

Gas Hydrates of the Southern Caspian

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Abstract—The geological structure and bathymetry of the deepwater part of the South Caspian indicate the possible formation of significant amounts of gas hydrates. The aim of the research is to calculate the volume of hydrocarbon gases of gas hydrates according to integrated geological–geophysical, geochemical, and thermodynamic data, as well as to study and predict the migration of hydrocarbon gases into the upper part of the section. For a regional characterization of gas hydrates to be used for 17 seismic profiles, 1282 gas survey samplings and thermodynamic data were collected in the deepwater area of the South Caspian. Estimation of the gas volume of gas hydrates is based on an interpretation of seismic ($8.06 \times 10^{12} \text{ m}^3$) and thermodynamic data ($1.15 \times 10^{13} \text{ m}^3$). The result of the gas survey indicates heterogeneous nature of gas hydrate by area. Finally, it has been established that hydrocarbon gases in bottom sediments and sediments of the upper part of the South Caspian section are closely related to the sources of hydrocarbon formation, migration and other processes occurring in deeply buried sediments, as well as in the upper part of the section.

Keywords: South Caspian, gas hydrates, gas, estimation, hydrocarbon

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INTRODUCTION

In Azerbaijan, the first major study on gas hydrates in the Caspian Sea was carried out from 1972 to 1986. Analysis of the pressure and temperature equilibrium parameters showed that the hydrate formation zone in the Caspian Sea exists below the 250 m isobath. As a result of marine studies on the Caspian Sea floor, the Buzdag and Elm gas hydrate accumulations were discovered, as well as one occurrence on the Abikha Rise. It was established that the Buzdag accumulation is confined to the mud volcano of the Shatsky Rise at depths of 480–500 m. Gas hydrates in the form of icelike translucent methane formations of various shape and size were found in 17 raised bottom cores. The Elm gas hydrate accumulation, with a length of about 4 km, is located at sea depths of 560 m. In five out of seven cases, the cores turned out to be hydrate-bearing [3, 5].

Paper [2] presents the results of marine studies carried out 5 NM from the Elm gas hydrate occurrence. A seismoacoustic record revealed a diapir structure. In the central part of the diapir, characteristic attenuation of the acoustic signal was observed, probably due to gas saturation of the deposits. Hydrate-bearing mud volcano deposits were found in 16 recovered bottom cores.

In 2004, paper [14] was published, based on a study of the thermobaric parameters of the South Caspian. Having analyzed the data, the author predicted the presence of gas hydrates in sedimentary rocks to a depth of 3000 m, in the marine zone, to depths of 1000 m.

The regional seismic and thermodynamic data were integrated by a group of researchers [12] for the Apsheron site. The authors examined two deepwater 20 s profiles crossing the South Caspian and found that gas hydrates were detected up to 2 s. They studied gas hydrates at sea depths from 200 to 715 m. From an analysis of the thermobaric stability zone of gas hydrates, the authors concluded that the depth of gas hydrates in the deposits of the Apsheron site can be established to ≈ 1350 m.

In terms of prospecting for gas hydrates, the upper part of the section of the deeply subsided sediments in the South Caspian is the least studied and described zone in the literature. Moreover, gas hydrate zones based on seismic data were studied on only one Apsheron structure [12].

GEOLOGY OF THE SOUTH CASPIAN

The geological structure of the Southern Caspian (Fig. 1a) involves deposits from the Jurassic to the Anthropogene (Fig. 1b). In the shelf zone, Anthropogene deposits are represented by poorly sorted sandy–clayey formations with a thickness of up to 650 m. Neogene deposits, with an average thickness of 5000 m, are represented by Pliocene (up to 3500 m) and Miocene (up to 1500 m) series. The first of them is composed of clays, sands, and sandstones, and the second is represented by clays with rare interbeds of sand and silt. In the Lower Pliocene, a thick sequence of sediments

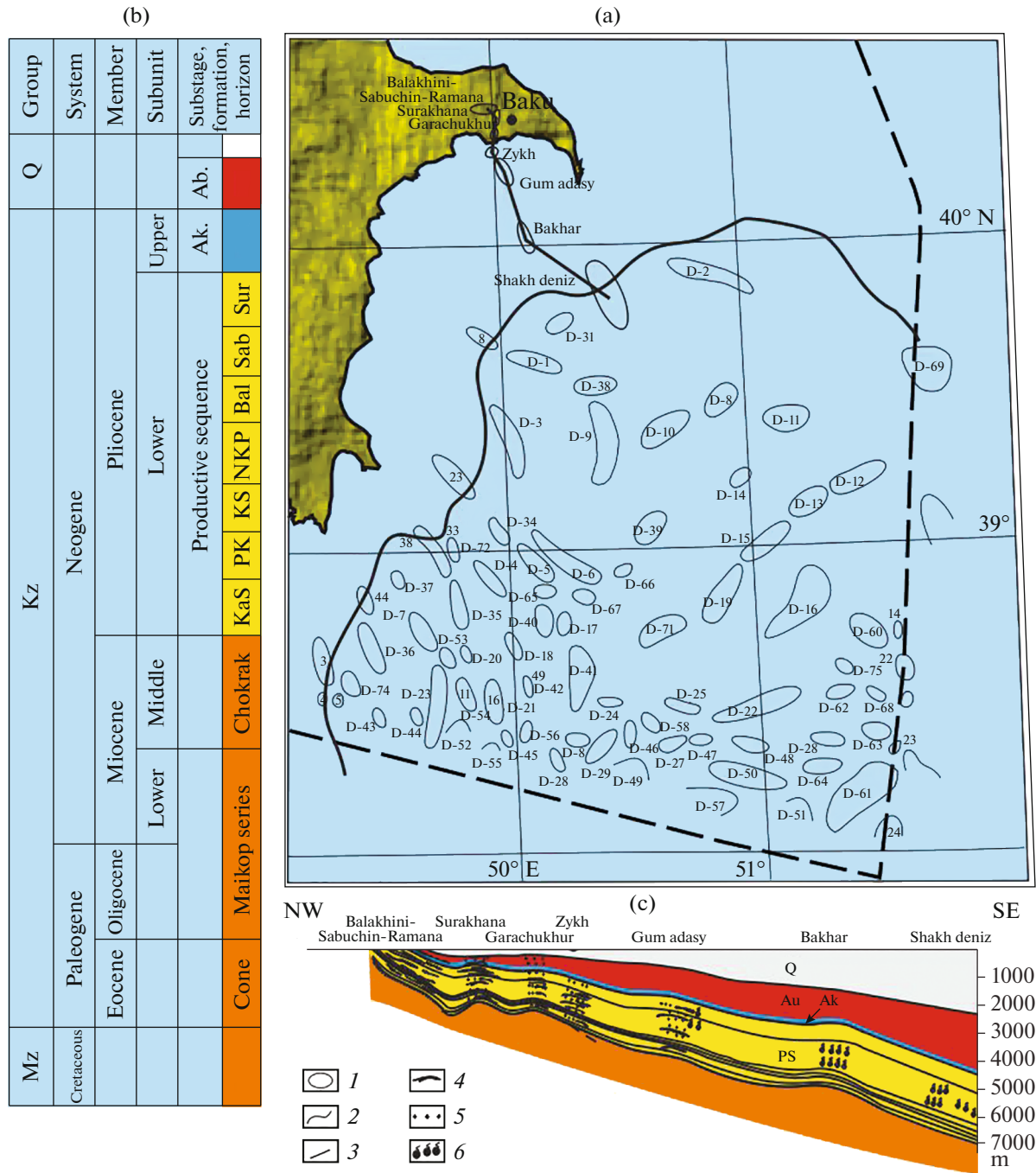


Fig. 1. Map of studied areas of South Caspian (based on tectonic zoning map of oil and gas territories of Azerbaijan [1]). (1) Oil and gas deposits; (2) isobath, 200 m.; (3) profile along NW–SE line; (4) oil deposits with gas dissolved in oil; (5) oil deposits with gas caps; (6) gas condensate deposits.

accumulated, the Productive Sequence (PS). The following stratigraphic formations are distinguished in it (Fig. 1c): the Surakhanskaya, Sabuchinskaya, Balakhanskaya, Kirmakinskaya (KS), Nadkirmakinskaya clay (NCF), Nadkirmakinskaya sand (NSF), Podkirmakinskaya (PK), and Kalinskaya (KA) formations [1]. The thickness of each stratigraphic horizon within the PS varies widely from 20 to 120 m on land and from

300 to 600 m in deeply subsided zones of the South Caspian. The thickness of all stratigraphic horizons increases toward the deepwater part of the South Caspian [4, 7].

There, seismic surveys of the Pliocene–Quaternary structural level revealed about 80 local uplifts of various orientations (from latitudinal to meridional).

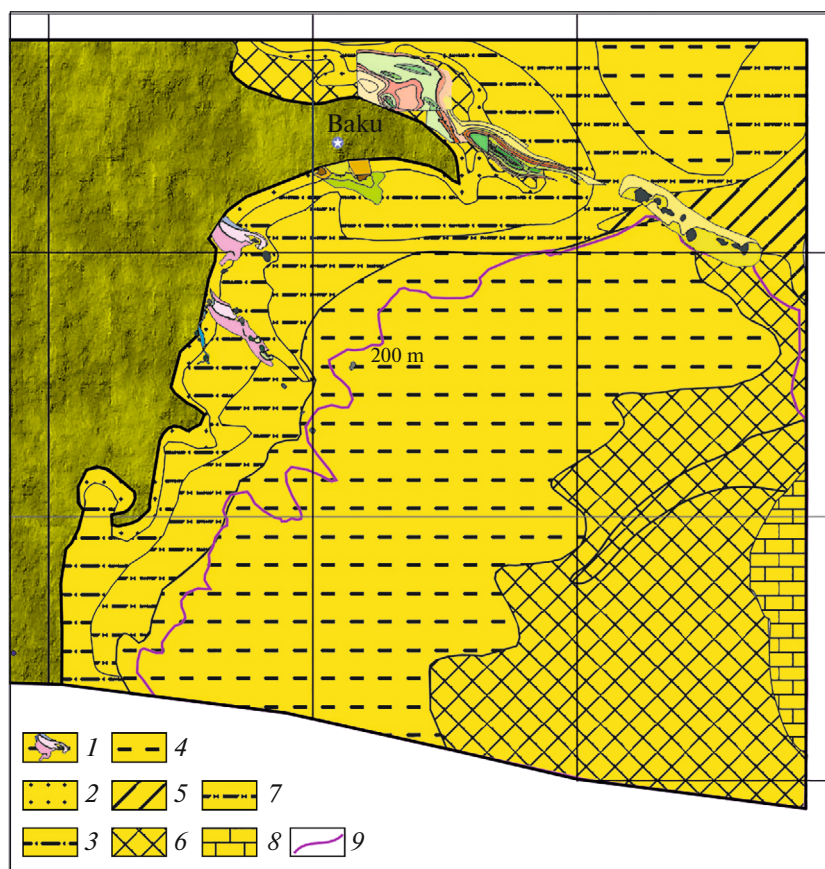


Fig. 2. Generalized distribution pattern of bottom sediments by area and their lithological and facies characteristics (according to data [1, 7, 8]). (1) Outcrops of Pliocene–Quaternary sediments; (2) terrigenous sand; (3) fine aleuritic silt; (4) poorly grained clayey silt; (5) silt sedimentation zone; (6) clayey silt; (7) aleuritic–clayey silt; (8) calcareous ooze; (9) 200 m isobath.

The largest tectonic element here is the Abikha Rise, stretching 140 km to the northeast. Within this rise, the roof of the Middle Pliocene lies at a depth of less than 3000 m, and in the adjacent synclinal troughs, it plunges to 6500–7500 m. The amplitude of the Abikha Rise, with respect to the adjacent troughs, is about 3500–4500 m. With such a large amplitude, the folding of the rise Abikha decays to the southeast. Geomorphologically, in addition to the Abikha Rise, the similar Shatsky rise with a northeast–southwest strike is distinguished. The thickness of the sedimentary cover here reaches 25 km [1]. The rhythmic alternation of sand reservoirs and clay caprocks and favorable structural conditions led to hydrocarbon saturation of the entire section of the PS on the Apsheron Peninsula and adjacent shelf. Within the region, up to 40 oil-and-gas-bearing objects have been identified (Balakhani-Sabunchi-Ramana, Surahani, Bibi-Heybat, Kala, etc.).

Bottom deepwater sediments in the South Caspian are mainly represented by Quaternary deposits. This is clearly visible based on the systematization and analysis of data from previous studies [1, 7, 8, 16]. As a result, a generalized scheme of the distribution of bot-

tom sediments over the area was compiled and their lithological-facies description was given (Fig. 2). As can be seen from the map, within the South Caspian, certain outcrop zones of Pliocene sediments are delineated, which are consistent with the general geological structure of the South Caspian. Clayey silts of various consistency have been established on the seafloor surface within the deepwater part.

MATERIALS AND METHODS

In studying of the upper part of the section (UPS) of the deeply subsided sediments of the South Caspian, 17 regional seismic profiles and regional thermodynamics data were used (Fig. 3) [13]. For two areas of the South Caspian, velocity analysis data were used. Seismic material was translated from a time section into a depth section via a depth–time diagram [16]. The locations of seismic profiles are shown in Fig. 4. The data were interpreted using the Kingdom Suite 2017 licensed software package. The use of seismic methods in studying gas hydrates is based on the direct relationship between the features of the geological structure of gas hydrate zones and the distribution of

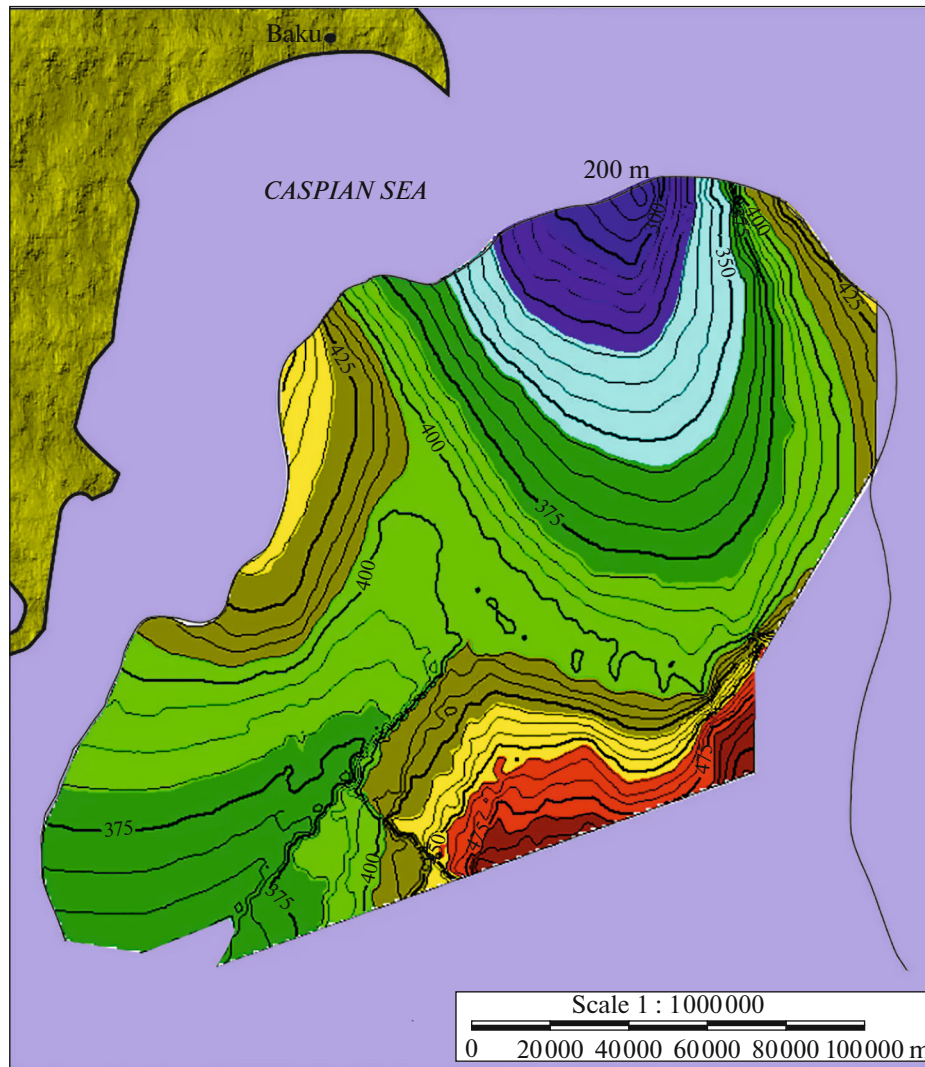


Fig. 3. Map of variation in seafloor depth at fixed temperature of 24°C (deepwater part of South Caspian) [9].

the physical parameters in the medium. An abnormal change in the seismic characteristics of waves can be an indicator of gas hydrates in the time section: amplitude, frequency, phase, longitudinal and transverse waves velocities, etc. The most widely used seismic feature for gas hydrates is the presence the Bottom Simulation Reflector (BSR) and bright spots on seismic records [3, 11, 12, 15]. All time sections in Fig. 4 were interpreted based on these criteria.

The study also used gas survey data (1282 gas samples) acquired within the Southern Caspian (Fig. 5), as well as data from geological and geophysical studies and other materials [4, 8, 16].

INTERPRETATION RESULTS

A map of the change in the bottom depth at a fixed temperature of 24°C was compiled (Fig. 3), and the thermodynamic equilibrium was calculated for gases of two gas hydrate accumulations, the Bozdag and

Elm [9]. Accumulations of crystalline hydrates in the South Caspian are characterized by an uneven distribution in the rocks. Their position is determined by the heterogeneity of the temperature field and pressure over the area and section. The volumes of gas hydrate zones were calculated from the thermodynamic equilibrium data. Based on the calculations, it was found that the total gas hydrate volumes for the studied sediment area are $1.15 \times 10^{13} \text{ m}^3$ [9].

Interpretation of 17 seismic time sections (Fig. 4a) cutting through the deepwater zone revealed the boundaries of the gas hydrate zones [11]. Calculations were done for the entire deepwater zone (Fig. 4b), the volume of rocks of which is $6.99365 \times 10^{12} \text{ m}^3$. The total gas volumes calculated for the study area are 8.06 tril. m^3 .

The results of gas surveys within the deepwater part of the South Caspian [10] showed that gas generation is characteristic of this zone with two predominant components: methane and ethane (Figs. 5a, 5b).

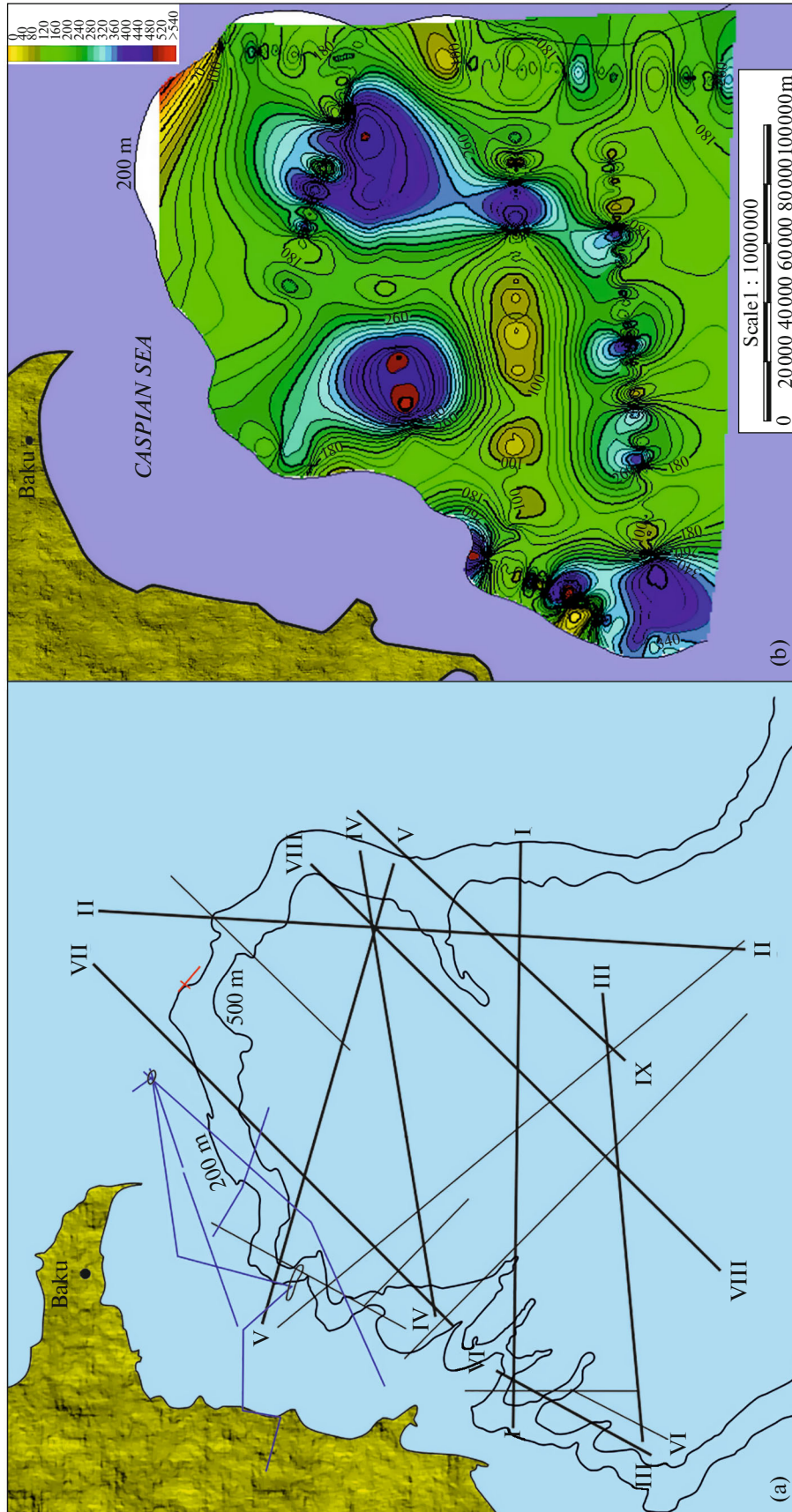


Fig. 4. Results of interpreting seismic data [11] within deepwater part of South Caspian: (a) location of seismic profiles; (b) map of thicknesses of gas hydrate zones.

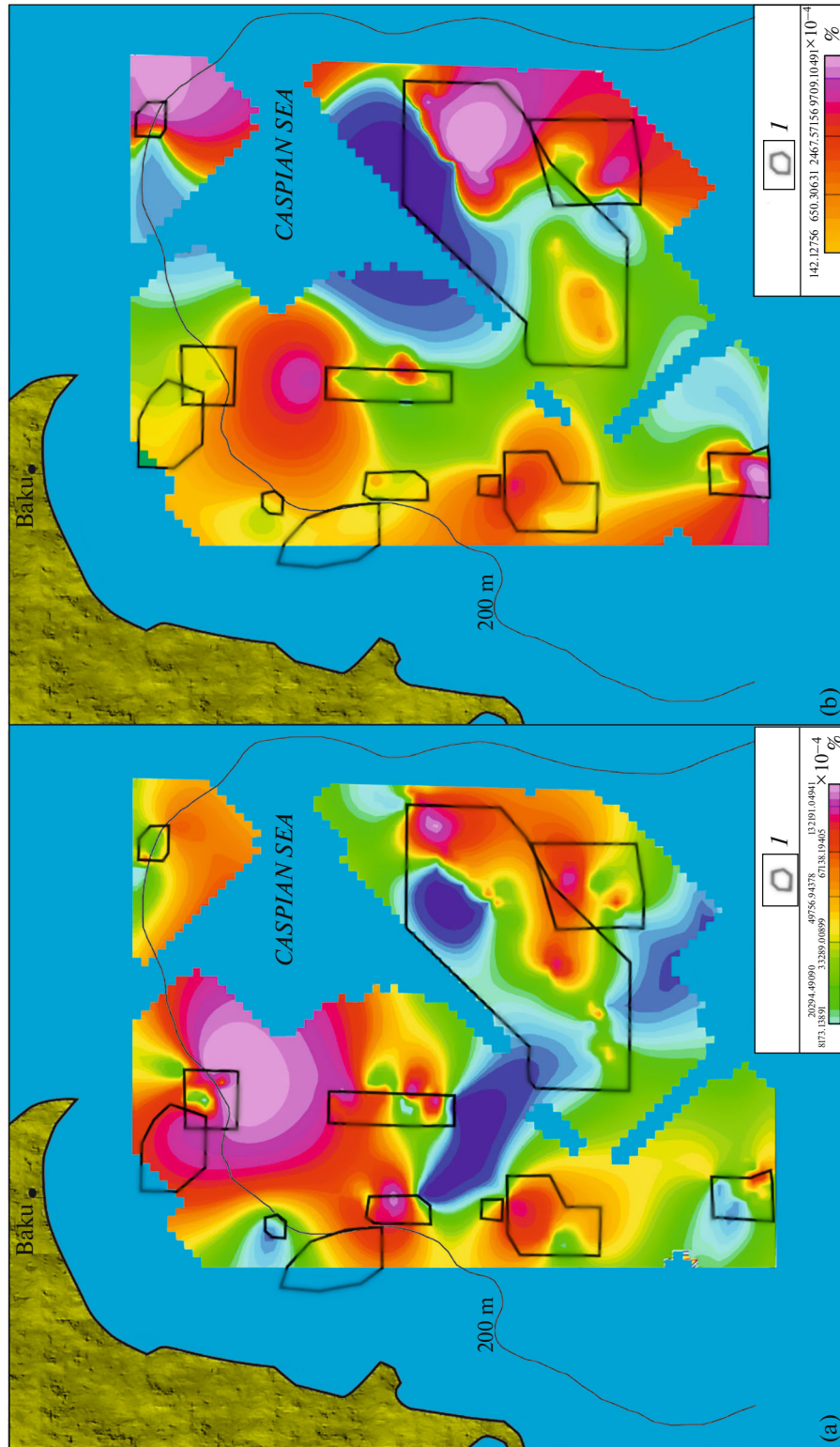


Fig. 5. Gas survey results [10] within deepwater part of South Caspian: (a) methane distribution, (b) distribution of total heavy hydrocarbons. (I) gas sampling area.

Table 1. Calculations of HC gas volumes for deepwater part of South Caspian

Stratigraphic age	Rock, in cm ³	Sediment density, g/cm ³	OM, g per 1 kg	γ	τ	Hydrocarbon gas volume
Khvalynskii horizon	4.38×10^{18}	1.6	10	0.01	3.00×10^{-8}	7.01×10^{17}
Early Khazarskii horizon	1.50×10^{19}	2.0	10	0.01	4.00×10^{-8}	3.00×10^{18}
Bakinskii horizon	8.11×10^{18}	2.1	10	0.01	5.00×10^{-8}	1.70×10^{18}
Turkanskii horizon	6.16×10^{18}	2.2	10	0.01	5.00×10^{-8}	1.36×10^{18}
Apsheron regional stage	3.60×10^{19}	2.35	10	0.01	5.00×10^{-8}	8.46×10^{18}
Akchagyl regional stage	4.63×10^{18}	2.4	10	0.01	5.00×10^{-8}	1.11×10^{18}

Intensive yields of methane homologs (Fig. 5b) were established only in a number of zones near the structures D-12, D-13, D-15, D-19, D-29, D-66, D-71, Guneshli, and Chirag. For other zones, the intensity of their occurrence is minimal. Thus, it can be expected that gas hydrates bearing methane homologs will be established in the zones of structures D-12, D-13, D-15, D-19, D-29, D-66, and D-71.

The lithification of sediments in the diagenetic zone to depths of 400–500 m and at subsequent stages of the conversion of organic matter in the overwhelming majority of cases leads to a reducing setting. It is clear that under such conditions, gases can be not only migratory, but also formed in modern South Caspian sediments. In order to assess the possible gas volumes, a quantitative analysis was attempted. To calculate the scale of gas generation in the deepwater part of the South Caspian (from the 200 m isobath), rock volume data from the New Caspian to the Akchagyl regional stage, inclusive, were used, along with average organic carbon content data. Table 1 shows the calculations of volumes of hydrocarbon gas generation.

The scale of hydrocarbon gas generation is calculated by the formula [6]

$$Q_{\text{TH}} = VdOB^* \gamma \tau \times 10^{-6},$$

where Q_{TH} is the scale of gas and oil generation, tril. m³; V is the volume of oil and gas source clay rocks, cm³; d is density, g/cm³; γ is the gas hydrocarbon generation coefficient; OB is the organic matter content in the studied complex (in grams per 1 kg of oil and gas source rocks); τ is a correction that takes into account the tectonodynamic conditions and adjusts the correspondence of the scale of gas formation in the sedimentary basin with experimental and actual data.

CONCLUSIONS

Based on integrated geological, geophysical, and geochemical data, a model of Pliocene–Quaternary sediments of the deepwater part of the South Caspian was constructed to identify gas hydrate accumulations (Fig. 6a). In addition, the model contains the results of calculating the thermodynamic equilibrium within the

deepwater part of the South Caspian. Analysis of the obtained model makes it possible to conclude that gas hydrates, which include methane homologs, will be established in the zones of structures D-12–D-15, D-19, D-45, D-56, D-59, D-66, and D-71. The ranking of data on volumes within the structures (Fig. 6b) showed [11] that in the first ten structures—1, D-11; 2, D-60; 3, D-10; 4, D-28; 5, D-25; 6, D-16; 7, D-41; 8, D-19; 9, D-13; 10, D-71—contain 6.12×10^{11} m³ of gas, while for all other 46 structures, the gas volume is 6.40×10^{11} m³.

From the model, it is clear that the thicknesses of hydrate-bearing horizons increase in areas where Pliocene deposits are located in more hypsometrically higher areas, which primarily include the Abikha zone, as well as areas in the zones of structures D-21 and D-42. In these zones, the thicknesses of hydrate-bearing horizons vary from 200 to 350 m, because the Pliocene deposits possess significant hydrocarbon volumes and have a high generation potential [10]. It should be noted that zones D-21 and D-42 are characterized by a complex geological structure, complicated by faults and mud volcanoes. The zones associated with mud volcanoes are characterized by the absence of significant thicknesses of gas hydrates, varying from 50 to 200 m.

It was established that gas hydrates form in the diagenesis zone, the lower boundary of which has been recorded at a depth of approximately 500 m at a maximum temperature of 24°C. Analysis of the gas-geochemical material shows that Anthropogene–Pliocene deposits are characterized by widespread intense hydrocarbon gas seeps, the activity of which varies depending on the territorial affiliation. Hydrocarbon gases that form in the diagenetic zone are present in sufficient volumes and can create crystallization sites. The formed gas hydrates cement marine sediments, making them practically impermeable to hydrocarbon gases. This significantly limits the diffusion dispersion of gas hydrocarbons and contributes to their retention [10, 16]. Another important factor is the increase in gas hydrates in stability zones. This is due to the influx of significant volumes of gas hydrates from the under-

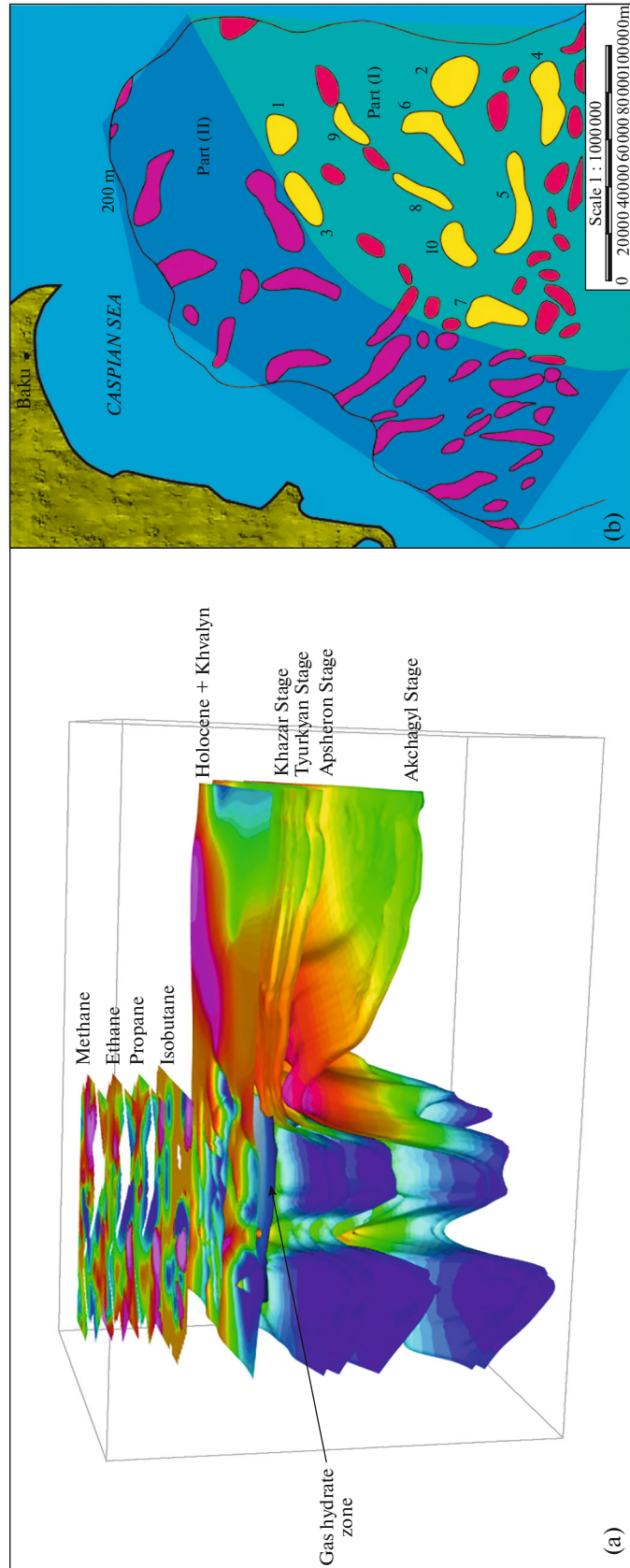


Fig. 6. Geological and geochemical model of Pliocene–Quaternary sediments (a) and distribution map of gas volumes [11] by area (b).

lying sediments into stability zones. The substrate sediments are underlying Pliocene–Quaternary deposits.

By analyzing the results of basin modeling and studying the isotopic composition of hydrocarbon gases in the South Caspian, it can be concluded that the oil and gas production processes cover a wide stratigraphic interval (from the Jurassic to the Early Pliocene inclusive) and are characterized by spatial variability. The supply of hydrocarbon gases to the upper part of the section occurs due to the vertical migration of hydrocarbons forming in the thermocatalytic zone. The hydrocarbon gases may not be confined to hypogene oil and gas or gas deposits. The porosity and permeability of the UPS significantly differ from the data on the underlying PS sediments. PS collectors form a powerful interbedded sequence in which each permeable layer is separated by thick, moderately compacted clays that isolate it from neighboring layers. The migration of hydrocarbon gases from the thermocatalytic zone contributes to the further accumulation of gas hydrates within the stability zone. Hydrocarbon gases in bottom sediments, as well as in sediments in the UPS of the Southern Caspian, closely depend on the sources of hydrocarbon formation, migration, and other processes occurring in Pliocene–Quaternary sediments.

Thus, the South Caspian has high prospects for gas hydrates in terms of area and section. Priority objects for gas hydrate prospected will be related to the Quaternary deposits of structures D-11, D-13, D-16, D-19, D-25, D-41, and D-71.

Based on the foregoing, two gas hydrate zones have been distinguished in the deepwater part of the South Caspian:

- the northwestern crystalline hydrate prediction zone;
- the southeastern zone prospect.

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