# The SHIELD'21 deep seismic experiment, Ukraine

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## Abstract

Carried out in 2021, the wide-angle reflection and refraction (WARR) SHIELD'21 profile crosses, from SW to NE, the main tectonic structures of Ukraine. It targeted the structure of the Earth's crust and upper mantle of the southwestern margin of the East European Craton with overlying Neogene Carpathian Foredeep and Vendian-Paleozoic Volyn-Podolian Monocline, Archaean and Paleoproterozoic segments of Ukrainian Shield and Late Paleozoic Dnipro-Donetsk Basin. The ~650 km long SHIELD'21 profile is an extension of previously realized RomUkrSeis profile carried out in 2014 and running from the Apuseni Mountains to the southwestern Ukrainian Shield (Starostenko et al., 2020). The WARR study along the SHIELD'21 profile using TEXAN and DATA-CUBE short-period seismic stations provided high-quality seismic records. The field work was performed during the summer of 2021, included the deployment of autonomous seismic stations and drilling-explosive works. A total of 264 seismic receivers were involved, (160 DATA-CUBE and 104 TEXAN stations). The average spacing between observation points is about 2.65 km. The sampling interval for all stations was 0.01 s. Seismic energy was generated at 10 shot points (SP) with total charge in all wells 5775 kg. The distance between the SPs was about 50 km.

The main recorded seismic waves are the refractions of P- and S- waves in sediments, basement, crust and uppermost mantle, and reflections from crustal boundaries, Moho interface and boundaries in the uppermost mantle. The correlation picking of their arrival times will allow to build a velocity model not only for P-, but also for S-waves and Vp/Vs ratio. The main objective of the SHIELD'21 project is to get new seismic data that increase our knowledge on the lithosphere structure and geodynamics of the study region.

## References

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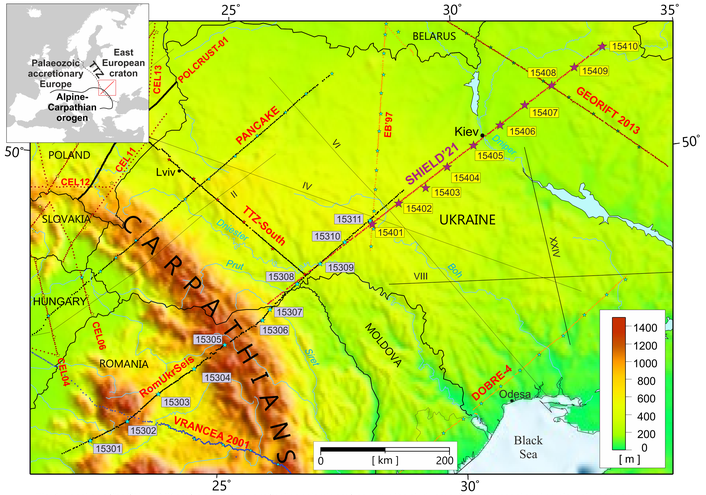


**Fig. 1.** Location of the SHIELD'21profile and previous refraction seismic profiles within the study area. Stars represent shot points, dots receivers.

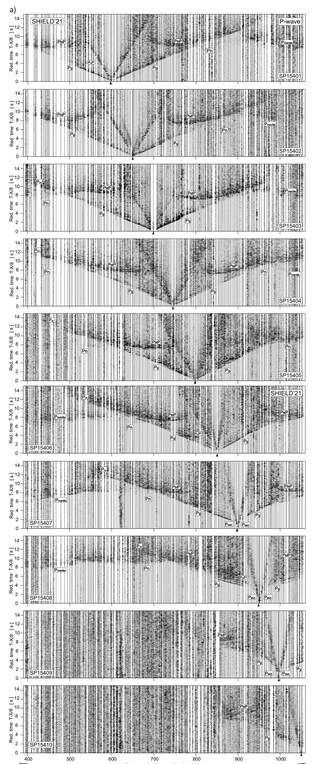


**Fig. 4a.** Examples of trace-normalized, vertical-component seismic record sections for a) SP15401-SP15410. A band-pass filter (2-15 Hz) has been applied. $P_{sed}$ – P refractions from sedimentary layers; $P_c$ – P refractions from the upper and middle crystalline crust; $P_{uc}$ – P overcritical crustal phases; P,P – P reflections from the mid-crustal discontinuities, $P_m$P – P reflections from the Moho boundary; P, – P refractions from the sub-Moho upper mantle; $P_{mantle}$ – lower lithospheric P phases. The reduction velocity is 8.0 km/s.

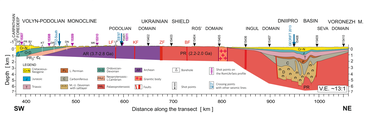


**Fig.3.** Generalized geological section is built on the basis of geological and geophysical data. The Volyn-Podolian Monocline segment is based on drill holes, derived of (Sipliyv and Shevchenko, 1972; Vashchenko, 2003) (marked as bright lines: DV–1 ДВ (NW – 19.11 km); SR–57 CP (NW – 16.44 km); PR– Porubnoe (SE – 11.30 km); BY– Bayraki (SE – 5.08 km); KT– Kotelovo (SE – 3.01 km); DR–Darabany (NW – 5.92 km); DN– Dnestrovka (NW – 0.85 km); MK–18674 (NW – 0.51 km); LP–11646 (NW – 8.68 km)). The Dnieper Basin section is composed according to the bottom depths of the main stratigraphic complexes derived of the maps set of (1:1 000 000), obtain from shallow reflection profiles (Arsiriy et al., 1984). Abbreviations: LF – Letichev fault; KF – Khmelnytsk fault; ZF – Zvizdal-Zalessky fault; BF – Brusilov fault.

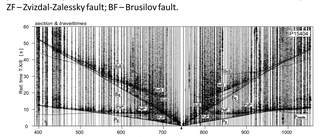


Fig. 6b. Example of seismic modelling of S waves SP15406 filtered by a bandpass filter (1–8 Hz). The reduction velocity is 4.62 km/s. Abbreviations as in Figure 4.

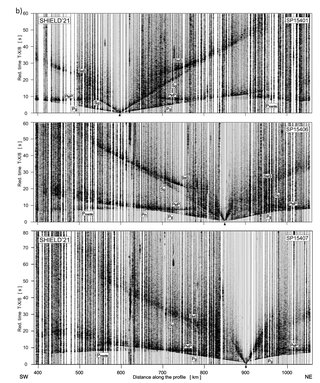


**Fig.4b.** Example of trace-normalized, vertical-component, common seismic record sections for P- and S-waves along RomUkrSeis profile (SP15401, SP15406, SP15407) filtered by a band-pass filter (1-8 Hz). The reduction velocity is 8.0 km/s. Phases are labelled as in Figure 4a.

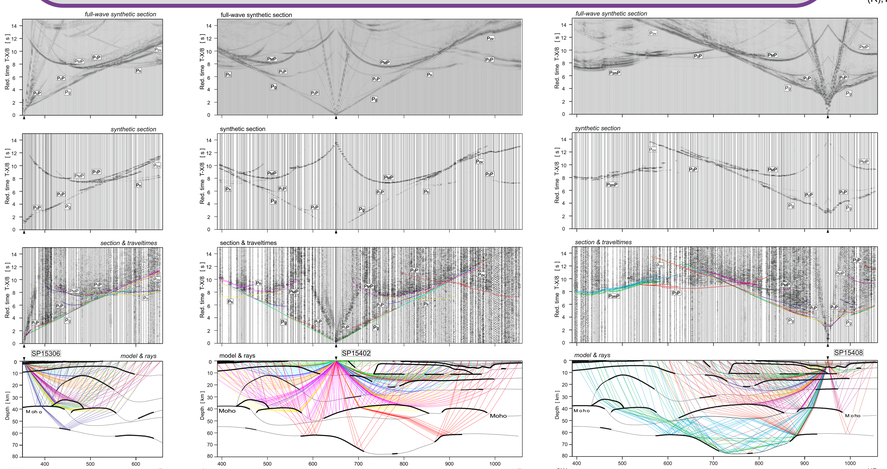


**Fig.6a.** Examples of seismic modelling along the SHIELD'21 profile, for the model presented in Figure 5: SP15306, SP15402 and SP15408. Diagrams: (top) Full-wave synthetic seismograms derived from the SEIS83 velocity model using TESSERAL package; (middle upper) Synthetic seismograms derived by using the SEIS83 package; (middle lower) Seismic record section (trace-normalized, vertical-component, 2–15 Hz band-pass filtered, reduction velocity of 8.0 km/s) of P-waves with theoretical travel-times calculated using SEIS83; (bottom) Selected rays from SEIS83 defining the prominent model interfaces. Abbreviations of seismic phases as in Figure 4a.

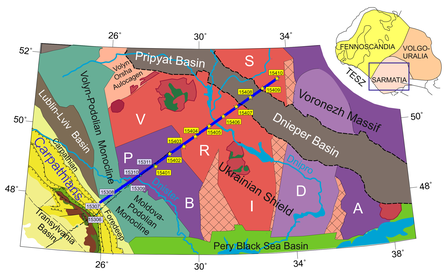


**Fig. 2**. Tectonic setting of the SHIELD'21 profile area with inset map of the EEC main crustal segments (after Khain and Leonov, 1996; Hursky and Kruhlov, 2004; Bogdanova et al., 2016; Stephenson et al., 2021). The SHIELD'21 crosses the tectonic domains aged from Archaean to Neogene: southwestern margin of the Precambrian EEC with overlying Ediacaran-Devonian Volyn-Podolian Monocline and Neogene Carpathian Foredeep, Archean and Paleoproterozoic segments of Ukrainian Shield, and Devonian-Triassic Dnieper Basin. The SHIELD'21 is an extension of the RomUkrSeis line running from the Apuseni Mountains in Romania to the southwestern Ukrainian Shield (Starostenko et al., 2020). The Ukrainian Shield is represented by: Azov (A), Podolian (P), Bug (B), Dnieper (D) segments of Archaean crust and Volyn (V), Ros' (R), Ingul (I) domains of Palaeoproterozoic crust being sutured in Palaeoproterozoic.

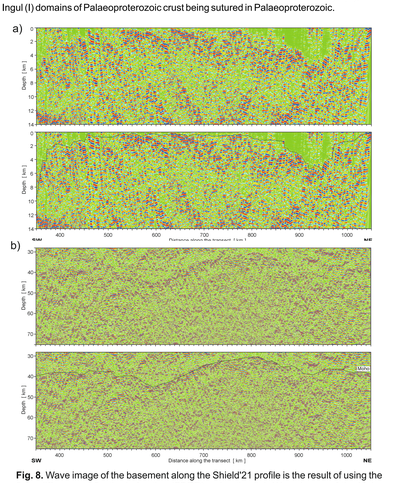


**Fig. 8.** Wave image of the basement along the Shield'21 profile is the result of using the finite-difference reflection/refraction (FDRR) migration (a). Wave image of the Moho thickness structure along the SHIELD'21 profile is the result of seismic data processing with finite-difference reflection/refraction (FDRR) migration (b). Upper diagrams - clean sections; lower diagrams - sections with interpretation.

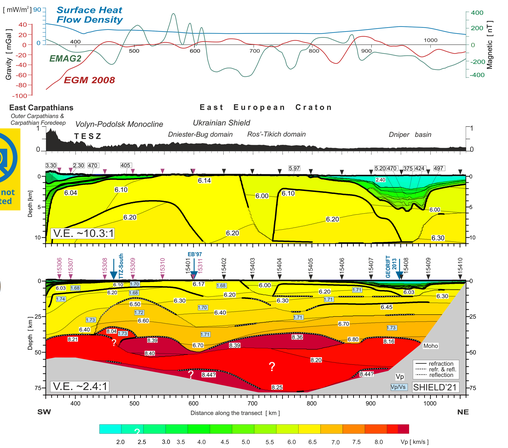


**Fig. 5.** Two-dimensional models of P- and S-wave seismic velocities in the crust and upper mantle along the SHIELD'21 profile derived by forward ray-trace modelling using SEIS83 (Červený and Pšenčik 1984). Values of the Vp/Vs ratios are shown in blue rectangles where available. Thick, black solid and dashed lines represent major velocity discontinuities (boundaries). Only those parts of the discontinuities that have been constrained by reflected or refracted arrivals of P-waves are shown: solid line – refraction only; dashed line – refraction and reflection; dotted line –reflection only. Thinner lines represent inferred velocity isolines with values in km/s shown in white boxes. The positions of tectonic units at the surface, including the approximate extent of the TTZ along the profile, are indicated. Inverted triangles show positions of shot points. Blue arrows show intersections with TTS-South, EB'97 and GEORIFT 2013 profiles. Vertical exaggeration is ~10.3:1 for upper part of the model and ~2.4:1 for the whole model. Gravity and magnetic anomalies as well as surface heat flow along the profile are also shown.

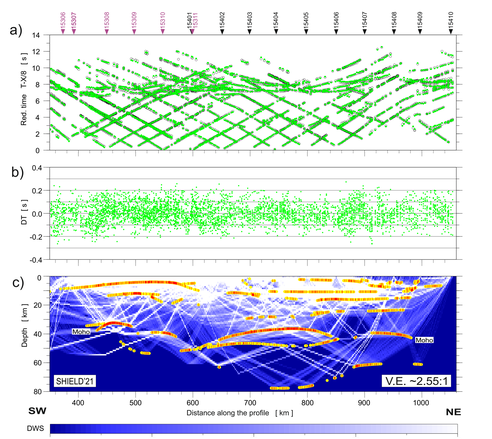


**Fig.7.** Diagrams showing theoretical and observed travel times (a), travel time residuals (b) and schematic ray coverage (c) from forward modeling along the profile. Green points – P-wave arrivals, black circles – theoretical travel times. Yellow lines – schematic fragments of discontinuities constrained by reflected phases. The red points plotted along the interfaces mark the theoretical bottoming points of reflected phases (every third point is plotted) and their density is a measure of the positioning accuracy of the reflectors. DWS – derivative weight sum. Reduction velocity is 8 km/s.

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