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OIL AND GAS GEOLOGY

GAS SHOWS WITHIN THE SOUTHEASTERN SHELF OF THE CRIMEA ACCORDING TO CONTINUOUS SEISMOACOUSTIC PROFILING DATA

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Abstract. The research was carried out by a team from the Institute of Oceanology of the Russian Academy of Sciences during the expeditions of the research vessels (RV) "Peleng" of the Sevastopol branch of the State Oceanographic Institute and "Professor Vodyanitsky" of the Federal Research Center InBYuM (115th, 116th, 124th and 126th voyages) in 2018–2023 in accordance with the Plan of Marine Expeditions on Research Vessels of the Ministry of Education and Science of Russia. At the same time, the tasks of depth measurements, continuous seismic profiling (CSAP) and acoustic sounding of sedimentary deposits, as well as panoramic survey of the bottom surface using a side-scan sonar were solved. The objectives of the study included: firstly, obtaining new geological and geomorphological data on the history of the development of the Crimean Peninsula shelf, necessary for restoring poorly studied stages of the paleogeographic history of the formation of the continental margin of Crimea in modern times, which will clarify the existing ideas about the change in the Black Sea level, and secondly, obtaining new geological and geomorphological data on the paleogeomorphology of the Crimean Peninsula shelf, which will clarify the position of the ancient hydrographic network and establish the connections of coastal and subaqueous morphostructures. In the process of interpreting continuous seismoacoustic profiling (CSAP) data, anomalous areas identified with gas accumulations were identified in the bottom part of the section.

Keywords: *shelf, Crimea, continuous seismoacoustic profiling (CSAP), sparker, acoustic profiler, echo sounder, gas seep, methane, seismic complex, reflecting horizon*

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INTRODUCTION

The research was carried out by a team from the Institute of Oceanology of the Russian Academy of Sciences during expeditions on research vessels (R/V) "Peleng" of the Sevastopol Branch of GOIN and "Professor Vodyanitsky" of FRC IBSS (cruises 115, 116, 124, and 126) in 2018–2023 in accordance with the Marine Expedition Plan for research vessels of the Ministry of Education and Science of Russia.

The research objectives included obtaining new geological and geomorphological data on the development history of the Crimean peninsula shelf, necessary for reconstructing poorly studied stages of the paleogeographic history of the Crimean continental margin formation in recent times, which will help refine existing concepts about Black Sea level changes, clarify the position of the ancient hydrographic network, and establish connections between coastal and subaqueous morphostructures. The tasks included depth measurements, continuous seismic profiling (CSP) and acoustic sounding of sedimentary deposits, as well as panoramic imaging of the seabed surface using side-scan sonar.

It should be noted that studies with similar goals and objectives in this area were conducted by a number of research organizations. Among them, the works of the Kovalevsky Institute of Biology of Southern Seas RAS, the Institute of Geological Sciences of the NAS of Ukraine, SSC JSC Yuzhmorgeologiya, Lomonosov Moscow State University, and others should be highlighted [1–6].

Technically, the implementation of research tasks included: echo sounding and seismoacoustic profiling of the shelf, performed to measure depths and obtain images of the structure of the upper layer

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of sedimentary deposits in the form of sections along the vessel's route using towed unmanned underwater vehicles (TUUV), in particular, seismoacoustic and acoustic profilers (Fig. 1). During the work, numerous anomalous zones associated with gas accumulations in the upper part of the sedimentary cover were identified. Given that seismoacoustic research using the CSP method in this part of the Crimean shelf was practically not conducted before, and acoustic profiling was carried out very limitedly, it can be stated that almost all near-bottom gas accumulations discovered by the seismoacoustic team of the Shirshov Institute of Oceanology RAS in 2018–2023 were identified for the first time.

RESEARCH METHODS

For CSAP, the "Geont-shelf" seismoacoustic complex based on an electric spark emitter ("sparker") and a receiving seismic streamer was used. Information obtained using the "Geont-shelf" seismoacoustic complex was supplemented with data from geoacoustic sounding using the AP-5T profiler with a working frequency of 5 kHz, which uses a frequency-modulated pulse.

The seismoacoustic complex "Geont-shelf" includes:

– SPES-600 seismic energy accumulator: discharge control unit and high-voltage capacitor unit,

– PSA-1 seismic signal input device,

– towed overboard part: sparker emitter and receiving antenna (seismic streamer),

The towed overboard part of the equipment consists of:

– multi-electrode sparker emitter (with 64 potential electrodes);

– receiving antenna: 25-meter seismic streamer with 10 piezoelectric receivers placed in a polyurethane hose at 2-meter intervals and filled with liquid paraffin;

– 5-meter towing rod ("Vystrel") with nylon halyard braces;

– towing cable for the sparker emitter and receiving seismic streamer;

The seismic streamer was towed from the starboard side using an extendable "Vystrel" rod, and the profiler gondola was lowered overboard using a U-frame (Fig. 2).

The design and operating principle of this equipment are described in detail in works [7, 8].

RECORDING PARAMETERS

Before starting operations, the seismic survey equipment was calibrated. Setup recordings of the CSAP were made, based on which the following recording parameters were established:

– emitter power not less than 600 J at C = 50 μF;
– frequency range 100–1200 Hz;
– emission period 1.5 sec;
– gain 20 · 100 = 2000;
– recording time 100 μs · 4000 = 400 ms;
– vessel speed 8–10 knots.

As depths changed, the recording parameters were adjusted. In addition to the profiler with a "sparker" type source, which was used to study the near-bottom section, a high-frequency acoustic profiler and shipboard echo sounder were used in these cruises. To investigate the structure of the upper sediment deposits, a method of continuous

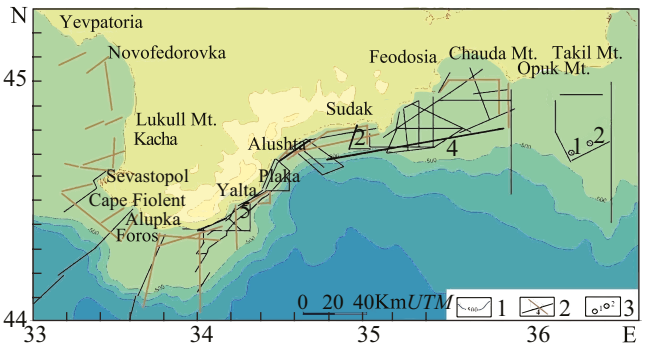

Fig. 1. Scheme of R/V "Professor Vodyanitsky" operations in 2018–2023. 1 – isobaths; 2 – seismoacoustic profiles of the "Geont-shelf" CSAP complex (black color) and acoustic profiles of the AP-5T profiler (brown color); 3 – wells from engineering-geological surveys (EGS).

Fig. 2. Photo of the R/V "Professor Vodyanitsky", showing the towing devices for seismic equipment. The arrow indicates the "Vystrel" towing rod.

acoustic profiling was applied while the vessel was moving, using acoustic pulses with linear frequency modulation (LFM) of the carrier frequency, which was implemented using the AP-5T acoustic profiler developed at the P.P. Shirshov Institute of Oceanology RAS. The AP-5T includes a towed body (carrier of acoustic antennas), a cable towing line, a storage cable winch, a ship's electronic unit, and a personal computer for data display and recording. When converting time to depth, the wave velocity was considered constant and was assumed to be equal to the velocity in the upper soil layer.

RESEARCH RESULTS AND DISCUSSION

Taking into account the study of the upper part of the sedimentary cover of the Crimean shelf and the Kerch-Taman shelf, as well as the results of ostracod fauna studies in the engineering-geological wells Glubokaya-1 and Glubokaya-2 (see Fig. 1), it was established that the structure of the seismic complexes identified on seismoacoustic profiles includes Holocene New Black Sea and Old Black Sea deposits (SC-7), New Euxinian deposits of the Upper Neopleistocene (SC-6), Karangatian and Uzunlarian (SC-5, SC-4), and Old Euxinian (SC-3) deposits of the Middle Neopleistocene. Seismic complexes SC-2 and SC-1 are represented, apparently, by older, Early Neopleistocene deposits of the Chaudian rhythm. The lower layers lie on the Triassic-Jurassic rocks of the Taurian series, which form the basement. A more detailed seismostratigraphic division of the Neogene-Quaternary deposits of the southeastern shelf of Crimea, tied to engineering-geological drilling wells on the Glubokaya structure, is provided by us in the paper [9].

When interpreting the obtained results, anomalous sections of the record were identified, stratigraphically confined to the Upper Pleistocene deposits and identified as natural gas accumulations. It was noted that some of the detected anomalies are confined to areas of paleodelta development within the Pleistocene buried hydrographic network. It is known that each river has a two-story structure. In addition to sand accumulations associated with alluvial fans of paleo-rivers, alluvial deposits of their subchannel bed can also serve as an accumulating reservoir on the southeastern shelf. Significant gas-fluid accumulations may be associated with this part of the paleodelta.

Fig. 3 shows a fragment of a seismoacoustic profile, where paleochannel deposits and associated gas accumulations are observed in the interval of 80–120 m.

The marked areas differ from adjacent ones by a number of dynamic and kinematic features characteristic of gas manifestations in the seismic wave field.

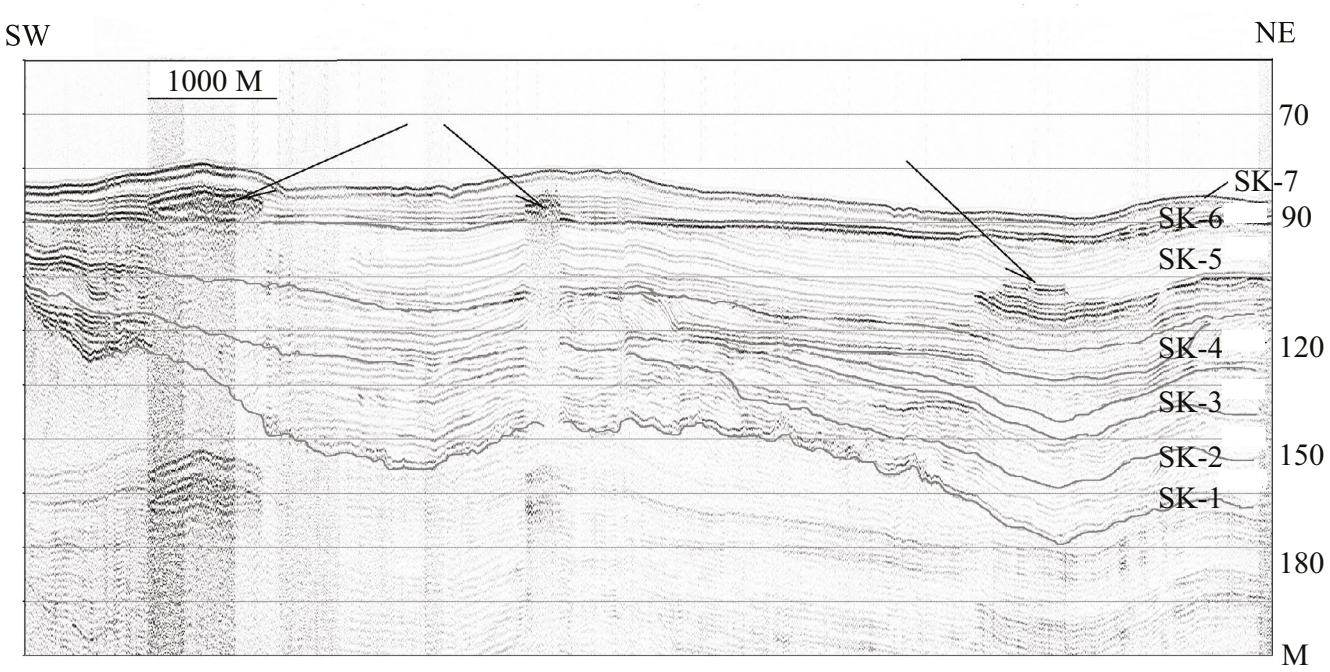

Fig. 3. Fragment of seismoacoustic profile 1 NSAP on the traverse of Yalta. Arrows indicate gas accumulations confined to Upper Neopleistocene deposits.

The most characteristic features creating anomalous effects in the reflected wave field are: sharp increase in amplitudes, changes in wave polarity from positive to negative, deflection of the underlying reflecting horizons beneath "bright spots" due to decreased wave velocity in gas-bearing soils.

The methodology for identifying gas anomalies and their interpretation in the seismic wave field of the Black Sea and other water areas is described in detail in several works [10-12].

Fig. 4 shows gas accumulations identified on seismoacoustic profiles in the near-bottom part of the section, confined to the Upper Pleistocene-Holocene deposits.

The anomalous zones identified by seismic features and associated with gas accumulations are divided by us into three types.

The first type of anomalies is associated with near-bottom "rootless" gas accumulations resulting from diagenesis in tertiary deposits. They form characteristic zones of correlation loss caused by the absorption of seismic signals in areas of gas accumulations. Identified by amplitude-frequency characteristics, the lateral dimensions of these accumulations can reach several kilometers. Fig. 5 shows a correlation loss zone associated with a local gas accumulation in the near-bottom part of the southeastern shelf at the meridian of Sudak city. Such accumulations are formed as a result of lateral fluid movement along the rise of layers. Apparently, the gas-fluid mixture migrates through sandy interlayers from the Western Black Sea depression upward along the rising layers toward the shore.

The second type of anomalies is caused by vertical flows of deep gas under the influence of abnormally high formation pressures, with characteristic narrow vertical zones, often referred to in publications as "fluid breakthrough." They are characterized by a vertical columnar shape and directionality with the formation of small elevations in the bottom relief, up to several meters in height and tens or even hundreds of meters in width. Within them, a complex recording pattern is observed, apparently associated with accumulations of sand carried by fluid flows through vertical faults from deep horizons, forming elevations in the bottom relief. In relation to the general nature of the recording, such areas have a clearly destructive character,

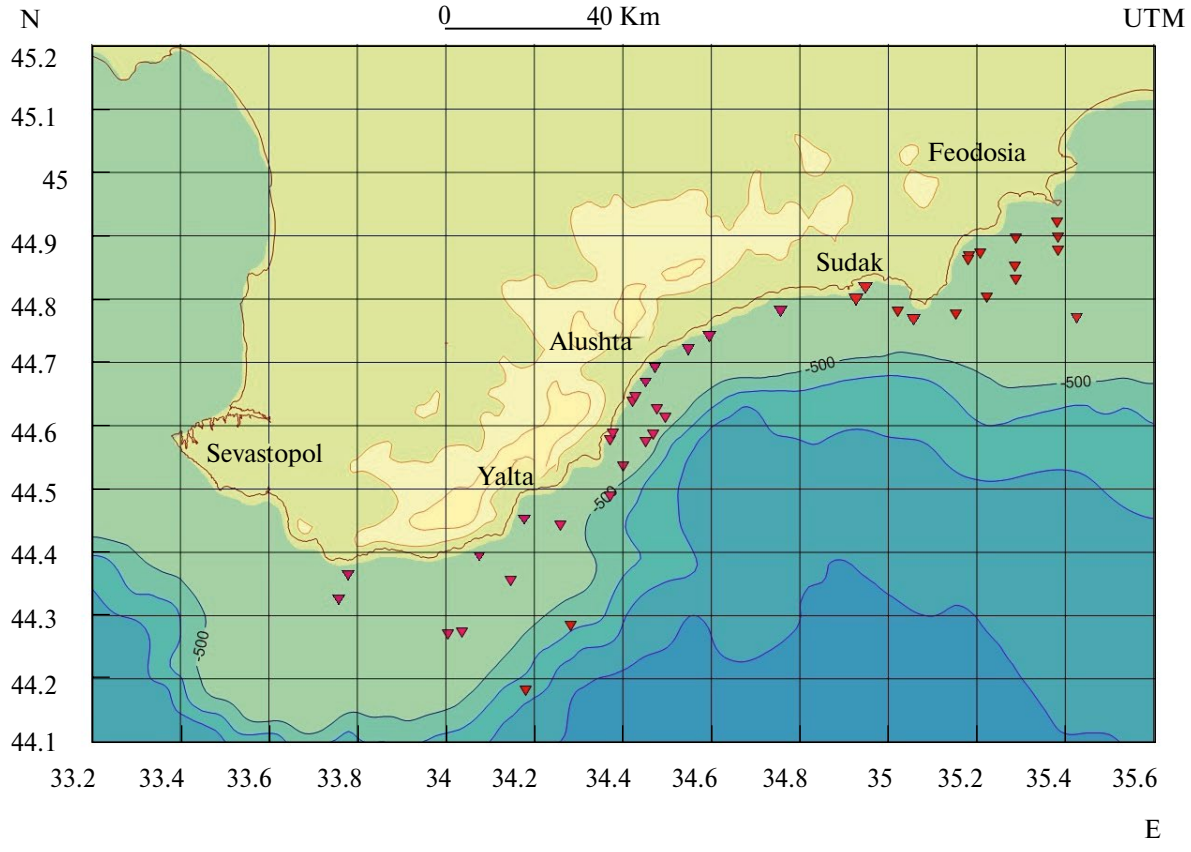

Fig. 4. Scheme of gas accumulations in the southeastern part of the Crimean shelf based on seismoacoustic profiling data.

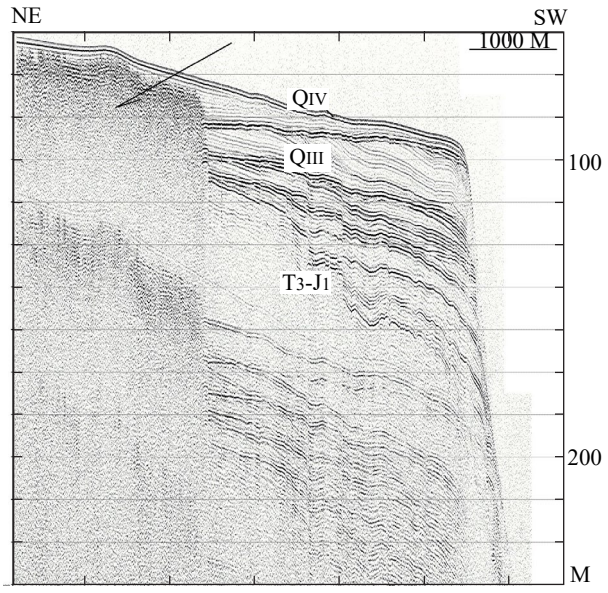

Fig. 5. Fragment of seismoacoustic profile 2 of NSAP of the shelf and slope in the area of Sudak Bay. The arrow indicates gas accumulation in Upper Pleistocene deposits.

therefore in specialized literature they are, in certain cases, called zones of destruction. In Fig. 6, arrows indicate elevations in the bottom relief in Quaternary deposits south of Alushta, apparently formed by the discharge of a gas-water mixture, with the removal of sandy material to the bottom surface.

The elevations in the seabed relief noted above are a manifestation form of local gas flows of deep hydrocarbons, usually accompanied, in addition to sand, by emissions of mud breccia, detrital material, water, and forming cone-shaped hills with craters at the tops. The formation of mud volcanoes is characteristic of hydrocarbon seepage sites. There are many examples of such formations, both in the Black Sea and in other water areas [12].

Geodynamic activity in the geological area from Yalta to Alushta manifests itself through fault systems and individual vertical zones of rock destruction. Traces of deep fluid flows are subvertical geological bodies that penetrate to the surface along major discontinuities in the sedimentary cover and are associated with intense localized discharge zones of hydrocarbon fluids. The noted subvertical geological bodies can serve as hydrocarbon migration channels, manifesting on the surface as gas, oil, and water seeps. As a consequence, volcanism, diapirism and vertical structure formation, release and jet vertical migration of hydrogen, lateral migration of mobile fluids, and other geological processes associated with this phenomenon are observed in these zones [13].

The gas composition was studied jointly by researchers from the A.O. Kovalevsky Institute of Marine Biological Research of RAS (Sevastopol) and Lomonosov Moscow State University. Samples of bubble gas were collected by them using special gas traps installed on the seabed in the area of Cape Fiolent, Laspi Bay, the coastal area of Yalta, and others. The conducted studies of the gas seeps composition showed that methane predominates in the component composition of the bubble gas. The polygenic composition of methane fluid flows established by these works is most likely explained by their deep migration [14, 15].

The third type of anomalies is related to the elevated basement rock blocks of the southeastern continental margin of Crimea. Gas accumulations are confined to them, which appear on seismoacoustic profiles as dynamically darkened areas within which there is a loss of correlation of

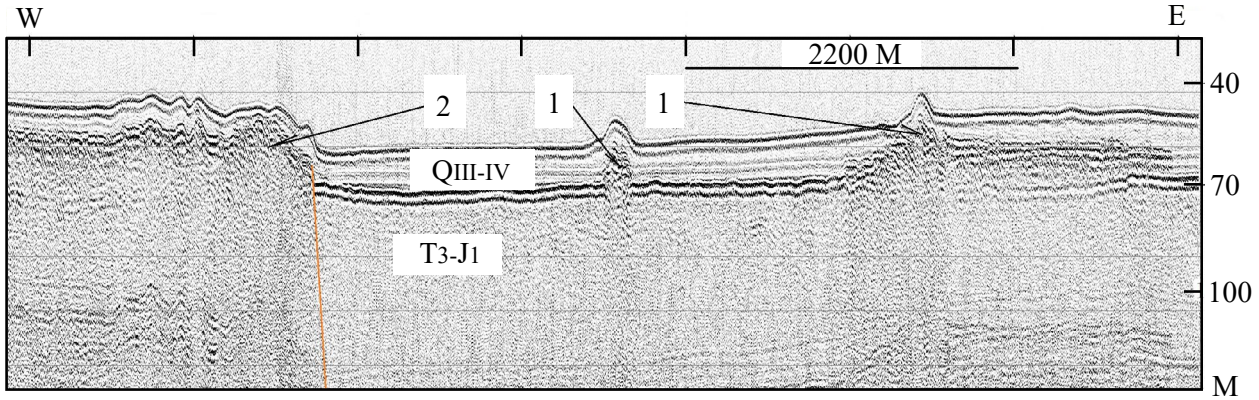

Fig. 6. Fragment of seismoacoustic profile 3 of NSAP of the shelf on the traverse of Alushta city. Arrows indicate: 1) gas manifestations, probably associated with mud volcanic activity (with coordinates 44. 36. 38 N, 34. 29. 36 E); 2) confined to modern elevations of the foundation of the southeastern continental margin of Crimea.

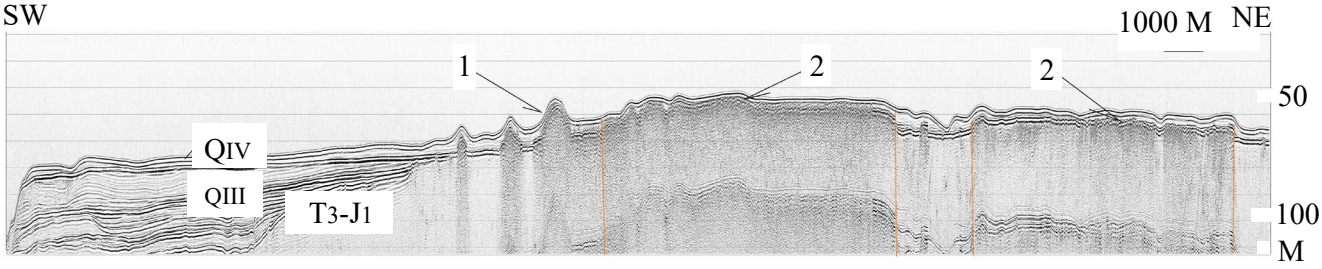

Fig. 7. Fragment of the regional latitudinal seismoacoustic profile 4 NSAP along the line Malorechenskoye settlement – Cape Chauda. Arrows indicate: 1) gas manifestations, probably associated with mud volcanic activity (with coordinates 44.42.80 N, 35.00.87 E); 2) confined to modern uplifts of the basement of the southeastern continental margin of Crimea.

reflecting horizons. On the latitudinal profile from the meridian of Malorechenskoye settlement to the meridian of Cape Chauda, elevated and lowered blocks of Taurian series rocks, uplifted along vertical faults and covered with thin Upper Pleistocene-Holocene deposits, are clearly distinguished. Areas of intensive gas occurrence are confined to tectonic blocks that have been uplifted in recent times, and the migration paths of the gas-fluid mixture are the faults that bound them (Fig. 7).

In the study area, the first type of anomalies is stratigraphically confined mainly to the near-surface part of the Upper Pleistocene-Holocene deposits, while the second and third types can cover a more significant recording interval.

The first type of anomalies is associated with strata of paleodelta and paleochannel accumulations. The manifestation of these gases and the formation of their accumulations are due to lateral migration up the uplift of layers.

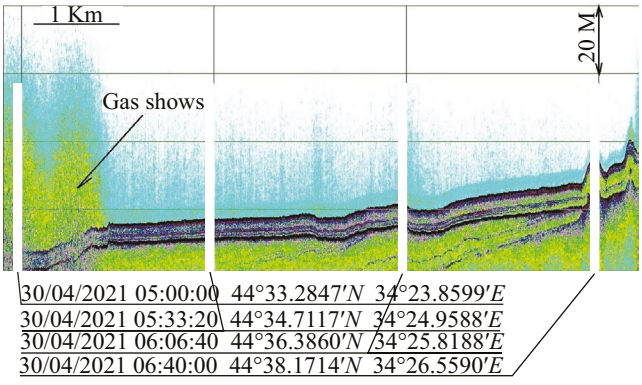

Fig. 8. Fragment of acoustic profile 5 near Yalta, in the area of Mount Ayu-Dag, showing gas release to the bottom surface at the point with coordinates 44.33.28 N, 34.23.85 E.

Anomalies of the second and third types are associated with manifestations of deep-migration gases and are confined primarily to active tectonic zones and areas of mud diapirism development. Large tectonic disturbances play a decisive role in creating vertical migration channels for gas-fluid flows and forming gas jets. The staff of JSC "Yuzhmorgeo" published analyses of the chemical and isotopic compositions of gases from sediments (percentage content of methane homologues, concentration of carbon dioxide and nitrogen) collected in soil samples in the northwestern part of the Black Sea in the fault zone on the continental slope and in clays of mud volcanoes. Their identical composition led the authors to conclude that methane gas is predominantly of deep origin. It enters the upper layers of the sedimentary cover by filtration or jet migration [16].

On acoustic profiles, gas seepage from sedimentary rocks into water in discharge zones is clearly distinguished (Fig. 8).

DISCUSSION OF RESULTS

Seismostratigraphic analysis of the obtained materials showed that the gas manifestations identified on the southeastern shelf of Crimea, totaling 40 anomalies, are stratigraphically confined to Upper Pleistocene-Holocene deposits. The deposits of Pleistocene paleodeltas, traces of which have been discovered by CHIRP data in the study area, can serve as accumulating rocks.

Genetically, the identified anomalies are divided into three types. The first type is associated with near-bottom "rootless" gas accumulations formed by lateral flows. The second type is caused by narrow vertical zones of gas-fluid mixture release under the influence of abnormally high pressures.

The third type of gas accumulations is confined to faults associated with elevated blocks of basement rocks.

The performed seismoacoustic studies have also shown that the continental margin of Crimea is characterized by a block structure. Differentiated vertical neotectonic movements have played and continue to play a decisive role in the structure of the southeastern shelf, in the formation of deep faults as channels for fluid migration from deep horizons to the seabed surface [17, 18]. It is in the zones of active fault tectonics that gas accumulations, mud volcanoes, and gas seeps are formed. Various types of gas-fluid manifestations identified by the research vessel "Professor Vodyanitsky" confirm this. Gas-saturated deposits with zones of abnormally high formation pressure are a feature of the subaquatic engineering-geological environment. Their distribution areas are hazardous for engineering construction. Pressure and gas emissions into the water column are accompanied by deformation of the seabed surface, formation of landslides, reduction of soil bearing capacity, etc. Depressurization of gas accumulations in the upper part of the section during drilling can lead to gas breakthroughs, formation of pits, and gas contamination of the water column [19, 20].

CONCLUSIONS

1. Near-bottom methane accumulations identified by seismoacoustic profiling are located in the southeastern part of the Crimean shelf and are confined to sandy deposits of Pleistocene-Holocene age, mainly near fault zones.

2. The identified anomalies are located in the area of paleodelta systems development, whose rocks have good accumulation properties.

3. Three types of gas accumulations have been identified, genetically associated with lateral flows, mud volcanic activity, and vertical migration along deep faults.

4. Gas seepages to the seabed surface are caused by seismic activity of the Mountainous Crimea structure and are a consequence of recent tectonic manifestations.

5. Periodic activation of fault blocks underlying the sedimentary cover contributes significantly to the formation of near-surface gas accumulations, which indicates the probability of their deep origin.

6. The identification of gas accumulations in the near-bottom part of the sedimentary cover is important for monitoring potentially dangerous areas for engineering construction and navigation.

7. To clarify the genesis and zoning of gas accumulations identified by seismoacoustics data, it is necessary to conduct an additional full range of studies along all lines of seismoacoustic NSAP profiles, including acoustic profiling, side-scan sonar studies, and echo sounding.

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