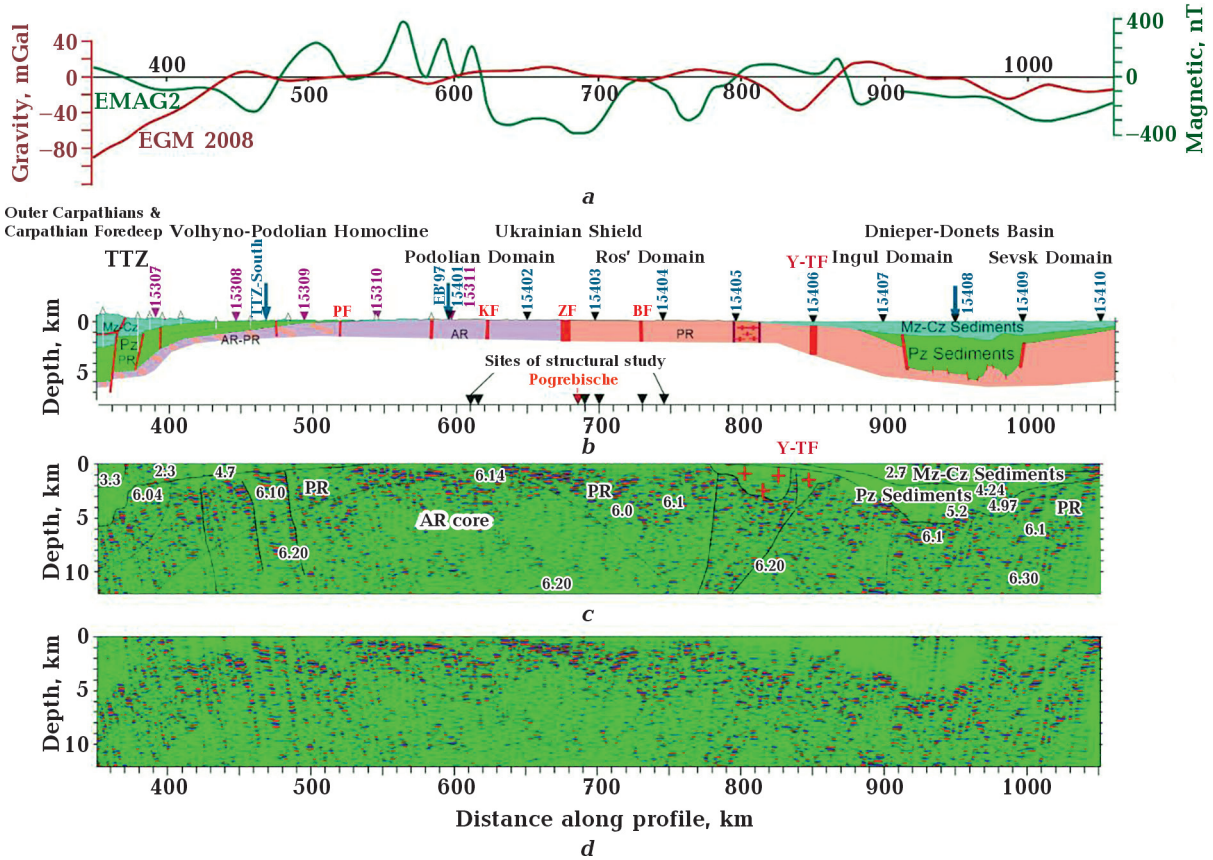

Fig. 1. Tectonic interpretation of the seismic image of upper crust along the SHIELD'21profile: *a* — gravity and magnetic fields, *b* — geological cross-section [Starostenko et al., 2024] (black triangles indicate projection of studied outcrops on the profile line), *c* — migration image with interpretation elements (*P*-waves velocities after [Starostenko et al., 2024]), *d* — pure migration image.

ian Foredeep with the adjacent VPH and DDB. The 3—5-km-thick upper layer of the Ukrainian Shield shows high stratification and gentle folding, especially at its flanks, while its central core is more homogeneous. Zones of deformation and high-angle faults are most clearly manifested on the flanks and dipping towards its center. The western most segment of the profile (km 350—430) is characterized by low-velocity crust [Starostenko et al., 2024], gravity low up to –90 mGal, and magnetic field of close-to-zero magnitudes due to the thick Palaeozoic-Riphean sediments. The migration image reveals a wide zone of increased deformation (km 410—480) steeply dipping beneath the southeastern margin of the East European Craton, covered by the VPH succession. A number of sedimentary complexes can be distinguished in this segment. The upper layer represents the Meso-Cenozoic deep-water turbidites of the Carpathian allochthon and Neogene molasse of the Carpathian Foredeep. They are underlain by a layer comprising Palaeozoic shallow-water and Ediacaran syn-rift deposits. Beneath the Ediacaran sequence, we identified another basin, visible at a depth of 10 km due to a high-reflectivity pattern and potentially corresponding to Riphean metasedimentary and metavolcanic rocks.

On the geological cross-section, the Podolian Domain of the Ukrainian Shield (km 520—680) is limited by the steeply dipping Podolian and Zvizdal-Zalisk faults. On the migration image, the Podolian Domain looks like a gentle «anticline» broken in the southwest by a wide deformation zone; in the northeast, it gradually turns into the Ros' Domain. On the migration image, the transition between the Podolian and Ros' domains (km 620—780) at the subsurface level is represented by a wide zone of increased stratification, while on the SHIELD'21 velocity model the junction is related to an asymmetric trough (km 680—730) as deep as ~10 km with rocks of relatively reduced velocity [Starostenko et al., 2024].

The Ros' and Ingul domains of the Ukrainian Shield and Sevsk Domain of the Voronezh massif form a single block of juvenile Paleoproterozoic crust [Bogdanova et al., 2016]. The block differs from the Podolian Domain on the migration image by its higher reflectivity (heterogeneity). In the northeastern segment of the Ros' Domain (km 790—875), we interpreted a wide zone of deformations and granitization, which includes the Yadlov-Trakhtemyriv southwest-dipping fault (continuation of the Palaeoproterozoic Golovanivsk suture zone) and a series of granite intrusions.

The northeastern segment of SHIELD'21 crosses the DDB. Its uppermost layer represents the Meso-Cenozoic to Permian continental and shallow-water post-rift sediments, underlain by a layer (down to the depth of 5.5 km) comprising Devonian and Carboniferous syn-rift sequences. Under the axial zone of the DDB, a trough with a relatively lower velocity (km 900—970), reaching a depth of 11 km, can be interpreted as a junction of the Ingul and Sevsk domains, inherited from the Sarmatian terrains assembly in Palaeoproterozoic [Bogdanova et al., 2016]. Pre-existing Palaeoproterozoic heterogeneity at the base of the DDB may have determined its emplacement in the Late Paleozoic, as it also supposed by [Stephenson et al., 2021].

Field geological-and-structural analysis. The recently studied outcrops are located within the Podolian and Ros' domains. They include the Neoarchean granitoids of the Letychiv dome and Khmilnyk fault, the sites cropped out in the Ros' Domain, including Zvizdal-Zalisk and Brusyliv faults, and the Uman granites (Fig. 1, *b* for the outcrop's location). Most outcrops exhibit a similar structural pattern with structural-textural elements forming gentle folding and a system of steep and gentle faults interpreted as reflecting a compressional and, following it, extensional stress fields.

A flat fault in the biotite granites of Neoarchean Tetiev complex and related kinematic stereogram are presented in Fig. 2. This outcrop is located in the Zvizdal-Zalisk fault zones of N-S strike at the contact of Podolian and Ros' domains (see Fig. 1, *b* for the outcrop location marked by the red triangle). On the base of the slicken-sides set, we have restored the W-E-trending extensional stress field (see Fig. 2). According to Mychak et al. [2022], faults and bands of gneisses dipping

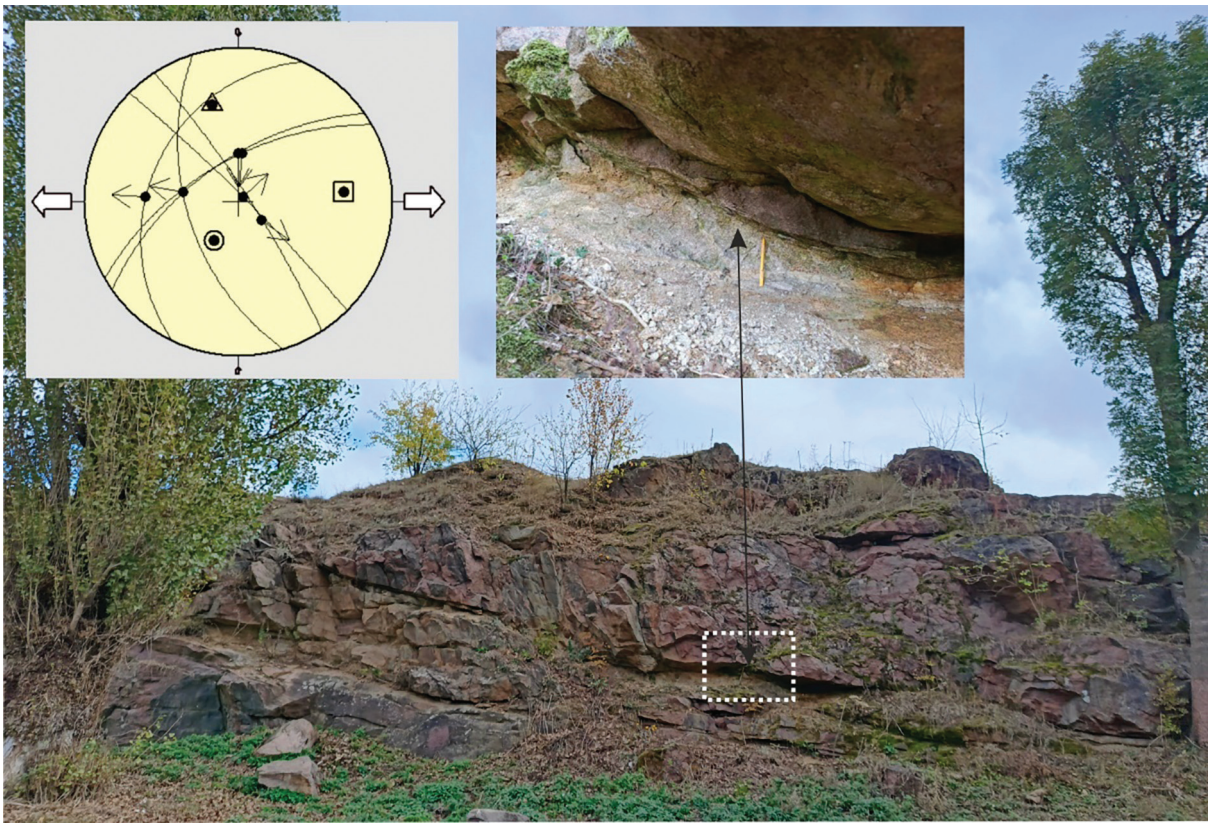

Fig. 2. Gentle faults with tectonic breccia and strike-slip surfaces in biotite granites of the Neoarchean Tetiev complex in the Zvizdal-Zalisk fault zone and the reconstructed stress field of W-E extension. The Pogrebishche outcrop is indicated in Fig. 1, *b* by a red triangle.

100°/50° and 295°/50° are widely developed in the Zvisdal-Zalisk fault zone and related to the W-E trending extension.

Conclusions. The seismic migration image of the upper crust along the SHIELD'21 profile reveals a dome-like structure of the EEC top with the Ukrainian Shield in its center part. The upper layer of the Ukrainian Shield, especially on its flanks, shows increased stratification and gentle folding. The steep faults (~50°—60°) on the flanks of the Ukrainian Shield are inclined towardits central zone. A similar situation of the interplay of gentle and steep structural-textural elements and faults was revealed in the studied terrain outcrops of the Ukrainian Shield in the vicinity of the profile.

The migration image pattern, SHIELD'21 velocity model [Starostenko et al., 2024], geological cross-section, reconstructed extension structures at the transition zone of the Podolian and Ros' domains of the Ukrainian Shield make it possible to hypothesize a Proterozoic large-scale extension that could provide crustal heterogeneity on which the DDB originated in Devonian time.

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Архітектура верхньої кори вздовж WARR глибинного сейсмічного профілю SHIELD'21 в межах України на основі сейсмічних та геологічних даних

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Вперше представлено сейсмічне зображення верхньої кори Східноєвропейського кратону між Карпатами та Дніпровсько-Донецькою западиною, отримане за допомогою кінцево-різницевої процедури міграції відбиття/заломлення результатів за глибинним профілем SHIELD'21, та його попередню геологічну інтерпретацію з урахуванням доступних геофізичних і геологічних даних. Міграційне зображення демонструє загальну куполоподібну форму поверхні докембрійського кристалічного фундаменту Східноєвропейського кратону, яка позбавлена осадового чохла вздовж центральної частини профілю — на Українському щиті — і нахилена на флангах щита на південний захід і північний захід під осадовим чохлом прилеглих платформних областей. Верхня частина сегмента Східноєвропейського кратону, який перетинається профілем, потужністю до 3—5 км характеризується добре розвиненою шаруватістю та пологою складчастістю, особливо на флангах щита, тоді як центральне ядро більш однорідне. Круті розломи проявлені на сейсмічному зображені переважно на флангах щита і занурюються до його центру. Структурний рисунок швидкісної моделі та міграційного зображення, а також тектонічні структури розтягу, виявлені на поверхні під час польових досліджень на контакті Подільського та Росинського домейнів Українського щита, дають змогу висунути ідею великомасштабного палеопротерозойського розтягу, внаслідок чого була сформована неоднорідність земної кори, яка могла пізніше вплинути на відкриття та еволюцію Дніпровсько-Донецького рифтового басейну в девонський час.

Ключові слова: WARR сейсмічний профіль SHIELD'21, міграційне зображення, поля напруження, Східноєвропейський кратон, Волино-Подільська монокліналь, Український щит, Дніпровсько-Донецький басейн.