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Biostratigraphy and Structure of the Upper Quaternary Deposits and Some Paleogeographic Features of the North Caspian Region

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Abstract—Among materials of the OJSC Lukoil obtained in the northern Caspian region, there are cores samples recovered from the depth of 7 to 37 m below bottom, piston cores, and high-resolution seismic profiles. These materials are used to measure ^{14}C age of sediments and to study biostratigraphy and structure of the Upper Quaternary deposits and paleogeography of the region. Mollusks, benthic foraminifers, diatoms, spores and pollen from sediments recovered by a series of boreholes characterize in detail and substantiate the discrimination and correlation of the Novocaspian, Mangyshlak, upper and lower Khvalynian, Atel', and upper Khazarian beds. The ^{14}C dates indicate that the beds accumulated in the time intervals of 0–7000, 7000–9000, 9000–16000, 17000–30000, and >30000 years, respectively. Lithologic and seismoacoustic data suggest four large sea-level drops relative to the current level in the time spans of the Mangyshlak (–40 to –50 m), Enotaevsk (–20 m), Atel' (–70 m), and the Chernyi Yar–Astrakhan' (or Intra-Khazarian) regressions (–90 m). The events are recognizable based on deep incision channels of the Paleovolga and on lacustrine deltaic and continental facies.

Key words: Caspian Sea, biostratigraphy, ^{14}C dating, paleogeography, Late Quaternary, marine sediments.

INTRODUCTION

The Quaternary stratigraphy of the Caspian Sea was investigated based on the sediments exposed or drilled on the adjacent land. The problem of stratigraphic units discrimination, their faunal characteristics, and ^{14}C dating, structure and paleogeography of the Caspian sediments, as well as the overview of available hypotheses are completely presented in papers by Fedorov [1] and Svitoch and Yanina [2]. Several stages, the Bakuan, Khazarian, Khvalynian, and Novocaspian, were distinguished in the Quaternary history of the basin. The transgression periods of a high sea level are well recorded on land, while the regressive marine deposits are almost unstudied as they are submerged. Accordingly, the Caspian Sea history is fragmentary understood because of scarce biostratigraphic data characterizing the regressive phases.

The uninterrupted geological history of the Caspian Sea can be reconstructed based on continuous sections of marine sediments. However, the most of data available up to now are those referred to shallow-water Novocaspian deposits recovered by piston cores that bear paleontological remains, mainly bivalve shells used to ground the Caspian stratigraphic scale. In addition, there are known scarce records in the Khvalynian and older sediments that occur at a considerable depth beneath the sea floor. Paleontological evidences of the youngest Mangyshlak and ancient regressive phases of the Caspian Sea are extremely scarce, and present concepts are mainly based on the echo sounding data that reveal the terrace-like ledges at the sea bottom [3] and, rarely, on the direct observations of bottom deposits [4]. In general, the observations are ambiguous and often discrepant. All the above is typical of the northern part of the Caspian Sea that is poorly understood in stratigraphic and paleogeographic aspects because of its shallowness.

In the course of the geologic prospecting in the northern Caspian Sea, which is sponsored by OJSC Lukoil, the geological engineering explorations included drilling of boreholes and seismic profiling aimed to provide the safe positioning of the self-hoisting drilling rig. Nineteen boreholes 25 to 100 m deep were drilled and over 300 piston cores up to 3.5–4.0 m long were sampled from the depth of 7 to 36.5 m in 1997–2001 in five areas located in the northern Caspian Sea within its middle zone extending for about 110 km from north to south. The two-frequency seismic profiling was carried out with resolutions of 0.3–0.5 and 1.5–2.0 m for subbottom intervals of 10–15 and 80–100 m,

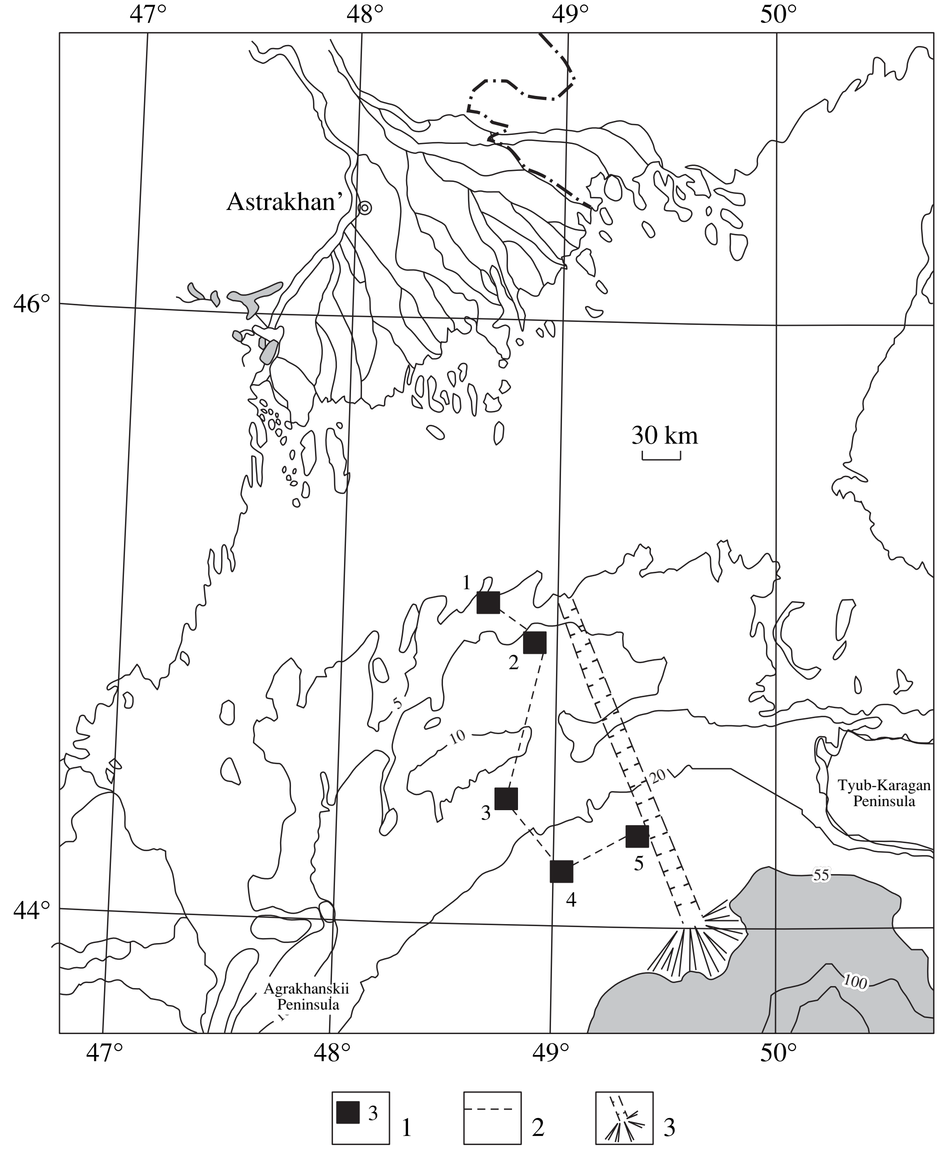

Fig. 1. Locations of studied areas and seismic profiles: (1) studied areas and their numbers; (2) seismic profiles; (3) buried river valley and terminal fan.

respectively. The regional seismic profiles of that time connect areas of regular profiling grids and enable correlation between all the boreholes drilled. The disposition of studied objects and regional profiles is shown in Fig. 1.

The materials obtained characterize the structure and composition of the Upper Quaternary sequence in a vast area of the northern Caspian region. Many continuous sections of the Upper Quaternary sediments are now described. Their facies interrelations and stratigraphy well substantiated geochronological dates, as well as the considered paleogeographic problems, represent an essential contribution to the knowledge of the basin's geology. The recovered sediments were tested for bivalve assemblages and benthic foraminifers (T.M. Maier), diatoms (L.G. Pirumova), pollen and spores (N.O. Rybakova), and biologic composition of organogenic deposits (O.N. Uspenskaya). They were subjected to radiocarbon dating as well.

INVESTIGATION RESULTS

Stratigraphy

Stratigraphic subdivision of the recovered Upper Quaternary sediments is based on the species composition of mollusks (Table 1), diatoms, benthic foraminifers, and other organic remains. The age inferences are confirmed by the ^{14}C dates (Table 2). The discriminated Novocaspian, Mangyshlak, Khvalynian, and Khazarian stratigraphic horizons are characterized below.

Table 1. Mollusk assemblages in the Pleistocene–Holocene sediments of the northern Caspian Sea

Area 1	Area 2	Area 3	Area 4	Area 5
Novocaspian Horizon (upper) (0–1 ka)				
Abra ovata (Philippi), *Mytilaster lineatus Gmel.*, *Cerastoderma lamarcki* (Reeve), *Didacna barbotdemarnyi* (Grimm), *D. trigonoides* Pall., *D. parallella* (Bog.), *Hypanis caspia* (Eichw.), *H. leviuscula* (Eichw.), *H. vitrea* (Eichw.), *Dreissena polymorpha caspia* (Pall.), *Dr. polymo-rpha polymorpha* (Pall.), *Unio* sp., *Pyrgula (Clessiniola) variabilis* (Eichw.), *P. (Micromelania) caspia* (Eichw.), *P. (Hydrobia)* sp., *Theodoxus pallasi* Lindch., *Viviparus viviparus* (L.)	*A. ovata, M. lineatus, C. lamarcki, D. barbotdemarnyi, D. trigonoides, H. caspia, H. vitrea,H. leviuscula, Dr. polymorpha caspia, Dr. rostriformis distincta, Unio* sp.*, P. caspia, Th. pallasi, V. viviparus.*	*A. ovata, M. lineatus, C. lamarcki, D. baeri* (Grimm)*, D. barbotdemarnyi, D. parallella, H. caspia, H. vitrea, H. leviuscula, Dr. polymorpha caspia,Pyrgula, Th. pallasi.*	*D. barbotdemarnyi, D. parallella, D. praetrigonoides Nal, H. caspia, H. vitrea, H. leviuscula, Dr. polymorpha caspia, Dr. rostriformis distincta*	
Novocaspian Horizon (middle) (1–4 ka)				
The same assemblage but missing *Abra ovata* and *Mytilaster lineatus*				
Novocaspian Horizon (lower) (4–7 ka)				
D. barbotdemarnyi, H. caspia,H. leviuscula, H. vitrea, Dr. polymorpha caspia,Dr. polymorpha polymorpha, Unio sp.*, P. variabilis,Th. pallasi*	*D. barbotdemarnyi, H. caspia angusticostata* (Borc.)*, H. vitrea, H.leviuscula, Dr. polymorpha caspia,Dr. polymorpha polymorpha, Unio* sp.*, P. variabilis*	*D. parallella, D.* cf. *cristata, H. caspia, H. vitrea, H. leviuscula, Dr. polymorpha caspia, Dr. polymorpha polymorpha, Dr. rostriformis distincta, Pyrgula, Th. pallasi*	*D. barbotdemarnyi, D. parallella, D. praetrigonoides,H. caspia, H. vitrea, H. leviuscula, Dreissena polymorpha caspia,Dr. rostriformis distincta*	
Mangyshlak Horizon (7–9 ka)				
Dr. polymorpha polymorpha, Hypanis caspia, H.vitrea, H. leviuscula, Unio pictorum (L.,), *Unio* sp., Limneidae				
Khvalynian Horizon (upper) (9–16 ka)				
D. parallella, D. cristata (Bog.), *H. caspia, Dr. polymorpha caspia, Dr. rostriformis distincta, P. caspia, P. elegantula* (Cless. et Dyb.), *P. variabilis, Lithoglyphus (Pseudamnicola) caspius Krin*	*D. parallela, D. cristata, H. caspia, H. plicatus, H. vitrea, Dr. polymorpha polymorpha, Th. pallasi*	*D. praetrigonoides, D. parallella, D. subcatillus Andrus., H. caspia, H. vitrea, Dreissena polymorpha caspia*	*D. barbotdemarnyi, D. praetrigonoides, D. cristata, H. caspia, H. vitrea, Dr. polymorpha caspia, Pyrgula*	*D. barbotdemarnyi, D. praetrigonoides, D. cristata, D. subcatillus, H. caspia, H. vitrea, H. leviuscula, Dr. polymorpha polymorpha, Dr. rostriformis distincta, L. caspius, P. caspia, Th. pallasi*
Khvalynian Horizon (lower) (17–>30 ka)				
D. parallella, D. subcatillus, D. praetrigonoides, H. caspia, H. leviuscula, Dr. polymorpha polymorpha, Dr. polymorpha caspia, Dr. rostriformis distincta, P. caspia, P. variabilis, P. grimmi, Th. pallasi	*D. parallella, D. subcatillus, D. cristata, D. praetrigonoides, D. zhukovi Fed., D. protracta Eichw., H. caspia, H. vitrea, Dr. polymorpha polymorpha, Dr. polymorpha caspia, Dr. rostriformis distincta, P. caspia, P. grimmi, Th. pallasi*	*D. subcatillus, D. cristata, H. caspia, Dr. polymorpha caspia,Dr. polymorpha polymorpha, Dr. rostriformis distincta, P. caspia, P. spica, L. caspius, Th. pallasi*	*D. subcatillus, D. parallella, D. praetrigonoides, D. cristata, D. cf. protracta, H. caspia, H. vitrea, H. leviuscula, Dr. polymorpha caspia, Dr. rostriformis distincta, Pyrgula, Th. pallasi*	*D. subcatillus, D. parallella, D. zhuckovi, D. praetrigonoides, H. caspia, r. rostriformis distincta, P. caspia, P. variabilis, L. caspius, Th. pallasi*

Table 1. (Contd.)

Area 1	Area 2	Area 3	Area 4	Area 5
Khazarian Horizon (upper)				
Corbicula fluminalis (Muller), *H. caspia.*	*D. baeri* (Grimm) (forms close to *D. surochanica Andrus., D. nalivkini Wass, D. subcatillus, D. parallela, D. protracta), Dr. rostriformis distincta, Dr. polymorpha caspia, Dr. polymorpha polymorpha, H. caspia, P. caspia, P. variabilis, P. grimmi, L. caspius, Th. pallasi*			
Khazarian Horizon (lower)				
	Didacna cf. subcatillus, D. cf. subovlis Prav., H. caspia, Dr. rostriformis distincta, P. caspia, P. grimmi, Th. pallasi			

The Novocaspian Horizon is subdivided based on the mollusk evidence from areas 1–3 and 5 (sea depth from 10–17 to and 36 m) into three beds (Table 1).

The upper bed yields the *Dreissena polymorpha caspia* (Pall.)–*Didacna baeri* (Grimm) assemblage and is clearly distinguishable because of presence of *Mytilaster lineatus* Gmel and *Abra ovata* (Philippi). The bed also bears *Cerastoderma lamarcki* (Reeve), *Hypanis (Monodacna) caspia* (Eichw.), *H. (Adacna) vitrea* (Eichw.), *H. (Adacna) leviuscula* (Eichw.), scarcer *Didacna barbotdemarnyi* (Grimm) and other didacnas, and gastropods *Pyrgula* and *Theodoxus.* The bed's base is about 1 ka old according to radiocarbon dates (Table 2).

The middle bed contains the *Dreissena polymorpha caspia* (Pall.)–*Didacna barbotdemarnyi* (Grimm) assemblage with the marker species *Cerastoderma lamarcki* (Reeve). The assemblage includes *Hypanis (Monodacna) caspia* (Eichw.), slightly scarcer *H. (Adacna) vitrea* (Eichw.), *H. (Adacna) leviuscula* (Eichw.), and rare *Dreissena rostriformis* (Andrus.) in association with didacnas and gastropods. The base of the bed is dated at 3–4 ka.

The lower bed is marked by absence of *Cerastoderma lamarcki* (Reeve). It was accumulated between 3–4 and 6.8 ka ago. In the Area 4, the Novocaspian mollusk assemblage from the depth of about 27 m is of a similar composition, also lacking *Cerastoderma lamarcki*, and the bed's base is about 6 ka old.

Diatoms from the Novocaspian deposits were studied in sediments of Area 2. A single sample bearing diatom remains is referred here to the lower bed. It yielded 32 taxa of freshwater diatoms only. These are the oligohaline species surviving salinity not greater than 5‰, and forms indifferent even to the value of 5‰ dominate among these species and associate with several halophilic taxa tolerant to such a salinity. All the identified taxa of the assemblage are referred to Centrophyceae, genera *Aulacosira* and *Stephanodiscus* included, and Pennatophyceae representing the other 11 genera. The assemblage consists of *Aulacosira italica, A. italica* subsp. *subarctica, A. granulata, Stephanodiscus astraea, Fragilaria bicapitata, F. brevistriata, F. brevistriata* v. *sulcapitata, F. construens, F. construens* v. *subsalina, F. inflata, F. intermedia, F. lanceolata* v. *minuta, F. leptostauron, F. pinnata, F. virescens, F. virescens* v. *capitata, Synedra uena, Cocconeis placentula, C. placentula* v. *euglypta, Eunotia pectinalis* v. *euglipta, Navicula placentula, N. placentula* f. *minuta, N. placentula* f. *rostrata, Pinnularia microstauron, Caloneis bacillum, C. silicula, Girosigma acuminatum, Amphora ovalis, Gomphonema abbreviatum, Nitzschia acuta, N. kuetzingiana*, and *N.* sp.

Centrophyceae forms are characteristic of the river and lacustrine plankton, and their representatives *Aulacosira italica* subsp. *subarctica* and *A. granulata* prefer cool waters. The genus *Fragilaria*, inhabitant of the intertidal zone in stagnant basins, stands out among the other benthic diatoms because of species diversity and abundance. Most species of this genus are epibiontic and often dwell on watered stacks and in mosses. Other diatoms of the assemblage are also widespread in intertidal zones of different basins as components of benthos or epibionts. Species *Eunotia pectinalis* var. *minor* inhabits bogs, damp mosses, and watered stacks. *Navicula* forms are inhabitants of the intertidal zone of alkaline basins. *Pinnularia microstauron* prefers alkaline or weakly acidic flowing and stagnant waters. *Caloneis* species are widespread on the bottom of different basins. *Girosigma acuminatum* dwells on the bottom and rarely in planktonic communities of various basins.

The investigation of spores and pollen showed their extremely irregular distribution in the section, from complete absence to relative abundance. The lower Novocaspian bed sampled in Area 2 is found to be the most fossiliferous. It yields 130 well-preserved palynomorphs. The pollen spectrum includes 25.4% of arboreal taxa, 64% of herbaceous and 10.6% of spores. The

Table 2. Radiocarbon dates of the northern Caspian Sea sediments

Sample	Borehole (station), interval (m)	Material	Age (years)
Area 1			
MSU-1566	Station 41, 42	Shells	Q_{IV} nk (3200 ± 50)
MSU-1567	Station 53 (0.4–0.5)	Shells	recent
MSU-1570	Station 36 (1.2–1.7)	Shells	Q_{IV} nk (4130 ± 70)
MSU-1571	Station 36 (0.8–1.05)	Shells	Q_{IV} nk (2895 ± 60)
MSU-1572	Station 36 (0.2–0.48)	Shells	Q_{IV} nk (860 ± 40)
MSU-1587	IGS-3 (24.5–25.0)	Shells	Q_{III} hv$_1$ (18330 ± 150)
MSU-1588	IGS-3 (21.1–21.2)	Shells	Q_{III} hv$_1$ (21460 ± 200)
MSU-1589	IGS-3 (9.0–10.1)	Shells	Q_{III} hv$_1$ (17645 ± 160)
MSU-1590	IGS-1 (6.5–7.5)	Shells	Q_{IV} nk (680 ± 30)
Area 2			
MSU-1493	Station 70, 69, 60, 18, 10, 9 (1.15–1.65)	Organic matter	Q_{IV} mg (9420 ± 60)
MSU-1494	Station 49 (3.38–3.55)	Organic matter	Q_{IV} mg (9860 ± 240)
MSU-1495	Station 19 (2.3–2.45)	Organic matter	Q_{IV} mg (9860 ± 330)
MSU-1496	Station 68 (2.4–2.5)	Organic matter	Q_{IV} mg (9300 ± 110)
MSU-1556	IGS-3 (21.0–22.5)	Shells	Q_{III} hv$_1$ (27200 ± 340)
MSU-1559	Station 38 (1.0–1.15)	Shells	Q_{IV} nk (6830 ± 60)
MSU-1561	Station 3 (1.68–1.77)	Organic matter	Q_{IV} mg (7630 ± 440)
MSU-1562	IGS-3 (8.2–9.1)	Shells	Q_{III} hv$_2$ (6620 ± 130)
Area 3			
MSU-1507	IGS-3 (21.6–21.8)	Shells	Q_{III} hv$_2$ (16900 ± 120)
MSU-1508	Well 1 (14.7–14.9)	Shells	Q_{III} hv$_2$ (9230 ± 165)
MSU-1509	Station 35 (2.95–3.05)	Shells	Q_{IV} nk (6610 ± 60)
MSU-1510	Station 25 (1.0–1.55)	Shells	recent
MSU-1511	IGS-3 (3.1–3.5)	Shells	Q_{IV} nk (1330 ± 60)
MSU-1512	Station 12 (3.25–3.35)	Shells	Q_{IV} nk (4780 ± 50)
MSU-1513	Station 31 (0.66–0.88)	Shells	recent
Area 4			
MSU-1555	IGS-2 (21.7–21.9)	Shells	Q_{III} hv$_1$ (21090 ± 320)
MSU-1557	IGS-2 (14.6–14.7)	Shells	Q_{III} hv$_2$ (16900 ± 110)
MSU-1558	IGS-2 (7.75–7.85)	Shells	Q_{IV} mg (8540 ± 70)
MSU-1560	Station 38 (0.8–1.05)	Shells	Q_{IV} nk (1690 ± 40)
MSU-1563	Station 54 (0.9–2.4)	Shells	Q_{IV} nk (5750 ± 80)
Area 5			
MSU-1591	IGS-1 (29.4–29.6)	Shells	Q_{III} hv$_1$ (22190 ± 400)
MSU-1592	IGS-1 (16.9–17.2)	Shells	Q_{III} hv$_1$ (19325 ± 175)
MSU-1593	IGS-1 (15.1–15.2)	Shells	Q_{III} hv$_1$ (16075 ± 120)
MSU-1594	IGS-1 (11.0–11.5)	Shells	Q_{III} hv$_2$ (15710 ± 170)
MSU-1595	IGS-3 (4.8–4.9)	Shells	Q_{III} hv$_2$ (12870 ± 100)
MSU-1597	IGS-1 (37.6–37.9)	Shells	Q_{III} hvv$_2$ (30150 ± 610)
MSU-1598	IGS-1 (22.3–23.7)	Shells	Q_{III} hv$_1$(30085 ± 600)
MSU-1599	IGS-1 (19.3–19.4)	Shells	Q_{III} hv$_1$ (>30000 ± 600)

pine pollen makes up the bulk of arboreal taxa and represents *Pinus* s/g *Haploxylon* (3.7%), *P.* s/g *Diploxylon* (1.5%), and *Pinus* sp. (3%). The birch pollen is rather common (14.7%). Large well-preserved pollen grains occur in association with smaller, light, and slightly crumpled pollen. Additionally we recorded *Salix* (1.5%) and a strongly deformed pollen grain of *Picea* (0.7%).

The herbaceous and fruticose pollen is markedly diverse. It primarily represents *Artemisia* (20%), Gramineae (19.2%), and Chenopodiaceae (6.2%), which are accompanied by Cyperaceae (1.5%), Liliaceae, Ranunculaceae, Compositae, Umbelliferae, Caryophyllaceae, Rubiaceae, Polygonaceae, etc. (up to 17% of the spectrum in sum). Among spores, *Bryales* constitutes 10% and *Sphagnum* 0.7%. It should be noted that small-sized green mosses commonly grow beneath the grass cover of meadow herbs, and presence of their spores in the spectra dominated by herbaceous pollen is quite explicable.

The Mangyshlak Horizon yields an impoverished *Dreissena polymorpha polymorpha* (Pall)–*Hypanis (Monodacna) caspia* (Eichw.) assemblage of mollusks that shows admixture of freshwater species and lacks *Didacna* forms. This assemblage is characteristic of the freshened waters of the modern Caspian Sea. The composition of benthic foraminifers, especially a great abundance of *Mayerella brotzkajae* (Mayer), also indicates the decreased salinity.

Five samples from Area 2, which are rich in peat- and sapropel-like matter, were tested for plant remains and other organisms. In the group microscopic biotic remains, higher plant taxa constitute 9.0–45.5%, diatoms 43.5–72.4%, yellow-green algae 1–5.6%. Green, blue-green, and clorococcalean algae are as abundant as 5.6–28.1%, and sponges represent 0.3–5.2%.

Macroremains of higher plants macerated by washing through the 0.25-mm sieve are represented by cane *Phragmites communis* (0.7–22.5%), *Typha* (0.5–1.5%), hornwort *Ceratophyllum demersum* (0.5–93.5%), Nymphaeaceae (0.5%), Gramineae, roots, caulis, and epidermis of herbaceous plants (up to 22.5%), and by the “mummified” remains of unrecognizable structure (0–75.0%). The diatoms are mainly represented by benthic epibionts inhabiting freshwater basins. Certain samples contain the insect, mollusk, and ostracode remains.

The composition of studied remains indicates the deltaic and coastal brackish- to freshwater settings overgrown with higher plants. These were areas of purer water with variable content of carbonates and organic matter, and with reducing conditions near the bottom, where deposits were enriched in iron sulfides, e.g., in hydrotroilite, and had admixture of gypsum crystals.

The composition of spores and pollen was identified in two samples of organogenic deposits from Area 2. The samples considerably differ in abundance of pollen and spores. One sample is rich in organic matter that consists of cells and fragments of plant tissue, fossil fungi remains, etc. Among 120 palynomorph taxa, the herbaceous and shrub pollen constitutes 56.7%, spores 42.5%, and arboreal pollen (*Betula*) 0.8%. The herbaceous group includes Gramineae (17.5%), Chenopodiaceae (18.3%), *Artemisia* (12.5%), and herbs (8.4%) with representatives of Liliaceae (1.8%), Umbelliferae (1.8%), Ranunculaceae (0.8%), Saxifragaceae (0.8%), Sparganiaceae (1.6%), and others. Spores belong to green mosses *Bryales* (41.7%) and ferns Polypodiaceae (0.8%). The second sample contains a great amount of spores and pollen. Among 510 palynomorphs, there are xerophyte grass pollen (78.2%) and spores (20%), which make up the bulk of the spectrum. The arboreal pollen is represented by pine (0.8%), birch (0.8%), and oak (0.2%). The herbaceous pollen is abundant and diverse. This group represents *Ephedra* (0.8%), Gramineae (13%), Chenopodiaceae (42%), *Artemisia* (7%), and herbs (16.2%). Among the latter, there are Umbelliferae (0.4%), Liliaceae (2.2%), Cruciferae (0.6%), Ranunculaceae (0.6%), Labiatae (0.4%), Compositae (9.6%), Leguminosae, Caryophyllaceae, Campanulaceae, Rosaceae, Polygonaceae, and Saxifragaceae (1.2%). Spores belong to green mosses (19.4%) and ferns Polypodiaceae (0.6%). Palynological assemblages from both samples characterize open landscapes almost lacking arboreal plants and predominance of steppe xerophytes. Abundant spores of green mosses characteristic of peat are explicable and do not point to humid conditions. The climate was rather arid.

The Khvalynian Horizon is distinguishable in the section because of its peculiar *Didacna* species: *Didacna praetrigonoides* Nal., *D. parallella* (Bog.), *D. cristata* (Bog.), *D. subcatillus* Andrus., *D. protracta* Eichw., and *D. zhuckovi* Fed. In all studied areas it is subdivided into two subhorizons.

The upper Khvalynian Subhorizon yields *Didacna praetrigonoides* Nal., *D. cristata* (Bog.), *D. parallella* (Bog.), *D. subcatillus* Andrus., and *D. barbotdemarnyi* (Grimm) in addition to *Hypanis* and *Dreissena* forms dominating in shallower areas 1 and 2. The radiocarbon dates suggest that accumulation of corresponding sediments took place in the time span from about 9 to 15–16 ka. The lack of benthic foraminifers, ostracodes, and diatoms can indicate either a significant depth, or the unfavorable conditions for their burial.

In the palynological assemblage of the upper Khvalynian sediments from Area 2, herbaceous pollen represents 91%, spores, 6%, and arboreal pollen only 3% of the spectrum. The xerophilous grasses like Chenopodiaceae (51%) and *Artemisia* (28%) absolutely predominate among the herbaceous plants. Herbs represented by Liliaceae, Ranunculaceae, and others, constitute 12% of the spectrum. Among the arboreal plants *Pinus* sp. (1.6%) and *Picea* (1%) were recorded. Spores of

Bryales (6%) and Polypodiaceae (0.6%) occur in association with ancient redeposited forms.

The lower Khvalynian Subhorizon is characterized by abundance of *Didacna* forms, which dominate in places over *Dreissena* and *Hypanis* species. Widespread among them are smaller *Didacna parallella* (Bog.), *D. subcatillus* Andrus., and their transitional forms, while *D. cristata* (Bog.), *D. protracta* Eichw., *D. zhukovi* Fed., and *D. praetrigonoides* Nal. are scarcer. The deposits are older than 17 ka, and some dates are over 30 ka. The subhorizon lacks diatoms, ostracodes, and benthic foraminifers like the upper Khvalynian Subhorizon.

In the palynospectrum from an upper part of the lower Khvalynian sediments (Area 2), the arboreal pollen is represented by a single grain of *Pinus* sp. The spectrum almost entirely consists of non-arboreal pollen of predominant Chenopodiaceae (52%) and *Artemisia* (16.4%). It also includes Gramineae (5.5%) and herbs (12.9%) including Liliaceae, Ranunculaceae, Rosaceae, Saxifragaceae, etc., and Cyperaceae (3%). The *Bryales* spores constitute 9.7% of the assemblage. Sediments also contain the fungi remains and redeposited forms, among which there is Permian *Triatopinites.*

The Khazarian Horizon. The Khazarian deposits bearing faunal remains were recovered in areas 1 and 2. In Area 1, numerous *Corbicula fluminalis* (Muller) and rare *Hypanis (Monodacna) caspia* (Eichw.) were identified. The sediments recovered in Area 2 yield a more diverse faunal assemblage. The most interesting forms of the latter are larger *Didacna nalivkini* Wass and *D. baeri* (Grimm), morphologically very close to *D. surochanica* Andrus., which coexist with smaller *D. parallella* Bog. Also typical of the assemblage are larger *D. subcatillus* Andrus. and more diverse gastropods. In Area 2, the oldest sample bearing fauna (interval 38.5–39.4 m) yielded large incomplete shells of *D.* cf. *subcatillus* Andrus. and *D.* cf. *subovalis* Prav. The above molluscan assemblages indicate at least the late Khazarian age of the recovered sediments. However, they can be assigned to the lower Khazarian as well based on the last species.

In the palynospectrum of the upper Khazarian deposits from Area 2, the arboreal taxa constitute 23%, herbaceous forms 54%, and spores 23%. The arboreal pollen group includes *Pinus* sp. (11%), *Betula* (9%), *Alnus* (1%), and *Corylus* (2%). The bulk of herbaceous pollen belongs to Chenopodiaceae (39%), Gramineae (5%), and *Artemisia* (3%). Herbs, among which there are Ranunculaceae, Compositae, and others, make up 7% of the spectrum. Spores are referred to green moss *Bryales* (17%), *Sphagnum* (4%), and Polypodiaceae (2%). The redeposited Mesozoic *Glechenia* spores are also recorded. Pollen, especially that of arboreal plants, is poorly preserved in the sample. However, the spectrum can be compared with that of Novocaspian deposits based on abundance of arboreal pollen and on presence of sphagnum mosses in the spore group. Assemblages of this kind are likely characteristic of a moderately humid climate.

The spectrum of older beds is quite different, containing arboreal (1.8%) and herbaceous (85.5%) pollen, and spores (12.7%). A single grain of *Betula* was found in the arboreal plant group. The herbaceous plants are represented by *Artemisia* (9%), Chenopodiaceae (54.5%), Gramineae (1.8%), Compositae (1.8%), Ranunculaceae (16.3%), and others. The spore group includes *Bryales* (9%) and *Sphagnum* (3.7%). Pollen is well preserved, and redeposited, mainly Mesozoic, spores were encountered.

Structure and Composition of Late Quaternary Sediments

The generalized lithologic sections with sampled levels and main results of our study are shown in Fig. 2. Their preliminary correlation is based on the regional seismic profiles. The Novocaspian, Mangyshlak, Khvalynian, and Khazarian complexes are distinguished in the studied sections.

The Novocaspian complex of the region overlies the upper Khvalynian and Mangyshlak sediments. It fills in and levels depressions in topography of the Mangyshlak time, being relief-forming on the other hand, because sediments of the complex form accumulative bodies on the bottom level of the Novocaspian time and recent rampart-like forms of different size. Depending on various factors, the complex thickness ranges from 0.2–0.3 m to 6.0–6.5 m. In the study region, the Novocaspian deposits are mostly represented by fine-grained sand with shell detritus beds and coquinas composed mainly of medium, coarse, and gravel-sized shells. The alternation of sandy and shelly stripes is observable directly on the bottom.

The structure and composition of the Novocaspian section is strongly different in the northern area 1 (Fig. 1), where the sea depth ranges from 7 to 9 m. The Novocaspian complex is 3.8–6.5 m thick here, and sandy-shelly grounds compose only its uppermost part. The most coarse-grained shelly deposits make up several rampart-like forms of latitudinal extension, which are up to 1.0–1.2 m high and situated at the altitudes of –34 to –36 m. Shells sampled from the base of one rampart are 860 years old. The altitude range, morphology, and available dates indicate that forms under consideration represent beach ridges of the Derbent regression time. The major part of the Novocaspian section in this area is mainly composed of mud intercalated with lens-like beds of fine-grained sand. Three sandy beds of different color, composition, and physical properties are recognized.

The Mangyshlak complex is represented in the study region by facies of greatly diverse genetic types, which reflect the consecutive southward movement of the deltaic zone and sea level lowering. Two genetic types distinguished in areas 1 and 2 are the river channel sediments and the intercalated lacustrine deposits.

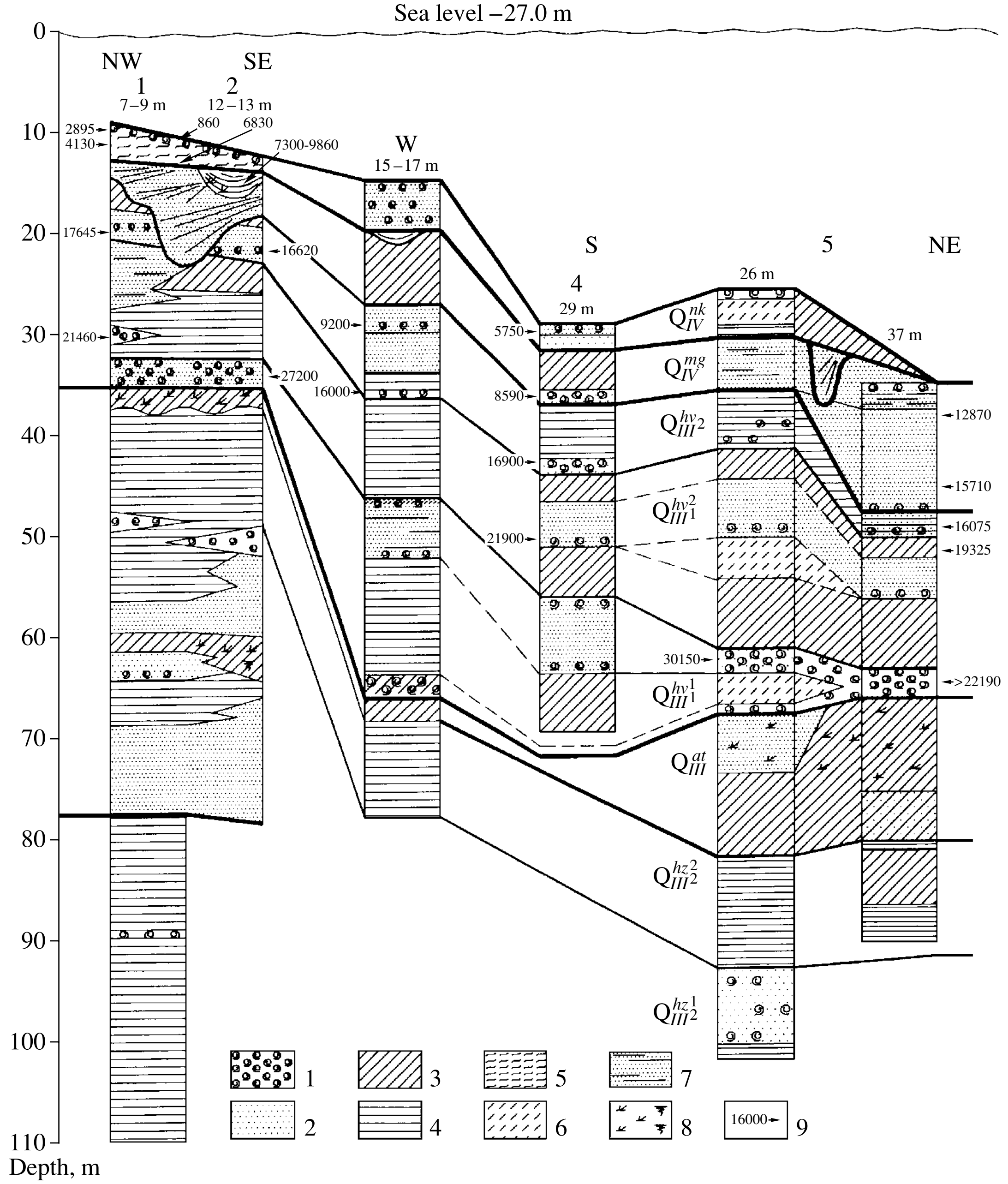

Fig. 2. Correlation scheme of studied sections: (1) coquina, coquina with sand; (2) fine-grained dusty sand; (3) dusty clayey deposits (clayey silt, loam); (4) clayey deposits; (5) clayey and loamy mud; (6) loamy sand; (7) sand with peat and organogenic mud intercalations; (8) plant detritus; (9) radiocarbon dates. Indices of stratigraphic horizons: (*nk*) Novocaspian; (*mg*) Mangyshlak; (*hv*) lower and upper (2) Khvalynian; (*hz*) Khazarian (upper). Shown at the top of columns are area numbers and sea depth values.

The former are represented by cross-bedded clayey fine-grained sand commonly bearing the fine plant detritus, scarcer shell fragments, “clay pellets,” and by clayey silt (loam). Prevailing among lacustrine deposits are flowing clays with sapropel and peat beds, and with minor intercalations of dusty sand. These sediments fill in the buried depressions of sublatitudinal extension, which are 6 to 8 m deep. Four radiocarbon dates for sapropel and peat organic matter from the lacustrine complex range from 9300 to 9860 years. One date for peat corresponds to 7630 years.

In areas 3 and 4 located southward, the Mangyshlak complex is composed of dust clays and intercalated sand beds, which bear fragmented shells of fresh- and brackish-water mollusk. The total thickness of deposits is 7 to 9 m here. According to the seismic records, the section is of a bedded structure with the layers inclined and protruding south- and eastwards. The age of shells from the sand beds is analogous to that of the organic matter from lacustrine sediments and corresponds to 9230–8590 years. The deposits are dissected by the buried river channels of a variable depth.

Table 3. Facies environment and maximum depths in the studied regions of the Caspian Sea in the Quaternary

Event	Northern region (areas 1 and 2). Sea depth 8–13 m	Intermediate region (Area 3). Sea depth 15–17 m	Southern region (areas 4 and 5). Sea depth 25–37 m
Novocaspian	~860 yrs. ago, coast at –34–36 m; 2895 yrs. ago, shoals nearby the delta; 4130 yrs. ago, avandelta, shoals	Shoals; 6610 yrs. ago, shoals	Shoals; shoals, >5790 yrs. ago, avandelta
Mangyshlak regression	Land; 9800–9420 yrs. ago, land delta with lakes	Land; 9230 yrs. ago, avandelta	Land; 8540 yrs. ago, avandelta
Late Khvalynian	17645–16645 yrs. ago, shoals	Later the depth of 60–75 m; 16000 yrs. ago, shoals	Later the depth of 70–80 m; 16900 yrs. ago, shoals
Enotaevsk regression	Avandelta at –45–50 m	Shoals	Shoals
Early Khvalynian	21460 yrs. ago, shoals; Deep water ~100 m; 27200 yrs. ago, shoals	Deep water ~110 m	21090 yrs. ago, transition to shoals; Deep water ~130 m; 30150 yrs. ago, shoals
Atel' regression	Land	–	Lagoon deltaic shoals at about –100 m
Late Khazarian	Sea depth 70–80 m	Sea depth of about 100 m	Sea depth of about 130 m
Chernyi Yar–Astrakhan' regression	Shoals nearby the delta at about –90 m	–	Shoals at about –120 m
Early Khazarian	Deep water	Deep water	Deep water

According to results of seismic profiling, the largest incised channel is situated on the east of the study region near areas 2 and 5. Judging from the bottom topography, the channel extends from the Volga River valley down to the depth of 44–45 m (altitude of –73 to –74 m), being fringed on the south by a vast fan distinctly outlined by the isobath of 55 m. The incised channel is 8 to 12 km wide, 25 to 30 m deep, and almost completely filled with sediments. The filling sequence structure well recorded in seismic profiles indicates that deposits mostly accumulated during the ingressive stage at the time of sea-level rise. The age dates mentioned above for different facies types suggest that the Mangyshlak regression maximum happened between 6830 to 8540 years ago.

The Khvalynian complex is characterized by thickness increasing southward from 22–23 m in the northern area 1 to 30–35 m in areas 3 and 4. It is represented by beds of clay, silty clay, and silty fine-grained sand commonly bearing shelly detritus. The coquina bed at the complex base has sandy to clayey matrix and is up to 3–4 m thick in the northern areas. According to our data, in the Khvalynian complex section there is a distinct isochron of 16–16.62 ka that is confined on the north (areas 1 and 2) to the base of fine-grained sand with shelly detritus interlayers, and on the south (areas 3 and 4) it traces thin layers of shelly detritus included in clayey sediments. A sharp change in sediment colors is seen across the isochron. Silty to clayey deposits above the isochron are brown and brownish gray, while below sediments are gray to dark gray owing to presence of dispersed hydrotroilite. The mollusk assemblage from the upper part of sediments includes species characteristic of the upper Khvalynian deposits.

Below the isochron, the thickness of the Khvalynian complex increases southwards from 13–15 m in northern areas 1 and 2 to 30 m in areas 3 and 4. This part of the complex is composed of clayey and sandy beds bearing shelly detritus and resting on the basal coquina bed with sandy and clayey matrix, the maximum thickness of which is 3–4 m on the north. The species composition of mollusks may be considered as characteristic in general of the early Khvalynian time, although the basal coquina bed in area 2 contains forms more characteristic of the late Khazarian time. On the other hand, the obtained ^{14}C dates of 21.09, 27.20, and 30.15 ka correspond to the early Khvalynian time span. The two latter values characterize the basal coquina bed.

The Khazarian complex was penetrated by boreholes in the northern area 1 to the greatest depth. Its section is analogous here to those studied previously along the Volga-Caspian Channel that is situated to the northwest [5]. The upper Khazarian Subhorizon composed of sandy clayey deposits is recognized in the depth interval of 35 to 78 m below the sea bottom. It is underlain by the lower Khazarian Subhorizon composed of homogeneous semisolid and plastic clay. In areas 1 and 2, the upper half of the upper Khazarian sequence is represented by silty-clayey sediments and the lower one by beds of sand and clay. The basal sand bed is about 9 m thick. The peculiar characters indicative of sea shoaling or complete exsiccation are recorded near the top of the upper Khazarian Subhorizon. Indications of this kind are the abundance of plant detritus that accumulates usually along the delta front, the occurrence of small plant roots, and holes left by burrowing organisms.

Late Quaternary Paleogeography

The discussed materials are useful for consideration of some paleogeographic aspects of the Caspian Sea history. All stages of the Caspian Sea level oscillations that were previously recognized in coastal sections and in the lower Volga region are recorded in the studied sections. The data considered above are presented in Table 3 to characterize in a generalized form the succession of major paleogeographic events in the study area. We indicated therewith the altitudes of shallow-water, deltaic, deltaic-coastal and lacustrine deposits, which record the sea level lowering during the regressive stages, and the inferred maximum depth of the sea in the northern Caspian region during the greatest transgressions. The depths are estimated based on published altitudes of the shore levels along the modern shoreline.

As it follows from Table 3, there were two periods of extreme lowering of the Caspian Sea level. The earliest one is recorded across the late Khazarian–early Khvalynian boundary. In the northern area, we found evidence of sediment accumulation in subaerial conditions at that time, and in the southern areas the lower Khvalynian sequence at the altitude of –100 m is underlain by the deposits bearing plant detritus and fragments of plant roots in their original position. We suggest that during that period corresponding to the so-called Atel' regression, the sea level dropped to the altitude of –100 m (about –70 m below the current level) and was even greater probably. The second large, so-called Mangyshlak regression took place in the terminal late Pleistocene– early Holocene time. The sea level was at that time at the altitude of –73 to –75 m, or about –45 m below the present-day level.

The shallow-water deposits of the coastal and deltaic-coastal types are recorded sections between the lower and upper Khazarian marine sediments at the altitude of about –90 m, and between the lower and upper Khvalynian marine sediments at the altitude of –45–50 m. These two events correspond to the Chernyi Yar (or Astrakhan) and Enotaevsk regressions, respectively.

During transgressions, the depth in northern areas of the Caspian sea was as great as 100–130 m in the early and as 70 m in the late Khvalynian time.

CONCLUSIONS

The comprehensive study of continuous sections of the Upper Quaternary sediments recovered by boreholes from depth range of 7 to 37 m and the results of continuous seismic profiling elucidated new facts of the Caspian Sea geologic history.

(1) Biostratigraphic analysis enabled discrimination of successive lower and upper Khazarian, lower and upper Khvalynian, Mangyshlak, and Novocaspian horizons. The mollusk assemblages from the deep-water deposits of the early and late Khvalynian time are first distinguished. They include characteristic species *Didacna parallella* (Bog.), *D. subcatillus* Andrus., and scarcer *D. praetrigonoides* Nal. and *D. cristata* (Bog.) of the early Khvalynian time and *D. praetrigonoides* Nal., *D. cristata* (Bog.), and rare *D. parallella* (Bog.) and *D. subcatillus* Andrus. of the late Khvalynian time. The assemblages slightly changing in composition over the study region substantiate a reliable correlation of the sections. They differ from concurrent assemblages of the northern Volga region, where the corresponding shallow-water deposits contain numerous *D. protracta* (Eichw.), *D. trigonoides* Pall. and scarcer *D. parallella* (Bog.) of the early Khvalynian time and *D. praetrigonoides* Nal. (Svitoch and Yanina, 1997).

(2) About 40 radiocarbon dates are first obtained for sediments recovered in the Caspian basin. These results clarify controversial views on the age and accumulation time spans of the distinguished horizons, which were discussed in a previous publication [2]. We established that the Novocaspian, Mangyshlak, upper and lower Khvalynian sediments were deposited in the time spans of 0–7, 7–9, 9–16, and 17 to >30 ka, respectively.

(3) The facies composition and attitudes of the Late Quaternary deposits are used to evaluate oscillations of the Caspian Sea level. We substantiate for the first time that the sea level lowered up to –60, –70, –20, and –45 to –50 m below the present-day stand during the mid-Khazarian, Atel', Enotaevsk, and Mangyshlak regressions.

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