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Results of Ultra-High-Resolution Seismoacoustic Survey Offshore Taman Bay in the Area of the Ancient City of Phanagoria

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Abstract—The first data on the eastern part of Taman Bay are based on an ultra-high-resolution seismic survey. The seismoacoustic complexes of a profile are compared with Novochernomorsk and Karangat sediments to Lower Chauda sediments of the Quaternary age. The fold structure of Quaternary sediments of this area is confirmed. An analysis of the bedding of the newest marine sediments of the bottom and the submergence of the ancient city of Phanagoria in the beginning of the 1st century AD indicate the Late Holocene tectonic activity of the Taman Bay depression. Two profile areas exhibit signal coherence gaps interpreted as areas of gas accumulations. The gas emissions are probably morphologically related to a wing of the adjacent Akhtaniz Anticline and are interpreted as a result of clay diapirism of the Maikop Group.

Keywords: Taman Bay, UHR seismic profiling, newest folding, gas accumulations

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INTRODUCTION

Phanagoria, one of the largest ancient cities to ever exist on coasts of the Black and Azov seas, was founded by Greek colonists on the Taman Bay coast in the 6th century BC. This area was colonized during the regression of the Black Sea because of seismotectonic movements in Bosporus. By the end of the first millenium BC, the regression was replaced by Nimphean transgression, which led to a significant change in contours of the Taman Archipelago (Trifonov, V.G. and Trifonov, R.V., 2006). Part of the city, which was located in the lower terrace, was flooded. The submergence of Phanagoria can be explained by the eustatic uplift of the sea level during transgression, as well as by tectonic sagging of the region, because the city was situated in the southern wing of the actively submerged Sennoy Syncline (Korsakov et al., 2013). At present, there is good evidence of seismotectonic movements in the Phanagoria area (Ovsyuchenko et al., 2017), in particular, the flexure of Neogene and Quaternary layers of the Phanagorian flexure fault zone and their submergence toward a descended block of the Taman Bay (Trifonov and Karakhanyan, 2004). To confirm the Late Holocene tectonic activity of the Phanagoria area, we conducted seismoacoustic measurements through the Taman Bay north of the city in summer 2018. The seismoacoustic studies of the Taman Bay began in the middle of the 2000s by the staff of the Institute of Oceanology, Russian Academy of Sciences. This survey spanned lower depths than our works. Further works with profilographers were conducted only in coastal areas. In this paper, we present the results of a single-channel cable seismic survey, which crossed the entire eastern part of the bay for the first time.

METHOD OF SEISMOACOUSTIC SURVEY

A seismoacoustic survey in Taman Bay was conducted from a 6-m-long aluminum motor boat, which maintained its minimum possible movement speed for high spatial resolution. The seismoacoustic equipment was hauled from the left side on a 2-m-long shot. The vessel was positioned using a Trimble SPS461 differential GNSS receiver. The real time kinematic (RTK) base station was located at a distance of <10 m from the working area, providing decimeter accuracy of the determination of the vessel position.

The first stage included a survey using an ultra-high-resolution seismoacousting survey (UHRSS) with a boomer as a source of elastic vibration. The test works were carried out using a 200-J energy and a 500-ms excitation period. The reflected waves were received and registered using a single-channel seismic cable and a 16-bit seismic station, which was hauled following the boom source to keep the center of the group at a distance of 3 m from the source center. Taking into account the low depth of the bay (<4 m), this provided for the registration of reflected waves without interference with direct wave. In total, 15 profiles were registered; the longest profile was 5 km (profile AA' in Fig. 1). Figure 2

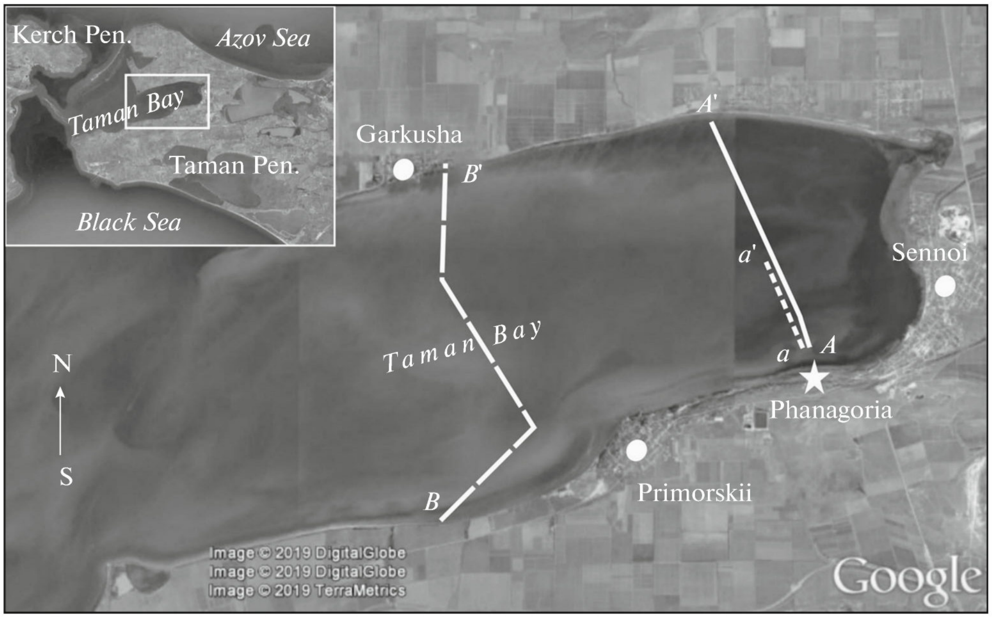

Fig. 1. Location of profiles in the Taman Bay. The UHRSS (AA'), profilographer (aa'), and geological (BB') profiles. The star indicates the position of the ancient city of Phanagoria.

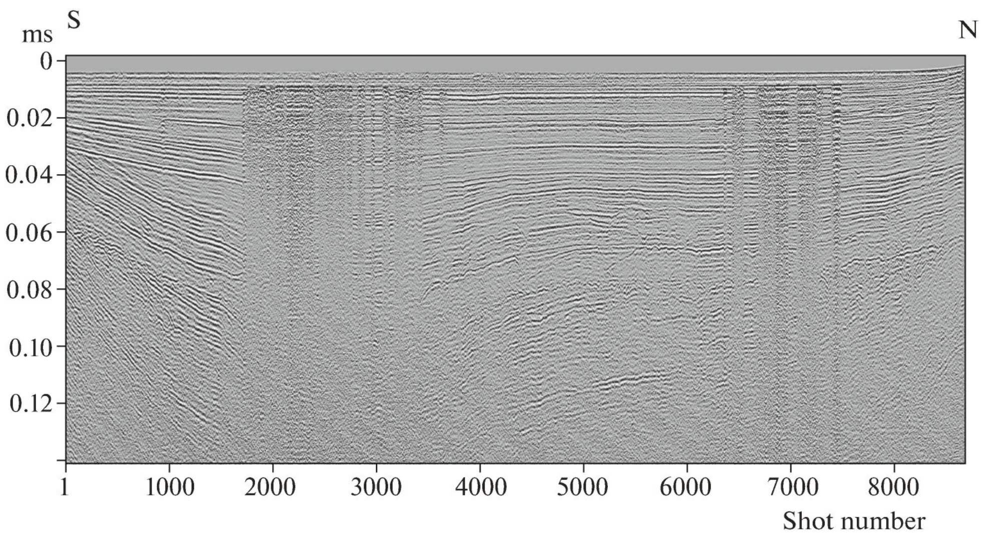

Fig. 2. Example of UHRSS profile after preliminary processing (line AA', Fig. 1).

shows an example of seismoacoustic profile after processing.

The data were processed in the RadExPro Professional 2018.2 software and included the downloading of field data, quality control and removal of unproductive fragments, geometrization, muting of direct wave, band filtration, amplitude correction for spherical difference, and Stolt time migration.

At the second stage, the survey was conducted using an EdgeTech SB-216S parametric profilographer (Shmatkov et al., 2018), which was hauled at a distance of 2 m from the vessel. The periodicity of radiation of elastic vibrations was ~10 times per second. Five profiles, the longest one being 4.5 km, were registered using this method. Figure 3 shows an example of the profilographer data (see also Fig. 1, profile aa').

GEOLOGICAL STRUCTURE OF THE TAMAN BAY

The Taman Peninsula is composed of the Neogene–Quaternary sediments, which compose wide syncline troughs up to 2-km-thick divided by narrow

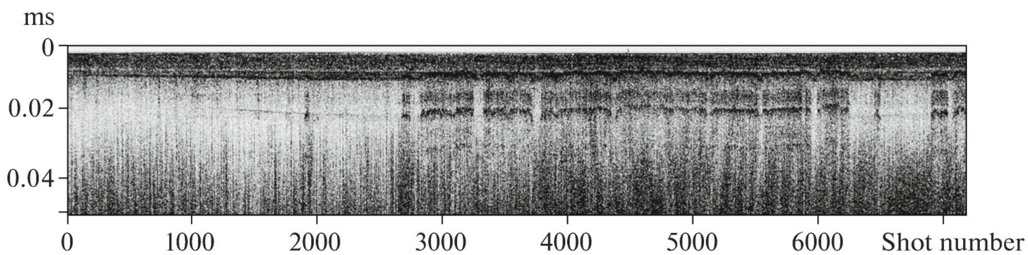

Fig. 3. Example of parametric profilographer data (line aa', Fig. 1).

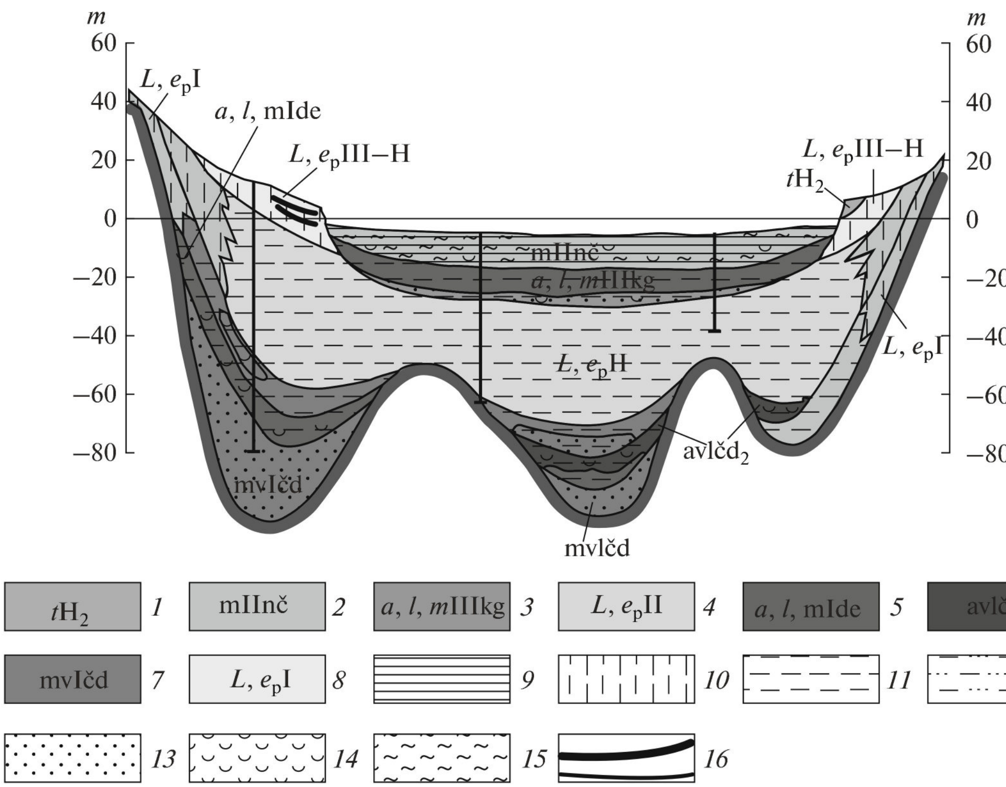

Fig. 4. Schematic geological profile of the western part of the Taman Bay after (*Gosudarstvennaya...,* 2000), line BB', Fig. 1). (*1, 2*) Holocene: (*1*) Late Holocene Technogene. Artificial loams, clays with relics of Antropogene furniture, fragments of dish, kitchen waste, etc. (1–3 m); (*2*) Novochernomorsk marinium: gravel, sands, clays, silts, muds, and shellstones (up to 10–30 m); (*3–8*) Neopleistocene: (3) Karangat alluvium, limnium, and limnomarinium: clays, sands, and shellstones (up to 15–20 m); (*4*) loess-soil complex: loams, clays, loamy sands, and fossil soils (up to 37 m); (*5*) ancient euxinic alluvium, limnium, and marinium: gravel pebblestones, sands, clays, and silts (up to 30–40 m); (*6*) Upper Chauda alluviomarinium: sands, clays, and shellstones (3–35 m); (*7*) Lower Chauda marine undalluvium: gravel sands, conglomerates, clays, loams, silts, and shellstones (from 2–3 to 30–35 m); (*8*) loess–soil complex: loams, clays, loamy sands, and fossil soils (10–37 m); (*9*) ribbon clays and silts; (*10*) loess, and loess loams; (*11*) clays; (*12*) loamy sands; (*13*) sands; (*14*) shellstones; (*15*) muds; (*16*) buried soils and pedocomplexes.

anticline zones (Blagovolin, 1962). In depressions, clay sediments of the Oligocene–Early Miocene Maikop Group up to 3 km thick are overlain by Neogene sediments up to 2 km thick (*Gosudarstvennaya*..., 2000) overlapped by Quaternary sediments (Fig. 4). In the western part of the bay (profile BB', Fig. 1), the thickness of the latter reaches 100 m (Fig. 4). The section consists of (top to bottom) (Korsakov et al., 2013)

• the Holocene Novochernomorsk marine sediments, the surface of which corresponds to the bottom of Taman Bay. The absolute heights of the bottom vary from –9.1 to –15.3 m. Gravel, sands, clays, silts, muds, and shellstones.

• the Late Neopleistocene Karangat alluvial and coastal marine sediments. Clays, sands, and shellstones (thickness in Taman Bay reaches 15 m).

• a Middle Neopleistocene areal loess–soil complex. Loams, clays, loamy sands, and fossil soils (thickness of up to 37 m).

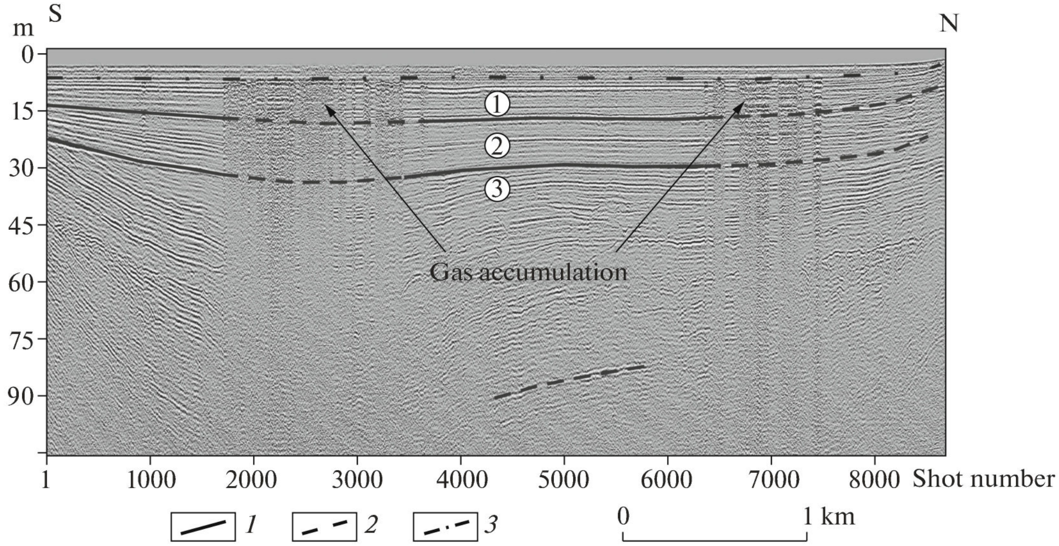

Fig. 5. Seismic complexes and gas accumulations in UHRSS profile. Boundaries of seismic complexes: (*1*) proven, (*2*) inferred, and (*3*) boundary of fluid-stop horizon. Numbers in circles are seismic complexes (see text for description).

• the Early Neopleistocene ancient euxinic alluvial and lacustrine-marine sediments, which composes the northern part of the Taman depression and include gravel pebllestones, sands, clays, and silts (thickness of up to 30–40 m).

• the Early Neopleistocene Upper Chauda alluvial-marine sediments, which form the deep parts of Taman Bay. Sands, clays, and shellstones (thickness of 3–35 m).

• the Early Neopleistocene Lower Chauda marine undaluivum, which composes the deepest parts of the Taman depression. Gravel sands, conglomerates, clays, loamy sands, silts, and shellstones (thickness from 2–3 to 30–35 m).

• an Early Neopleistocene loess–soil complex, which composes the southern part of the Taman depression (the southern wing of the Sennoy Anticline). Loams, clays, loamy sands, and fossil soils (10–37 m thick).

INTERPRETATION OF SEISMIC DATA

Three seismoacoustic complexes have been identified in the eastern part of the Taman Bay according to UHRSS (Fig. 5). The bottom of complexes 1 and 2 is determined by angular unconformity of reflectors, which are distinguished below them in the marginal parts of the bay. Their thickness is ~15 m. The bottom of complex 1 is also identified from the profilographer data (Fig. 6). The complexes contain constant flat reflections. Well-stratified complex 3 has strong reflections and no angular unconformities. No acoustic horizons have been identified below the acoustic basement, which is a fragment of the section at a depth of 80–90 m (Fig. 5).

According to the seismoacoustic data, there are three evident signal coherence gaps, which are related to the areas of gas accumulations, the southern and northern of which are ~1 km and 600 m, respectively (Fig. 5). The upper sedimentary sequence (part of seismic complex 1) is a fluid-stop horizon. Because the gas caps screen the deep reflections, nothing can be said about the position of fluid-moving faults. A discrete character of synphase axes along the vertical zones of gas seepage in some areas, however, indicates possible local faults (Fig. 7). Some areas of the profile demonstrate the structures interpreted as erosion gaps, which are *V*-shaped zones up to 7-m-deep and 10-m-wide (Fig. 7). They are most likely related to the activity of the paleo-Kuban River bed.

Some segments of reflectors exhibit sharp changes in amplitude of the reflected signal along the same phases: bright spots, which can be interpreted as the penetration and accumulation of an interlayer fluid (Fig. 8).

The lines of geological profile (BB', Fig. 1) occur ~5 km west of the line of seismoacoustic works. This hampers the correlation between seismic and geological data. The seismic complexes can be interpreted as follows. Seismic complex 1 can be compared with layer 1 of the Novochernomorsk sediments (the layer and complex have similar thicknesses of 15 m). Seismic complex 2 can be considered layer 2 of the Karangat sediments (the height of the bottom occurs at a depth of 30 m). Seismic complex 3 corresponds to loess–soil sediments (layer 3), the bottom of which cannot confidently be identified from seismic data.

DISCUSSION

Genesis of Gas Caps

The areas of gas accumulations have been identified at a depth of 7–10 m. The ideas on the genesis of gas caps are related to the process of clay diapirism of

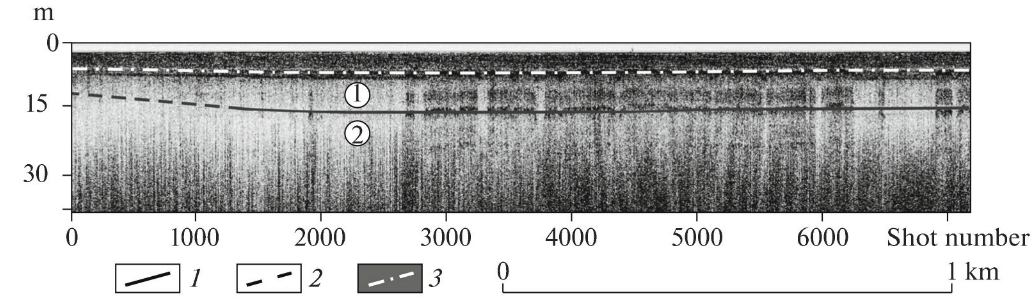

Fig. 6. Seismic complexes and gas accumulations on profilogram. See Fig. 5 for symbols here and in Figs. 7 and 8.

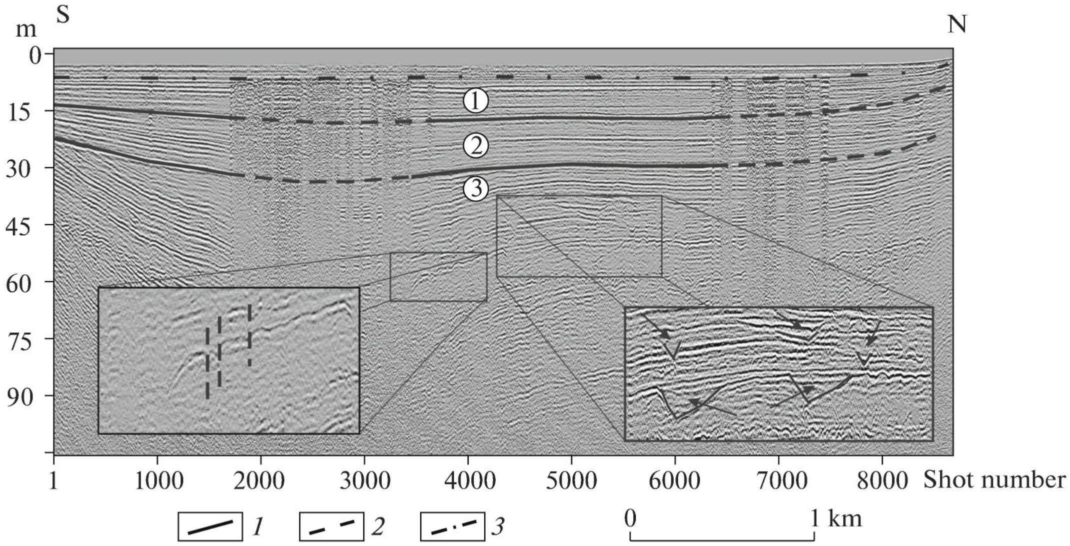

Fig. 7. Faults (left inset) and erosion gaps (right inset) in the UHRSS profile.

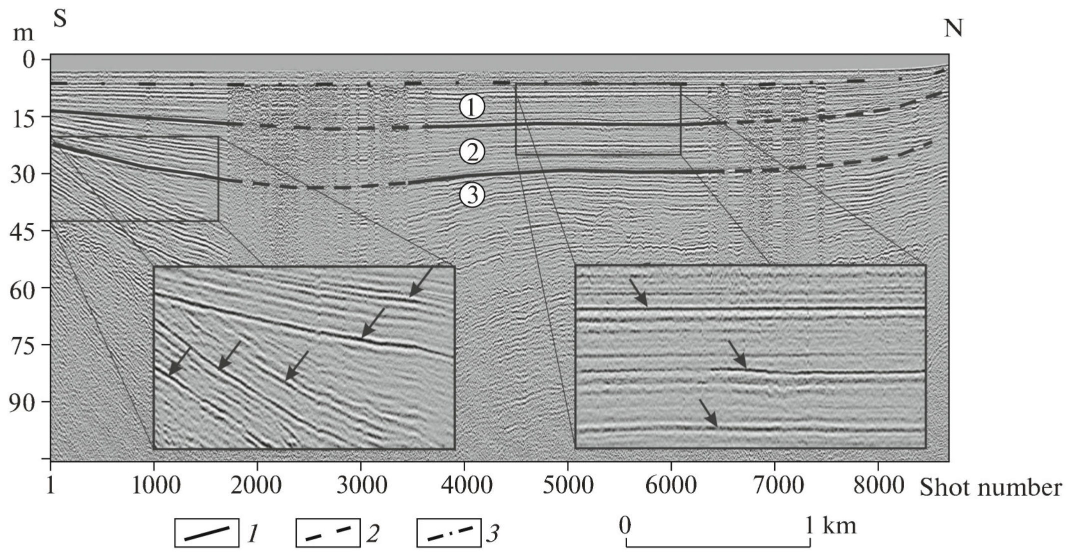

Fig. 8. Areas of fluid interlayer penetration in the UHRSS profile.

the Maikop Group (Shnyukov et al., 1986). The West Akhtaniz petroleum area with economic hydrocarbon contents is located 5–6 km eastward of the UHRSS profile (AA', Fig. 1). The deposit is confined to the central part of the Akhtaniz Anticline (Engibaryan, 2007). It can be suggested that the gas anomaly on a seismic profile in a syncline area of the Taman Bay is related to gas emission on an anticline wing (Fig. 1).

Late Holocene Sagging of the Taman Bay

The total thickness of Quaternary sediments in synclines is 100–125 m (Korsakov et al., 2013). The bottom of synclines is sagged below the present-day sea level in almost all depressions. The Late Holocene Novochernomorsk sediments occur in the central part of Taman Bay at a depth of 15 m. This indicates the newest age of submergence of the bottom of Taman Bay, which is somehow reflected on coastal constructions, in particular, in the flooding of the coastal part of the ancient city of Greek Phanagoria, which resulted in it being abandoned in the 10th century.

CONCLUSIONS

The first ultra-high-resolution seismic survey along the eastern part of Taman Bay has supported the presence of young folding in Quaternary sediments. The submergence of Phanagoria is partly related to tectonic sagging of the bay and indicates present-day movement in this area.

The gas accumulations were identified as a result of a seismoacoustic survey. Due to irregular observation network, the identification of areas of gas-saturated sediments is difficult and requires further studies: the expansion of a covering area of seismoacoustic profiles, sampling or drilling, and the identification of gas content in a water column.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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