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GAS SIPS AND SHALLOW ACCUMULATIONS OF GAS ON THE SHELF OF TURKEY IN THE BLACK SEA

It has been suggested that shelf and slope sediments of high deposition rate are methane sources, whereas the deep basin is methane sink. The methane production and migration in sediments may cause massive slope failures so methane is geologically important. Methane production is also economically important as methane seeps may indicate the presence at depth of hydrocarbon reservoirs, and methane hydrate may be an important source of energy.

Recent studies in marine geology indicate potential geo-resources in the Turkish coast of Black Sea. The Black Sea sediments are rich in calcite and organic carbon, the latter showing a high degree of preservation due to anoxia in the waters below 100-150 m. Different marine geophysical surveys at different times were carried out in order to understand the sedimentary features of gas-saturated sediments in the Black Sea. Multibeam, side scan sonar, sub-bottom profiler and multi-channel seismic data were collected to make both high-resolution batyhmetric and reflectivity maps of the seafloor. In some cruises, deep-tow combined side scan sonar and subbottom profiler was used to obtain acoustic images of both the seafloor surface and subbottom sediments. Several different structures were observed in the Black Sea basin as slumps, pockmarks, faults, gas chimneys, shallow gas accumulations and dome-like structures. Structures, which contain gas hydrates, are present on the seismic sections as strong acoustic reflections.

Keywords: *Black sea, gas sips, gas accumulations, Turkish shelf, seismic sections*

The Black Sea is the largest anoxic basin in the world with persistent H2S reserves, and large rivers contribute large volumes of dissolved organic material and potentially affect the iron and sulphide cycle in bottom sediments. On the southern coast of the Black Sea, rivers (Pabuch, Kazan, Chilingos, Kuzulu, Riva, Goksu and Sakarya, Kyzylirmak

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and Esilirmak) bring on average 10 thousand tons of precipitation per year. Due to the anoxic conditions, the deposits of the Black Sea are rich in carbon and calcite. A huge amount of plant residues and organic material coming from rivers causes the biochemical generation of gases [9, 22, 25]. It should be assumed that the level of mineralization and the content of sulfides in the studied areas with a high flow of precipitation will be higher than in the deep-water basin. Due to the high rate of sedimentation, areas of the shelf and slopes are considered sources of methane [32]. Mud volcanoes observed in the deep-water basin are also sources of methane [5, 6, 13, 21, 22].

Shallow gas migration and outcrops can create morphostructures such as pockmarks (pockmarks) on the seabed, which are usually associated with gas and/or liquid discharges into near-surface sediments. In addition, methane migration is a potential factor affecting slope stability. An increase in pore pressure, due to the accumulation of free gas in the pores of the sediments, reduces the effective shear resistance of the sediments and can cause destruction of slopes.

Many scientists have studied parts of the southern coast of the Black Sea. Shallow gas accumulations in the coastal Yesilirmak delta have been mapped using continuous acoustic observations [5]. Methane seeps are usually located along the perimeter of the Black Sea deep-water basin [3, 9, 22, 25]. Okyar and Ediger (1999), as a result of studies on the eastern shelf of the Black Sea, substantiated the development of potential methane generation zones.

Along the entire length of the Turkish shelf, shallow gas under the bottom was recorded from the profiler records. Pockmarks are found on a sub-horizontal plateau and a gentle slope. On the steep slope, landslides and fluidity of sediments are found. Unlike the concave Russian continental slope, the Turkish continental slope has a convex morphology. The slope becomes steeper as the tracing is downward, which is the result of mass movement or structural features.

Below are materials from different voyages on the research vessels (R/V) «K. Piri Reis», «Poseidon» and «Professor Ligachev» in which the authors took part. These data include shallow gas accumulations, BSR reflections as indicators of gas hydrates, and mud volcanoes (Figs. 1, 2).

The Black Sea includes the entire spectrum of morphological structures characteristic of ordinary deep-sea basins: shelf, continental slope, continental uplift (foot of the ledge) and abyssal valley. In the Black Sea basin, shelf expansion is correlated with coastline morphodynamics and canyon formation. Canyons are more densely represented in the southern and eastern parts of the Black Sea with the mountainous Turkish coast, narrow shelf and coarse-grained sediments [31].

In the southwestern part of the coastal zone of the Black Sea coast of Turkey, the slope is cut by systems of underwater valleys with densely located canyons [24]. The shelf area and alluvial fans are located between bathymetric isobaths of 100-2000 m with a continental slope of 1 -30. The canyons are a system of underwater valleys oriented across the coastline. In particular, the length of the main canyons northeast of the Bosphorus is 50-55 km. and at least 12 of them are located quite close to each other on an area of about 115 km^2, while the distance between them is about 7-8 km [311].

The Anatolian zone, which is the largest mountainous coast of the Black Sea, stretches from east to west for a distance of 900 km (Fig. 1). Steep slopes and shelf sections (Eregli-Inebolu and Rize-Trabzon), 2-4 km wide, alternate with less common areas of a wide shelf (7-10 km in the Fatsa-Sinop and Eregli-Kefken sea zones) and a

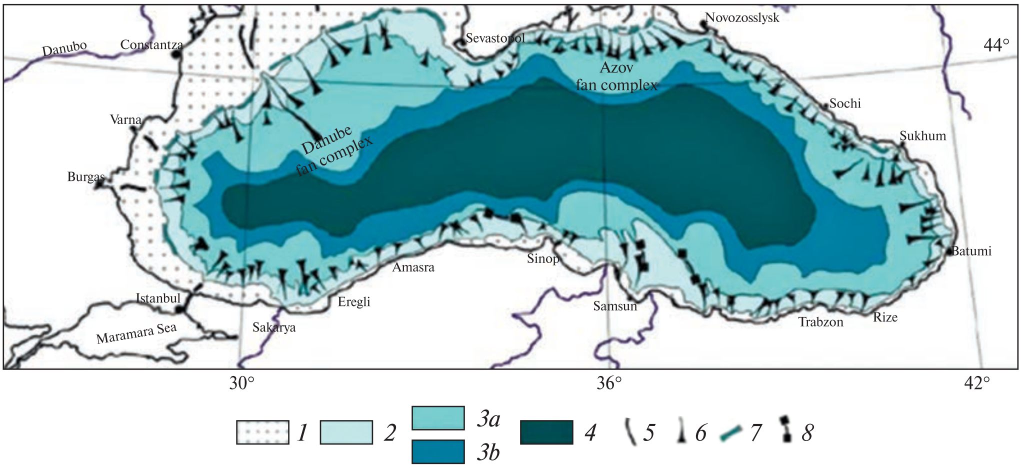


Fig. 1. Geomorphology of Black Sea Coasts: *1* — continental shelves; *2* — continental slope; *3* — basin-apron 3, a — deep sea fan complexes; 3, b — lower apron; *4* — Abyssal plain; *5* — Paleo channels on the continental shelf filled with Holocene and recent fine sediments; *6* — Main sub marine canyons; *7* — Paleo-cliffs nerar the shelf break; *8* — Fracture zones on the sea bottom morphology [31]

gentler slope associated with deep-sea removal cones. On the Sakarya coast, the sea depth at the shelf edge is about 100-130 m [2]. Beyond the shelf edge, the continental slope extends to a depth of 1400 m, and the slope gradient reaches 30° [11, 27]. The rise has a relatively lower gradient between the deep-water basin and the continental slope.

Studies have shown that erosion processes are especially active on the continental slope and uplift in the western part of the Black Sea [2, 11, 18, 26, 28, 29]. The depth of the continental rise usually ranges between 1400-2000 m. After continental rise, a deep depression begins, which reaches a maximum depth of 2200 m. It is an almost flat abyssal plain.

The main canyons (Sakarya and Esilirmak) stand out on more gentle slopes. They have a higher dendritic trend and are systems with a main thalweg and several tributaries. On large-scale bathymetric maps, some canyon peaks reach the 100-meter isobath and can be considered incised into the shelf. This concerns the Sakarya canyon. As indicated in [2], the two summits of the Sakarya canyon are at a depth of about –50 m and –10 m, respectively.

The continental slope near the estuary of the Esilirmak River is dissected by a very dense dendritic system of canyons [10]. The upper reaches of the canyons are 3 to 9 km from the shelf cliff at a depth of 500 to 800 m, which is a good example of canyons bounded by slopes [31].

Studies of bottom sediments of the Black Sea were started by N.I. Andrussov in 1893 [4]. But it was only after the Atlantis II cruise in 1969 that the general features of the Black Sea sedimentology became widely known [8, 33, 34]. Limonov et al. [21] identified five main lithological subsections.

Subsection 1. The upper part of these deposits is a very liquid substance. In some cores, thin streaks of pale gray silt are visible in the upper part. Below it is a thin (usually less than 1 mm) layered sequence of alternating veins of white coccolith, sapropel and pale gray ooze. There is a very sharp lower boundary. The formation of these veins depends on seasonal fluctuations in the generation and transport of particles in the

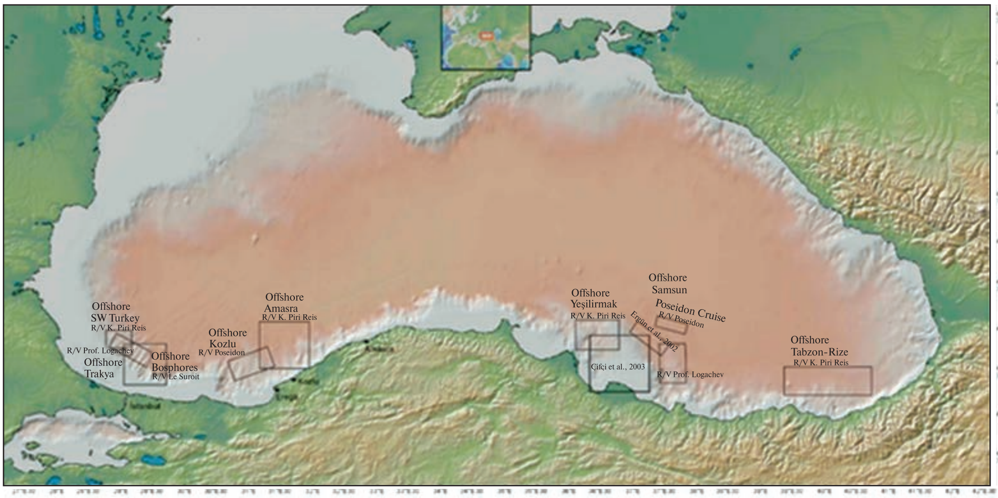


Fig. 2. Location of the studies that comprise this volume

basin. The organic carbon content in sediments varies, reaching 4 % (w/w). The $\delta^{13}C$ isotope value indicates that about 25 % of organic matter was brought in from land [21]. Very fine-grained turbidites (up to 20 cm thick) are found here.

Subsection 2 is represented by sapropels and sapropel silt with interlayers of very soft pale greenish gray silt. The upper part of the sapropel contains several very thin veins of coccolith ooze, and sometimes the remains of fish and plants are found. The border between subsections 1 and 2 is usually pronounced [33]. Subsection 2 also includes turbidites. Sapropel contains over 14% (by weight) organic carbon. This subsection is characterized by the $\delta^{13}C$ isotope values, which correspond to the maximum accumulation of organic carbon and indicate an almost entirely marine origin of organic matter in sapropel. The $\delta^{13}C$ value indicates an increasing role of terrestrial organic matter towards the sapropel base. This continues until subsection 3.

Subsection 3 is represented by a series of layered moderately calcareous clays with turbidite interlayers, characterized by a low organic carbon content (about 0,6 %). These lamellas or thin veins show slight color variations within shades of gray. Subsection 3 contains organic carbon with a $\delta^{13}C$ value of terrestrial origin. The lacustrine facies of this subdivision were formed at a time when the Black Sea was isolated from the Mediterranean as a result of eustatic lowering of the sea level. After this period, climatic changes and reunification with the Mediterranean Sea over about 9000 years to date have resulted in an influx of salt water, displacing nutrient-rich deep waters into the light penetration zone and, accordingly, an impulse to increase marine productivity noted in subsection 2 (sapropel). Based on the dating of the 14C isotope, sapropel deposits began in the Black Sea about 6000 years ago, ended in shallow water about 4000 years ago, and persisted in deep waters up to 1600 years ago. According to estimates of seasonal layering, the deposition of sapropel began 5100 years ago and continued until 1000 years ago [17, 21].

Subsection 4 includes black to dark gray silts that are very rich in reduced iron or hydrotroilite. They can be massive or have colored streaks caused by varying hydrotroilite concentration.

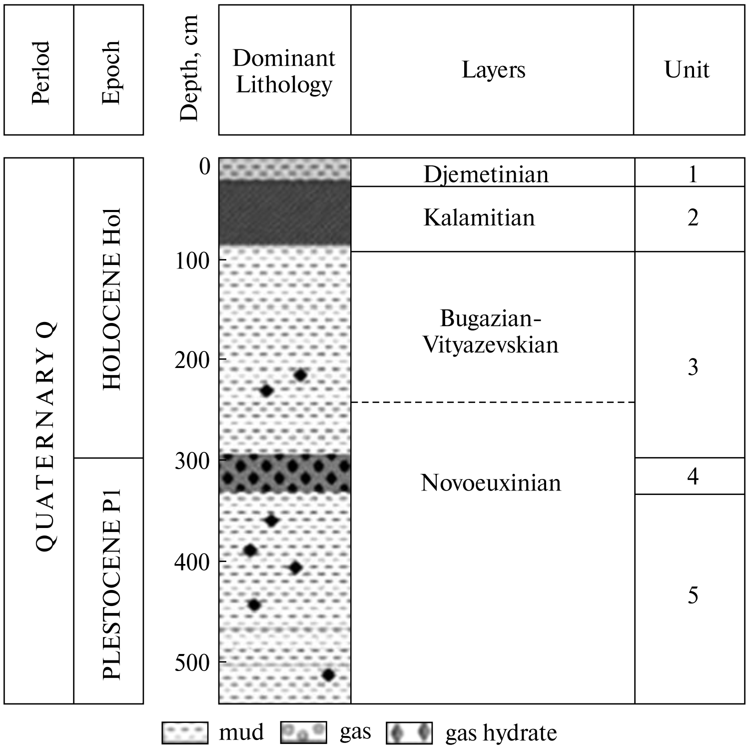


Fig. 3. Major lithological unites in the Black Sea [21]

Subsection 5 is characterized by gray thin-bedded silt with rare interlayers of thin sediments and inclusions of black hydrotroilite. At the bottom of this subsection, the sediments become coarser and gradually turn into silt. Rock debris from streaming sediments are also found here [35].

The above studies cover the shelf and slopes of the western and eastern parts of the Black Sea (Fig. 2) — polygons: Southwest, Trakya, Bosphorus, Kozlu, Amasra, Yesilirmak, Samsun, Trabzon-Rize.

Southwestern polygon (Fig. 2). Figs. 3, 4 show the distribution of gas-related seismic facies and gas seeps in the southwestern polygon [30], which terminate in the south a strip of gas flares along the Bulgarian coast.

Polygon Trakya. Seismic multichannel data were obtained in 2005 at the Trakya test site (Fig. 2) as part of a training and research cruise on board the R/V Professor Logachev. As a result, several possible mud volcanic structures and manifestations of gas hydrates in the core of the uplifted pipes were discovered. A short-term survey with OKEAN sonar and a profilometer was carried out to map the seabed for hydrocarbon seeps (Fig. 5).

The study covers a part of the dissected slope of the canyon at sea depths of 800-1600 m northwest of the Bosphorus Strait. Several objects with a high level of backscattering were detected along the crests of the ridges when they were crossed by a 3,5 kHz profiler. Profile 02BS recording showed that one of the objects is a positive acoustically transparent anomaly, suggesting that it may be a mud volcano (Fig. 6). Shallow accumu-

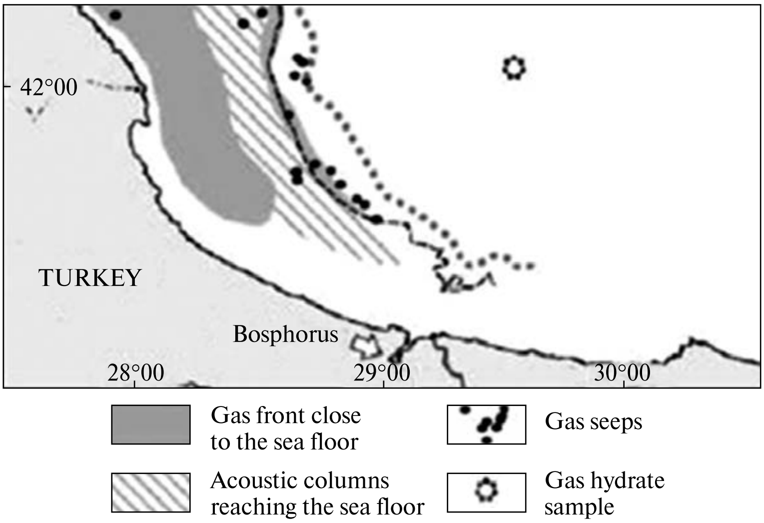


Fig. 4. Distribution of the gas-related seismic facies and BSRs in the western Black Sea from Popescu et al.,2007. Dotted grey line shows the minimum theoretical water depth for methane hydrate stability in the Black Sea. The location of gas seeps also indicated (including information from Egorov et al., 2003; Shnyukov et al., 2003), gas hydrate samples [23, 38]

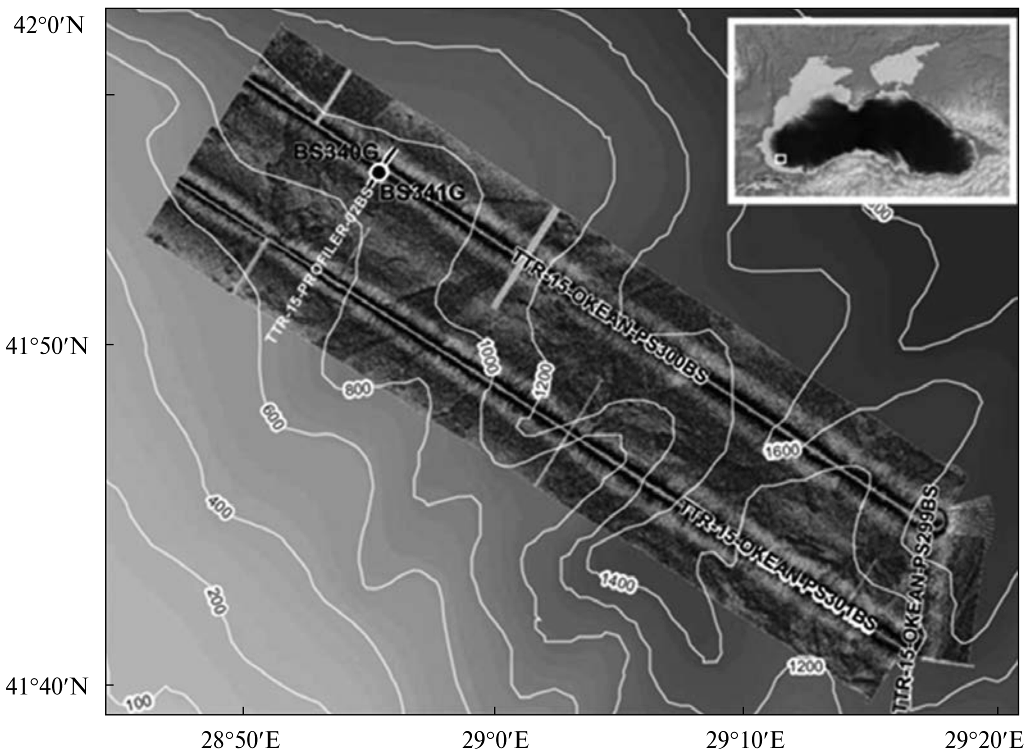


Fig. 5. Location map and the OKEAN sonar image of the Trakya area. Two gravity core locations [15]

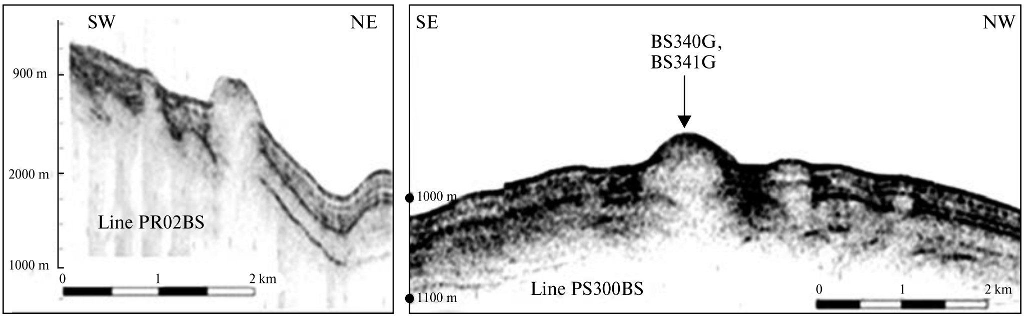


Fig. 6. Two 3.5 kHz sub bottom profiler profiles acquired at Trakya area showing a possible new mud volcano and sampling stations location [15]

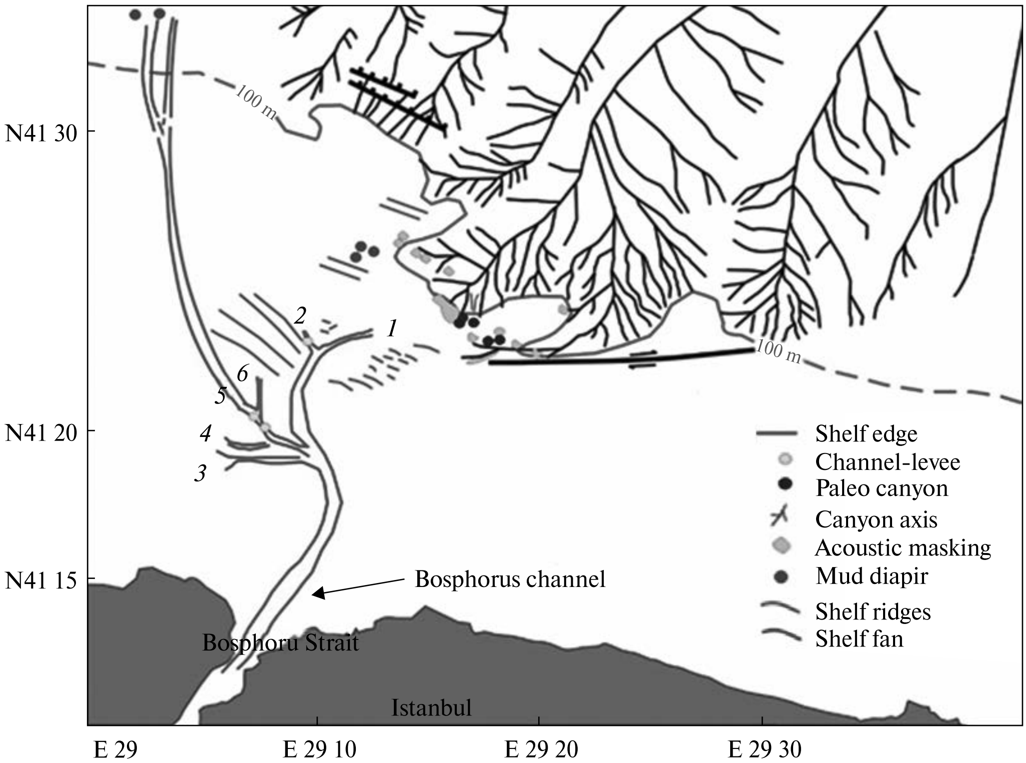


Fig. 7. Acoustic masking locations at the shelf edge (Okay,S., 2008)

lations and gas flares were not displayed in the seismic sections, but cores included gas-saturated layers, and individual crystals of gas hydrates were found in the core of gravity pipes at BS 340G [15] (Figs. 7, 8).

In 2008, from the R/V «K. Piri Reis» multi-channel seismic reflections were obtained in the area of the Igneada well. Direct indicators of hydrocarbons in the form of bright, dull and dim spots are observed in almost all high-resolution seismic sections in the northern part of the southwestern Turkish coast of the Black Sea. The sections also show BSR reflections, which are a direct indicator of the presence of gas hydrates. On the seismic section of the study area, shown in Fig. 9, a high-amplitude reflection is observed [26].

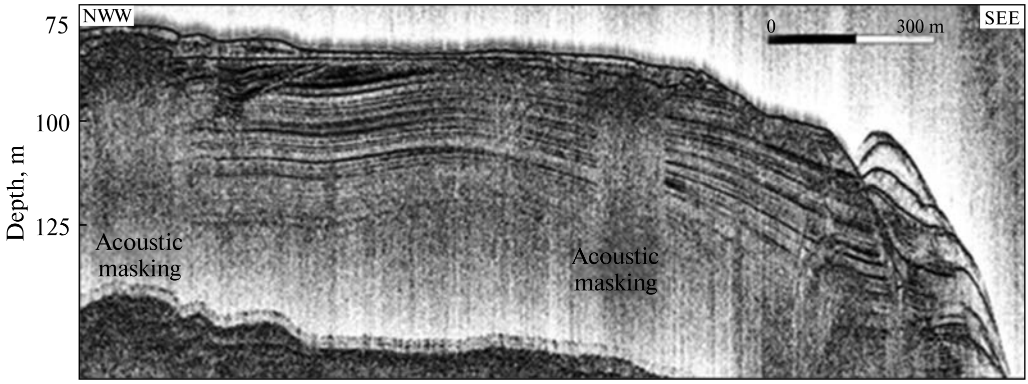


Fig. 8. The 3.5 kHz Chirp Profile at the shelf edge showing acoustic masking areas (Okay, 2008)

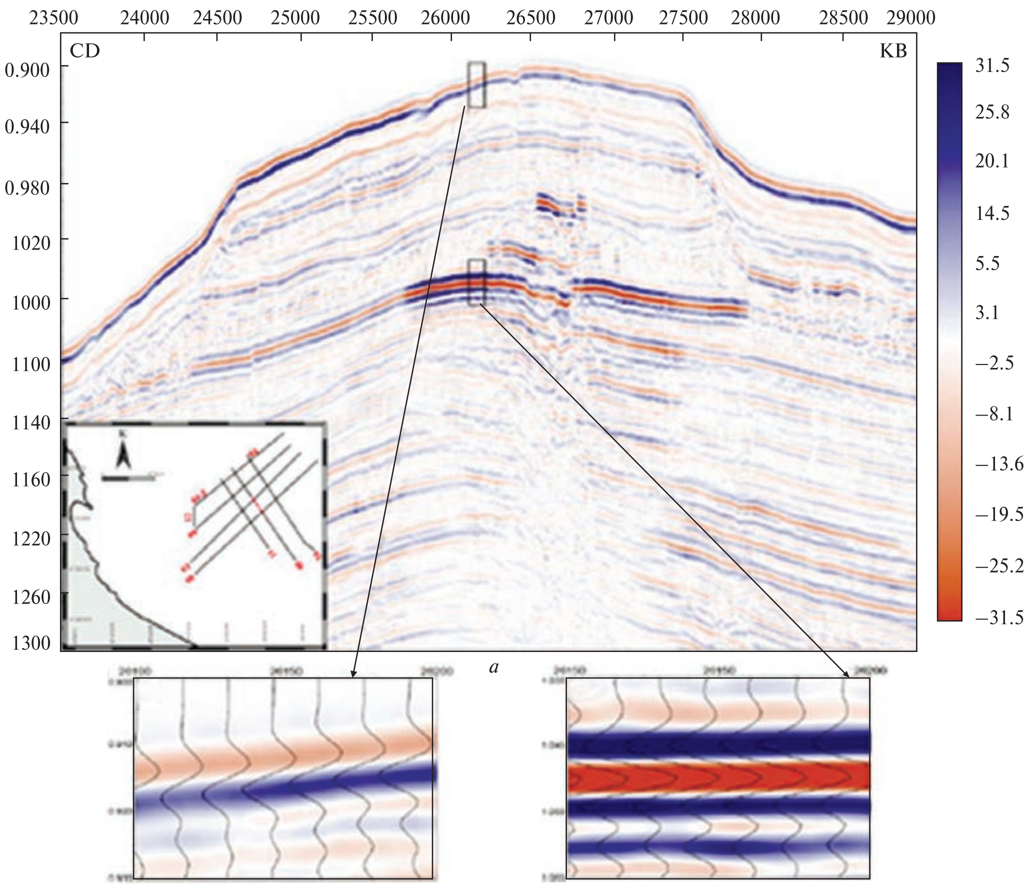


Fig. 9. Mcs05 high amplitude reflection area on amplitude seismic section *(a)*; seafloor reflection with wiggle trace just above high amplitude reflection area *(b)*; high amplitude anomaly with wiggle-trace *(c)* [26]

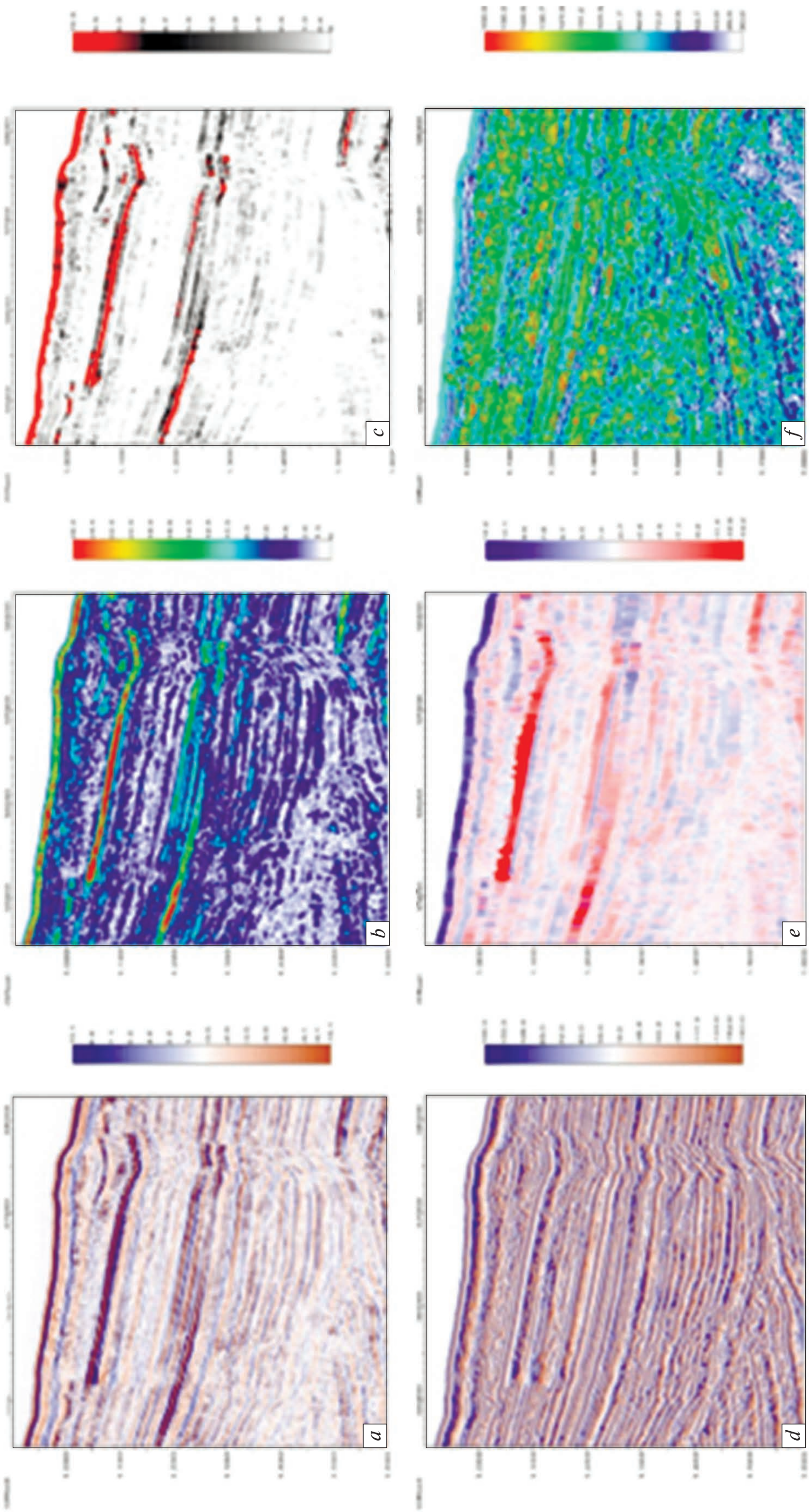


Fig. 10. Migration section *(a)*, envelope (instantaneous amplitude) section *(b)*, avarge energy section *(c),* instantaneous phase *(d),* apparent polarity *(e),* instantaneous frequency section *(f)* [26]

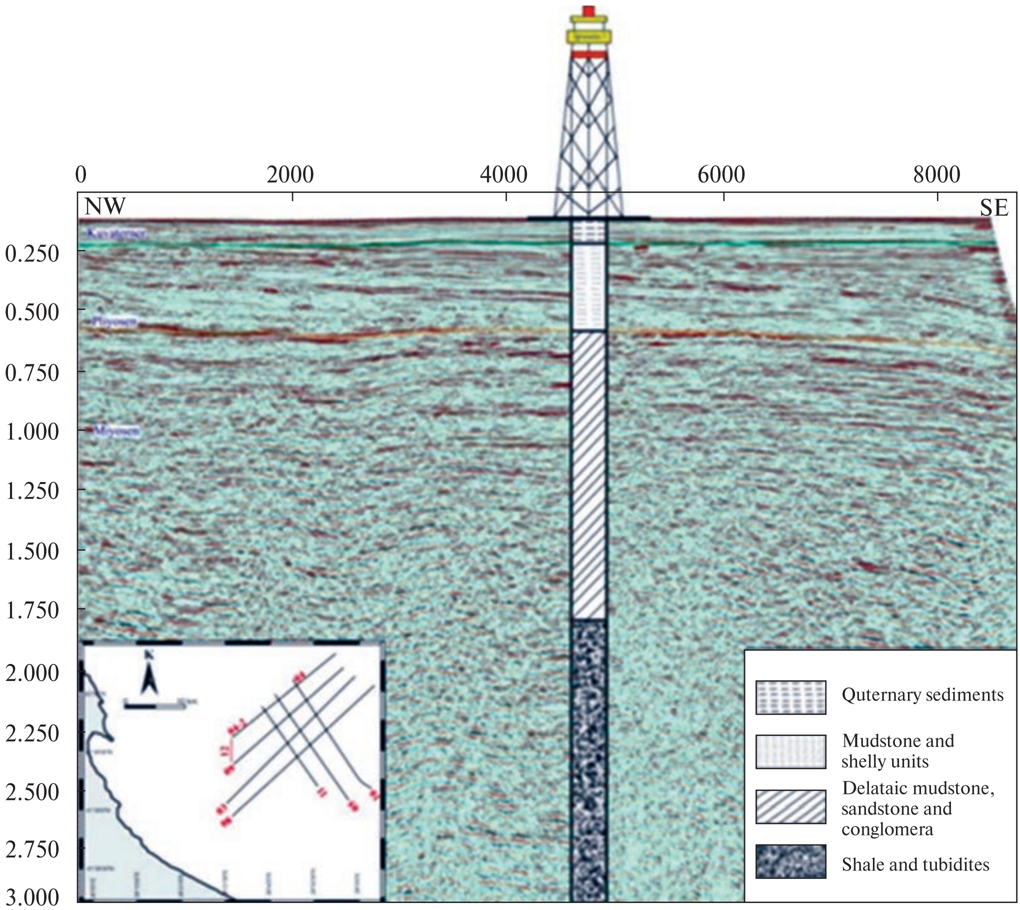


Fig. 11. Quaternary, Pliocene, Miocene units are correlated from Igneada 1 well stratigraphy [26]

Attribute analysis was used to identify shallow gas reservoirs. Areas of high amplitude in the seismic sections were taken as target anomalous zones, and the complex attribute analysis was applied to the high-resolution seismic sections. The sections of apparent polarity, high amplitude, envelopes (instantaneous amplitude) and average-energy sections were investigated [26]. In addition, on frequency sections below high-amplitude and reverse polar reflections, the presence of low-frequency zones is associated with shallow gas accumulations (Fig. 10).

Correlation of seismic stratification of the study area with the section of the Igneada 1 well is shown in Fig. 11. Quaternary deposits are displayed as well-stratified parallel reflections. Small accumulations of gas are mainly observed in the Quaternary jejunum.

Also on some seismic sections paleochannels are observed. The observed shallow gas accumulations and the BSR reflection are shown in Fig. 12. Shallow gas accumulations are interpreted in relation to normal faults in the area. Seismic sections also indicate that gas does not form in situ but migrates upward through deep faults in high porosity strata. A similar model is described in [14] for the central part of the Black Sea. According to this model, normal faults reach the seafloor due to the uplift of the

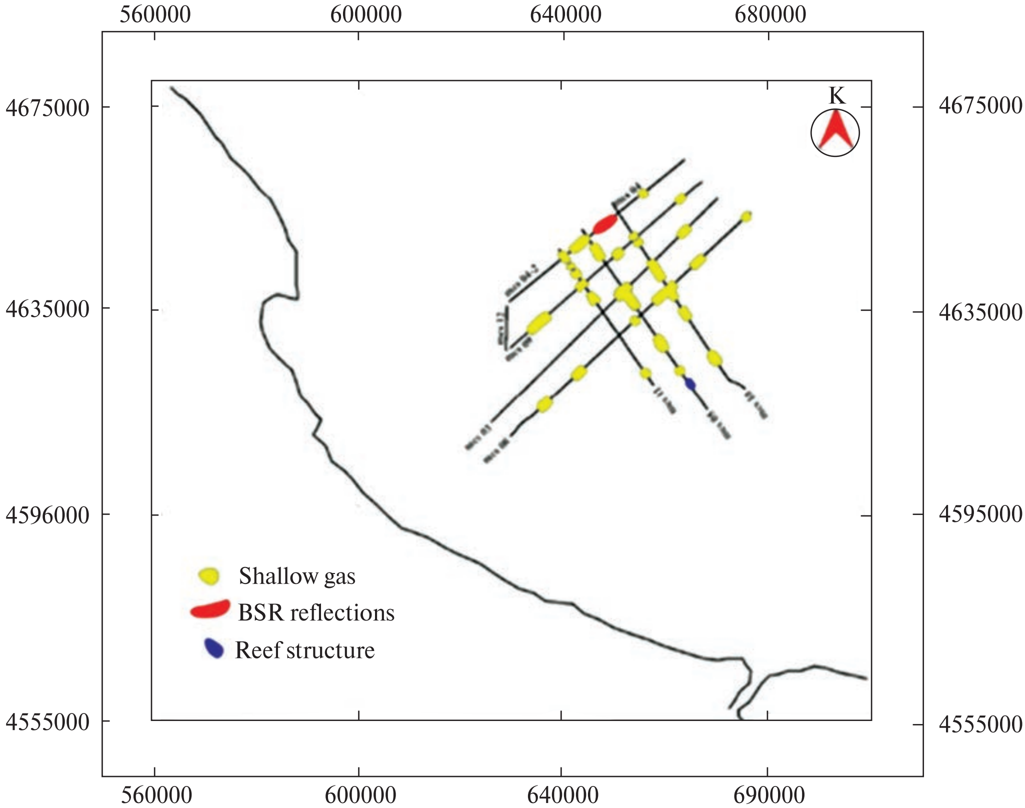


Fig. 12. Shallow gas accumulations, BSR reflection [26]

Miocene strata, and gas that forms in deeper horizons migrates through these faults to shallow water parts. Migratory gas is trapped by impermeable sediments and accumulates mainly under anticlinal structures and canyon ridges. Gas accumulations in seismic sections are reflected in eroded areas along the fault zones, and the fault zones give low frequency reflections. This indicates the migration of gas from deeper to bottom sediments through fault zones [26].

Polygon Bosphorus (Fig. 2). In 2002, the French vessel «Le Suroit» carried out a vibroseismic survey by multibeam scanning using the BlaSon2 apparatus on the shelf and slope areas up to the abyssal plain. Canyon systems have been identified using multi-beam scanning [20, 24]. Using the chirp signal, the acoustic diaphragm was fixed at the shelf edge (Fig. 7).

Since no gas sampling has been carried out in the mapped areas, we prefer to describe the acoustic diaphragm zone in time sections. Fig. 12 shows a 3,5 kHz vibroseismic section at the shelf edge, showing acoustic diaphragm, which may indicate shallow gas accumulations in the peripheral part of the shallow-water shelf system. It is believed that shallow gas accumulations in some areas are associated with faults. But this can mainly be due to organic matter coming from the Bosphorus.

Polygons Kozlu and Amasra (Fig. 2) are located in the western coastal waters of Turkey [19]. Shown in Fig. 13 data on the distribution of indicators of gas manifestations at these landfills were collected in 2008 within the framework of the TUBİTAK

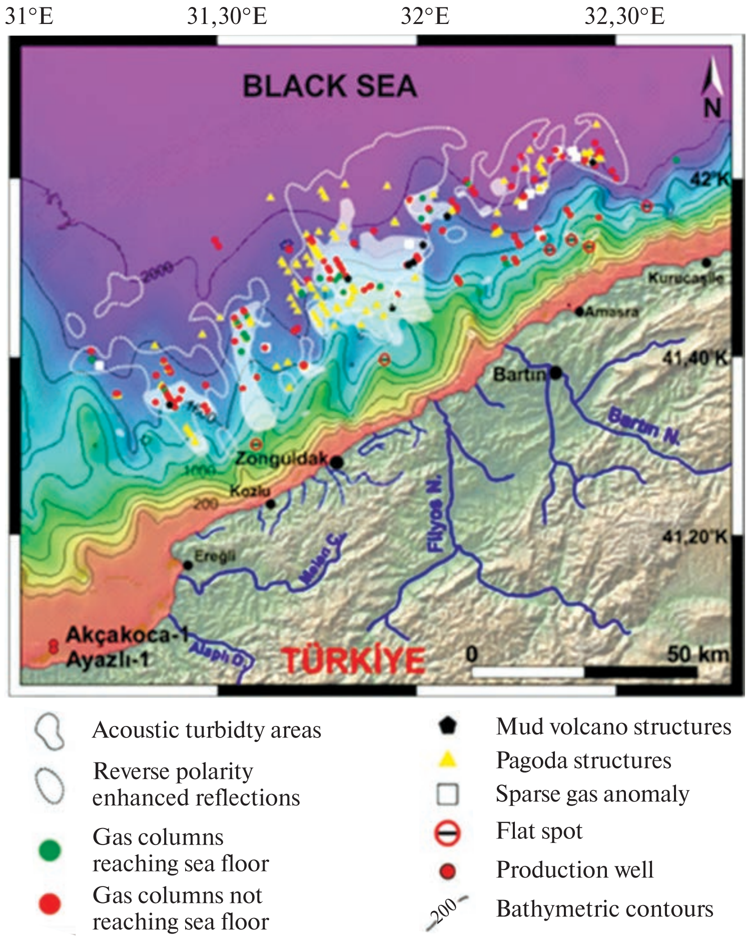


Fig. 13. Distribution of shallow gas indicators in the study area [19]

project. Multichannel seismic observations detected BSR reflections, gas pipes reaching the seabed, as well as enhanced reversed polarity reflections and acoustic diaphragm areas. The width of the buried and reaching the seabed gas pipes varies within 45-300 m. This type of gas structures exposes the surface of the Miocene sediments, where their upper horizons reach shallower depths along the continental uplift (Fig. 14).

In 2004, on the Eregli area from the R/V Poseidon, an underwater survey was carried out with a profiler and a side-scan locator. In addition, the Ocean Floor Observation System (OFOS) was used, which is a towed device for mapping the geological and biological features of the seabed. The study area is located in the southern part of the Western Black Sea basin and is part of the Northern Pontids region. The area includes many potential hydrocarbon anomalies that are similar to other gas or oil finds in the western Black Sea basin (Fig. 15).

The study area contains both structural and stratigraphic elements. The Kozlu megastructure and the structures of the eastern fold belt are composed mainly of pre-rift deposits. Pliocene and Miocene submarine fan systems associated with the Danube and

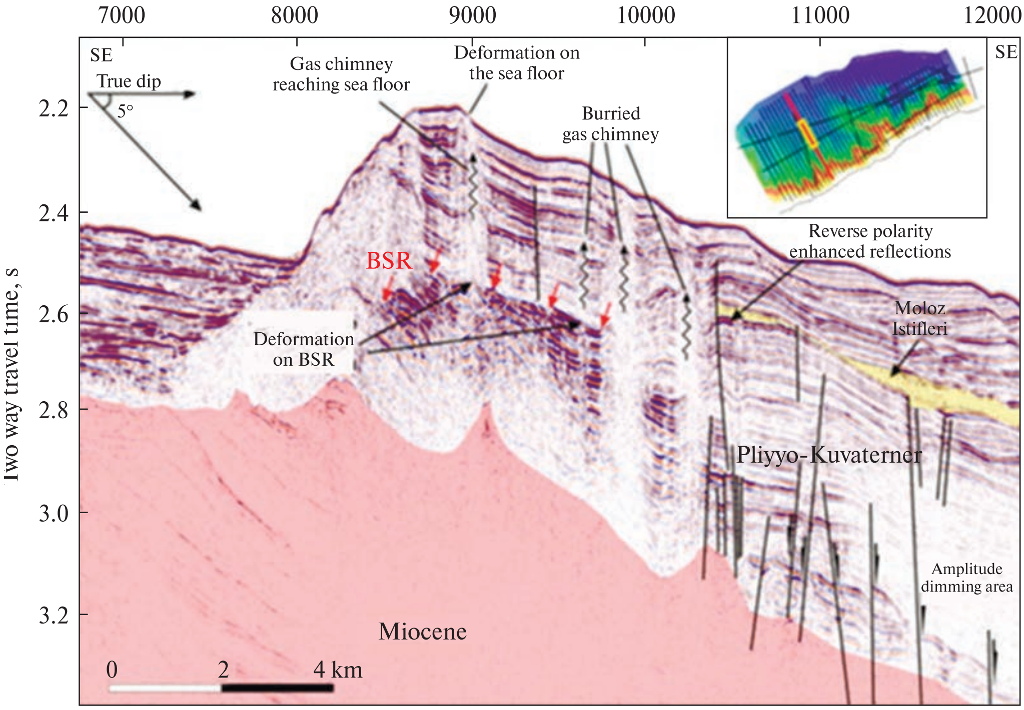


Fig. 14. Buried gas chimneys observed on the high resolution seismic reflection section in the study area [19]

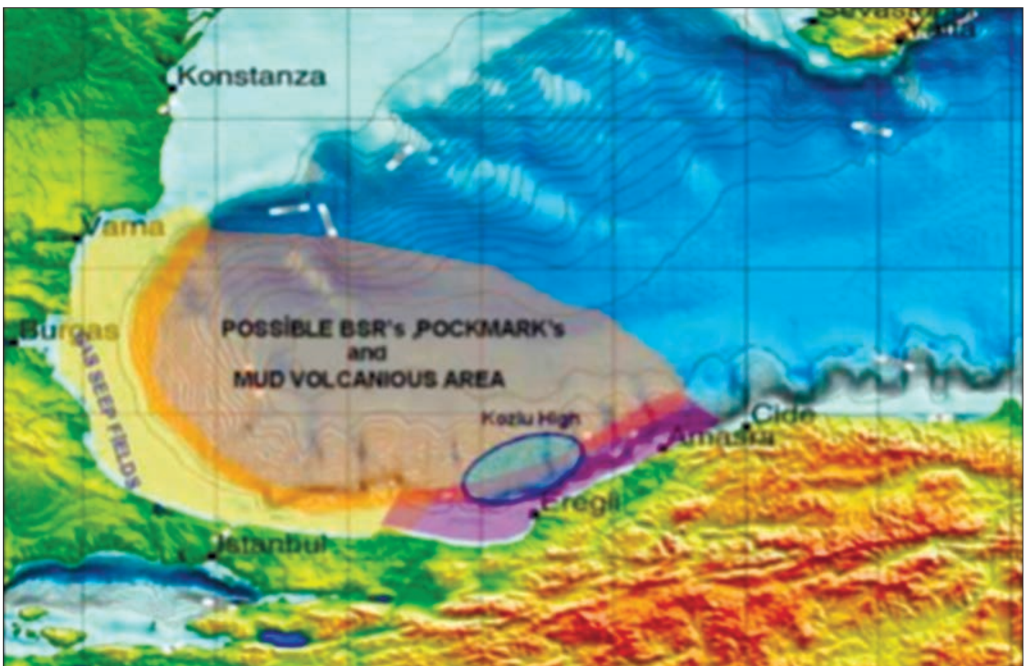


Fig. 15. General overview of geological provinces in the western Black Sea. This overview is based on the interpretation of seismic lines kindly provided by TPAO. Examples for pockmark and mud volcano-like features are given in Fig. 17) [35]

Sakarya rivers are likely to include potential reservoir rocks overlying productive Maikop source rocks (Figs.16, 17).

Organic-rich Carboniferous deposits are expected to be the main source rocks near the coastline and along the Eregli (or Kozlu) paleo-uplift. The Oligocene-Miocene Maikop spring is present in most of the territory and is considered gas-prone. In addition, the Middle and Late Miocene sediments sampled from the Limanka wells have excellent source rock potential and should be sufficiently mature in the deeper parts of the basin.

Further, near the coast and east of the study area, there are Eocene compression structures. These compressive structures develop on the surface of the Cretaceous

Table 1. **Acoustic and Seismic methods and acquisition parameters**

Working Area	Data	Method	Frequency	Streamer Length	Number of channels	Source
Offshore SW Turkey		Multi-Channel Seismic Reflection	30-100 kHz (2 option modes)	600 m	96	GI gun (75+75 inch3)
Samsun Area Offshore (Ergün et al., 2002)		MAK-1 Deep-Towed Side Scan Sonar				
		Mak1 Sub-Bottom Profiler	6 kHz			
Offshore Rize-Trabzon		Multi-Channel Seismic Reflection		1350 m	216	GI gun (45+45 inch3) GI gun (45+45 inch3)
Offshore Amasra	June2010 October2010 June2012	Multi-Channel Seismic Reflection		1500 or 1350 m 1350 m 1050 m	240 or 216 216 168	GI gun 2x(45+45 inch3) GI gun (45+105 inch3)
	June2010 October2010 June2012	Chirp	2.75--6.75 kHz			Transducer
TTR Trakya 2005 and Eastern Black Sea		Multi-channel seismic reflection		Two active sections of 50 m	16	GI-Gun (2x1.71 chamber volume)
		Sub-bottom profiler	5.1 kHz			
		Long-range Sonar	9.5 kHz (15 km swath each side)			
		MAK-1M deep-towed Hydroacoustic system	30-100 kHz			
R/V Posedion Cruise		DTS-1 Side Scan Sonar	75-410 kHz			
Eregli-Offshore Samsun		OFOS Sea floor observations			24	
Offshore Samsun Çifçi et al.,2003		High-resolution seismic				
		MAK-1 Deep-towed side-scan sonar	100 kHz			
		Sub-bottom profiler	5-kHz			

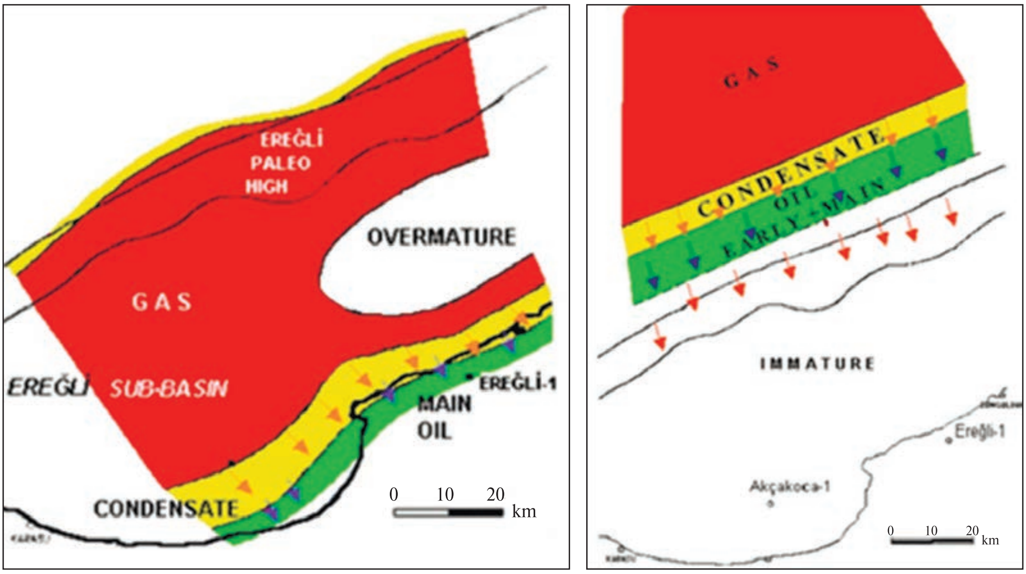


Fig. 16. Scheme of source rocks in the area of Kozlu High kindly provided by TPAO

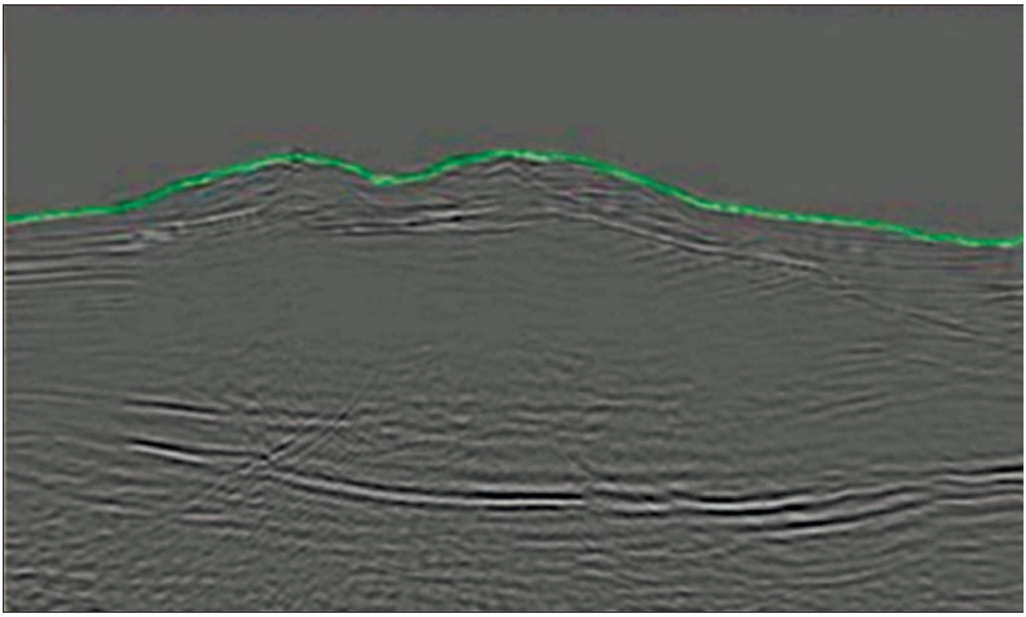
deposits [37]. In the Akçakoca-1 well, which was located in the immediate vicinity of the study area, about 10 miles offshore at a depth of 90 m (Fig. 13), gas was discovered in Eocene turbidites in 1976. Traditional multichannel seismic data also indicate gas accumulations at sea depths greater than 1000 m. Bottom mimics (BSRs) are observed in relatively deeper waters of the polygon with significant gas accumulations below the gas hydrate stability zone (Fig. 17, unpublished data).

Observations in the Eregli area, together with the first preliminary data processing during the cruise of the R/V «Poseidon» [35], revealed the presence of gas fronts in the bottom zone almost throughout the entire study area. However, in most cases, these gas fronts were recorded at a depth of 10 to 25 meters below the seabed. Only in a few locations did the gas front reach the seabed and DTS-1 sonar records showed gas plumes or other indications of active fluid seeps (Table 1). Fig. 18 shows an example of an acoustic dimming zone (No. 6 in Table 2).

Signs, which indicate at active fluid seeps, include gas plumes in the water column (Fig. 19), areas of very high backscatter intensity in a low backscatter environment (Fig. 20) and ring structures of intermediate to high backscattering intensity, confirmed by gas shielding in the bottom profiler recordings (Fig. 18).

Some of the gas flares observed did not show a characteristic backscatter pattern in the processed side-looking locator data, which may indicate either sporadic or very recent gas leakage. Unfortunately, the sampling attempt in this area was unsuccessful, so no evidence of methane seeps was obtained.

Evidence for gas in sediments and modern gas exits comes from DTS-1 sonar data, which has shown many signs of recent massive sediment destruction, especially on the flanks of the ridges. Rather intensive formation of ditches, ravines is observed here, deep traces of landslides are often found. No deposits were observed from these destructions. Also, signs of massive destruction are found in the deeper parts of the study area with the transfer of sediments only over short distances in various directions, including to the south.



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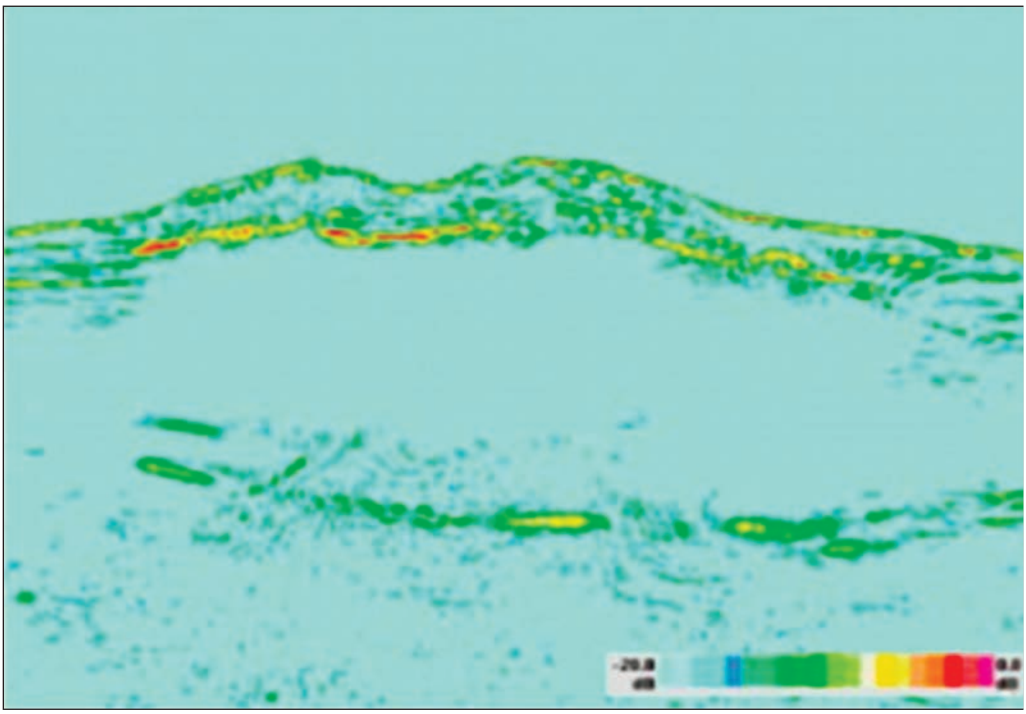
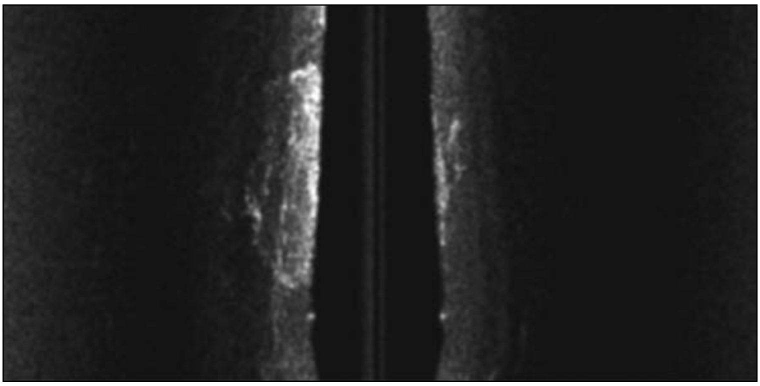


b

Fig. 17. Seismic profile (*a*) and amplitude section (*b*) showing a ridge structure in the area of Kozlu High provided by TPAO. The BSR is interrupted below the local heights, which could indicate the ascending gas, giving the structure the appearance of a mud volcano [35]



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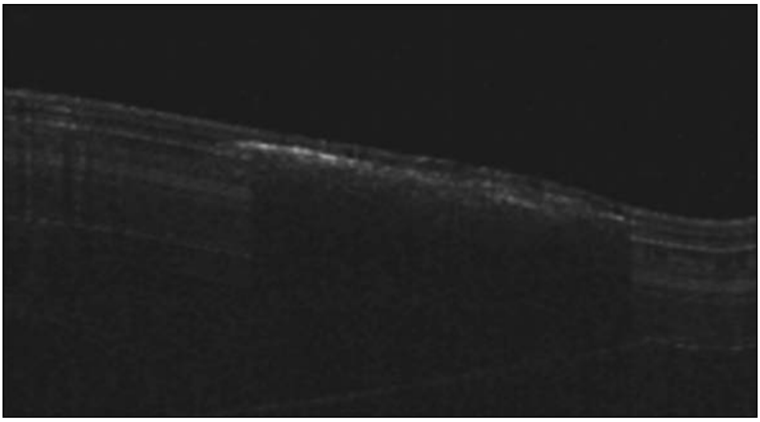

b

Fig. 18. Online sidescan sonar image (*a*) of a circular feature with high backscatter which we named Ereğ li Patch in the area of Kozlu High (No. 6 in Table 2). The subbottom profiler (*b*) indicates the presence of gas [35]

Table 2. **Gas seeps on Kozlu High surveyed during R/V Poseidon cruise P317/4**

No	Latitude	Longitude	Remarks
1	41°29.60′N	30°47.70′E	Small patch of high backscatter
2	41°31.20′N	30°49.05′E	Several small patches of high bakscatter(Fig. 22)
3	41°32.70′N	30°54.55′E	Patch of high backscatter with flare
4	41°44.02′N	31°06.10′E	«Kozlu Flare» Well developed flare without backscatter anomally
5	41°44.10′N	31°05.15′E	Possible flare associated with small high backscatter patch
6	41°28.50′N	30°51.60′E	«Eregli Patch» Circular structure with intermediate backscatter and underlying acoustic blanking (Fig. 20)
7	41°27.80′N	30°51.70′E	Circular structure with intermediate backscatter and underlying acoustic blanking
8	41°33.00′N	31°00.50′E	«TPAO Flare» Ridge with flares and adjacent area of patchy backscatter
9	41°32.20′N	31°00.75′E	Small patch of high backscatter
10	41°31.14′N	31°00.26′E	Gas Flare (Fig. 21)

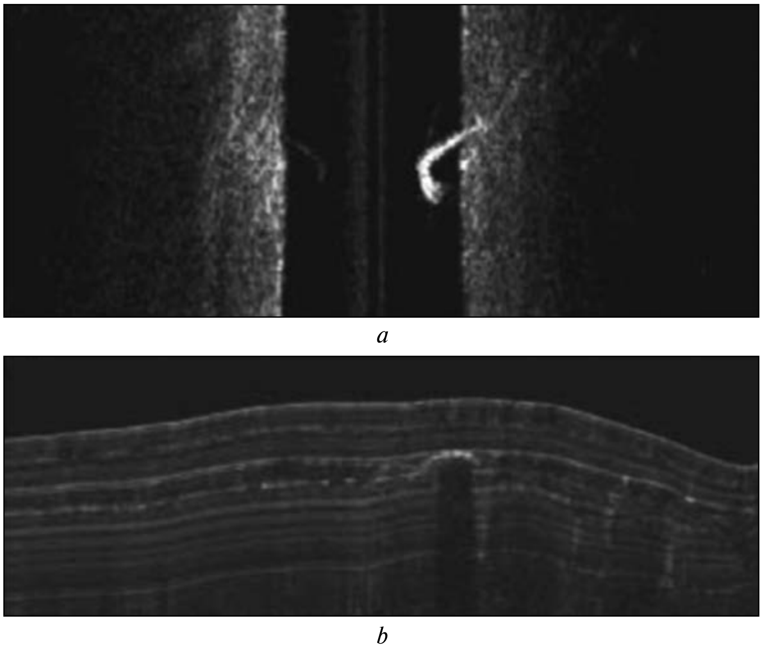

Fig. 19. Online sidescan sonar (*a*) image of a gas flare (No. 10 in Table 2) in the area of Kozlu High. The subbottom profiler (*b*) indicates the presence of gas. The attempt to sample this site unfortunately failed, as the core did not reveal any evidence for methane seepage [35]

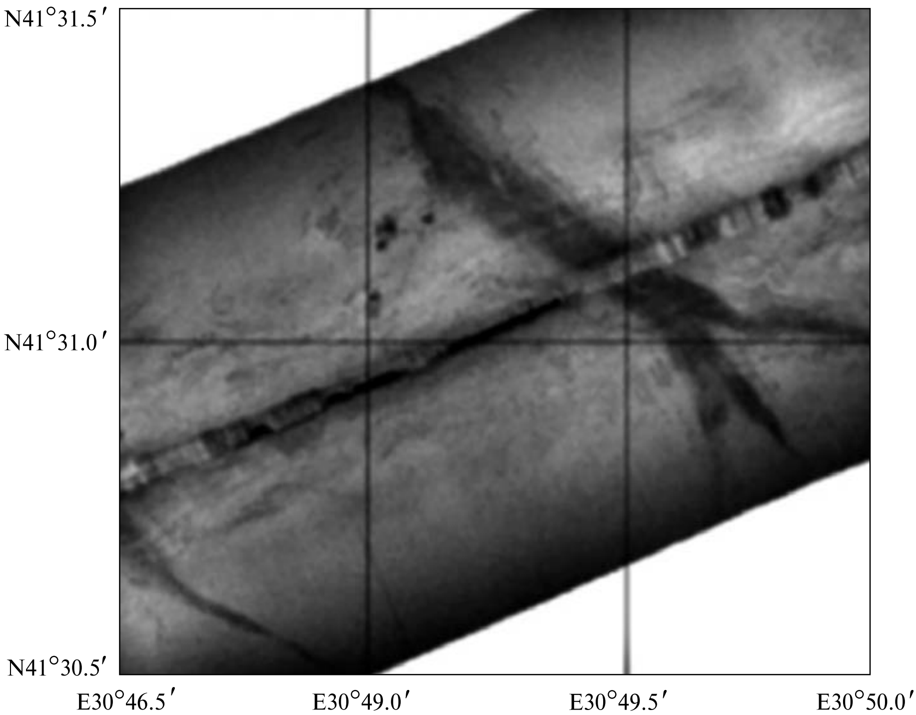

Fig. 20. DTS-1 sides can sonar image showing localised patches of very high backscatter in a low backscatter environment (No. 2 in Table 2). Such features could be related to gas seeps [35]

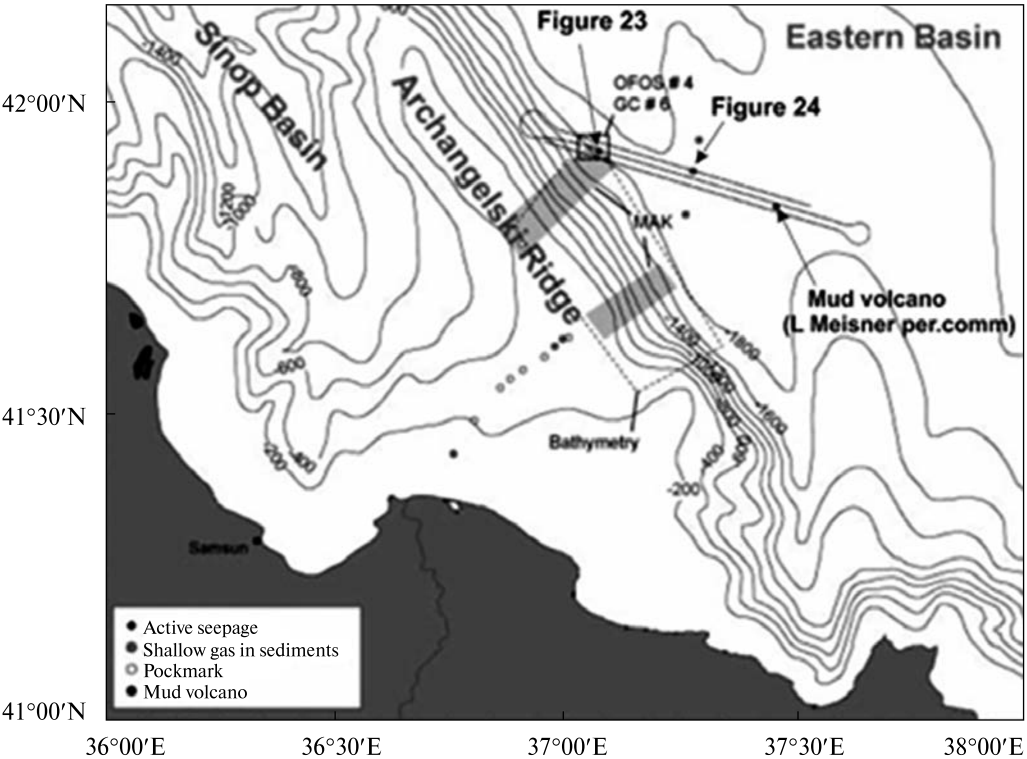

Fig. 21. Location of potential sites with methane seepage in the working area Samsun (Ergün et al., 2002 were intensively worked the area before). MAK side scan sonar and bathymetry images exist from the slope of Archangelski Ridge(R/V Poseidon P317/4 cruise report). Seismic lines indicated pockmarks and shallow gas in sediments. DTS surveys and locations of OFOS and GC of R/V Poseidon cruise [35]

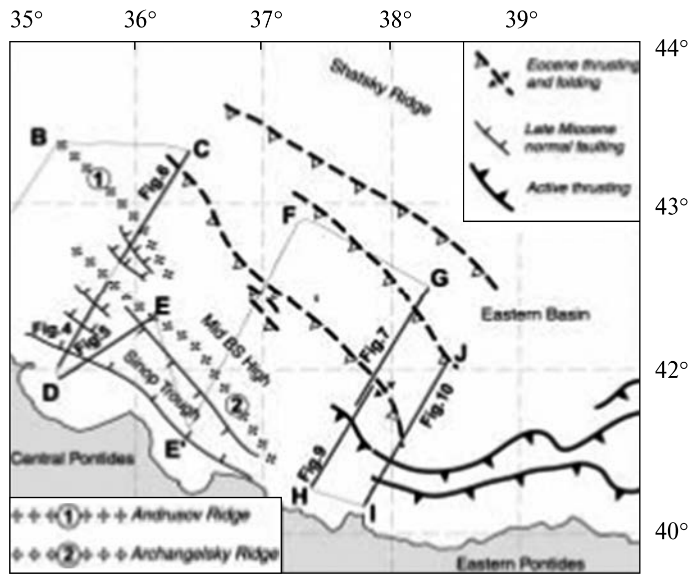

Fig. 22. Structural map based on the interpretation of the BLACKSIS profiles, illustrating the three distinct tectonic events identified in the area (from Rangin et al. 2002)

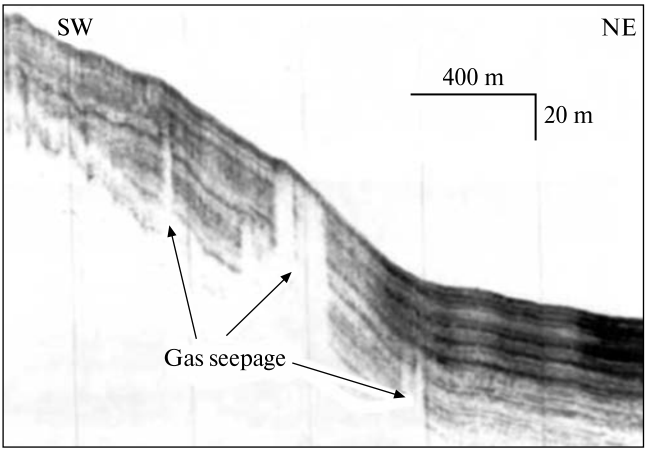

Fig. 23. Gas seepage on subbottom profiler record from the transition zone of the continental slope to abyssal plane [13]

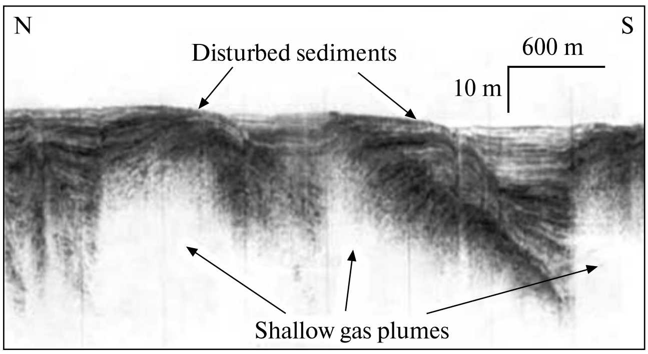

Fig. 24. Sub bottom profiler from the Turkish apron region. Uplifting of shallow gas plumes has disturbed the uppermost sediments [13]

Finally, the areas between the various ridges show a characteristic pattern with many ruled areas of very high backscattering, which are usually oriented parallel to the ridges.

The Yesilirmak landfill (Fig. 2) was investigated within the framework of the 7-th European framework project entitled «Climate and Tectonic Hazards on the Anatolian Plateau» (ALERT) in 2013 [1, 7].

Acoustic image blur is observed below the BSR. BSR reflections are distinguishable on slope areas as the gas hydrate stability zone can be easily identified in sloped layers. However, since the zone of stability of gas hydrates in parallel layers may look like the layer itself, it becomes difficult to determine it. To determine the boundary of the stability zone of gas hydrates in the section, instantaneous amplitudes are calculated [7].

Samsun test site is located in the southern part of the Median-Black Sea uplift on the slope of the Arkhangelsk ridge (Fig. 2). Previously, this water area was studied in order to find the location of potential sites for the development of methane seeps for subsequent expeditionary studies [13]. On the R/V Poseidon [35], hydroacoustic observations were carried out on 3 profiles (Fig. 21).

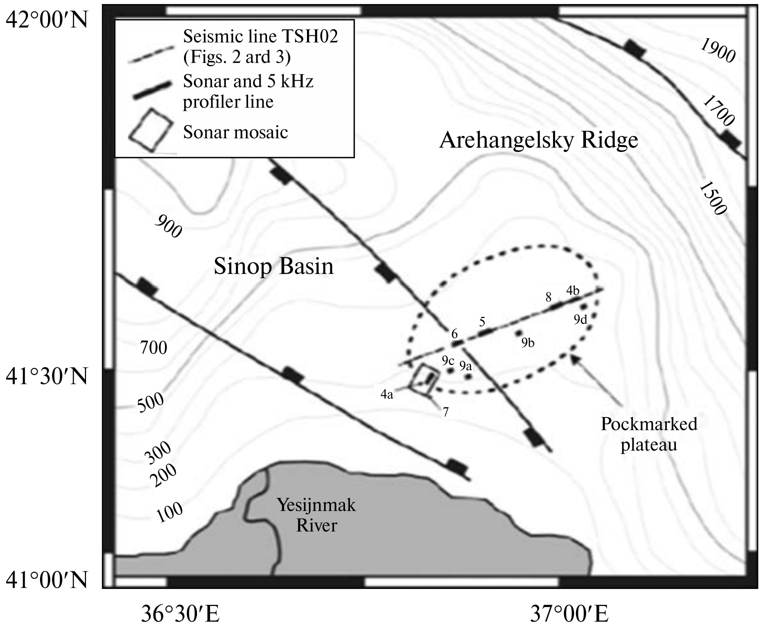

Fig. 25. The study area map with doted eliptic area showing pockmark area. The dotted line is a seismic line and the short black lines show the figure numbers in their work No. 6 is our Fig. 26 [6]

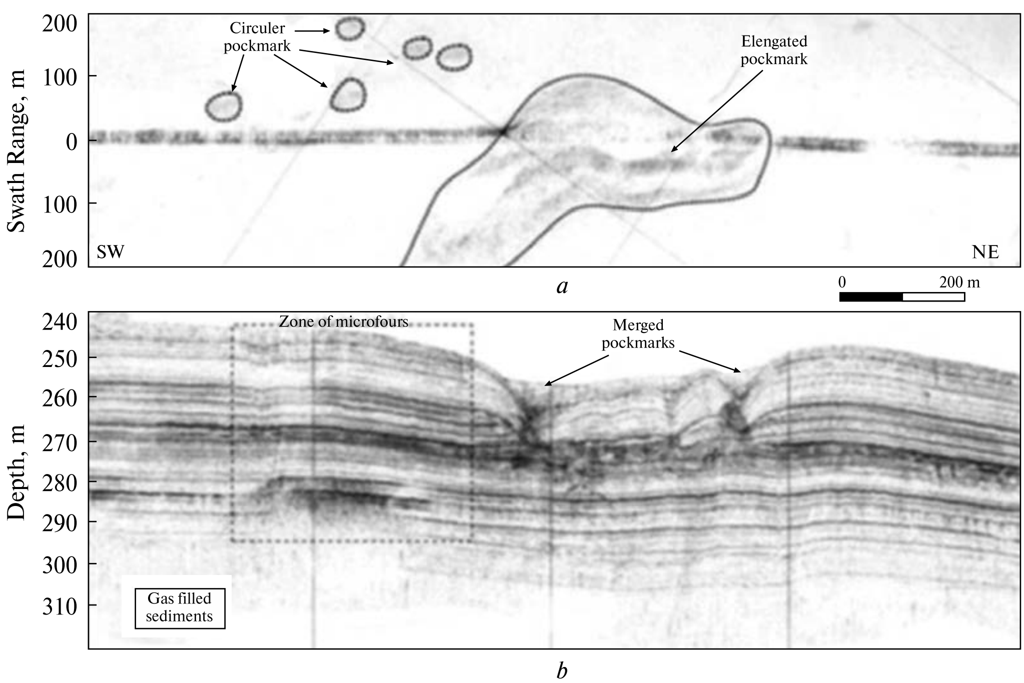

Fig. 26. Side-scan sonar (*a*), 5-kHz sub-bottom profiler records (*b*) [6]

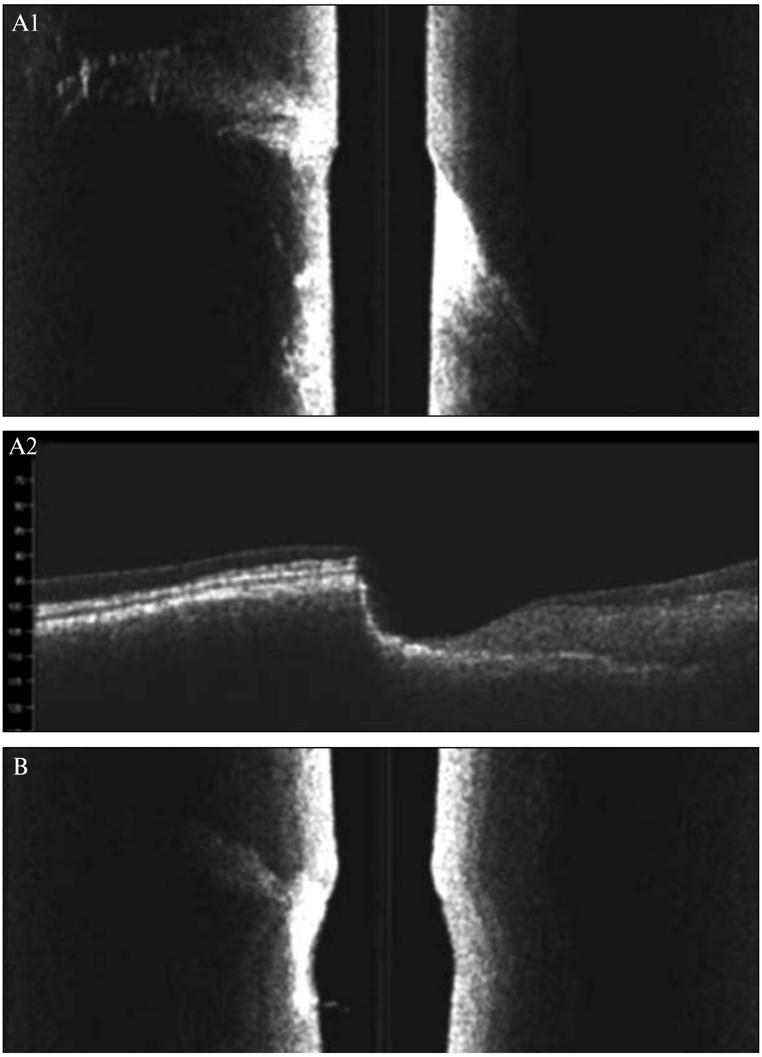

Fig. 27. Screen shots of DTS in the working area Samsun onboard R/V Poseidon. A(1)Backscatter and sub bottom profiler A(2) image of a 20m high fault scar. Small acoustic anomaly B may indicate gas seep in the water column. The area was surveyed by OFOS and sampled but didn't reveal any evidence for methane seepage (Sahling, H. et al., 2004)

The data of the lateral looking locator and the bottom high-resolution profiler (MAK-1) indicate the presence of shallow gas-saturated sediments in the coastal zone at a depth of about 100 m and in the area of continental rise at a depth of about 1700-2000 m (Fig. 22—24) [13]. The gas in these sediments causes strong acoustic blurring effects in the lower parts of the profilogram, masking the sedimentary layers. The edges of the gas-bearing deposits in the coastal zone are quite distinct, while the gas-bearing deposits at the continental elevation have a more or less dome-like structure with a concave upper surface. The upper surface of the gas front in this area is located, as a rule, less than 10 m below the bottom [13]. Some of the gas columns appear to be reaching the surface of the seabed and possibly forming a zone of active gas seepage into the water

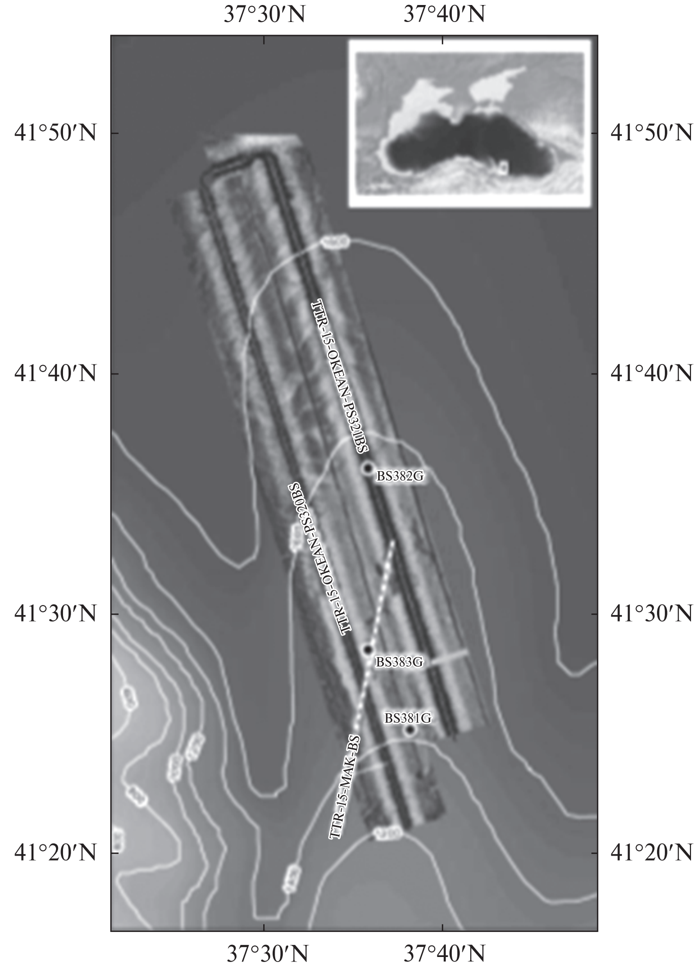

Fig. 28. Location map of the Samsun area [15]

column. There is also a vast plateau on the shelf where pockmarks are visible, consisting of several circular and elongated structures [6].

The second sample of data is devoted to the study of deep and shallow pockmarks in the fan of the Esilirmak River (Fig. 25).

As is known, the migration and displacement of shallow gas can create pockmarks on the seabed, which are usually associated with the seepage of gas and / or liquid into the near-surface sediments. Pockmarks are developed at a depth of about 180-300 m and are directly related to subsidence and collapse of sediments [6].

Fig. 26 shows pockmarks on the seabed from the side-scan locator and a seismoacoustic section from the bottom profiler on the southern flank of the Arkhangelsk ridge, which is characterized by shallow extensional faults. In the article [6], the authors interpret these faults as active channels for the formation of permeable zones of gas and fluid migration to the seabed surface.

The third data sample was obtained in 2004 using the built-in side-scan sonar DTS-1, as well as a high-resolution bottom profiler from the R/V Poseidon (Fig. 21). Side-scan sonar recordings showed a number of sediment transport characteristics as well as fracture traces. The clear reflections in the bottom profiler records likely overlap the gas-

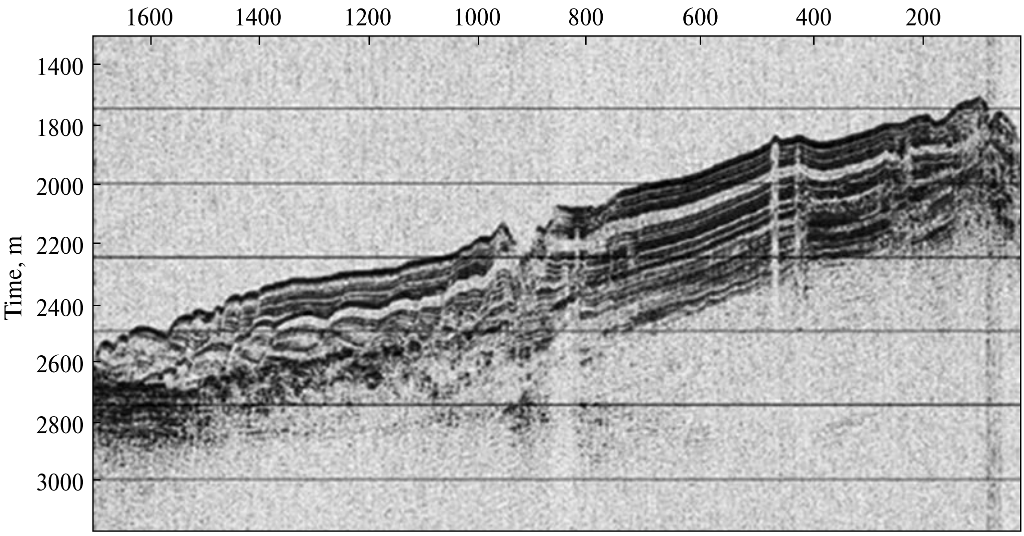

Fig. 29. The seismic section offshore Samsun area showing gas columns disturbing parallel sediments to the seafloor [15]

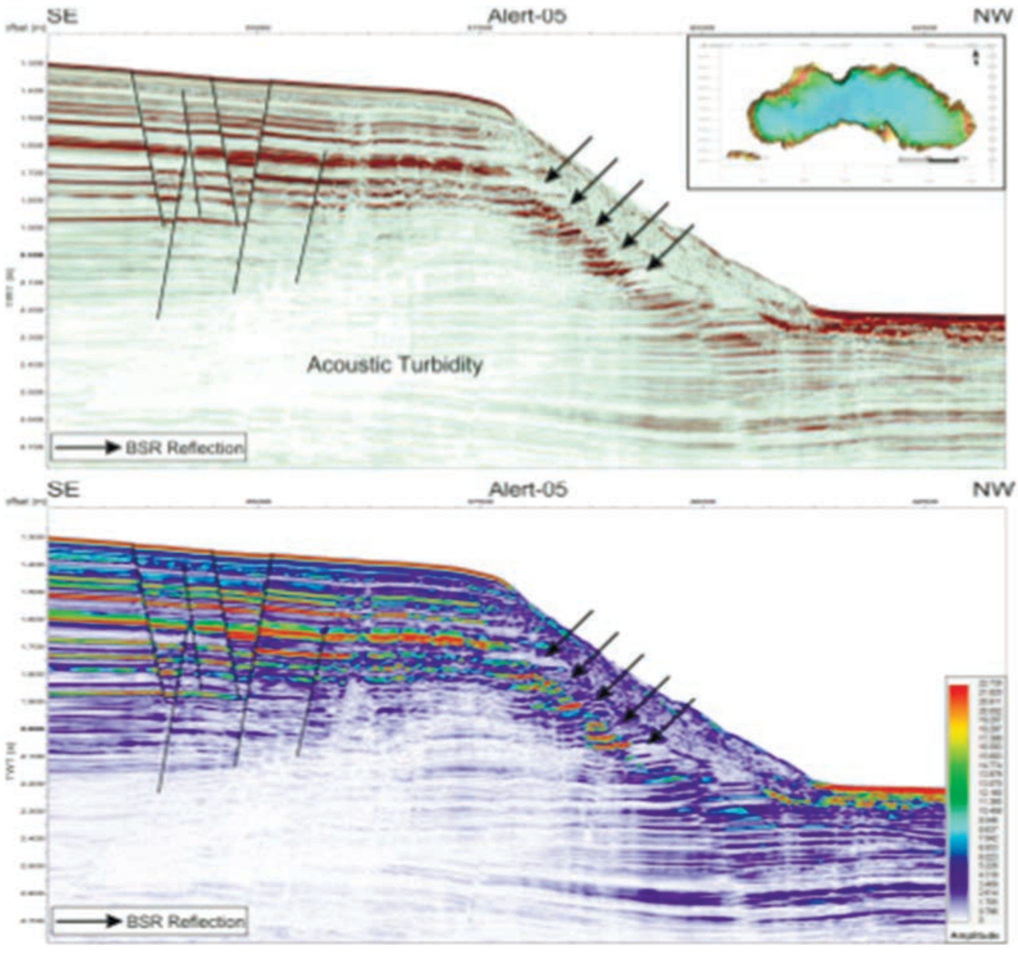

Fig. 30. Seismic line offshore Samsun. BSR reflection is obvious and instantaneous amplitude section [7]

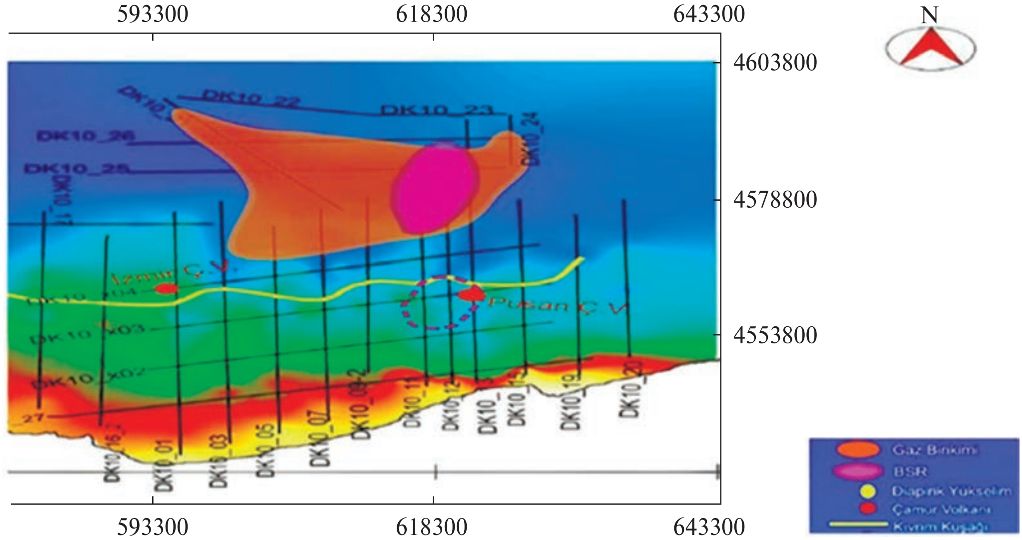

Fig. 31. Map showing interpreted structures in the area [26]

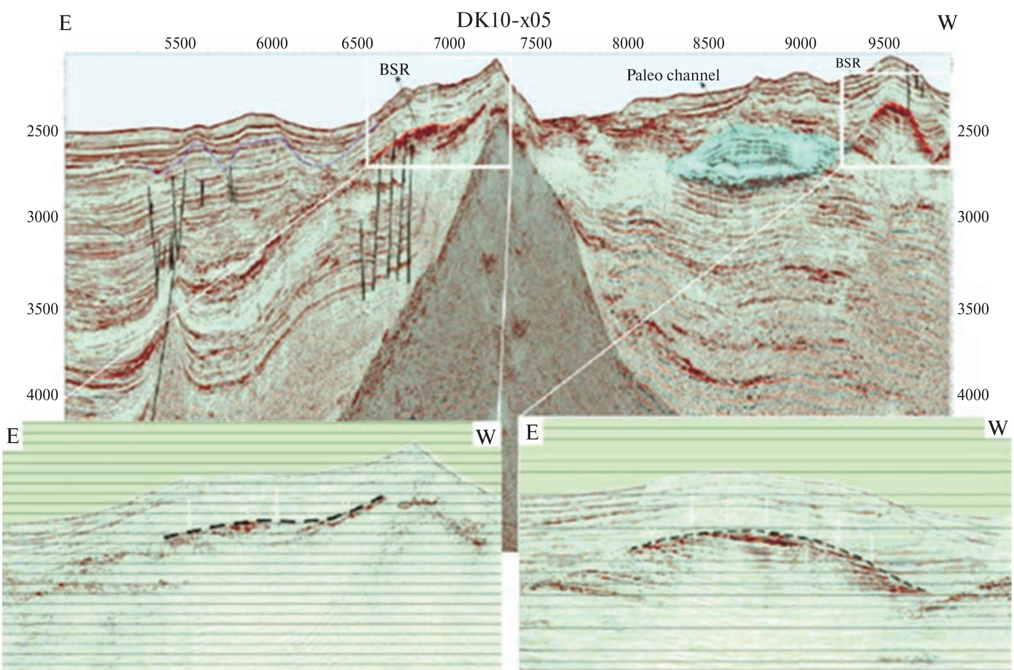

Fig. 32. 2D seismic line parallel to coastline off-shore Trabzon area, showing fault related volcanic dome structure at the eastern side of the section and a BSR at around 300ms below the seafloor (Gündüz,S., 2015). The Trabzon fault is a strike-slip fault. Acoustic blanking below the BSR may indicate free gas. Acoustic blanking is also present in deeper parts of the section

rich sediment strata that pinch out on fault cliffs where methane outflows can be expected. Fluid seepage in this area is very rare. Despite the fact that in many places along the profiles there are bright reflections in the bottom sediments, which may indicate possible accumulations of gas, only one small acoustic anomaly was recorded (strong backscatter at the point with coordinates: latitude — 41°55.47′N, longitude —

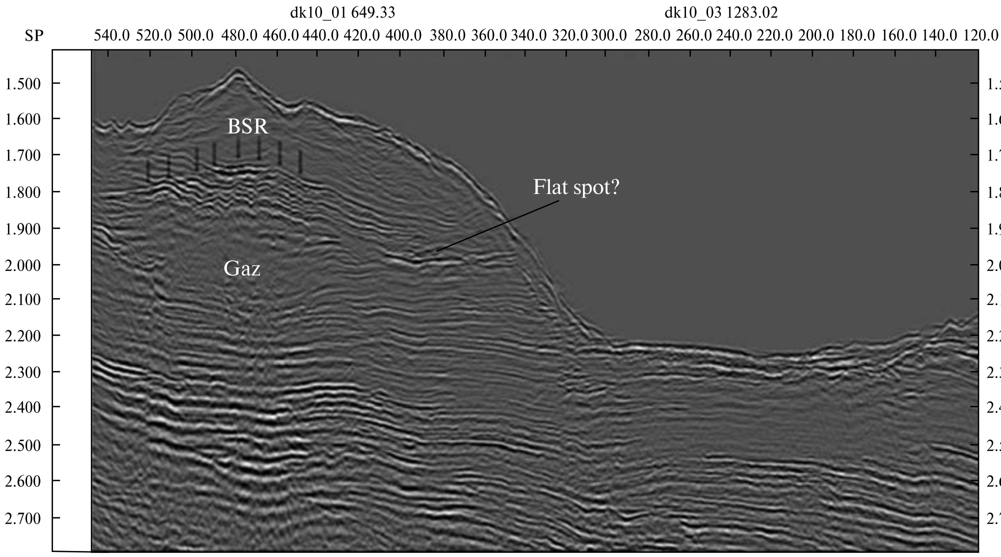

Fig. 33. BSR reflection and shallow gas below on seismic reflection section [26]

37°04.05′E), indicating, probably, outlets of gas bubbles (Fig. 27). However, neither observations nor sediment samples extracted by gravity tubes found evidence of methane seepage [35].

The fourth data sample reflects the materials of seismic observations carried out in 2005 from the R/V Professor Logachev in order to obtain information about such sub-bottom structures as diapirs, uplifts and mud volcanoes, as well as signs of the presence of gas and / or gas hydrate-containing sediments and potential areas for the development of gas seeps. During the expedition, several seismic lines were worked out along the Turkish border (Fig. 28).

Fig. 29 shows an example of a seismic time section at the Samsun test site. The sediments are generally well stratified, but show vertical amplitude variations below 100 ms below the bottom. In the upper part of the slope, the sediments are disturbed by several gas columns characterized by acoustic transparency. On the northern side of the profile, between points 1040-1400, undulating deposits are observed in the near-surface layer, probably generated by turbidite flows. At the southern edge of the profile, deposits are affected by recently active faults. Between points 860 and 960, the channel cuts into the sediments for about 150 m. Gas hydrates were recovered in two gravity tubes between 3-4 m core sections at stations BS381G and BS383G, the location of which is shown in Fig. 28.

The Trabzon-Rize test site is located on the eastern coast of Turkey (Fig. 2) Multichannel seismic data were obtained at the test site in 2010. Fig. 30 shows a diagram of the location of anomalous zones of signs of gas and / or gas hydrate-containing sediments (shallow gas accumulations, diapir structures and mud volcano) and BSR reflections on the Rize-Trabzon polygon [26].

On the eastern side of the study area, BSR reflections (Fig. 31) are observed on several seismic time profiles at depths of 1800-2700 ms from the seabed, and their width reaches 2-4 km (Fig. 32). There is no evidence of gas accumulations on some sections, but on some profiles, they are recorded below the BSR reflections (Fig. 33). Acoustic attenuation below the BSR may indicate free gas in deeper parts of the cut.

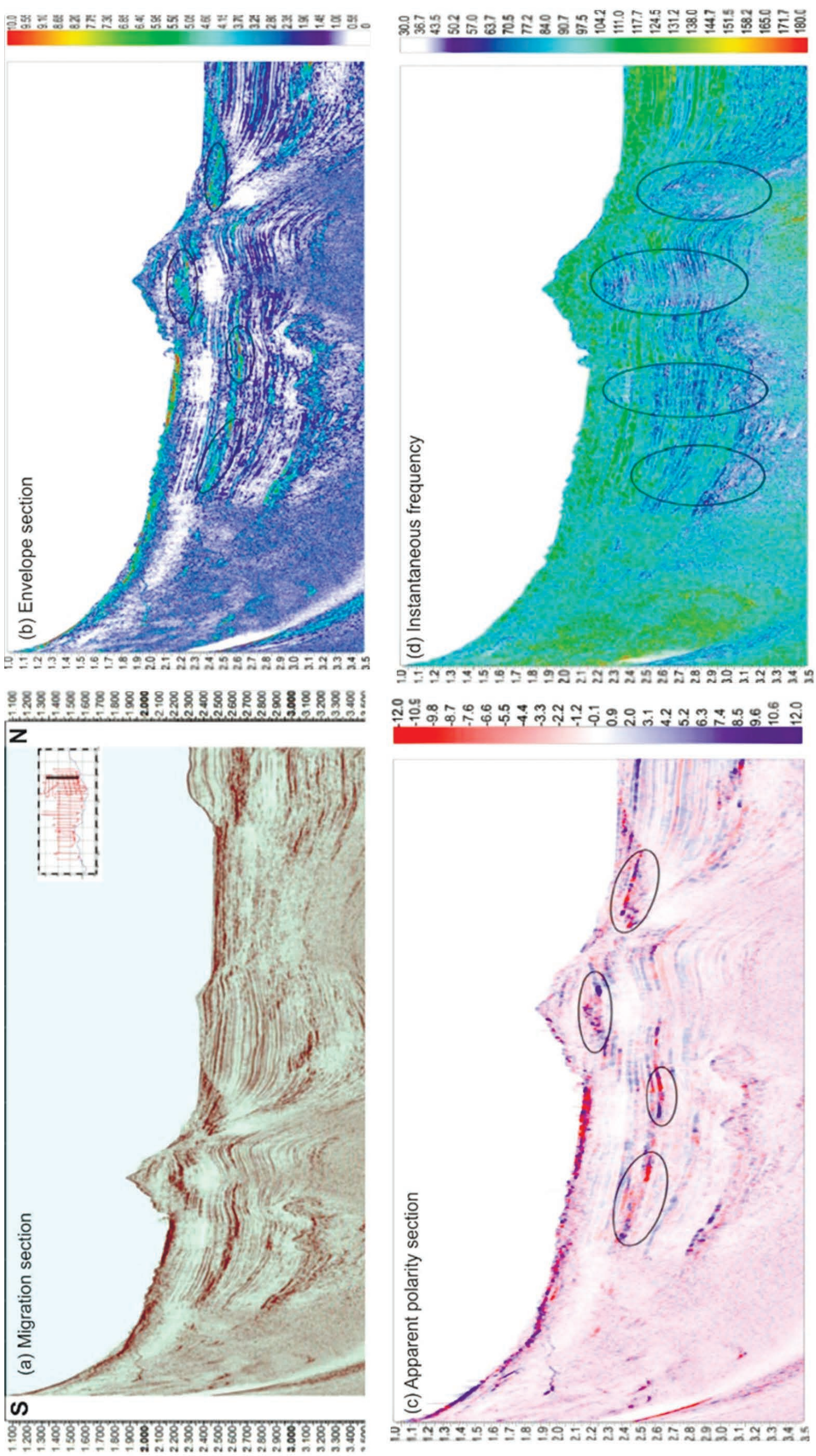

Fig. 34. A seismic line from the study area (*b*) and (*c*) black circles show negative polarity enhanced reflection areas, (*d*) black circles show low frequency areas [26]

The entire southern edge of the East Black Sea basin is under the control of progressive tectonics. It is dominated by high-energy river deltas and shallow marine sediments, and the areas of their basins are complexes of fans of pelagic and hemipelagic sediments.

Attribute analysis of time seismic sections are shown in Fig. 34. Gas and gas structures are characterized by negative anomalies in the polarity section, and in the frequency sections, low frequency zones may indicate shallow gas accumulations.

The Turkish framing of the Black Sea represents a transition from a flat and expressionless abyssal plain to a continental slope and coast. This area contains a large number of accumulations of methane and gas seeps on the seabed. The depth of shallow gas within the Turkish framing of the eastern part of the Black Sea is usually less than 10 m. Discontinuities within the bottom sediments of the framing are commonly observed by suppression of acoustic signals by shallow gas. It seems that shallow gas accumulations have a great influence on all processes taking place in this area. Deep seismic sections (unpublished data) also show deeper gas accumulations in the framing area, and therefore it can be concluded that the detected gas may be of thermogenic origin and be of economic interest, although the results of gas chromatography are not available. Round and elongated pockmarks are found at a depth of 180 to 300 m on the eastern shelf of the Black Sea.

Conclusions

The western and eastern parts of the Black Sea have extensive methane accumulations, and gas-bearing sediment structures in acoustic shielding, as well as acoustic columns in the form of pipes, enhanced reflections and reflections of BSR can be observed throughout the Black Sea coast of Turkey. The transfer of large quantities of organic matter leads to the extensive production of biochemical methane on the Turkish shelf. However, the deposits of the framing may be of thermogenic origin and have economic significance since there is also a connection between gas accumulations and fault tectonics.

Along the Turkish coast, we could observe gas seeps only in the Kozlu area from the R/V Poseidon, since the study included observations of the shallow-water sections of the bottom with a profiler. In other areas, mostly multichannel seismic data are presented, where gas seeps are difficult to see, since the source frequency is lower compared to the bottom profiler. Thus, more shallow water surveys are needed to detect gas seeps. We believe that almost all of the data we presented would indicate the presence of gas seeps if we had the opportunity to obtain other high frequency data. It is also necessary to drill wells for sampling for the purpose of seismic stratification of deposits and determination of gas composition.

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ГАЗОВІ ФАКЕЛИ І НЕГЛИБОКІ СКУПЧЕННЯ ГАЗУ НА ШЕЛЬФІ ТУРЕЧЧИНИ В ЧОРНОМУ МОРІ

Було висловлено припущення, що шельфові і схилові відкладення з високою швидкістю осадження є джерелами метану, в той час як глибокий басейн є поглиначем метану. Утворення і міграція метану в осадових породах може викликати масові провали схилів, тому метан має геологічне значення. Утворення метану також має економічне значення, так як метанові просочування можуть вказувати на наявність на глибині вуглеводневих резервуарів, а гідрат метану

може бути важливим джерелом енергії.

Останні дослідження в галузі морської геології вказують на потенційні георесурси на турецькому узбережжі Чорного моря. Чорноморські відкладення багаті кальцитом і органічним вуглецем, останній демонструє високу ступінь збереження через аноксію в воді під 100—150 м. Для розуміння особливостей седиментації газонасичених відкладень в Чорному морі були проведені різні морські геофізичні дослідження в різний час. Були зібрані дані багатопроменевого, бокового гідролокатора, донного профілографа і багатоканальної сейсморозвідки для складання батиметричних карт високої роздільної здатності та карт відбивної здатності морського дна. У деяких експедиціях для отримання акустичних зображень як поверхні морського дна, так і донних відкладень використовувався глибоководний буксир з гідролокатором бічного огляду і донним профілографом. У басейні Чорного моря спостерігалося кілька різних структур, таких як просадки, кишені, розломи, газові труби, неглибокі скупчення газу і куполоподібні структури. Структури, що містять газові гідрати, присутні на сейсмічних розрізах у вигляді сильних акустичних відображень.

Ключові слова: *Чорне море, газові сипи, газові скупчення, турецький шельф, сейсмічні розрізи.*