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An attempt to preserve archival analog seismic records from geotraverses in Ukraine

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Between 1960 and 1990, extensive deep seismic studies were conducted in Ukraine, significantly enhancing the understanding of the Earth's crust and mantle, particularly within the Ukrainian Shield. This paper introduces a methodology for digitizing analog seismic records preserved on photographic paper, representing a crucial step in safeguarding historical data. Test digitization of a section of the Geotraverse IV demonstrated the feasibility of creating vectorized images, enabling the modern interpretation of seismic

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data. The results confirmed the potential to extract new insights, particularly regarding shear waves, and process them further in the SEG-Y format. Comprehensive scanning and systematic organization of these archives could support the reinterpretation and long-term preservation of valuable scientific data.

Key words: Ukraine, geotraverses, deep seismic studies, seismic records.

Deep Seismic Research in Ukraine (1960—1990). Deep seismic studies (DSS) conducted in Ukraine during 1960—1990 were a pivotal phase in the development of geophysics and geology, uncovering the crust and mantle structure in the region. These studies employed state-of-the-art methods at the time, utilizing seismic waves traveling through different Earth layers [Sollogub, 1982].

One of the key achievements was implementing seismic profiling, enabling the construction of detailed geological models of various Ukrainian regions. Special attention was given to the Ukrainian Shield, one of Europe's oldest geological formations. These studies revealed its deep structure, including crustal thickness, deep faults, and their role in forming mineral deposits [Sollogub et al., 1980; Chekunov, 1988].

In the 1970s—1980s, multichannel seismic methods were introduced, significantly improving data quality. Signal processing techniques such as band pass filtering and automated gain control enhanced the accuracy, allowing researchers to delineate deep layers and analyze tectonic dynamics [Sollogub, Chekunov, 1983; Chekunov, 1987].

Modern Developments and Challenges. The modern phase of deep seismic research in Ukraine began in 1997 with the EURO-

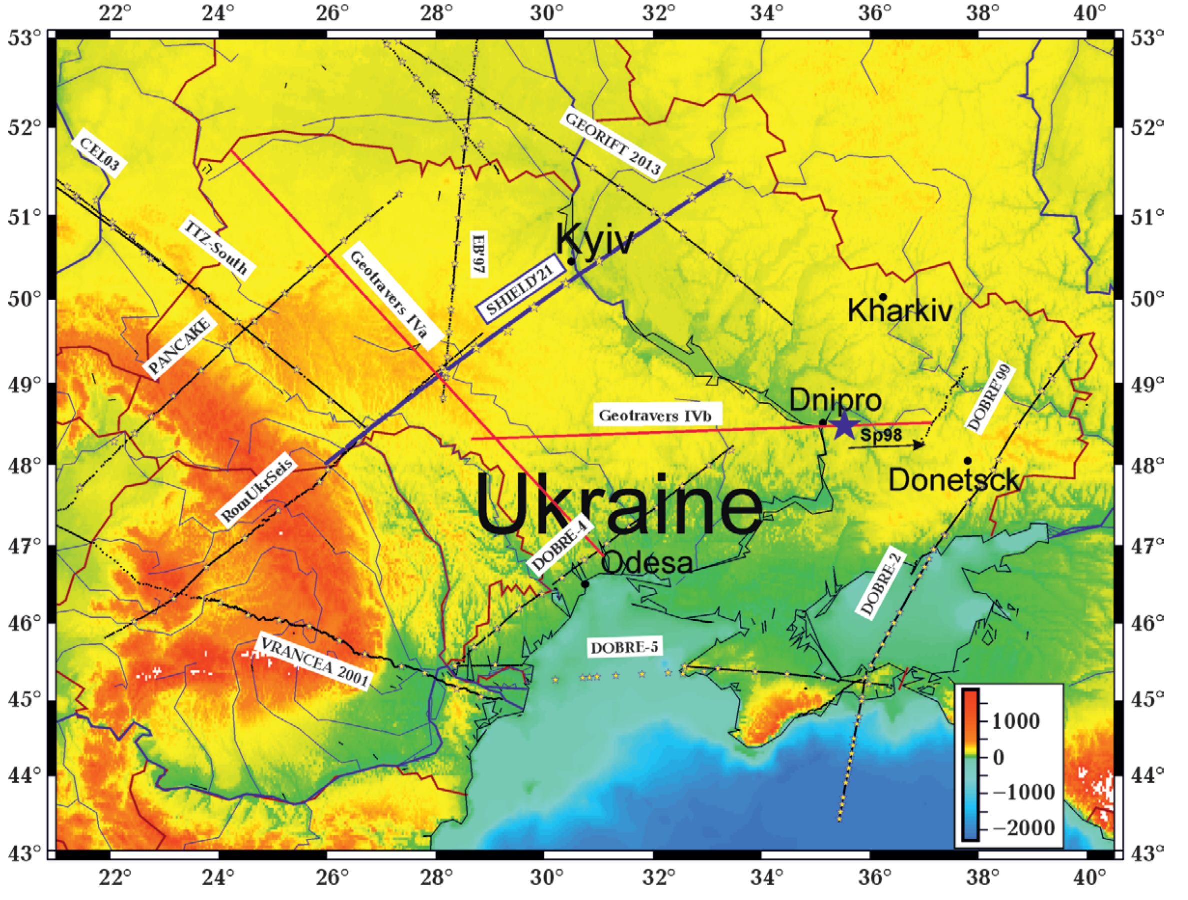

Fig. 1. Location of the Geotraverse IV profile (red lines) and modern refraction seismic profiles (yellow stars — shot points and black dots — recording stations). The big blue star represents shot point 98, the studied seismograms were recorded to the right of shot point 98.

BRIDGE'97 project, employing wide-angle reflection and refraction (WARR) methods using digital recording equipment [Thybo et al., 2003]. Over the next two decades, numerous WARR seismic studies explored the crust and upper mantle across tectonic regions like the Carpathians, Ukrainian Shield, Black Sea Basin, and Dnieper-Donets Basin [Starostenko et al., 2013a, b, 2015, 2016, 2018, 2020, 2024; Janik et al., 2022].

During the same period at tempts were made to reinterpret the available seismic materials, which hallowed obtaining velocity models of the section structure along some geotraverses [Kozlenko, et al., 2009, 2013; Baranova, Yegorova, 2020].

Unfortunately, due to Ukraine's current economic, environmental, and military challenges, continuing such studies using chemical explosions as seismic sources seems impractical. However, the archives of the Institute of Geophysics hold extensive analog seismic records on photographic paper collected during earlier studies. Most of these records are well-documented, with information on project affiliation, geophone placement along profiles, and time markers for seismic wave arrivals.

Initial Digitization Attempt. An initial attempt was made to digitize these records, focusing on a portion of Geotraverse IV (Fig. 1). The total length of Geotraverse IV exceeds 1,000 km, with fieldwork conducted over three years (1969—1972). The research employed the DSS methodology with maximum shot-receiver offsets of approximately 200 km and a geophone spacing of 100 m. Fifteen 48-channel analog records from 1969 were selected for digitization. In the processed section, geophones were spaced at 100 m, covering offsets from 25 to 100 km.

This effort highlights the importance of preserving seismic data, enabling reinterpretation using modern computational tools and providing insights into historical seismic research outcomes.

Digitization Process. To obtain digital raster images, the authors constructed a specialized tripod for the camera, enabling uniform scaling for all 15 seismograms. The next step involved correcting optical distortions in the photographs, cleaning the background from mechanical damage to the paper montages, and enhancing the contrast and brightness of the seismic channel lines. This preparation facilitated tracing seismic records and their conversion from raster to vector format.

For each of the 15 seismograms, vector images were prepared while preserving temporal and spatial scales. This enabled the compilation of a common shot-point seismogram for all 15 48-channel records, as shown in Fig. 2. This vector image can be freely scaled zoomed on a monitor screen, with advantages visible even on a journal page.

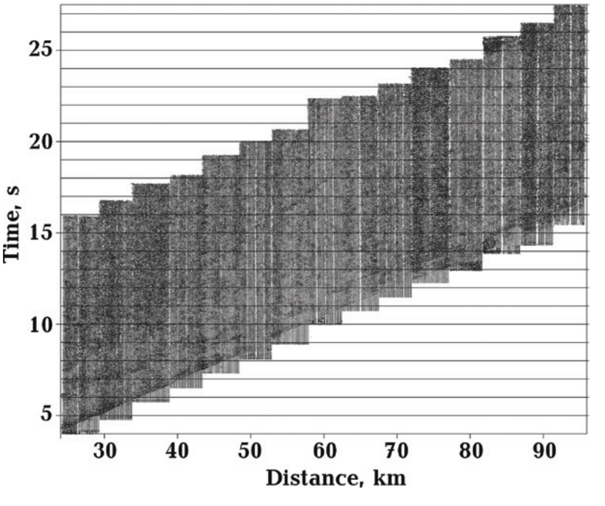

Fig. 2. Common shot-point gather seismogram for all 15 48-channel records.

Interpretation and Findings. The time section in this format allows the identification and correlation of the axes of seismic wave coherence of different types and apparent velocities. It clearly highlights the first arrivals, reflected, and refracted waves in various sections of the Earth's crust, including the Moho reflection. Most corresponding traveltime curves were identified and interpreted during the original research period. However, the computational tools for determining seismic velocities and the depth and geometry of reflecting horizons were significantly less advanced than modern modeling tools for seismic wave propagation in the Earth's crust and upper mantle.

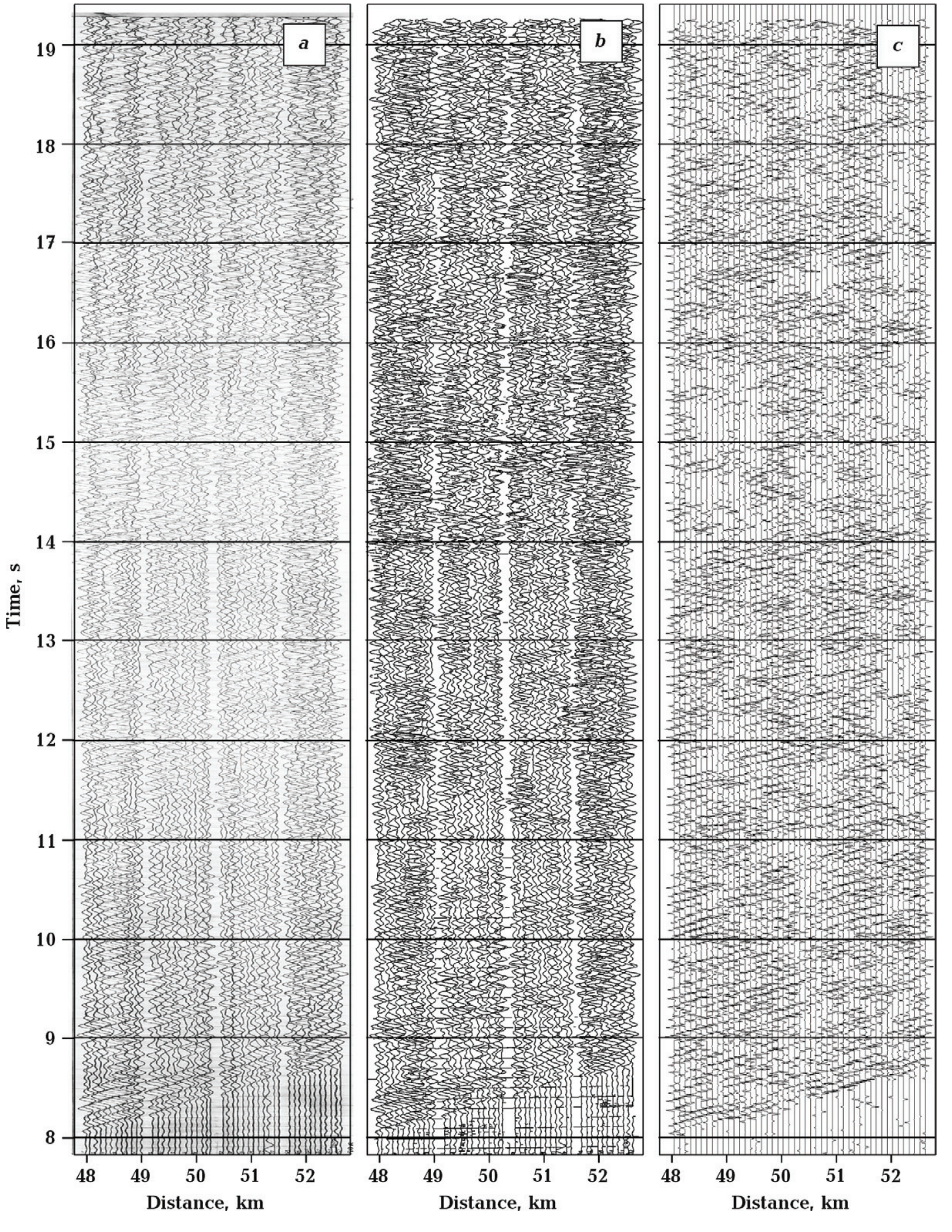

Fig. 3. 48-channel seismogram 6/15: *a* — scanned raster copy of the recording on photo paper; *b* — vectorized seismic traces; *c* — digitized seismic traces in SEG-Y format.

A second major advantage of the seismic section (see Fig. 2) is that it provides interpreters with a comprehensive view of the seismic profile across the entire study area, as opposed to individual 48-channel seismograms, which were 2—4 m long and inconvenient to manipulate due to their 45 cm width.

The third and most intriguing discovery in this seismic section (see Fig. 2) is the detection of transverse waves in the records. These appear as repeated high-energy wavefield arrivals against the background of noise at large times. These arrivals fit a travel-time curve observable on nearly all 48-channel sections. At close distances of 25—30 km, this wave is recorded at 11 seconds, and further along the profile, up to 90 km, it correlates across the entire section with increasing times up to 13 seconds. To our knowledge, identifying and interpreting shear waves in analog seismic observations was not conducted on Geotraverse IV or other projects in Ukraine. This opens significant opportunities for extracting unique new information from seismic archives.

It logically follows that, first, a comprehensive scanning of available analog seismic records stored on photographic paper as 48-channel station records should be undertaken. Second, the raster images should be organized by geotraverses, offsets, observation parameters, and visualizations, creating a corresponding database. Third, raster images should be prepared for vectorization (tracing) of seismic records. Fourth, common shot-point seismograms for all analog records should be created in vector format. In this form, the data will be ready for constructing travel-time systems of useful seismic waves and their interpretation using modern software.

SEG-Y File Creation. At this stage, the preservation of analog seismic records can be considered complete. In the second stage, we propose digitizing the traces and converting them into the standard SEG-Y seismic format, as was done by the authors for marine seismic data from Profile 25 [Malovitskiy, Neprochnov, 1972] in the Black Sea for reinterpretation in the DOBRE5 project [Starostenko et al., 2015].

The task of digitizing analog seismograms is not new. Software has been developed for preserving and digitizing historical earthquake data [Ishii et al., 2014], detecting and recognizing seismic waves in raster images [Bogiatzis, Ishii, 2016], and digitizing analog seismograms using combined automatic and manual methods for recognizing seismic signals [Wang et al., 2016]. The creation of digital archives of analog seismograms and the standardization of data formats are discussed in Lee & Benson [2008].

However, in our case, the problem with using these approaches lies in their design for processing a small number of individual traces. Existing commercial software (IMAGETOSEG-Y), designed for large number of seismic traces, is intended for the CDP method.

We attempted to recognize seismic traces on raster images containing 48 traces with significant overlap. An example of such a seismogram is shown in Fig. 3, *a*, *b* shows the result of vectorizing the raster image of the first seismogram, which was included in the seismogram in Fig. 2 at the corresponding distance and time intervals, albeit at a significantly reduced scale.

For further digitization, the vector image was converted back to the black-and-white raster format, then to a two-dimensional array of zeros and ones, where zero represented white and one represented black. This transformation allowed for cross-correlation of this array with a calculated elementary seismic signal, determining positive and negative maxima, which could be considered signal arrival times, with the correlation coefficient representing the amplitude of the elementary signal. Thus, we determined the signal's time and amplitude.

The next step involved associating arrival points with traces, i.e., determining offsets. It should be noted that offset may affect amplitude since overlapping traces can cause the signal to belong to a neighboring trace, resulting in a significantly higher amplitude. We used an approach that distributes arrivals among traces based on the minimum distance between the nearest trace and the signal arrival point. This approach permits a significant number of errors in amplitude determination but ensures the alignment of maxima on raster and digital seismograms. The result of digitization and SEG-Y file creation is shown in Fig. 3, *c*.

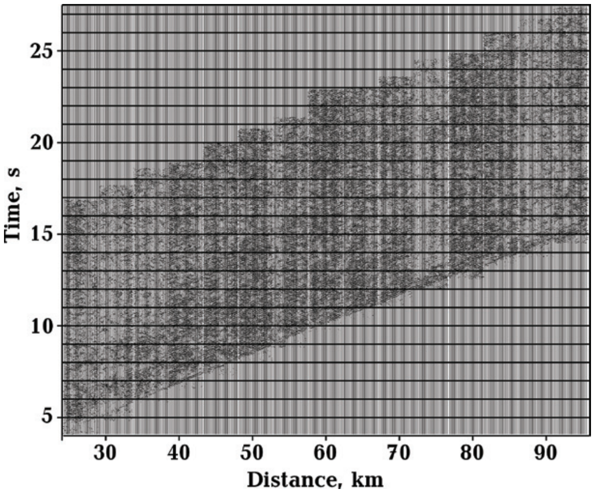

Fig. 4.The general time section containing all 15 digitized and converted to SEG-Yformat seismograms.

The general time section containing all 15 seismograms is presented in Fig. 4. This is a complete SEG-Y that enables all standard seismic data processing procedures used in interpreting deep seismic studies, including velocity reduction, filtering, correlation, and constructing digital travel-time systems for identified waves.

Notably, first arrivals and travel-time curves for reflected waves in the upper/middle crust and even reflections from the crust-mantle boundary can be identified in this section. This is a definite positive outcome. However, shear waves present in the initial section in Fig. 2 are largely absent in the digital SEG-Y records. This is due to significant signal amplitude increases, causing considerable overlap between adjacent traces, complicating signal arrival identification or causing confusion in assigning arrivals to specific traces.

Another drawback of the digital SEG-Y records is the presence of «white spots» throughout the section, resulting from difficulties in determining signal arrivals and offsets in areas of significant amplitude growth.

Conclusions. The archives of the Institute of Geophysics contain analog seismic records on large paper media obtained during 1960—1990 for Geotraverses I—VIII and other regional projects. The total length of just Geotraverse IV, part of which is discussed in this study, exceeds 1000 km.

To preserve the archive of analog seismic data, comprehensive scanning of available photomontages with careful identification of project details, excitation point numbers, distances, and time marks is required.

The successful test digitization of a section of Geotraverse IV presented in this study demonstrates that the proposed processing not only preserves the valuable results of previous seismic studies but also enables obtaining entirely new data, such as shear wave investigation.

In the future, digitized old analog seismic records can be reinterpreted using modern computer processing and modeling tools.

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Спроба збереження архівних аналогових сейсмічних записів з геотраверсів в Україні

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У період 1960—1990 рр. в Україні було проведено масштабні глибинні сейсмічні дослідження, які значно розширили знання про будову земної кори та мантії, зокрема в межах Українського щита. Стаття присвячена розробці методики оцифрування аналогових сейсмограм, що зберігаються на фотопапері, для їх подальшого аналізу сучасними методами. Пілотний проєкт на ділянці геотреверсу IV підтвердив можливість створення векторизованих зображень, що відкриває нові перспективи для дослідження навіть за поперечними хвилями. Також продемонстровано потенціал перетворення цих даних у формат SEG-Y, що сприяє їх довгостроковому збереженню та повторному аналізу.

Результати підтверджують необхідність систематизації архівних матеріалів, їх сканування та переведення у цифровий формат для подальшого моделювання. Це дасть змогу отримати нову корисну інформацію з архівних даних і застосувати сучасні комп'ютерні методи для їх обробки.

Ключові слова: Україна, геотраверси, глибинні сейсмічні дослідження, сейсмічні записи.