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Seismic Indicators of Potential Gas Hydrate Manifestations in the Black Sea

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SUMMARY

Gas hydrates in the Black Sea are an important object of marine geological and geophysical studies. Their identification from seismic data remains a challenging task, because related indicators may be weakly expressed, discontinuous or masked by marine noise and the complex structure of the sedimentary sequence. The aim of this study is to analyse seismic indicators of potential gas hydrate manifestations using marine multichannel seismic profile V-2 in the northwestern part of the Black Sea as an example. The interpretation focuses on indirect features of hydrate-bearing or gas-saturated sediments, including bottom-simulating-reflector-like geometry, polarity changes, amplitude anomalies, reduced-reflectivity zones and high-amplitude events. The profile was processed using Seismic Unix to improve signal quality and prepare the section for preliminary interpretation. The processing workflow included geometry assignment, muting of early arrivals, band-pass filtering, automatic gain control, normal moveout correction, sorting by common depth points and stacking. As a result of processing, the noisy initial wavefield was transformed into a more ordered stacked time section. The obtained section demonstrates better continuity of reflecting horizons and clearer amplitude variations. These results provide a basis for identifying possible gas hydrate-related features along profile V-2. At the same time, the identified features remain indirect indicators, and their confirmation requires further velocity analysis, seismic attribute analysis and comparison with regional geological data.

Keywords: Gas hydrates; Black Sea; Seismic indicators; Bottom-simulating reflector; Seismic profile; Seismic Unix; Stacking.

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Introduction

Gas hydrates are an important object of marine geological and geophysical studies because their formation is associated with methane accumulation in the sedimentary sequence and specific pressure-temperature conditions of the marine environment. They form in the presence of water, a sufficient amount of gas, mainly methane, high pressure, relatively low temperature and appropriate sediment properties. The Black Sea is considered a promising region for gas hydrate research due to its thick sedimentary cover, deep-water areas, continental slope, paleo-deltaic complexes, tectonic faults, mud volcanism and natural methane seepage from bottom sediments. These factors create favourable conditions for the formation of gas hydrate systems, especially in the northwestern part of the basin and near the Dnieper paleo-delta (Kobolev & Verpakhovskaya, 2014; Mohamed et al., 2026; Wang et al., 2026).

Marine seismic methods are one of the main tools for studying gas hydrates because they allow indirect indicators of hydrate-bearing or gas-saturated sediments to be detected. The most important indicator is the bottom-simulating reflector, or BSR, which usually follows the morphology of the seafloor but may cross stratigraphic horizons, as it is related not to a lithological boundary but to the lower boundary of the gas hydrate stability zone or to the transition to a free gas zone. The physical nature of the BSR is controlled by acoustic impedance contrast: gas hydrates may increase sediment stiffness and P-wave velocity, whereas free gas decreases compressional-wave velocity and changes the amplitude response. Therefore, potential gas hydrate manifestations should be analysed using a combination of features, including BSR-like geometry, polarity changes, amplitude anomalies, reduced-reflectivity zones and high-amplitude reflections below the BSR-like boundary. However, these indicators are not unambiguous, as similar features may also be caused by lithological changes, porosity variations, structural features or seismic data quality (Carcione & Tinivella, 2000; Clairmont et al., 2021; Shi et al., 2025).

The interpretation of such indicators strongly depends on the quality of digital seismic data processing. Marine seismic records are often complicated by water-layer reverberations, multiple waves, ghost reflections, low-frequency noise and source-related effects. These components may mask weak BSR-like events, distort amplitudes and reduce the continuity of reflecting horizons. Therefore, digital processing should be aimed at improving the signal-to-noise ratio while preserving diagnostically important characteristics of the wavefield, including reflector geometry, amplitude expression and polarity (Verpakhovska et al., 2022). The aim of this study is to analyse seismic indicators of potential gas hydrate manifestations in the Black Sea using marine multichannel seismic profile V-2 as an example. Special attention is paid to the role of Seismic Unix processing in preparing the seismic wavefield for the recognition of BSR-like reflections, polarity changes, amplitude anomalies, reduced-reflectivity zones and high-amplitude events that may be associated with hydrate-bearing or gas-saturated sediments.

Method and Theory

The study is based on the analysis of indirect seismic indicators of potential gas hydrate manifestations and on the digital processing of marine multichannel seismic data from profile V-2. The interpretation focused on a set of features that may indicate hydrate-bearing or gas-saturated sediments, including BSR-like reflections, polarity changes, amplitude anomalies, reduced-reflectivity zones, high-amplitude reflections and velocity-related effects.

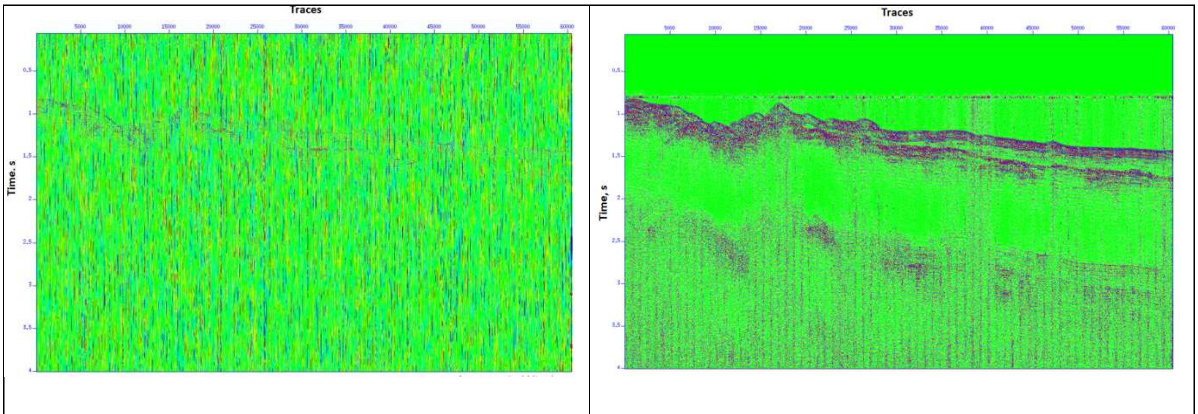
A BSR-like reflection is considered the main seismic indicator because it usually follows the morphology of the seafloor, but may cross stratigraphic horizons. This boundary is related not to a lithological contact, but to the lower boundary of the gas hydrate stability zone or to the transition between hydrate-bearing sediments and an underlying free gas zone. Additional indicators may include polarity changes caused by acoustic impedance contrast, reduced-amplitude zones above the BSR-like boundary and high-amplitude reflections below it, which may be associated with possible free gas accumulation (Carcione & Tinivella, 2000; Clairmont et al., 2021; Shi et al., 2025).

The input data are represented by marine multichannel seismic profile V-2, which belongs to a set of seismic observations carried out by the S. I. Subbotin Institute of Geophysics of the National Academy of Sciences of Ukraine in the northwestern part of the Black Sea. The profile was acquired in 2013 using the reflected wave method and the common depth point acquisition scheme on board the research vessel Professor Vodyanytskyi. The acquisition system included the XZone® Bottom Fish digital seismic telemetry system, air-gun sources and a 72-channel towed streamer.

To prepare the data for interpretation, profile V-2 was processed using Seismic Unix. The processing workflow included conversion of seismic records into SU format, merging of shot gathers, trace header control, acquisition geometry assignment, calculation of source and receiver coordinates, offset definition, muting of early arrivals, band-pass filtering, automatic gain control, normal moveout correction, CDP sorting and stacking. As a result, a CDP stacked time section was obtained and used for analysing reflector geometry, reflection continuity, amplitude variations and possible gas hydrate-related features along profile V-2.

Results

The processing of marine seismic profile V-2 was performed to improve the quality of the recorded wavefield and to prepare the data for the preliminary analysis of possible seismic indicators related to gas hydrates. The initial records were characterized by noise, early arrivals and insufficient continuity of reflecting horizons, which complicated the interpretation of the deeper part of the sedimentary section (Figure 1a).



a *b*

Figure 1. *Observed wavefield of marine seismic profile V-2: a - before preliminary digital processing; b - after muting of early arrivals, band-pass filtering and automatic gain control in Seismic Unix*

At the first stage, the seismic records were converted into SU format, merged into a single dataset and checked using trace headers. Then, the acquisition geometry was assigned by defining source and receiver coordinates, offset values, field record numbers and common depth point (CDP) numbers. This stage was necessary for the correct application of normal moveout correction and further stacking.

Preliminary digital processing included muting of early arrivals, band-pass frequency filtering and automatic gain control. The early part of the record up to 0.8 s was muted to reduce the influence of waves that do not provide useful information about the deeper part of the sedimentary sequence. Band-pass filtering made it possible to suppress low- and high-frequency noise, while automatic gain control improved the visibility of weaker reflections at later recording times. After these procedures, the wavefield became more ordered: the influence of noise decreased, reflecting horizons became more continuous, and their amplitude expression improved (Figure 1b).

This improvement is important for the aim of the study, because potential gas hydrate indicators may be weak or partly masked in the initial records. In particular, BSR-like events, reduced-reflectivity zones and local amplitude anomalies require sufficient signal quality and reflection continuity for further analysis.

The next processing stage included normal moveout correction, sorting of traces by CDP and offset, and stacking. NMO correction compensated for differences in arrival times of reflected waves caused by different source-receiver offsets. After sorting and stacking, traces corresponding to the same subsurface area were combined into one representative CDP trace. As a result, coherent reflected signals were enhanced, while random noise was partly suppressed.

The main result of the processing is the CDP stacked time section of profile V-2 (Figure 2). Compared with the initial wavefield, the stacked section provides a more ordered image of the sedimentary sequence and allows the main reflecting horizons to be traced more clearly. In addition, it makes it possible to evaluate lateral changes in reflection continuity and amplitude variations along the profile.

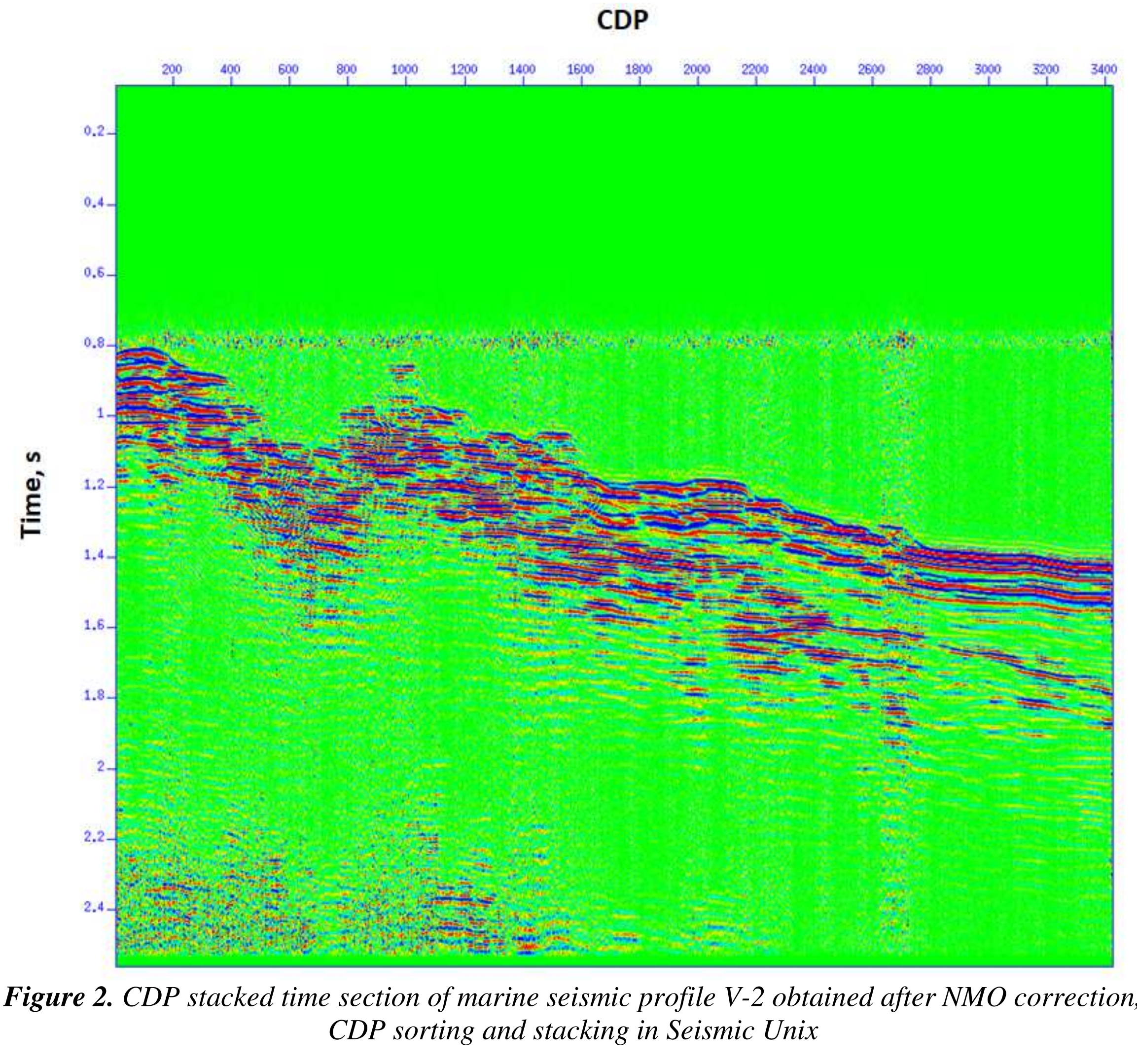


Figure 2. *CDP stacked time section of marine seismic profile V-2 obtained after NMO correction, CDP sorting and stacking in Seismic Unix*

The most informative interval is approximately 0.8-1.8 s, where the main reflection packages are expressed most clearly. Within this interval, special attention should be paid to the geometry of reflecting horizons, their continuity, amplitude changes and possible local high-amplitude events. Such features may indicate changes in sediment properties or fluid saturation and can be considered as possible indirect indicators of hydrate-bearing or gas-saturated sediments.

Thus, the applied Seismic Unix processing workflow made it possible to transform the noisy initial wavefield into a CDP stacked time section suitable for preliminary analysis. The obtained section provides a basis for identifying possible BSR-like reflections, reduced-reflectivity zones, amplitude anomalies and high-amplitude events that may be associated with gas hydrate-related processes in the Black Sea. At the same time, these features cannot be considered direct evidence of gas hydrates; they require further verification using velocity analysis, seismic attributes and regional geological information.

Conclusions

The study shows that potential gas hydrate manifestations in the Black Sea should be interpreted using a combination of indirect seismic indicators. The most important features include BSR-like reflections, polarity changes, amplitude anomalies, reduced-reflectivity zones and high-amplitude events that may indicate the presence of hydrate-bearing or gas-saturated sediments. Processing of marine seismic profile V-2 in Seismic Unix made it possible to improve the quality of the recorded wavefield and obtain a CDP stacked time section. The applied processing workflow included geometry assignment, muting of early arrivals, band-pass filtering, automatic gain control, normal moveout correction, CDP sorting and stacking. The obtained stacked section demonstrates better continuity of reflecting horizons, clearer amplitude variations and a more ordered structure of the sedimentary sequence. The interval of approximately 0.8-1.8 s is the most informative for preliminary analysis, because the main reflection packages are most clearly traced within it. The prepared CDP section provides a basis for further analysis of possible gas hydrate-related features along profile V-2. At the same time, the identified features remain indirect indicators and require verification using velocity analysis, seismic attributes and comparison with regional geological data.

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