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GEOLOGY

New Data on Seismostratigraphy and Sedimentation on the Western Slope of the Middle Caspian

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The sedimentary sequence of the Caspian Sea is generally well studied by geological and geophysical methods [1], particularly multichannel seismic profiling, which was mainly aimed at study of the deep structure of the sedimentary cover with perspectives for the discovery of hydrocarbon traps (see, e.g., [2]). However, data available for the upper part of the Pliocene–Quaternary sedimentary sequence are insufficiently detailed, because the majority of regional continuous seismic profiling (CSP) works were carried out in the 1970s–1980s using low-resolution equipment [3]. New detailed data on the structure of these sediments in the Middle Caspian area near the Dagestan coast from the upper part of the western slope to the adjacent deep part of the Derbent basin were obtained by a team of scientists from the Institute of Oceanology and Moscow State University during Cruise 19 of the R/V *Rift* in autumn 2004–winter 2005 (Fig. 1). The expedition was conducted in the framework of the Federal Targeted Program "The World Ocean" (Subprogram 8 "Complex Study of Processes, Characteristics, and Resources of the Caspian Sea") simultaneously with engineering-geological prospecting of the Yalama–Samur structure for the Lukoil Company.

A *Geont-shelf* high-resolution single-channel seismoacoustic profiler equipped with a spark transmitter (sparker with capacity of 600 J), which provided vertical resolution up to 2 m at a depth of 300–400 mbsf, was used to study the fine structure of the upper sedimentary sequence. Geological works in the cruise included sampling of sediments with gravity piston corers and study of their physicochemical properties at the Yalama–Samur test site (Figs. 1, 2).

The study area is located in the steepest area of the western slope of the Derbent basin characterized by the highest dip angles and maximal relief differentiation in the entire Middle Caspian [4]. The CSP data show that the slope is composed of two distinct sedimentary complexes with different seismic record patterns. They are separated by a near-horizontal intense reflector (R-2), which extends in the eastern part at a depth of approximately 400 m and gently rises toward the coast (Fig. 2). Comparison with previous materials, including drilling

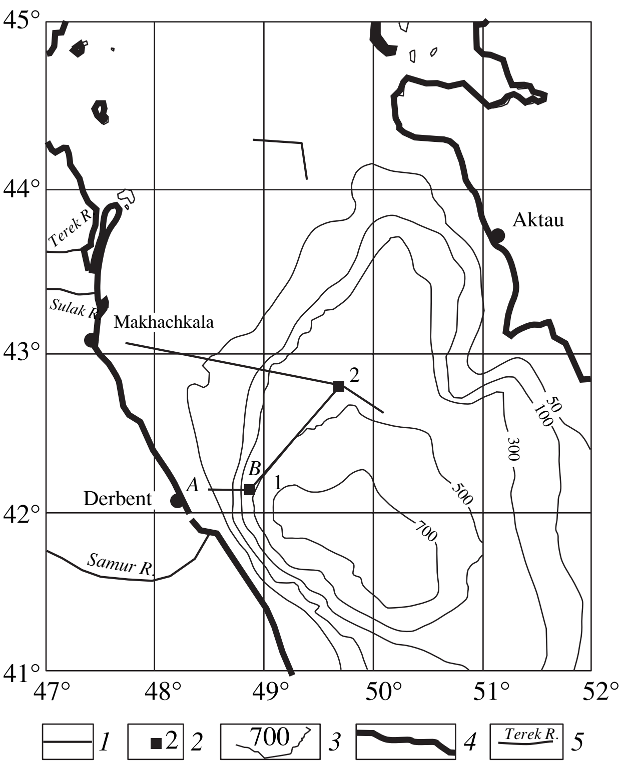

Fig. 1. Schematic map of the study area. (*1*) Regional seismic profiles; (*2*) areas of detailed works: (1) Yalama-Samur, (2) Tsentral'nyi; (*3*) isobaths, m; (*4*) shoreline; (*5*) rivers.

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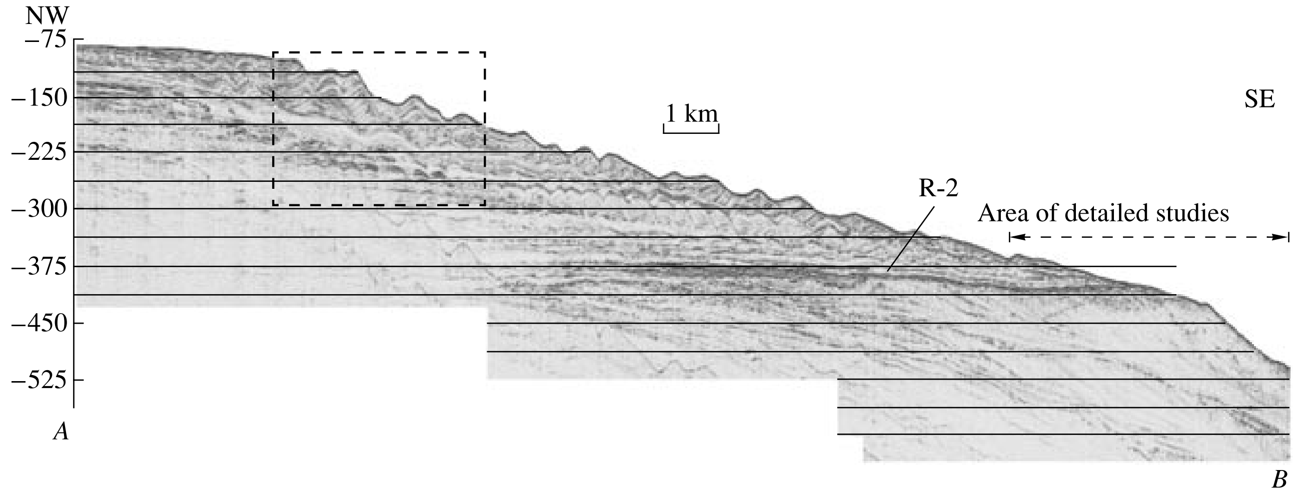

Fig. 2. Regional seismic profile 1. (R-2) Major regional unconformity (reflector). Position of the profile is shown in Fig. 1 (Line *AB*). Outlined box demonstrates a fragment of the profile shown in Fig. 3.

data on adjacent land, suggests that this distinct regional unconformity surface is related to the prolonged lowstand of the Caspian Sea level during the pre-Bakuan [4–6] or Tyurkyan (880 ± 250 ka ago) [7] regression. Correspondingly, the age of underlying sediments is Apsheronian or older, whereas the overlying sediments have a Pleistocene–Holocene age. The leveling surface morphologically probably corresponds to the pre-Bakuan shelf. Moreover, the edge of this ancient shelf is well manifested in the present-day bottom topography as a distinct slope bend at a depth of 410 m.

The lower complex limited at the roof by the leveling surface mentioned above consists of several cross-bedded members with a wedge-shaped morphology across the strike. In most of the CSP records, the base of this complex is unrecognizable and its thickness exceeds 400 m in the slope bend area. External (frontal areas) of the cross-bedded members are characterized by steeper dip angles of reflectors and the appearance of zones with diffracted patterns of the seismic record, probably related to uneven surfaces and the intricate structure of slumps [8]. The observed wave patterns of the record allow us to interpret the lower complex as a thick accumulative body produced by lateral progradation toward an uncompensated depression which already existed in the late Pliocene in the Derbent basin area. This classic structure of the lateral progradation is composed of successive clinoforms related to avalanche sedimentation on the western slope of the Caspian Sea [8]. Progradation of this accumulative body was accompanied by the slumping of sediments in its frontal part. Internal unconformity surfaces, which separate individual cross-bedded sequences, indicate the formation of the complex in several stages. Such a structure can primarily be related to fluctuations of the Caspian Sea level and, to a lesser extent, regional tectonic events.

The upper (Pleistocene–Holocene) stratified complex occurs between the bottom and the pre-Bakuan leveling surface. Its thickness increases to maximal values at the shelf edge (approximately 250 m) and decreases toward the deep-water area up to the point of its complete pinchout at a depth of 410 m in areas where the pre-Bakuan surface is exposed at the bottom. In the segment extending from the shelf edge to the pinchout line, the upper complex is characterized by a running wave-type pattern of the seismic record. These remarkable structures of bottom sediments represent a succession of asymmetric seamounts with steeper western (i.e., facing the shore, which serves as a source of sedimentary material) slopes. All these features are typical of specific accumulative structures (migrating sedimentary waves) that form as a result of the deposition of material transported by several cycles of high-density turbidites under certain specific conditions (inclination of the primary sedimentation surface, development of initial irregularities, and others) [9, 10]. Such an interpretation explains all peculiarities in the complex regular structure of the section in the CSP records. For example, thickening of layers on the coast-facing wave slopes and their thinning on the basin-facing slopes are caused by specifics of turbidite sedimentation. During each flow of turbidites down the slope, the major portion of the coarser material was deposited on the slope of the obstacle facing the upstream zone, while the minor portion of the finer material accumulated on the opposite slope. Such a differentiated sedimentation mode is responsible for the asymmetric structure of waves and migration of their summits up the slope (upward along the flow) at the transition to each overlying reflecting horizon (Fig. 3). The real thickness of individual laminae in sedimentary waves is very low (millimeters to a few centimeters). Therefore, even high-resolution records reveal only some integral fringe patterns.

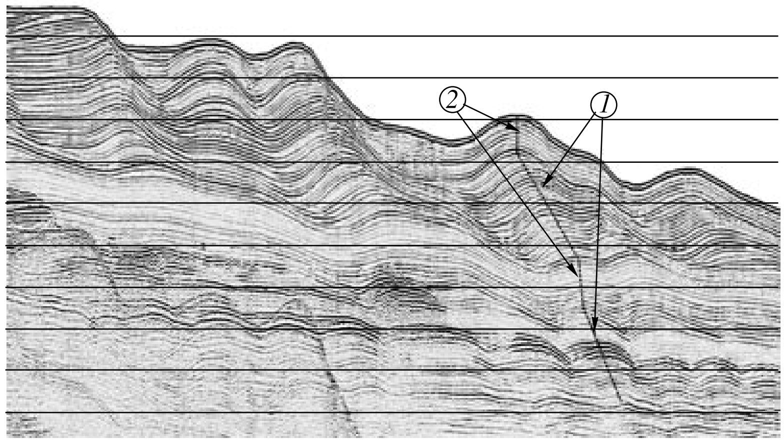

Fig. 3. Internal structure of the upper sedimentary complex. Fragment of the regional CSP profile (see Fig. 2) illustrating the (*1*) migration of summits of sedimentary waves up the slope and (*2*) the vertical growth (aggradation) of sediment thickness.

The sedimentary waves were evidently most intense during the lowstand of the Caspian Sea level, when the shoreline approached the shelf edge and large volumes of terrigenous material provided by mountain rivers could be transformed into high-density turbidites and transported to the continental slope. The terrigenous material could be delivered from both west and north, i.e., from paleoestuaries of the Terek and Sulak rivers. The upper complex of sections includes several generations of sedimentary waves, each corresponding, probably, to a certain regressive stage in the Pleistocene history of the Caspian Sea. These wave generations are separated by parallel-bedded sedimentary sheets accumulated during the highstand period, when the shoreline retreated from the shelf edge and the activity of gravitational processes on the slope attenuated. Migration of summits, which is typical of sedimentary waves, was replaced by aggradation, i.e., overlapping of layers, during such episodes. A horizon of this type probably related to the youngest (Novocaspian) transgression underlies the seafloor and partly smoothes away the topography of sedimentary waves of the last generation. If detailed offshore drilling data on the western continental slope of the Caspian Sea are absent, it is impossible to correlate reliably seismic units and reflectors in the CSP records with lithostratigraphic units. Nevertheless, mapping of these various generations of sedimentary waves and their seismostratigraphic analysis may allow us to reconstruct the relative stratigraphic succession of the main transgressive–regressive events for the study region.

Results of sampling at the test site (Figs. 1, 2) revealed a substantial difference between cores recovered from the gentle slope (depth interval 375–410 m) and beyond the slope bend (depths 490 and 510 m). Sediments from the first interval are characterized by almost identical composition and structure at different stations. They are represented by gray clayey–silty mud with shell fragments and thin discrete intercalations of silty material (core length up to 3 m). Cores from stations located below the slope bend are composed of compact hard brownish and greenish clays. They occur at a depth of $10n$ cm below the seafloor, and their strength measured by a manual impeller is 0.71 kg/cm^2. For comparison, the strength of sediments sampled above the slope bend amounts to 0.1 kg/cm^2. Although the age of sediments is unknown thus far, the obtained data are quite consistent with the CSP data: pinchout of the Pleistocene–Holocene complex in the slope bend area and exhumation of the older (presumably, Apsheronian) sediments at the bottom.

The materials obtained in Cruise 19 of the R/V *Rift* by high-resolution seismoacoustic survey and geological sampling provided new insights into processes and stages of sedimentation on the western slope of the Middle Caspian. The morphology of the continental slope reflects the main stages of its development. The lower, steep part of the slope is a relict structure related to the lateral progradation of sediments during the Apsheronian. In the Pleistocene, it served as a transit zone for the delivery of sediments to the foothill, where they were eroded by various gravitational flows. The upper, gentler part of the slope, which extends from the shelf edge to a depth of 400 m, formed in the Pleistocene–Holocene with the participation of a specific sedimentation process (formation of sedimentary waves under the influence of high-density turbidite flows). This process activated during regressions and decelerated during transgressions. It should be noted that similar wavy patterns observed in the structure of bottom sediments in seismic records obtained in the Dagestan segment of the Derbent basin near the Cruise 19 (R/V *Rift*) area were considered as slumps [1]. Many similar peculiar structures recorded in various areas of the World Ocean (for example, in Cadiz Bay, the Gulf of Alaska, the Adriatic shelf, and the northern California coast) were initially interpreted as deformations caused by underwater slumping on the continental slope. However, subsequent high-resolution seismoacoustic survey and physical modeling of sedimentation showed that these structures represent, in fact, domains of sedimentary waves [9]. The almost complete absence of Pleistocene–Holocene sediments in the slope bend area is unclear so far. This occurrence can be related to erosion by high-density flows or vertical water circulation, which appears above sharp bends in the bottom profile and hinders sediment deposition [11]. In general, the data obtained in Cruise 19 of the R/V *Rift* make it possible to outline top priority directions in high-resolution seismoacoustic profiling and detailed geological sampling carried out for elucidating specific features of sedimentation on the northwestern slope of the Middle Caspian in the Pliocene–Quaternary time.

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