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OCEANOLOGY

New Data on Quaternary Processes of Underwater Slumping on the Western Slope of the Derbent Basin (Caspian Sea)

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The structure of the sedimentary sequence of the Caspian Sea has been scrutinized by geological and geophysical methods, including seismic profiling [1]. It is mostly concerned with relatively deep Lower Cenozoic–Upper Mesozoic horizons with the potential presence of hydrocarbon traps [2]. However, the uppermost sedimentary horizons of the Quaternary age are poorly studied, because it is rather difficult to sample these slightly lithified sediments during exploration drilling. For example, the published data on the lithology and stratigraphy of marine sediments on the western slope of the middle Caspian region near the Dagestan coast are limited by geological columns only up to some meters [3]. The same situation is true for the extent of study of the sedimentary sequence structure by continuous seismic profiling (CSP). The CSP investigation was mainly carried out in the 1970s and 1980s using low-resolution profiling systems [4]. The superhigh-resolution CSP investigation was carried out for the first time in the Yalama–Samur structure with petroleum potential within the framework of the Federal Program "World Ocean" (Subprogram 0008 "Comprehensive Studies of Processes, Characteristics, and Resources of the Caspian Sea") and a geological–engineering survey carried out for the Lukoil Company during Cruise 19 of the R/V *Rift* on the western slope of the Derbent basin in the autumn of 2004 (Fig. 1).

A unique narrow-beam SES-2000 standard parametric profilograph (Innomar Technology GmbH, Germany) was used in this cruise for the first time in the Caspian Sea for studying the fine structure of the uppermost sedimentary horizons. This is a basically new acoustic system of profiling based on nonlinear (parametric) acoustics. The parametric effect shows up in the generation of acoustic waves with a calibrated difference frequency of 4–15 kHz at coaxial generation of high-frequency acoustic signals with a close frequency of ~100 kHz. Depending on the frequency and duration of the sounding signal, the vertical resolution in SES sections may reach 5 cm. High horizontal resolution, an order of magnitude higher than in common linear profilographs, is gained due to a narrow beam of less than 2° without side lobes and a high reproduction of excitations (up to 50 exc/s). The electron stabilization of beam verticality and the compensation of vertical displacement of antenna within ±5 m (accurate to <5 cm) even under poor hydrological conditions essentially increase the performance of the high-resolution survey as compared to linear systems.

This work presents a seismoacoustic latitudinal SES profile conducted on the western slope of the Derbent basin near Dagestan in the Russian sector of the Yalama–Samur segment with hydrocarbon potential. For the age correlation of the seismic sequences of their boundaries, we relied upon [6] and took consulted with Yu.A. Volkov (Geological Institute, Russian Academy of Sciences, Moscow) and A.G. Roslyakov (Moscow State University, Moscow). According to the seismic record, one can clearly distinguish the western, central, and eastern areas of the section (Fig. 1). The western part includes an eastward pinching out sequence of Neopleistocene (Bakunian–Khvalynian, $Q_{I–III}$b–hv) sandy–clayey deposits (up to 20 m thick) lying on the surface of the pre-Bakunian regional unconformity. They are overlain with a sharp unconformity by a thin (~2 m) horizon of Holocene (Neocaspian, Q_{IV} nk) clays (Fig. 2). The pre-Bakunian surface is underlain by a progradation sequence of E-dipping clinoforms represented in the uppermost part by Apsheronian–Turkianian (Q_I ap–t) sandy–clayey deposits. The sequence is probably exposed on the bottom surface in the eastern part of the profile (Fig. 3). In the central part of the profile where Neopleistocene deposits are missing, a thin (~1 m) layer of Neocaspian sediments rests directly on Apsheronian–Turkianian deposits.

Neopleistocene deposits in the western part of the profile (Fig. 2) are characterized by a monoclinal occurrence of reflectors with a low-angle (0.5°–1°) dip

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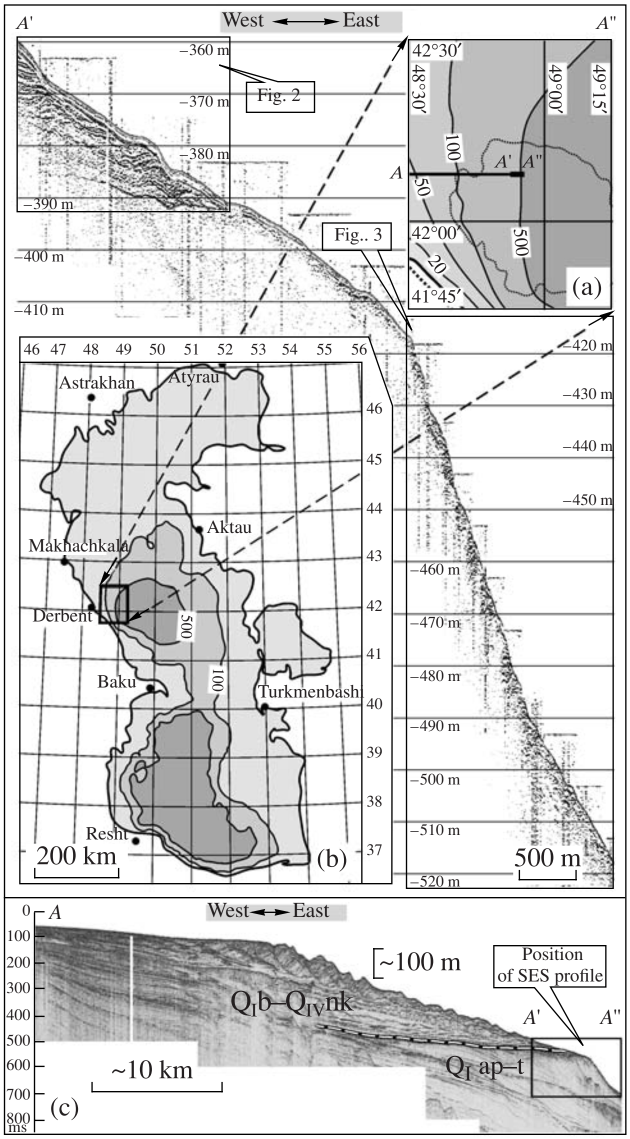

Fig. 1. Latitudinal seismoacoustic SES section along line *A*'–*A*''. Western slope of the Derbent basin, Yalama–Samur promising area, Caspian Sea ($Scale_h : Scale_v$ = ~1 : 55). Insets (a) and (b) show the position of the SES profile in the Caspian region (isobaths in meters). Inset (c) shows the position within the regional CSP (with sparker) profile *A*'–*A*'' [12]. Boxes denote SES areas of the profile presented in Figs. 2 and 3. The dotted line in inset (a) outlines the Yalama–Samur Uplift along the 2200-m isohypse in the horizon of Jurassic–Cretaceous deposits [1]. The dotted line in inset (c) denotes the surface of the pre-Bakunian unconformity that separates the underlying Eopleistocene (Apsheronian–Turkianian) and overlying Neopleistocene–Holocene (Bakunian–Neocaspian) deposits.

to the east (hereafter, in the plane of the presented seismic section) conformable with the dip of the underlying basal surface of the pre-Bakunian unconformity. In addition, some areas show abrupt knee-shaped bends of layers with reversed dips, overlapping (doubling) of reflectors, and intraformational truncation of bedding in some places [7] (Fig. 2). Such behavior of reflectors can indicate that the Neopleistocene sequence includes a nappe series with a stepwise trajectory of fault planes (duplexes) and related folds [8], which were formed here probably due to gravitational forces. In this interpretation, more extended fragments of reflectors with a gentle eastward dip should correspond to interlayer detachment areas connected by relatively short and reversely dipping displacement zones, which intersect the bedding (closing thrusts [9]). It should be noted that the stepwise trajectory of thrust surfaces is a very characteristic feature of the shear deformation of layered sequences [7–9 and many others]. The persistent eastward vergence of nappes indicates the eastern direction of slumping concordant with the dip of both the Derbent basin slope and the pre-Bakunian planation surface. We previously reported slump duplexes from the Central basin of the Indian Ocean [10]. This region incorporates the largest slump duplex among such structures developed in oceanic areas of Miocene–Quaternary intraplate shear deformations initiated in the oceanic crust [11 and many others].

Most of the inferred slump duplexes are situated near western slopes of anticlinal uplifts (Fig. 2), i.e., at barriers standing in the pathway of sediments slumping along the regional inclination plane represented by the pre-Bakunian unconformity plane. Some areas of the profile show an abrupt termination of reflectors of the lower (Bakunian–Khvalynian) sequence by reflecting boundaries at the base of overlying (Neocaspian) deposits (Fig. 2). This is an indicator of active underwater erosion after the accumulation of Neopleistocene sediments, probably, during the Mangyshlak regression. Later, the uppermost Holocene horizon was deposited on this erosional surface.

Interrelations of reflectors near the pinchout of the Neopleistocene sequence in the eastern part of the seismic profile fragment (Fig. 2) suggest the presence of a thrust-type wedge of Bakunian–Khvalynian deposits in the overlying Holocene deposits. Should our interpretation be correct, the horizontal amplitude of wedging, which is assessed on the basis of overlapping of an intense reflector at the base of Holocene deposits by deformed deposits of the underlying sequence, would be 100 m. The detection of such a structure is likely to indicate active underwater slumping on the slope of the Derbent basin in the Holocene after (or during) the accumulation of Neocaspian sediments, i.e., probably right up to the Recent epoch. Based on the time interval of 7000 yr corresponding to the Neocaspian epoch [6], the minimal average velocity of the slump wedging in the studied area makes up 1.5 cm/yr. However, the real velocity is probably higher because the given structure should be formed in a much shorter time than the whole period of the Neocaspian transgression. This slump-related thrust wedge can be related to a rapid one-act process, for instance, an intense earthquake, since the Yalama–Samur Uplift area falls within an isoseismic zone with a magnitude of 7 [1].

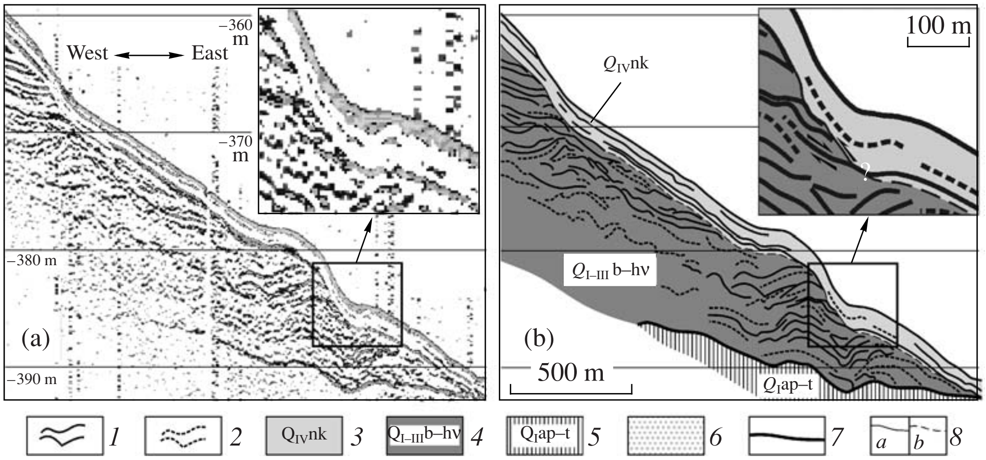

Fig. 2. Fragment of the SES seismoacoustic profile (a) and its interpreted section (b) illustrating the structure of the upper part of the sedimentary cover in the eastern Dagestan shelf (see Fig. 1 for position). Closeup of the profile illustrating an inferred slump wedge of Neopleistocene deposits thrusted into Holocene deposits. Here and in Fig. 3: (*1, 2*) Reflectors: (*1*) established, (*2*) inferred; (*3–6*) basic sedimentary sequences: (*3*) Holocene (Neocaspian), (*4*) Neopleistocene (Bakunian–Khvalynian), (*5*) Eopleistocene (Apsheronian–Turkianian?), (*6*) slump sequence presumably composed of Apsheronian–Turkianian (in Fig. 2) and Bakunian–Khvalynian? sediments (in Fig. 3); (*7, 8*) boundaries between main sedimentary sequences: (*7*) surface of the pre-Bakunian unconformity, (*8*) base of Holocene deposits (pre-Neocaspian unconformity): (*a*) established, (*b*) inferred.

Hence, one cannot rule out that the whole Neopleistocene sequence in the studied area represents a piling up of nearly bedded slump bodies, which also continued to move toward the Derbent basin in the Holocene (Recent?) Epoch. In this case, the previously mentioned concordant (anticlinal and synclinal) bends of reflectors of the Neopleistocene sequence, which enveloped individual irregularities of the pre-Bakunian unconformity surface, can be accounted for by their consecutive overlapping by nearly bedded bodies moving from the west.

The seismic record is basically different in the eastern part of the profile (Fig. 3) where the slope dip increases to 3°–4° (or more). One can see numerous reflectors dipping to opposite sides, both along and across the strike of the continental slope. The clear layered structure is virtually missing. At the same time, this area includes a series of lenticular bodies dipping concordant with the slope, as well as individual isometric blocks bounded on the west and east by reflectors with the corresponding opposite dip direction. The record also contains areas with a chaotic pattern. The observed picture can be interpreted as a combination of separate slump (and collapse?) blocks that are moving (or moved recently) down a relatively steep slope of the Derbent basin along numerous shear surfaces.

In [1, Fig. 34], Glumov et al. present seismic sections of the upper and lower parts of the near-Dagestan slope of the Derbent basin approximately in the area of Cruise 19 area of the R/V *Rift*. These sections show slump structures in the near-bottom sequence in the upper and lower parts of the slope, whereas the middle (steeper) part lacks collapse and slump structures. This is caused by the transit nature of sedimentation—slump deposits are not retained and are carried away downward [1].

Our original data on the superhigh-resolution seismoacoustic SES profiling made it possible to reveal many structural details of the upper part of the sedimentary sequence. The data show that uplifts in the upper part of the western slope of the Derbent basin do not represent individual slump bodies moving along the seafloor surface. Nevertheless, the internal structure of the Neopleistocene sequence in this area suggests the presence of numerous intraformational slump duplexes. In the steepest part of the slope (Fig. 3), we also revealed clear indications of disintegration of bottom deposits and processes of collapsing and slumping.

It should be noted that the above-mentioned anticlines (Figs. 1c, 2), where slump duplexes are concentrated, can be specific sedimentary structures of the slope (sedimentary waves). Previously, we came to this conclusion based on records of continuous seismic profiling with a sparker obtained in Cruise 19 of the R/V *Rift* [12]. The CSP sections clearly show a specific pattern of the seismic record resembling a traveling wave. All arguments in favor of such interpretation are discussed in [12]. Under some conditions (a certain inclination of the initial sedimentation surface, the presence of initiating irregularities on the surface, and others), migrating sedimentary waves are formed from the material repeatedly transported by high-density turbidite flows, which propagate across the sea shelf onto the continental slope. The SES seismic profiling data indicate that processes of such turbidite sedimentation in the studied area of the western slope of the Derbent basin in the Neopleistocene–Holocene were probably accompanied by active underwater slumping. This fact should be taken into account in the designation of engineering structures within the petroliferous Yalama–Samur structure. This issue is especially important

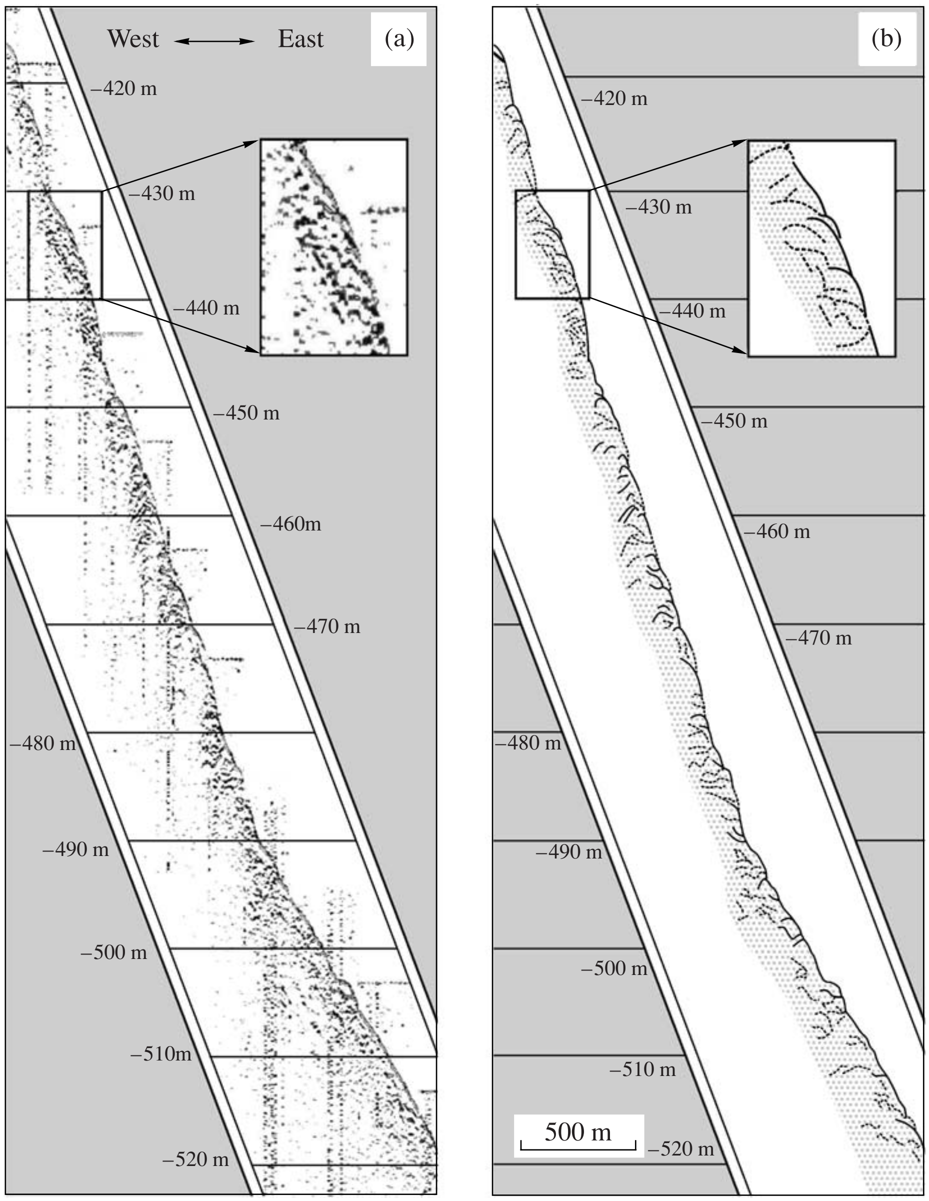

Fig. 3. Fragment of the SES seismoacoustic profile (a) and its interpreted section (b) illustrating slump bodies within the western slope of the Derbent basin (see Fig. 1 for position). Insets show closeups of the profile.

because of the substantial thickness (more than 200 m) of Neopleistocene deposits west of the studied area (Fig. 1c). Thus, our new conclusions concerning the structure and formation of the uppermost part of the sedimentary sequence on the Dagestan slope of the central Caspian Sea are based on application of the super-high-resolution narrow-beam parametric SES profilographs. Therefore, we recommend their application in further analogous studies.

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