УДК 550.834 DOI: https://doi.org/10.24028/gj.v47i6.339540

Kinematic and dynamic processing of seismic data along EUROBRIDGE'97 profile

K.V. Kolomiyets, O.O. Verpakhovska, O.A. Chorna, D.V. Lysynchuk, 2025

S. Subbotin Institute of Geophysics of National Academy of Sciences of Ukraine, Kyiv, Ukraine
Received 18 September 2025

The article presents the principal procedures for kinematic and dynamic processing of wavefields observed using the deep Wide-Angle Reflection and Refraction seismic profiling method. It demonstrates that combining their results enhances the level of subsequent interpretation.

Kinematic processing of seismic data is a conventional approach, typically based on ray-tracing modeling, which produces a calculated velocity model of the medium. These velocity parameters are the input data for dynamic processing.

Dynamic processing operates with the amplitude-frequency and phase characteristics of the wavefield, involving the construction of an image of the deep section with its existing interfaces and tectonic features of the study area. In global practice, the main procedures of dynamic processing include various migration techniques; however, they are not designed for processing WARR data recorded at large distances of several hundred kilometers from the source. At the S. Subbotin Institute of Geophysics of National Academy of Sciences of Ukraine, a specialized finite-difference migration method for reflected/refracted waves has been developed specifically for Wide-Angle Reflection and Refraction data processing.

Both kinematic and dynamic processing were applied to wavefields recorded along the EUROBRIDGE'97 seismic profile. Two alternative velocity models are presented, showing a similar overall structure along the profile down to a depth of 15 km, along with a migrated image to the same depth obtained using the finite-difference migration method for reflected/refracted waves.

Application of dynamic processing to the seismic dataset has, for the first time, produced an image of the deep structure of the crystalline basement along the EUROBRIDGE'97 profile, providing additional structural details to the results of kinematic processing.

Key words: wide-angle reflection and refraction, kinematic processing, dynamic processing, migration of reflected/refracted waves, seismic modeling.

Introduction. The seismic survey acquisition scheme for the wide-angle reflection and refraction (WARR) method differs from standard surveys, which typically use the reflected-wave method based on multiple reflections. Firstly, wave fields recorded by the WARR method are registered at several hundred kilometers from the source. At the same time, not only the sources, but also the receivers are located along the profile with an irregular step that reaches several kilometers. The limited interval of recording reflected waves from the source does not allow, under such observation conditions, to consider them as reference waves. As a result, standard processing methods, designed to record reflected waves using a regular observation system, will not be effective when applied to the WARR data.

Based on the properties of the observed

Citation: Kolomiyets, K.V., Verpakhovska, O.O., Chorna, O.A., & Lysynchuk, D.V. (2025). Kinematic and dynamic processing of seismic data along EUROBRIDGE'97 profile. *Geofizychnyi Zhurnal*, *47*(6), 3—14. https://doi.org/10.24028/gj.v47i6.339540.

wave field, seismic data processing is categorized into kinematic and dynamic. Kinematic processing of the WARR seismic data is a traditional approach for deriving velocity models along regional profiles. Kinematic processing methods include ray-tracing modeling (for example the SEIS83 program [Červený, Pšenčík, 1984]), seismic tomography (the program by Hole [1992]), and seismic inversion (the FAST program [Zelt, Barton, 1998]). Tomographic inversion is a highly effective technique for resolving first-arrival seismic velocity distributions and is commonly used to quickly obtain a model of the deep structure. An interesting comparison of three different seismic tomography programs is presented by Janik et al. [2016], where they were used to study a very complex structure of the section along the DOBRE-4 profile. A comparison of the computational capabilities and limitations of different modeling codes was published by Malinowski [2013]. Over the past three decades, direct ray-tracing modeling has been used to derive velocity models across all regional WARR profiles recorded in Ukraine [Kendzera et al., 2019; Starostenko et al., 2018, 2020, 2024; Janik et al., 2022].

Kinematic processing belongs to the inverse problems in seismic exploration, and its accuracy depends on factors such as data coverage gaps and systematic biases in the measured travel times. At the same time, the result of kinematic processing can be validated with dynamic processing. Dynamic processing includes various methods of seismic migration. Migration forms an image of the deep structure of the section along the profile in the dynamic characteristics of the observed wave field. In this case, it is necessary to have previously determined velocity characteristics of the geological environment. Therefore, an obtained velocity model provides the necessary information about the velocity distribution in the section for further dynamic processing of the WARR data using migration.

Recent publications on advanced methods of dynamic processing demonstrate a trend towards the development of such methods as high-precision demigration for active faults [Zhang, Li, 2023] and Q-migration for modeling seismic wave propagation in highly attenuative environments, such as forest plateaus and shallow gas areas [Xu et al., 2024]. The reverse time migration is gaining widespread application due to its ability to produce high-resolution images with balanced amplitude characteristics [Lu et al., 2025]. However, each of the above methods is not perfect; they typically allow for repositioning the recorded seismic data to their true subsurface locations only within limited areas, and often the results are demonstrated on synthetic or test examples. Regarding the dynamic processing of WARR data, several studies mention «pre-stack migration» (migration before summarizing traces by the common depth point method or directly from the observed data) but use reflected waves and do not demonstrate the effectiveness of its application. Meanwhile, wide-angle seismic observations are being conducted worldwide, including the continental shelves of French Guiana and Suriname [Klingelhoefer et al., 2021], Japan [Shiraishi et al., 2022], and Italy [Ryberg et al., 2023]. This confirms the relevance of developing and improving methods and techniques that guarantee the accuracy of processing of such data and enhance the quality of their interpretation.

At the S. Subbotin Institute of Geophysics of National Academy of Sciences of Ukraine, Pylypenko V.M. proposed finite-difference migration of refracted waves back in 1990 [Pylypenko, Sokolovskaya, 1990]. This method was improved, particularly in forming an image of the deep structure of the crystalline basement using the WARR data from the reflected/refracted waves [Verpakhovska, 2021]. Practical applications and recent literature reviews demonstrate that this methodology remains the only effective tool for the dynamic processing of profile data obtained by the WARR method, which has proven its effectiveness in studying the deep structure of various regions of the world, including Ukraine [Verpakhovska, 2021; Murovskay et al., 2023; Verpakhovska, Chorna, 2023]. This methodology considers all the unique aspects of the WARR observation system and allows to obtain additional details that may be missing in the velocity model derived from ray tracing.

The purpose of this work is to demonstrate the effectiveness of combining kinematic and dynamic processing results for wavefields observed using the WARR method, with a focus on the structure of the Earth's crust in the Ukrainian Shield along the EUROBRIDGE'97 seismic profile.

For several decades, the S. Subbotin Institute of Geophysics of the National Academy of Sciences of Ukraine has been conducting seismic surveys using the WARR method along regional profiles in various regions of Ukraine as part of international projects to study their deep structure. One of such profiles is EUROBRIDGE'97, which runs from north to south (Fig. 1) and allows us to study the deep structure of the crust [Thybo et al., 2003; Ilchenko, 2002; Yegorova et al., 2004].

Since enhancing the informativeness of deep structural studies remains a key objective in seismic data interpretation, this article demonstrates that incorporating the dynamic characteristics of the observed wavefield to the processing of WARR data allows for a more detailed reconstruction of the deep structural features than is achievable through kinematic processing alone.

Kinematic Processing. For the kinematic processing of WARR seismic data, the ray-tracing modeling is traditionally used. This method is implemented in various software

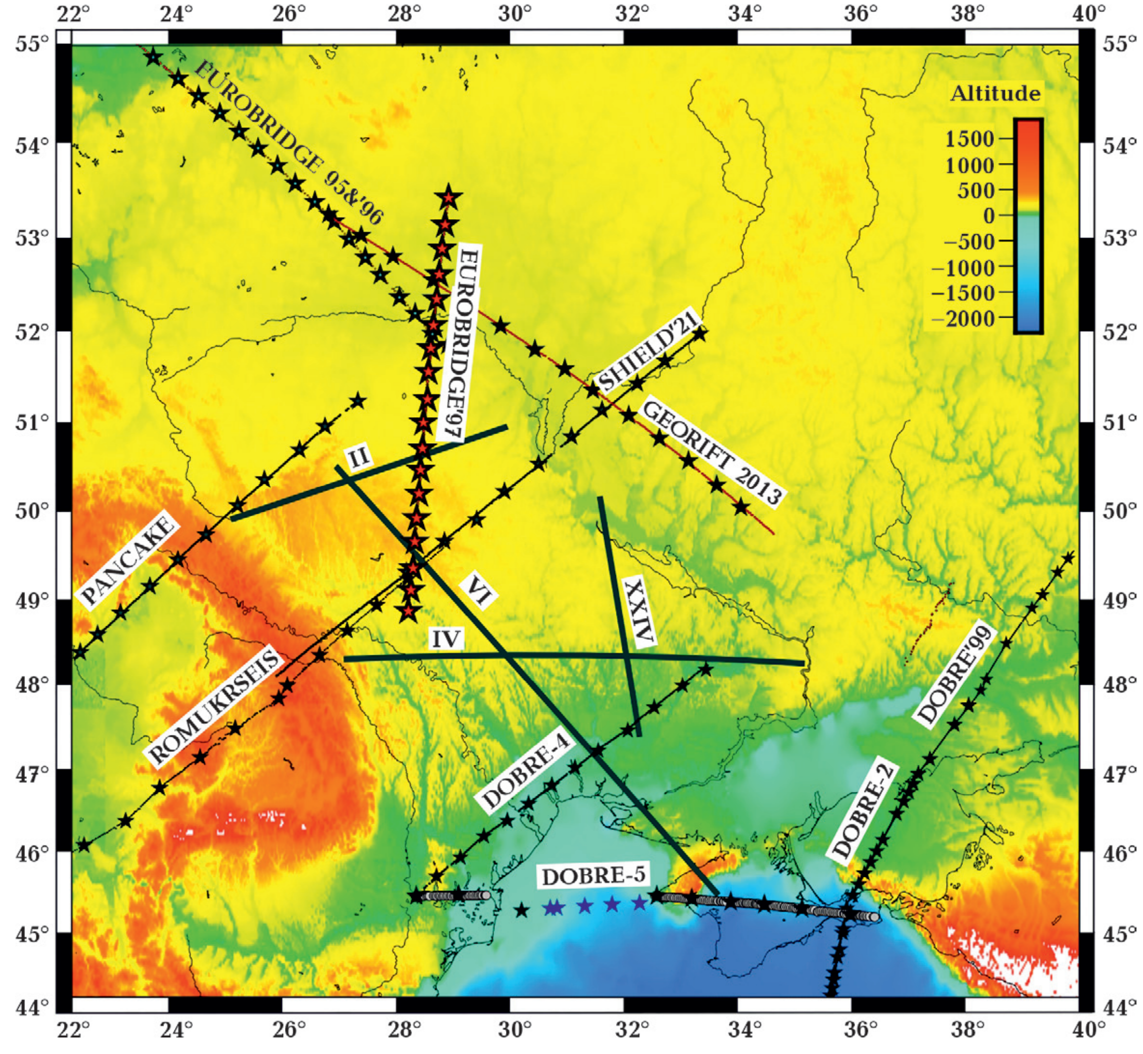

Fig. 1. Location of the WARR seismic profiles in Ukraine, including the EUROBRIDGE'97 profile. The stars indicate the Shot Points' locations.

packages, including automated tools for solving the inverse seismic problem based on the inversion of recorded travel-time curves, as well as more labor-intensive approaches that involve manually adjusting the velocity model by matching the travel-times of selected seismic waves with calculated travel-time curves.

The interpretation of the EUROBRIDGE'97 data involved methods based on forward or inverse modeling of certain phases of travel times of seismic waves in the Earth's crust and mantle using ray theory. Programs vary in their model parameterization conditions and the data sets used for modeling. Velocity models based on the inversion of refracted and reflected waves allow to obtain the overall distribution of velocity characteristics along the studied section relatively quickly. The velocity model calculation programs, built on ray theory, allow seismic rays to be traced in a medium with specified velocity characteristics, providing the corresponding travel times of the wave from the source point to the receivers. The velocity model is then updated to reduce the difference between observed and calculated travel-time curves.

Constructing a velocity section typically follows one of two approaches. The first involves solving a forward problem, where ray paths and wave travel times between the source and the receiver are calculated using an initial velocity model. The model is then iteratively updated to improve agreement between the observed and calculated wave arrival times. This process continues until the differences between the theoretical and recorded travel-time curves are less than a predefined threshold, set at 100 milliseconds in our study. Alongside refining the velocity model, this approach also helps identify and correct errors in seismic wave correlation.

The second approach relies on a more automated algorithm, which applies regularization through the least-squares method over multiple iterations. This method systematically adjusts the initial model to minimize the differences between the observed and the calculated wave travel times [Zelt, Smith, 1992].

A key advantage of inversion techniques is their efficiency and simplicity in processing input data, enabling rapid development of velocity models [Thybo et al., 2003]. Refinements were carried out using the SEIS83 program [Červený, Pšenčík, 1984], which implements a ray-tracing algorithm. The modeling algorithm implements ray theory and calculates the paths and arrival times of rays. For the EUROBRIDGE'97 profile, the kinematic modeling input data included a set of correlated travel-time curves for various seismic wave types from 18 source points and an initial velocity model derived from inversion results. The model consists of layers in which the velocity changes smoothly. Within each layer, P-wave velocities are parameterized on an irregular rectangular grid and interpolated using bicubic splines. The velocity model for deeper layers is refined interactively. Travel times are calculated for the initial model and compared to the observed data, with subsequent adjustments made to minimize misfits. Iterations proceed until the correspondence between observed and modeled data reaches an acceptable quality.

The basis for kinematic modeling of the EUROBRIDGE'97 profile was a series of travel-time curves for various types of seismic waves, determined using traditional correlation of seismic phases for refracted and reflected waves. During the ray-tracing procedure, seismic wave travel times were calculated simultaneously for all explosive sources. The model was then progressively updated by the interpreter to improve the match between the observed and the calculated travel times for each seismic phase. At the start, the velocity in the uppermost part of the profile was determined by fitting the nearest refracted seismic phases to the source points. After aligning the topmost layer, modeling progressed to deeper layers. Typically, the velocity of a layer is determined first using refracted phases, followed by calculating the layer's thickness based on reflected phases. In the deeper layers, first, the velocity is established, and then, using this velocity and the travel times of reflected waves, the geometry of the boundary and the thickness of the layer are determined. This process is repeated from one layer to the next, until the entire depth section is constructed. Usually, only over-critically reflected waves are strong enough to be confidently identified in seismic records and used for calculating reflective boundaries.

It is necessary to note the inherent ambiguity in a velocity model based on a system of profile travel-time curves received by the WARR method. The main challenges for a definitive solution to the inverse kinematic problem are the lack of data and systematic errors in the interpreted travel-time curves [Ilchenko, 1985].

Data insufficiency arises from several factors. First, the discreteness of observation systems always causes incomplete data. This, in turn, leads to the existence of multiple solutions that equally plausibly explain the observed waves' kinematics. Secondly, data incompleteness is related to how certain elements of the medium are represented in seismic wave travel-time curves. For instance, a «missing layer» or a low-velocity zone might only be illuminated by refracted waves. In such cases, it is impossible to determine their velocity and geometric parameters. These parameters can be assigned differently while still aligning with the available data. Thirdly, inherent ambiguity occurs when the modeling of the layer relies only on hodographs of waves reflected from its bottom. While this makes it possible to clearly define the sequence of layers, it does not permit a unique correlation between the velocity and thickness of individual layers.

Systematic errors in the interpreted hodographs, which cannot be corrected through statistical processing within the ray-tracing method, also contribute to ambiguity in the results. These errors transform the experimental travel-time curve from a precise line into a band, the width of which reflects the magnitude of potential errors along the profile.

Dynamic processing. Dynamic processing operates with the amplitude, frequency, and phase characteristics of the wavefield. It constructs an image of the depth section, which includes seismic boundaries and tectonic features of the study area, by transforming the observed wavefield. The method of finite-difference migration of reflected/refracted wavefields is applied. This seismic migration method, originally developed by the authors, obtains a depth section of the geological strata based on the dynamic characteristics of the observed wavefield along profiles recorded using the WARR method. At present, the use of the finite-difference migration method for reflected/refracted wavefields remains the only approach capable of representing the geological structure in the dynamic characteristics of the wavefield observed *via* the WARR method, as confirmed by practical examples [Verpakhovskaya, 2021; Murovskay et al., 2023; Verpakhovska, Chorna, 2023].

The finite-difference migration method for reflected/refracted wavefields is designed to pick critically reflected and refracted waves recorded from the basement layers in the far-offset zone from the source. In this case, the full path of seismic waves passing through a two-layer medium is taken into account, at the boundary of which there occurs a significant velocity difference [Verpakhovska, 2021; Verpakhovska, Chorna, 2023].

Seismic migration requires the velocity parameters of the medium to be known. Consequently, the output of kinematic processing, specifically the derived velocity model of the medium, is used as input.

For the EUROBRIDGE'97 regional profile, finite-difference migration of reflected and refracted waves was applied to research the deep structure of the crystalline basement. Shot records were reviewed and edited, and the quality of the initial data was evaluated for all available shot points, discarding those that lacked sufficient information. Additionally, a reduction was applied to the input data, with the reduction velocity corresponding to the propagation velocity of seismic waves in the basement.

Fig. 2 illustrates the wavefields along the profile, reduced at a velocity of 6.2 km/s for shot points 4 and 14, located at 98.3 km and 399.3 km along the profile, respectively. The figure highlights the detailed geological information that can be retrieved by applying migration to these wavefields.

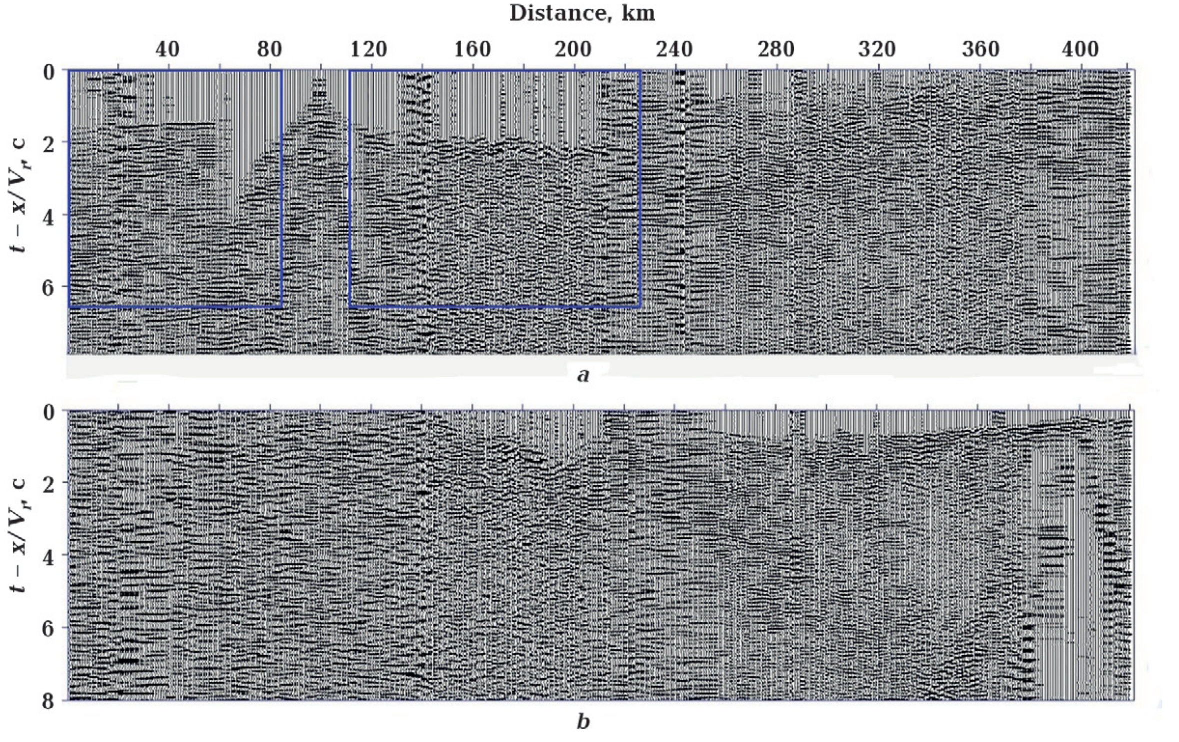

Fig. 2. The observed wavefield for Shot Points 4 (98.304 km) (*a*) and 14 (399.336 km) (*b*) with a reduction velocity V_r=6.2 km/s. The intervals of the wavefield corresponding to the structure of the basement are marked with rectangles.

For all high-quality wavefields, a specific interval (marked by a rectangles in Fig. 2) containing waves that represent the structure of the crystalline basement is identified. Finite-difference migration of reflected and refracted wavefields is applied to these intervals.

Fig. 3 illustrates the wavefield interval for Shot Point 1, located at 0 km along the profile, before (*a*) and after (*b*) applying finite-difference migration. The migrated image (Fig. 3, *b*) preserves all the features of the observed wavefield (Fig. 3, *a*) while accurately displaying their depths. The migration images obtained for each high-quality Shot Point are analyzed, and the clearest representations of all structural details are selected to construct the depth image of the crystalline basement along the entire regional profile.

Finite-difference migration of the reflected and refracted wave's field is based on the extensions of the time and wave fields, which are performed by finite-difference solution of differential equations — the eikonal and the wave equation, respectively. Proofs of the correctness of the calculations are presented in [Verpakhovska, Chorna, 2023].

Thus, the dynamic processing of WARR data using finite-difference migration of the field of reflected/refracted waves yields a correct image of the structure of the crystalline basement layers and allows to confirm and provide additional information to the result of kinematic processing.

Results and discussion. The EUROBRIDGE'97 profile is 530 km long and runs from north to south through the Pripyat Trough, the Korosten Pluton, and the Volyn Block to the Podolian Block of the northwestern part of the Ukrainian Shield [Thybo et al., 2003; Ilchenko, 2002]. Seismic waves were generated by eighteen Shot Points located at approximately 30 km intervals along the profile. Recording was performed by 120 mobile three-component seismographs with a nominal distance of 3—4 km between stations.

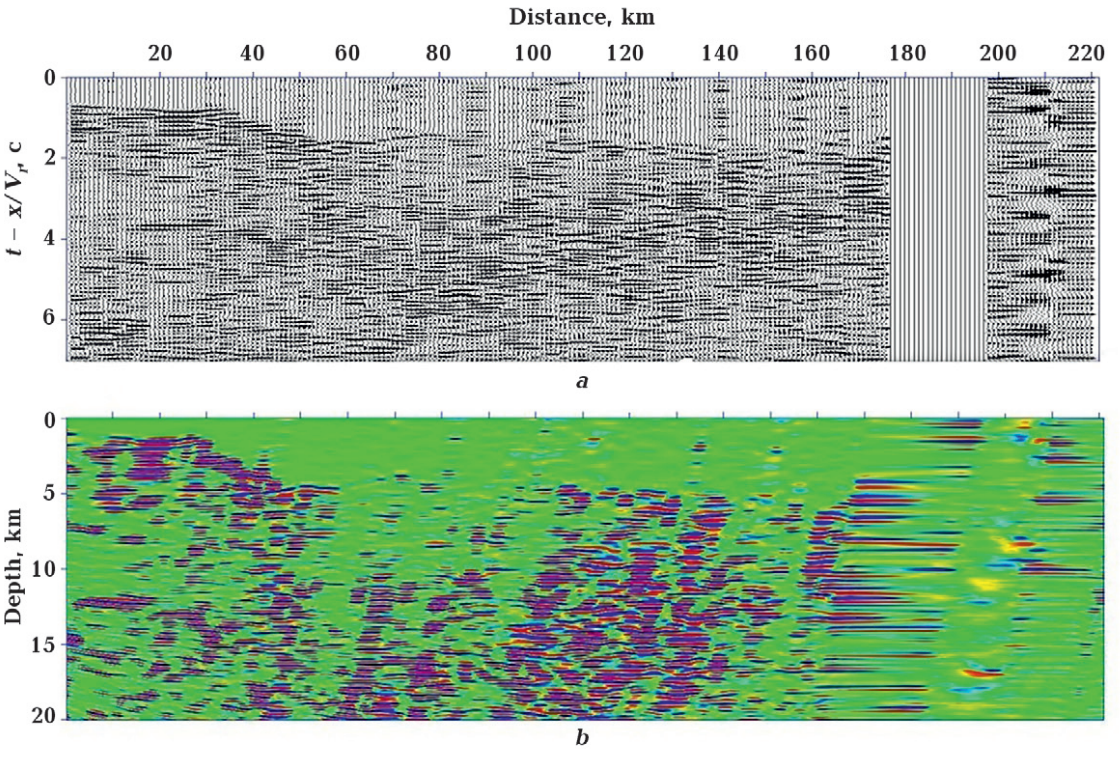

Fig. 3. The observed wavefield interval for Shot Point 1 (0 km) (*a*) and the result of applying finite-difference migration of reflected/refracted wavefields (*b*) showing the deep structure of the crystalline basement.

Within the framework of an international project, kinematic processing of observed seismic wave fields was implemented. As a result, two variants of velocity models along the profile were constructed, which are described in detail in the works [Thybo et al., 2003; Ilchenko, 2002]. We will focus on the modeling results up to a depth of 15 km. Two velocity models, calculated using kinematic processing techniques, are presented in Fig. 4, *a*, *b*. They illustrate the structure of the crystalline basement of the Ukrainian Shield. Both models share a broadly similar structure, with minor size variations that approach the method's resolution limit, however, some differences are still observed in the images.

Therefore, it was appropriate to apply an imaging technique to the wavefields observed along the EUROBRIDGE'97 seismic profile, using finite-difference migration of reflected and refracted wavefields [Verpakhovska, 2021], in order to generate a migrated image of the crystalline basement along the profile. According to the model [Thybo et al., 2003], a significant lateral change in seismic velocity was found along the EUROBRIDGE'97 profile (Fig. 4, *a*). Distinct lateral transition zones were modeled in the upper crystalline crust at distances of 150—210 km from the beginning of the profile (in the southern half of the Pripyat Trough) and 300—350 km. The exact shape and nature of these zones cannot be determined using the wide-angle deep seismic sounding method, which interprets data based on the modeling of refracted and reflected waves at a wide angle. These zones divide the overall deep cross-section of the profile into structural units (crustal blocks) with distinct velocity characteristics: northern, central, and southern parts of the profile, which may spatially correlate with the Osnitsk-Mikashevichi igneous belt, the Volyn Block (which includes the Korosten Pluton), and the Podolian Block.

The most complex and significant structures are located in the upper crust, extending to the depths of 10—15 km. In the northern segment (60—220 km), low *P*-wave velocities

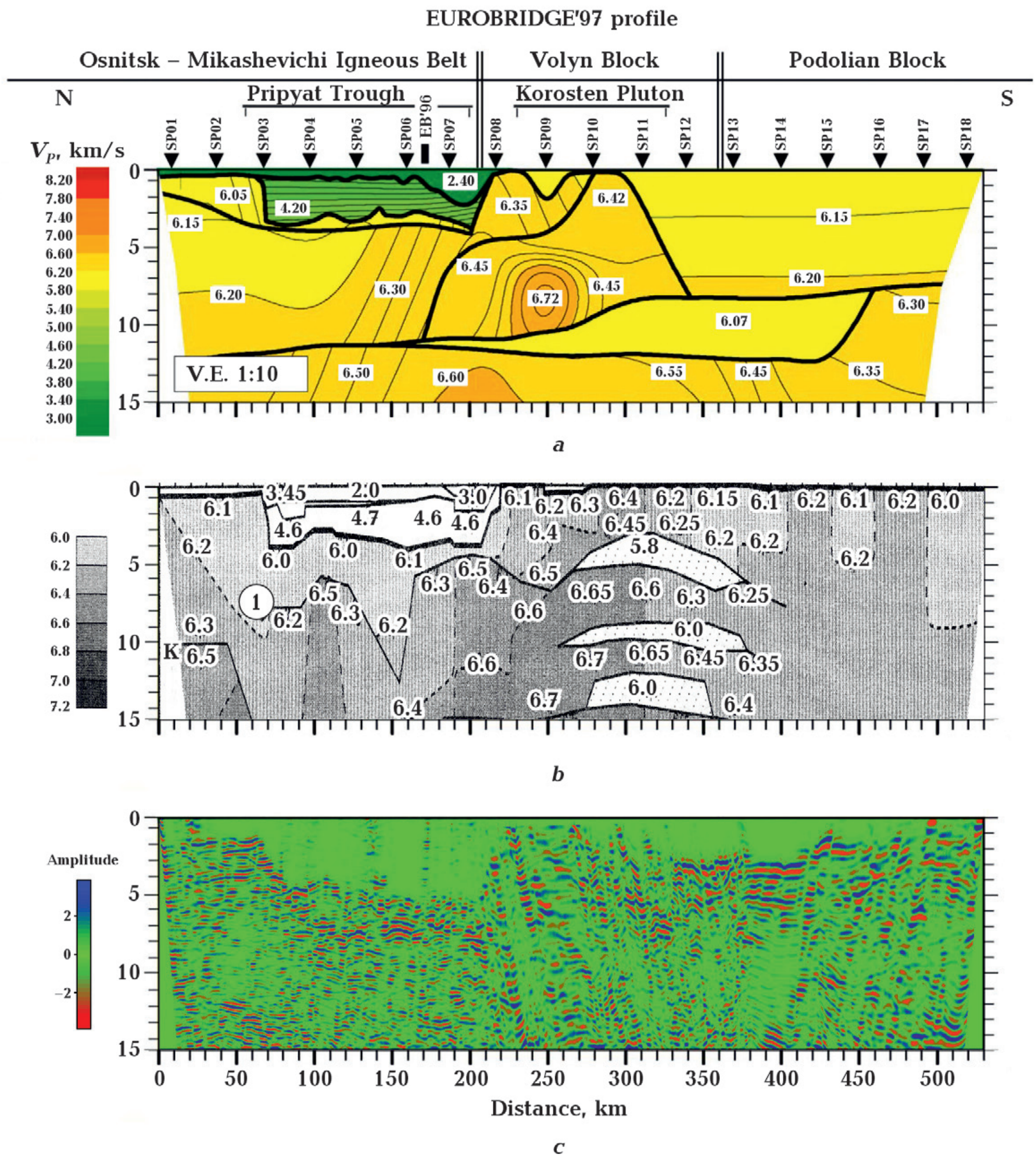

Fig. 4. Results of kinematic and dynamic processing of the EUROBRIDGE'97 profile: *a* — velocity model along the profile down to a depth of 15 km based on [Thybo et al., 2003]; *b* — velocity model along the profile down to a depth of 15 km according to [Ilchenko, 2002]; *c* — the result of applying finite-difference migration of reflected/refracted wavefields.

of approximately 2.4—4.2 km/s are observed within a 4-km-thick layer, representing the sedimentary cover of the Pripyat Trough. The central portion of the profile, near the Korosten Pluton, is characterized by higher velocities typical of the crystalline crust (6.4—6.7 km/s), which are unusually high for the shallow depth interval (0—10 km) where they occur. In both the northern and southern parts of the profile, *P*-wave velocities in the upper crystalline basement range from 6.1 to 6.2 km/s. In the southern part, a small low-velocity zone lies at the base of the crystalline basement and partly overlaps the high-velocity zone of the Korosten Pluton. This low-velocity zone was modeled with a fairly small velocity contrast of approximately 0.1 km/s relative to the surrounding rocks, although its exact velocity could not be determined from the available data.

At the same time, according to the model presented in Fig. 4, *b* [Ilchenko, 2002], a highly complex velocity distribution is observed in the upper crust of the Volyn Block. The most noticeable feature of this model is the presence of vertical velocity inversions, formed by alternating high- and low-velocity layers. The low-velocity layers (up to 6.0 km/s) remain laterally constant, while the rest of the velocity field shows significantly higher values in the northern part of the block.

The profile crosses the Podolian Block of the Ukrainian Shield between 380 and 530 km. The simplest structure of the crust is found here (Fig. 4, *b*), consisting of unstratified upper and lower levels. The upper crust is characterized by alternating velocity values of 6.1 and 6.2 km/s along the basement, which increase with a very low gradient. The transition from the Volyn Block to the Podolian Block is clearly indicated in the velocity model by the absence of low-velocity layers in the upper crust in the Volyn Block.

Along kilometer marks 217—380, the Volyn block of the Ukrainian Shield is replaced by the Prypiat Trough, which the EUROBRIDGE'97 profile crosses mainly on its western edge.

The wavefields along the profile were processed using an imaging method based on finite-difference migration of reflected and refracted waves to visualize the structure of the crystalline basement. The resulting migrated-depth image of the Ukrainian Shield's basement structure is shown in Fig. 4, *c*. Analysis of this image reveals the heterogeneous structure of the Volyn and Podolian Blocks, not visible in the velocity models.

Conclusions. The WARR method of seismic observation has specific features that require a more careful selection of processing techniques. Usually, the main outcome of such data processing is the result of kinematic processing, namely, a velocity model calculated along a regional profile. However, processing based solely on the kinematic characteristics of the recorded wavefield, observed at distances of several hundred kilometers from the source, cannot produce an unambiguous result. This is because the solution to the inverse kinematic problem of seismicity is *a priori* ambiguous. The ambiguity in constructing velocity models is illustrated by comparing two ray-tracing results along the EUROBRIDGE'97 profile. The primary causes of this uncertainty in the WARR data processing include systematic errors in the interpreted travel-time curves and limited data coverage. To obtain more reliable results, it is recommended to apply dynamic processing to regional WARR profiles using the finite-difference migration of reflected and refracted wavefields. This method has demonstrated its effectiveness in processing data recorded at large distances from the source in various parts of the world. According to the literature, it remains the only effective tool in the world for forming deep structural images based on the dynamic characteristics of wavefields observed using the WARR method.

At the same time, the method of the finite-difference migration requires detailed information about the velocity of the geological environment, which can be obtained using kinematic processing. The velocity parameters of the geological section along the EUROBRIDGE'97 profile were derived from the analysis of two calculated velocity models. For the first time, using the finite-difference migration method of reflected/refracted waves, an seismic image of the deep structure of the crystalline basement along the profile was obtained. The presented results have demonstrated the effectiveness of combining kinematic and dynamic processing of WARR data to enhance the informativeness of subsequent interpretation.

The research supports the conclusion that the migrated image obtained through dynamic processing of seismic data recorded at significant distances from the source complements the velocity model derived from the kinematic characteristics of the wavefield, providing additional information about the deep structural features of the study area, leading to a more comprehensive and accurate understanding of the of the structure and dynamics of the Earth's interior.

References

Červený, V., & Pšenčík, I. (1984). SEIS83 — Numerical modelling of seismic wave fields in 2-D laterally varying layered structures by the ray method. In E.R. Engdal (Ed.), *Documentation of Earthquake Algorithms* (pp. 36—40). Rep. SE-35, World Data Center A for Solid Earth Geophysics, Boulder, USA.

Hole, J.A. (1992). Nonlinear high-resolution three-dimensional seismic travel time tomography. *Journal of Geophysical Research: Solid Earth, 97*(B5), 6553—6562. https://doi.org/10.1029/92JB00235.

Ilchenko, T.V. (1985). Methodology for Determining Velocity Models Based on Profile Hodographs of Waves in DSS. *Geofizicheskiy Zhurnal, 7*(1), 40—45 (in Russian).

Ilchenko, T.V. (2002). Research Results Using DSS Method along the Eurobridge-97 Transect. *Geofizicheskiy Zhurnal, 24*(3), 36—50 (in Russian).

Janik, T., Środa, P., Czuba, W., & Lysynchuk, D. (2016). Various Approaches to Forward and Inverse Wide-Angle Seismic Modelling Tested on Data from DOBRE-4 Experiment. *Acta Geophysica, 64*, 1989—2019. https://doi.org/10.1515/acgeo-2016-0084.

Janik, T., Starostenko, V., Aleksandrowski, P., Yegorova, T., Czuba, W., Środa, P., Murovskaya, A., Zayats, K., Mechie, J., Kolomiyets, K., Lysynchuk, D., Wójcik, D., Omelchenko, V., Legostaeva, O., Głuszyński, A., Tolkunov, A., Amashukeli, T., Gryn, D., & Chulkov, S. (2022). Lithospheric Structure of the East European Craton at the Transition from Sarmatia to Fennoscandia Interpreted from the TTZ-South Seismic Profile (SE Poland to Ukraine). *Minerals, 12*, 112. https://doi.org/10.3390/min12020112.

Kendzera, O.V., Omelchenko, V.D., Lysynchuk, D.V., Legostayeva, O.V., Gryn, D.M., Kolomiets, K.V., Tolkunov, A.P., & Chulkov, S.S. (2019). *Deep structure of the lithosphere and seismic hazard in Ukraine.* Kyiv: Naukova Dumka, 197 p. (in Ukrainian).

Klingelhoefer, F., Roest, W., & Graindorge, D. (2021). Raw data from a wide-angle seismic survey offshore French Guyana and Surinam. *SEANOE*. https://doi.org/10.17882/79396.

Lu, C., Liu, Y., & Gao, J. (2025). Reverse Time Migration Method for Joint Imaging of Multiples and Primaries in Vertical Seismic Profiling. *Applied Sciences, 15*(5), 2820. https://doi.org/10.3390/app15052820.

Malinowski, M. (2013). Models of the Earth's crust from controlled-source seismology — where we stand and where we go? *Acta Geophysica, 61*(6), 1437—1456. https://doi.org/10.2478/s11600-013-0156-7.

Murovskay, A., Verpakhovska, O., Hnylko, O., Chorna, O., & Yegorova, T. (2023). Transcarpathian Depression: Study of Low-Velocity Zones in the Earth's Crust Based on the Seismic Regional Profiles Data. *Geofizicheskiy Zhurnal, 45*(2), 30—43. https://doi.org/10.24028/gj.v45i2.278310.

Pylypenko, V.N., & Sokolovskaya, T.P. (1990). Formation of Images of Refracting Boundaries Using the Finite-Difference Method. *Geophysical Journal, 12*(5), 48—54 (in Russian).

Ryberg, T., Haberland, Ch., Weber, M., Bauer, K., Wawerzinek, B., Stiller, M., Krawczyk, Ch., Zanetti, A., Ziberna, L., Hetényi, G., & Müntener, O. (2023). Wide-angle seismic data («fixed spread») from the Oct. 2020 3D survey across the Ivrea Zone, Italy (project SEIZE). GFZ Data Services. https://doi.org/10.5880/GIPP.202016.

Shiraishi, K., No, T. & Fujie, G. (2022). Seismic reflection imaging of deep crustal structures via reverse time migration using offshore wide-angle seismic data on the eastern margin of the Sea of Japan. *Earth Planets and Space, 74*, 28. https://doi.org/10.1186/s40623-022-01590-w.

Starostenko, V., Janik, T., Mocanu, V., Stephenson, R., Yegorova, T., Amashukeli, T., Czuba, W., Środa, P., Murovskaya, A., Kolomiyets, K., Lysynchuk, D., Okoń, J., Dragut, A., Omelchenko, V., Legostaieva, O., Gryn, D., Mechie, J., & Tolkunov, A. (2020). RomUkrSeis: Seismic model of the crust and upper mantle across the Eastern Carpathians — From the Apuseni Mountains to the Ukrainian Shield. *Tectonophysics, 794*. https://doi.org/10.1016/j.tecto.2020.228620.

Starostenko, V., Janik, T., Murovskaya, A., Czuba, W., Środa, P., Yegorova, T., Aleksandrowski, P., Verpakhovska, O., Kolomiyets, K., Lysynchuk, D., Amashukeli, T., Burakhovych, T., Wójcik, D., Omelchenko, V., Legostaeva, O., Gryn, D., & Chulkov, S. (2024). Seismic lithospheric model across Ukrainian Shield from the Carpathians to the Dnieper-Donets Basin and its tectonic interpretation. *Tectonophysics, 892*, 230540. https://doi.org/10.1016/j.tecto.2024.230540.

Starostenko, V., Janik, T., Yegorova, T., Czuba, W., Środa, P., Lysynchuk, D., Aizberg, R., Garetsky, R., Karataev, G., Gribik, Y., Farfuliak, L., Kolomiyets, K., Omelchenko, V., Komminaho, K., Tiira, T., Gryn, D., Guterch, A., Legostaeva, O., Thybo, H., & Tolkunov, A. (2018). Lithospheric structure along wide-angle seismic profile GEORIFT 2013 in Pripyat-Dnieper-Donets Basin (Belarus and Ukraine). *Geophysical Journal International, 212*(3), 1932—1962. https://doi.org/10.1093/gji/ggx509.

Thybo, H., Janik, T., Omelchenko, V.D., Grad, M., Garetsky, R.G., Belinsky, A.A., Karatayev, G.I., Zlotski, G., Knudsen, E., Sand, R., Yliniemi, J., Tiiro, T., Luosto, U., Komminaho, K., Giese, R., Guterch, A., Lund, C.E., Kharitonov, O.M., Ilchenko, T.V., Lysynchuk, D.V., Skobolev, V.M., & Doody, J.J. (2003). Upper lithospheric seismic velocity structure across the Pripyat Trough and the Ukrainian Shield along the EUROBRIDGE'97 profile. *Tectonophysics*, *371*(1-4), 41—79. https://doi.org/10.1016/S0040-1951(03)00200-2.

Verpakhovska, A.O. (2021). Technique for the imaging crystalline basement according to the DSS data. *Geofizicheskiy Zhurnal, 43*(5), 127—149. https://doi.org/10.24028/gzh.v43i5.244076 (in Russian).

Verpakhovska, O., & Chorna, O. (2023). The correctness of the finite-difference problems of the time- and wave fields continuation for the migration image of the basement boundary. *Geofizicheskiy Zhurnal, 45*(6), 36—49. https://doi.org/10.24028/gj.v45i6.293306.

Xu, W., Liu, H.X., Mi, H.G., Zhang, B., Guo, J.-Ch., Ge, Y., & You, J. (2024). High-precision Q modeling and Q migration technology and its applications in loess plateau regions. *Applied Geophysics, 21*, 835—847. https://doi.org/10.1007/s11770-024-1110-y.

Yegorova, T.P., Starostenko, V.I., Kozlenko, V.G., & Yliniemi, J. (2004). Lithosphere structure of the Ukrainian Shield and Pripyat Trough in the region of EUROBRIDGE-97 (Ukraine and Belarus) from gravity modelling. *Tectonophysics, 381*(1-4), 29—59. https://doi.org/10.1016/j.tecto.2002.06.003.

Zelt, C.A., & Barton, P.J. (1998). Three-Dimensional Seismic Refraction Tomography: A Comparison of Two Methods Applied to Data from the Faeroe Basin. *Journal of Geophysical Research: Solid Earth, 103*, 7187—7210. https://doi.org/10.1029/97JB03536.

Zelt, C.A., & Smith, R.B. (1992). Seismic traveltime inversion for 2D crustal velocity structure. *Geophysical Journal International, 108*(1), 16—34. https://doi.org/10.1111/j.1365-246X.1992.tb00836.x.

Zhang, Y., & Li, W. (2023). High-accuracy migration and demigration techniques for active fault seismic exploration. *Applied Geophysics, 20*, 198—208. https://doi.org/10.1007/s11770-023-1011-5.

Кінематична та динамічна обробка сейсмічних даних вздовж профілю EUROBRIDGE'97

К.В. Коломієць, О.О. Верпаховська, О.А. Чорна, Д.В. Лисинчук, 2025

Інститут геофізики ім. С.І. Субботіна НАН України, Київ, Україна

Розглянуто основні процедури кінематичної та динамічної обробки відбитих і заломлених хвиль, зафіксованих методом ширококутового сейсмічного профілювання, та показано, що поєднання їх результатів забезпечує підвищення рівня подальшої інтерпретації.

Кінематична обробка сейсмічних даних є традиційною і базується здебільшого на використанні методу променевого моделювання, результатом якого є розрахована швидкісна модель середовища. Швидкісні характеристики геологічного середовища є необхідними для проведення динамічної обробки.

Динамічна обробка оперує амплітудно-частотними і фазовими характеристиками хвильового поля і передбачає побудову зображення глибинного розрізу з наявними в ньому межами розділу та тектонічними особливостями будови району досліджень. До основних процедур динамічної обробки відносяться різні варіанти міграції, але для обробки сейсмічних даних, зареєстрованих на відстані кількох сотень кілометрів від джерела, вони не розраховані. В Інституті геофізики ім. С.І. Субботіна НАН України розроблено спеціальний метод скінчено-різницевої міграції відбитих/рефрагованих хвиль, який спрямований на обробку саме даних ширококутового сейсмічного профілювання і не має аналогів у світовій практиці.

Як кінематичну, так і динамічну обробку було застосовано до хвильових полів, спостережених уздовж сейсмічного профілю EUROBRIDGE'97. У статі наведено два варіанти швидкісних моделей, які мають схожу загальну структуру вздовж профілю до глибини 15 км, і міграційне зображення до цієї ж глибини, отримане методом скінчено-різницевої міграції відбитих/рефрагованих хвиль.

У результаті залучення динамічної обробки сейсмічних даних уперше сформовано зображення глибинної будови кристалічного фундаменту вздовж профілю EUROBRIDGE'97, що дало змогу отримати додаткові деталі до швидкісної моделі, отриманої кінематичним методом.

Ключові слова: ширококутове сейсмопрофілювання, кінематична обробка, динамічна обробка, скінчено-різницева міграція відбитих/рефрагованих хвиль, сейсмічне моделювання.