ISSN 1819-7140, Russian Journal of Pacific Geology, 2024, Vol. 18, No. 5, pp. 498–511. © Pleiades Publishing, Ltd., 2024.
Russian Text © The Author(s), 2024, published in Tikhookeanskaya Geologiya, 2024, Vol. 43, No. 5, pp. 39–53.

Middle Holocene Marine Sedimentation on the Southwestern Coastal Margin in Primorye, Russia

Yu. A. Mikishin[a, *], I. G. Gvozdeva[a, **], and E. A. Elbakidze[a, *]**

[a] *Far East Geological Institute, Russian Academy of Sciences, Vladivostok, 690022 Russia*
**e-mail: yurimikishin@fegi.ru*
***e-mail: gvozdika@fegi.ru*
****e-mail: ekato21@mail.ru*

Received March 28, 2024

Abstract—A comprehensive study of marine sediments deposited on the southwestern margin of the Primorye region (near the settlement of Khasan) allowed us to consider in detail the paleogeography of the coast in the second half of the Atlantic Period of the Holocene, about 6500–6000 BP/7400–6800 cal BP. Marine environment sedimentation, as a result of the development of postglacial oceanic transgression, began around 6500 BP/7400 cal BP. A shallow marine gulf formed on the coastal accumulation plain, into which flowed the Tumannaya (Tumangan) River, the largest in the Sea of Japan Basin. The estuarine area of the river created an avalanche sedimentation environment in the bay, which developed at an average rate of 16–24 mm/year. The final sedimentation phase, which occurred after 6200 BP/7100 cal BP, did so at a time when the sea transgression slowed and sea level reached its maximum height of +1 m in this coastal area. The distribution of multispecies broadleaved forests predominated by oak and with increased participation of thermophilic hornbeam in the area adjacent to the coast at this time clearly indicates optimal climatic conditions. The end of marine sedimentation occurred around 6000 BP/6800 cal BP. It did not resume for a long time, until the middle of the Sub-Atlantic Period of the Holocene.

Keywords: Atlantic Period of the Holocene, postglacial oceanic transgression, avalanche sedimentation, landscape and climatic oscillations, radiocarbon dating, pollen assemblage, diatoms, lithology of marine sediments

DOI: 10.1134/S1819714024700283

INTRODUCTION

The southwestern margin of Primorye, adjacent to the state border with China and North Korea, occupies the southernmost position in the Russian Far East. The territory between the southern shore of Expedition Bay and the mouth of the Tumannaya (Tumangan) River stretches for approximately 40 km from north to south and 25 km from west to east. It is characterized by a low-lying accumulative plain with shallow lakes and lagoons, at the bottom of which marine sediments up to 8–12 m thick are exposed (Fig. 1). The first results of their study showed that marine sedimentation occurred in the Middle Holocene [7, 10, 16, 19]. At this time, during the maximum of the postglacial transgression of the World Ocean, the main volume of marine sediments was formed in the ingression bays of the Primorye coast [11–13, 17, 31]. At the bottom of Reid Pallas bay (head of Posyet Bay), adjacent to the southwestern margin of Primorye, their maximum thickness (11 m) was recorded in the section of well 2 [5]. From bottom to top, they are represented by the following facies: 1, shallow lagoon (absolute elevations of bedding intervals –32.4 to –31.5 m); 2, shallow bay (–31.5 to –30.3 m); 3, open shallow water (–30.3 to –27.0 m); 4, deeper open sea (–27.0 to –21.4 m). The authors compared the time of their formation with the Blitt–Sernander Holocene periodization scale: 1 and 2 are attributed to Late Boreal–Early Atlantic; 3, to the Early Atlantic; 4, to the Late Atlantic–Subboreal. A detailed stratigraphic division of Mid-Holocene deposits in accordance with short-period changes in nature was unsuccessful. Short-period, or rapid, changes lasting several hundred years have been established in many regions of the Northern Hemisphere [3, 6], including in southern Primorye [21–24, 44, 45]. The first results of studying Middle Holocene marine sediments of the southwestern margin did not allow such a detailed stratigraphic division either. To achieve this goal, as well as to refine the conditions of marine sedimentation, an additional, detailed study of sediments of the Talmi well section was carried out by granulometric, spore–pollen, and diatom analyses.

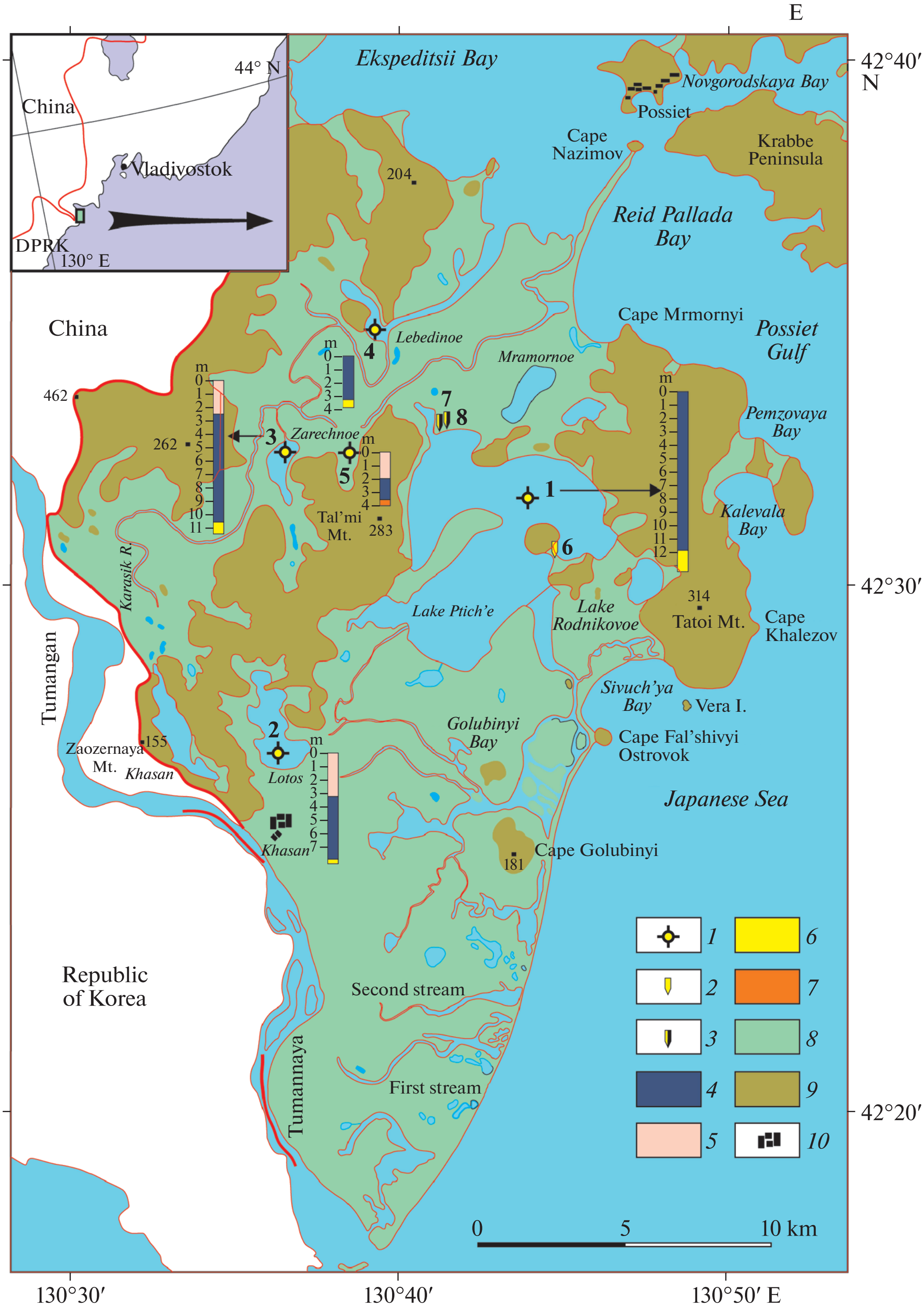

Fig. 1. Location of studied sections of mid-Holocene deposits in southwestern margin of Primorye: *1,* wells; *2,* pits studied by authors; *3,* outcrops studied by other researchers; *4,* Middle Holocene marine sediments; *5,* Upper Holocene lacustrine and bog sediments; *6,* Upper Pleistocene alluvial–marine deposits; *7,* bedrock weathering crust; *8,* low accumulative plain and terraces; *9,* hills and low mountain ranges; *10*, settlements. Sections: 1, Talmi well; 2, Doritsyn well; 3 Sak-Pau well; 4, Lebediny well; 5, Mar' well; 6, Lagerny [19]; 7, 5-m terrace of Lake Talmi [1, 2]; 8, 1-94 [7, 10].

MATERIALS AND METHODS

The Talmi well section is located in the waters of the Ptichye lagoon-lake, 1.7 km from the northern shore (42°31′22″ N, 130°45′01″ E) (Fig. 1). The well was drilled by a UGB-50 rig from ice in early March 1991, which yielded a core with an undisturbed structure 127 mm in diameter. From top to bottom, from the surface of the lake bottom (the depth of the lake at the drilling site was 1.5 m), the following layers were exposed, in m:

0.0–0.5, fine-grained silty sand, dark gray in color, with shell detritus;

0.5–1.0, sandy loam, bluish black in color, soft-plastic consistency, with an inclusion of mollusk shells and their fragments;

1.0–11.9, black clay, soft-plastic consistency, with an inclusion of mollusk shells and their fragments;

11.9–13.5, fine-grained silty sand, greenish gray, dense, dry.

The sediments were studied in 5-cm-thick core samples. The grain size distribution was studied in 64 samples taken with a step of 20 cm. The analysis was performed using T.S. Ivashinnikova's combined water-mechanical analysis method [26] (Coastal Research Center, Far East State University).

Spore–pollen analysis was carried out in 44 samples taken at intervals of 25–40 cm; in the upper (0–2 m) layer, at intervals of 5–10 cm. Samples were processed according to the standard method [25]. The participation of taxa in the spore–pollen spectra was calculated separately in the groups of pollen of tree species, grasses and spores. The paleovegetation was reconstructed based on correspondence of the subfossil spore–pollen spectra to the modern vegetation cover [18], the characteristics of which on the southwestern margin of Primorye were significantly augmented by research in 2020.

Diatom analysis was used to study 40 samples taken at intervals of 15–45 cm. Technical preparation of samples for analysis was carried out according to standard methods [9]. The taxonomy and ecological–geographical characteristics of algae are given according to literature sources [4, 37–42].

The mollusk fauna in marine sediments was previously studied in 33 samples [16].

Absolute age was determined by radiocarbon analysis at the accelerator mass spectrometry center of Livermore National Laboratory, California, USA (three datings, CAMS index), at the University of Arizona, USA (four datings, AA index), at the Woods Hole Oceanographic Institute, Baltimore, USA (2 datings, index OS) and the laboratory of Cenozoic paleoclimatology of the Institute of Geology and Mineralogy SB RAS (2 datings, COAH index). Date calibration was performed in the Cal Pal [46] and Marine 04 [36] programs for marine samples.

Stratigraphic division of sediments was done in accordance with the Blitt–Sernander Holocene periodization scheme, modified for Northern Eurasia [32].

RESULTS

Granulometric analysis made it possible to identify ten lithological horizons in sediments of the Talmi well section, which were grouped into 4 layers (Table 1).

The first layer, uncovered at the base of the section at a depth of 13.5–11.9 m, consists of dry silty sands of a greenish gray color, most likely formed in conditions of open shallow seawater, near the mouth of a large river (horizon 10). The content of the fine sand fraction in it is 60%; the admixture of the clay fraction (<0.01 mm) is almost 20%. The layer accumulated at the beginning of the Late Pleistocene [27].

The second layer, 5.2 m thick (11.9–6.7 m), reflected the initial stage of Middle Holocene sedimentation, which occurred in the sea bay under quiescent sedimentation conditions. It is represented by sediments with the finest grain size distribution: pelites and silty-pelites, with a high, on average 50–80%, content of the clay fraction and an inclusion of shells of marine mollusks (horizons 9–6). As the study of modern sediments of the coastal zone of southern Primorye shows, such a high content of the pelitic fraction is observed only in bottom sediments of semi-closed (or completely closed) water areas into which lowland rivers flow, carrying a large amount of suspended detrital material [27]. On the southwestern margin of Primorye, such a river could only be the Tumannaya (Tumangan), the largest in the Sea of Japan Basin.

The third layer, with a thickness of 5.7 m (6.7–1.0 m), accumulated under increased hydrodynamic activity, compared with the conditions of formation of the previous layer, indicating a greater openness (possibly completely open) of the paleobay that existed at the site of the modern Ptichye lagoon-lake. Sediments are represented mainly by fine silts, with a thin, less than 1 m, silty-pelite layer (horizons 5–3). They also contain shells of bivalves and their fragments.

The surface layer of the section (1–0 m) formed in a shallow sea bay, possibly near the mouth of the river, which is evident from the abundance of sand in it, almost entirely represented by the fine fraction. Its content increases from bottom to top along the section from an average of 17 to 86%, while the clay fraction, conversely, drops to 10% (horizons 2–1). An inclusion of mollusk shells is noted in the lower part of the layer, in horizon 2.

Spore–Pollen Analysis. In the spore–pollen diagram (Fig. 2), one spore–pollen spectrum (SPS) and two spore–pollen assemblages (SPA) are distinguished.

Table 1. Grain size distribution of sediments Talmi well section

Lithological horizons	Burial depth, m	Content of fractions, %, extrema/average values				
		1–0.1 mm sands	0.1–0.01 mm silts	0.01–0.001 mm pelites	<0–001 mm colloid	Σ <0–01 mm
(1) Sands fine, silty	0.5–0.0	81–86/83	6–11/8	2–4/3	4–7/5	8–9/8
(2) Silts coarse, sandy	1.0–0.5	17–36/27	46–77/61	4–6/5	2–22/6	6–27/11
(3) Fine silts	4.0–1.0	3–10/6	50–85/64	4–27/14	4–28/15	8–47/30
(4) Silty pelites	4.6–4.0	1–2/1	31–48/38	20–37/31	27–30/29	50–67/60
(5) Fine silts	6.7–4.6	2–13/6	40–72/56	9–36/20	4–29/17	18–55/37
(6) Coarse pelites	7.7–6.7	1–2/1	38–43/41	25–31/28	26–31/29	56–61/57
(7) Small pelites	8.7–7.7	1–3/2	11–28/19	15–51/33	36–55/45	69–87/79
(8) Silt-pelites	9.5–8.7	2–4/3	45–51/47	21–27/24	19–27/24	46–51/48
(9) Small pelites	11.9–9.5	0–6/1	6–27/15	32–59/39	37–53/45	69–91/84
(10) Sands fine, dusty	13.5–11.9	60	22	9	9	18

1. The Ta-1 SPS from Upper Pleistocene sands is described in their roof, at a depth of 11.95–11.90 m. Pollen of tree species is dominated by pollen of broad-leaved trees, mainly oak (54%), elm (9%), and walnut (7%). Coniferous species are represented by pollen of Korean cedar (16%), pine (up to 3%), fir, and spruce (0.2–0.4%). Pollen of small-leaved trees is extremely rare: birch, less than 6%; alder and willow, 1.5%.

2. SPA Ta-2 is contained in the lower layer of marine clays, in the 11.9–1.75 m interval. The general composition of the assemblage is dominated by pollen of trees and shrubs, indicating the dominance of forest vegetation near the section. Among them, broadleaved species prevail, mainly oak (36–67%), elm (4–10%), walnut (2–7%), linden (up to 4%), hornbeam (1–5, on average, 2.4%), and hazel (up to 3%). The remaining taxa (aralia, ash, maple, lilac, velvet, viburnum, grape, and beech) are rare. Among coniferous pollen, Korean cedar predominates (4–34%); pine (*Pinus densiflora*) is less common, up to 3%; spruce, up to 2%; fir, up to 1%; and larch, up to 0.3%. Pollen from small-leaved trees is more frequently represented by birch (2–17%) than by alder and willow. Among grass pollen there is a lot of wormwood (37–72%); sedge, forbs, grasses, rose family, and aquatic plants are less common.

3. SPA Ta-3, contained in the upper horizon of marine sediments (1.75–0.0 m), also indicates the predominance of forest vegetation in the area adjacent to the paleobay. Among the pollen of tree species, broadleaved trees dominate: oak (40–55%), elm (2–8%), hornbeam (2–6.5, on average, 4%), walnut (2–7%), hazel (up to 5%), and linden (up to 2%). Small-leaved trees occupy second place due to a twofold increase in the role of birch (12–27%). Korean cedar pollen is recorded almost twice as rarely as compared to the previous assemblage (1–19%). Grasses are still represented by a high content of wormwood pollen, and to a lesser extent, forbs, cereals, and sedge. Among the spores, ferns of the family Polypodiaceae, and, much less frequently, *Osmunda* remain dominant

Diatom Analysis. Diatom flora in sediments of the Talmi well section is represented by 135 species and intraspecific taxa. They are attributed to the following ecological groups: marine pelagic, marine neritic, marine subtidal planktonic, marine subtidal benthic, brackish water planktonic and benthic diatoms that lived in the paleobay that existed on the site of the modern Ptichye lagoon-lake. In addition, there is a group of freshwater and redeposited diatoms that were transported into marine sediments by the waters of the Tumannaya River. Based on the change in dominant

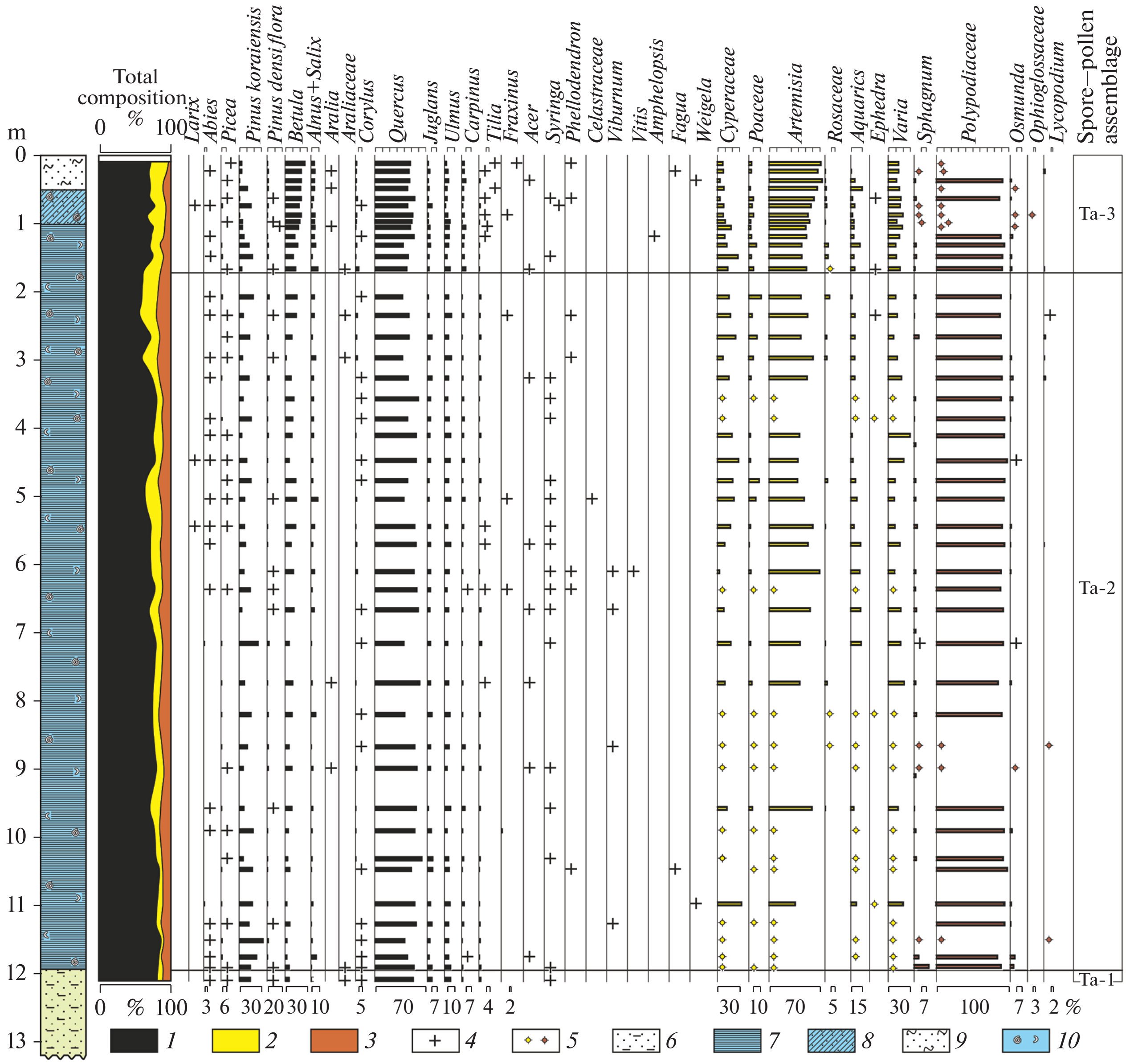

Fig. 2. Spore–pollen diagram of sediments of Talmi section well. Pollen and spores: *1,* pollen of trees and shrubs; *2,* pollen of grasses; *3,* spores; *4,* pollen and spore content less than 1%; *5,* contents of pollen of grasses and spores were not calculated due to small number of grains detected. Lithology: *6,* fine-grained, silty sand; *7,* clay; *8,* sandy carboniferous; *9,* fine-grained sand, silty; *10,* mollusk shells and their fragments.

diatom taxa and the ratio of representatives of different ecological groups in the sediments of the section, three diatom assemblages were identified (Fig. 3).

The first assemblage (interval 11.9–8.5 m) is distinguished by the predominance of sublittoral benthic diatoms, including, among others, species that develop in desalinated coastal areas of the seas. The genus *Diploneis* has the greatest abundance among them, with estimates of dominants and subdominants and *Tryblionella*, living on silty marine sediments [35, 47]. Marine neritic diatoms are observed less frequently, mainly *Actinoptychus senarius,* which favors well-warmed shallow waters [33]; *Chaetoceros ssp.*; and *Cyclotella striata*. Freshwater and redeposited diatoms also have a significant admixture.

Two subassemblages are distinguished in the assemblage, of which DK-1.1, in the section interval of 11.9–10.5 m, marks the predominance (31–53%) of marine subtidal benthic diatoms. The dominant among them is mesohalobe *Diploneis smithii* (up to 25%); the subdominant is *D. subcincta* (before 18%). Among neritic diatoms, the subdominant is *Chaetoceros* (up to 18%); massive, *Cyclotella striata* (up to 13%), characteristic, among other things, of estuarine

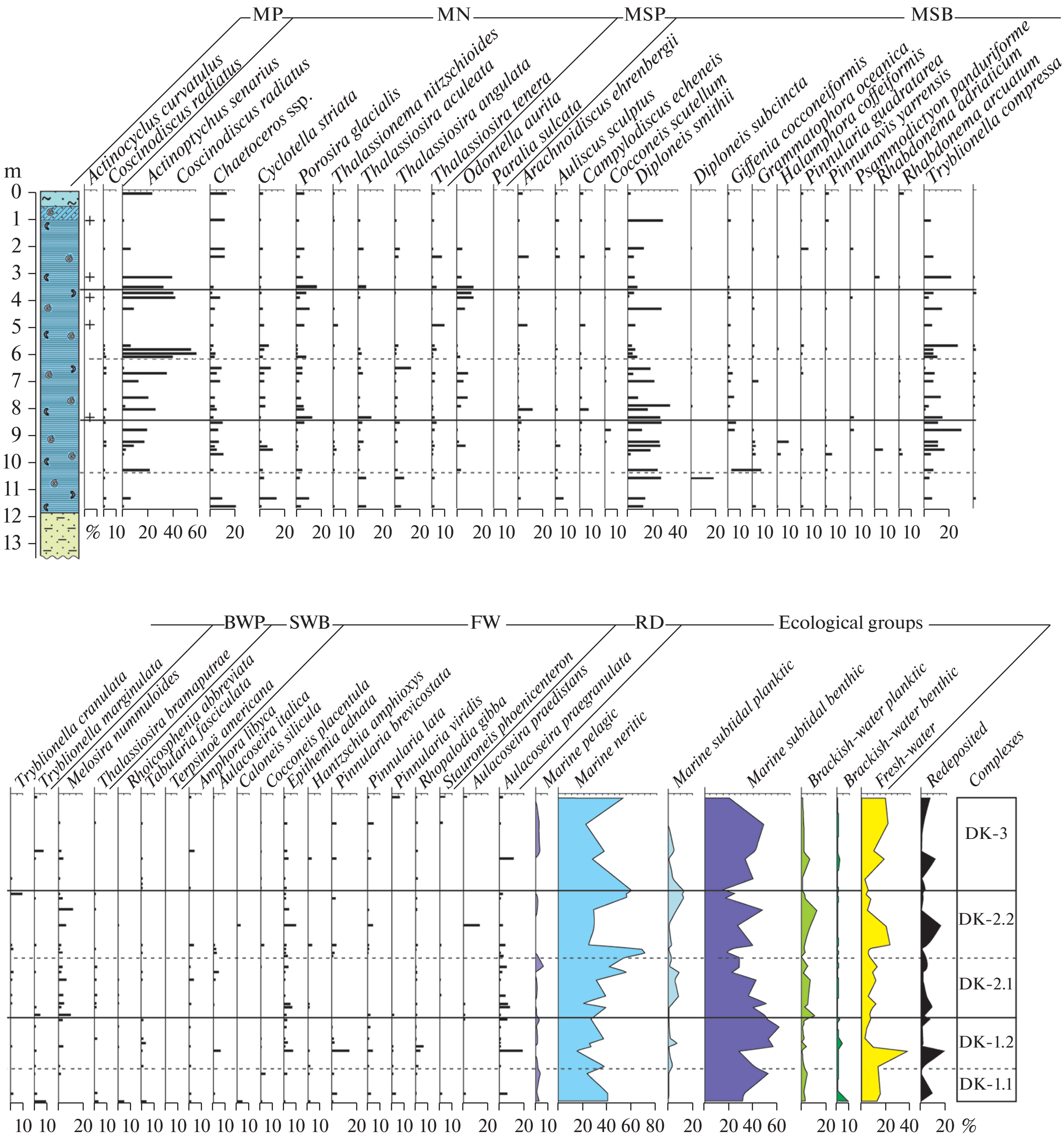

Fig. 3. Diatom diagram of sediments of Talmi well section. Ecological groups of diatoms: MP, marine pelagic; MN, marine neritic; MSP, marine subtidal planktonic; MSB, marine subtidal benthic; BWP, brackish water planktonic; BWB, brackish water benthic; FW, freshwater; RD, redeposited. See Fig. 2 for legend.

environments. Subassemblage DK-1.2 (10.5–8.5 m) shows a further increase in the proportion of benthic diatoms, with the close participation of both *Tryblionella compressa* (6–30%) and *Diploneis smithii* (1–25%). Among neritic diatoms (14–37%), the presence of *Actinoptychus senarius increases* (up to 21%). In the group of subtidal planktonic diatoms, the number of *Odontella aurita increases up to 11%.*, which prefers coastal waters, including desalinated waters of seas and river estuaries [33]. The increasing desalination effect of river runoff on the waters of the paleobay, which reached its maximum extent over the entire period of sedimentation, is emphasized by a sharp increase in the diversity (49 taxa) and abundance (up to 38%) of freshwater diatoms.

The second assemblage (8.5–3.6 m) is distinguished by the predominance of neritic diatoms, the role of which increases from bottom to top along the section by almost 1.5 times and, accordingly, the participation of sublittoral benthic species decreases. Among the former, *Actinoptychus senarius dominates* and *Porosira glacialis*; the latter are more frequently represented by *Diploneis smithii* and *Tryblionella compressa*.

Two subassemblages are distinguished in the assemblage, the lower of which, DK-2.1 (8.5–6.3 m), records a moderate increase in the abundance of marine neritic (on average from 28 to 35%), to a lesser extent, brackish water planktonic (from 2 to 5%) and marine pelagic (up to 6%) diatoms, occurring against a weakening role of subtidal benthic species (up to 51%). Among the former, there is an increase in the value of *Actinoptychus senarius* (up to 35%) and *Porosira glacialis* (up to 12%). In the group of brackish water planktonic diatoms, the participation of *Melosira nummuloides* (up to 8%) increases, a common taxon for coastal-marine and estuarine areas [43]. Among subtidal benthic species, the dominant role of the mesohalobe *Diploneis smithii* continues (3–32%), which that of *Tryblionella compressa* decreases (1–15%). Subassemblage DK-2.2. (6.3–3.6 m) reflects the increasing role of neritic diatoms, reaching a maximum content of up to 70%. The dominant species *Actinoptychus senarius* reaches its maximum development (up to 59%), as does the subdominant *Porosira glacialis* (up to 16%). The content of valves of sublittoral benthic species decreases to a greater extent (up to 47%), in contrast to the first subassemblage, with the participation of the mesohalobe *Diploneis smithii* drops to minimal values (on average up to 6%).

The third assemblage (3.6–0.15 m) is characterized by a weakening role of planktonic neritic (on average from 50 to 34%), marine subtidal and brackish water planktonic species, along with an increased participation of subtidal benthic diatoms, primarily inhabitants of desalinated areas of the seas. Among neritic taxa, the value of *Actinoptychus senarius decreases* (up to 23%), *Porosira glacialis* (up to 6%), *Cyclotella striata* (up to 3%) and *Thalassiosira aculeata* (up to 4%). *Terpsinoë americana appears* at a depth of 1.15 m – a brackish water tropical epiphyte [34], indicating significant summer warming of the waters of the paleobay. A significant increase in abundance is observed among the mesohalobes *Diploneis smithii* (up to 26%) and *Pinnunavis yarrensis* (up to 2%), as well as *Cocconeis scutellum* (up to 5%). Valves of freshwater diatoms brought by river waters are again recorded more frequently (on average 17%).

Analysis of malacofauna in the sediments of the Talmi well section showed the presence of five species of gastropods and ten species of bivalves, making it possible to distinguish three shell assemblages [16]. The first, related to the initial marine sedimentation stage, is found in the lower horizon of marine clays, in the 11.9–10.5 m interval. It includes *Tritia acutidentata* and *Turbonilla multigyrata*, ordinary marine gastropods that now live in the well-warmed bays of southern Primorye. The second assemblage (10.5–1.0 m) includes the oyster *Crassostrea gigas* and other mollusks (*Mya* cf. *japonica*, *Tritia acutidentata*) living on oyster banks. The third assemblage, widespread in the surface layer (1.0–0 m) of sandy sediments, is formed by *Macoma incongrua*, *Ruditapes philippinarum*, *Tegula rustica*, and *Batillaria cumingii*, which lived in the final stage of oyster settlement. The assemblages reflect three stages of the formation of malacofauna [16] caused by changes in sedimentation conditions. In the first, on the site of the modern Ptichye lagoon-lake, a shallow bay was formed, in which mollusk settlements with a predominance of *Tritia acutidentata appeared*. The second stage was characterized by the formation of oyster banks that developed on muddy sediments in a shallow semiclosed bay with slightly desalinated waters, indicated by the presence of the mollusk *Potamocorbula amurensis*, a euryhaline marine species. In addition, warm-water mollusks *Anadara* cf. *inaequivalvis*, *Dosinia angulosa*, and *Trapezium liratum* with a tropical–subtropical range developed in large numbers in the bay, indicating significant warming of water in the summer. And while the latter still lives in the coastal waters of southern Primorye, the first two live only off the coast of southern Korea and China [30]. They appear at a depth of 10.5 m and disappear at a level of 1.75 m. At the third, final stage of development of the malacofauna, the oyster bank died out and the shallowed bay was colonized by euryhaline marine and brackish water species [16].

Radiocarbon Dating. Already the first results of radiocarbon dating of mollusk shells from the Talmi well section [10] cast doubt on their correspondence to the actual age of the deposits. Two dates based on shells of the same species (*Anadara inaequivalvis*), lying in the 10.30–1.75 m interval (absolute elevations –11.40 to 2.85 m), showed the same age: about 4900–4800 radiocarbon years ago (hereinafter referred to as BP), corresponding to 5200–5000 calendar years (hereinafter referred to as cal BP) (Table 2). Later, the shells of another species (*Crassostrea gigas*) yielded two more dates close to them, about 4800 BP/5000 cal BP, from a depth of 10.40 m (–11.50 m), and more ancient, about 5300 BP./5700 cal BP, from a level of 8.95 m (–10.05 m) [19]. The dates indicate the final moments of the late phase of the Atlantic period, according to the Holocene chronological standard modified for Northern Eurasia [32]. At the same time, for deposits of this age on the coast of southwestern Primorye, a different nature of the SPA has been established [21, 23]. Also, these dates contradict the chronology of development of the postglacial transgression of the World Ocean. Its variability, well studied on the coast of southeastern China [48], showed that the ocean level could have been at absolute elevations of –10 to 12 m for a long time: about 7150–6750 BP/8000–7600 cal BP in a tectonically stable area; 6600 BP/7500 cal BP, in a zone of weak uplifts; and 6350–6200 BP/7300–7100 cal BP, in areas of weak subsidence adjacent to the deltas of large rivers. The rejuvenation of the dates of the section is therefore very significant and can range from 1 to 2.3 ka. Such large-scale age inversions are apparently not exceptional in radiocarbon analysis of marine mollusk shells. Determination of the age of mid-Holocene sediments of core 1877, located at a depth of 4–3 m from the bottom surface (–22.5–21.5 m) in Reid Pallas Bay, showed both a rejuvenation of dates close to 1 ka and an older date of 2.5 ka if we consider the date 6200 BP to be accurate from the base of the layer [5, 29]. A significant increase in age (at least 1 ka) of one of the dates was also noted during a study of a Neolithic shell midden on the coast of Boisman Bay [14]. Like the previous one, it was written off as redeposition of shell material. More precisely, the absolute age of marine sediments was reflected by the dates obtained from the Doritsyn well section on Lake Lotus, the current water area of which was part of a single paleobay that existed on the southwestern margin of Primorye. For the 7.90–4.70 m interval of the section (–6.9–3.7 m), it was 6800–6100 BP/7300–7000 cal BP (Table 2). Of the three determinations, the date of 6250 BP/7200 cal BP on wood from a depth of 4.70 m (-3.7 m) seems preferable. It appears to have been largely unaffected by age distortion, as indicated by a date of about 6200 BP/7100 cal BP, obtained for marine sediments of the coast of Boisman Bay, occurring at a close elevation of –2 m [20, 21]. The accumulation of the upper horizons of the layer containing SPA Ta-2 (–13.00–2.85 m) therefore occurred in the second half of the middle phase of the Atlantic Holocene period, around 6250–6200 BP/7200–7100 cal BP.

The lower horizons that make up the base of the Talmi well section most likely began to form around 6500 BP/7400 cal BP, since for an earlier time, about 6550 cal BP/7500 cal BP, in terrace deposits in the Vinogradnaya River valley (near the coast of Expedition Bay), a different SPA was established, reflecting the distribution of coniferous-broadleaved forests with a greater role than now for cedar and a smaller (7–12%) participation of oak [44]. If the lower horizons of the section had accumulated earlier than 6500 BP/7400 cal BP, they would contain the same SPA. There is a high probability that precisely this was discovered in the sediments of the deeper open sea facies from the well 2 at the bottom of Pallas Reid Bay [5]. Similar changes in vegetation at almost the same time were recently noted for low-mountain areas of other regions of southern Primorye, such as the Shufan Plateau [45]. They clearly indicate cooler than modern climatic conditions of the initial phase of relative cooling of the Middle Atlantic period of the Holocene. The restoration of climatic parameters to modern levels most likely occurred very quickly. As shown by the study of marine sediments of the Shkotovo section (–2.49–5.60 m) on the coast of Ussuri Bay, the SPA contained in them and similar to Ta-2 also began to form no later than 6400 BP/6900 cal BP [8], taking into account the possible rejuvenation of the date obtained from the shell.

For the upper layer of sediments of the section (0.0–1.75 m), lying at a depth of –1.5–3.25 m, only one shell date was obtained, about 4000 BP/4100 cal BP (Table 2), which is clearly rejuvenated, because it indicates its formation at the beginning of the middle phase of the subboreal period of the Holocene. This conclusion is contradicted by SPA Ta-3 contained therein. It has a more thermophilic character than that established for the initial warming of the Middle Subboreal climate, bringing it closer to SPA I-2 from deposits of well 3 (–0.9–2.4 m) on the coast of Boisman Bay [20, 21]. The latter reflected vegetation that developed in warmer climatic conditions than the modern, around 6200–5900 BP/7100–6700 cal BP The upper boundary of the event was later extended to 6000 BP/6800 cal BP [23], keeping it in the Middle Atlantic phase. Taking into account the close geomorphological position occupied by the above-described layers of marine sediments on the seacoast, and the similar pollen spectra contained in them, we consider it possible to apply a chronological framework of 6200–6000 BP/7100–6800 cal BP for the time of formation of the upper horizon of the Talmi well section.

DISCUSSION

The marine sedimentation environment on the southwestern margin of Primorye began to form when the level of the Sea of Japan reached an absolute elevation of -13 m. Analysis of the results of radiocarbon dating of marine sediments and data accumulated in recent decades on the composition of the dated Holocene SPAs of southwestern Primorye [21–23 , 44] allow us to attribute this event to 6500 BP/7400 cal BP It should be noted that, according to the existing scheme (the modern one, based on a detailed study, is still lacking) of the variability of the postglacial transgression of the Sea of Japan on the coast of southern Primorye, at this time the sea level already occupied its current position [12, 13]. This discrepancy with our results is largely explained by poor knowledge of the final period of postglacial transgression on this section of the sea coast. In addition, most of the radiocarbon dates used to construct sea level curves are from shells, which, as can be seen, are frequently subject to significant age distortion.

The encroachment of seawater into the landmass of the southwestern margin during the postglacial transgression occurred along a system of depressions on the

Table 2. Radiocarbon dating of Middle Holocene deposits in southwestern margin of Primorye

No.	Section	Geomorphological position, coordinates	Lab. no.	Sampling depth, m	Material	Sample age	
						radiocarbon, BP	calendar, BP cal
1	Talmi well [19]	Lake Ptichye, 42°31′22″ N, 130°45′01″ E	CAMS-33129	10.40	Shell *Crassostrea gigas*	4870 ± 50	5230 ± 99
2	Same [10]	There	OS-2319	10.30–10.25	Shell *Anadara inaequivalvis*	4760 ± 30	5015 ± 61
3	Same [19]	There	CAMS-33130	8.95	Shell *Crassostrea gigas*	5330 ± 50	5685 ± 58
4	Same [10]	There	OS-2320	1.8–1.75	Shell *Anadara inaequivalvis*	4770 ± 30	5025 ± 61
5	Same [19]	Same place	CAMS-33131	0.65	Shell *Crassostrea gigas*	4060 ± 60	4085 ± 88
6	Doritsyn well [19]	Lake Lotus, 42°26′51″ N, 130°38′48″ E	AA-36901	7.90	Same	6760 ± 40	7280 ± 54
7			AA-36956	7.90	Wood	6140 ± 60	7048 ± 89
8			AA-36455	4.70	Same	6250 ± 40	7170 ± 69
9	Camp [19] isthmus	Lagerny Peninsula on lake. Bird's eye, 42°30′28″ N, 130°45′51″ E	AA-36382	0.70–0.60	Shell *Crassostrea gigas*	3220 ± 35	3035 ± 58
10	5-meter terrace of lake. Talmi [1, 2]	Ancient coastal rampart on northern shore of lake. Ptichye	GIN-739 a	0.80–0.40	Shells *Anadara subcrenata*	5630 ± 110	6000 ± 124
11			GIN-739 p	Same	Same	6000 ± 130	6405 ± 135
12	1-94 [10]	Same place, quarry, 42°32′47″ N, 130°43′02″ E	OS-3026	0.50	Shell *Anadara subcrenata*	5320 ± 45	5660 ± 49
13			OS-3028	1.50	Same	5360 ±35	5715 ± 49
14	Vinogradnaya-272 [44]	Terrace on river bank Grape, 1.2 km below bridge 42°42′59″ N, 130°57′02″ E	COAH-7179	1.95–1.90	Peat	7995 ± 45	8871 ± 93
15			COAH-7181	1.75–1.68	Same	6555 ± 40	7470 ± 28

surface of the Late Pleistocene accumulative plain, to which the current basins of large lakes are confined. In the western part of the margin, north of the Lake Khasan (near the state border with China), seawater appeared quickly, perhaps less than 100 years after the start of the encroachment, having overcome the absolute elevation mark of -10 m. Near this place, 30 km north of the modern position, most likely the mouth area of the Tumannaya (Tumangana) River existed there at that time, the largest artery of the Sea of Japan Basin. It had a decisive influence on sedimentation, creating avalanche sedimentation conditions [15] in the newly formed sea bay. The average sedimentation rate, taking into account the maximum thickness of clayey sediments (8–12 m) and period of evolution of the paleoenvironment (about 500 years), ranged from 16 to 24 mm/year in different parts.

A comprehensive study of sediments of the Talmi well section distinguished three stages in the history of marine sedimentation on the southwestern margin of Primorye.

The early stage, recorded by a sequence of pelitic sediments (interval 11.90–6.70 m), developed under conditions of low wave activity, which could only have been the result of an accumulative coastal form that arose on the southern boundaries of the margin, possibly between low-mountain massifs (at that time the Golubiny Utes islands and the Falshivy Island). The accumulative barrier completely or mostly covered the emerging paleobay from strong southerly waves. Otherwise, sand and pebble sediments of coastal facies should have occurred at the base of the section. The resulting semiclosed water area supported water exchange with Expedition Bay through the straits north of the modern Ptichye lagoon-lake. They also carried large masses of suspended debris transported by the Tumannaya River. The composition of diatoms (assemblage 1, subassemblage 2.1), with a predominance of sublittoral benthic species over neritic planktonic taxa, is evidence of shallow depths of the paleobay, and the high abundance of mesohalobes and inhabitants of estuarine areas of seas indicates low water salinity. A modern analog of this paleoenvironment can be the head of Amur Bay, where the large Razdolnaya River flows. Among diatoms in the bottom sediments of the shallow Tavrichansky estuary adjacent to the river mouth, a high content of mesohalobe *Diploneis smithii,* up to 21%, was recently revealed [28], similar to the first assemblage. Shellfish fauna (presence of *Rapana venosa*) also confirms the development of shallow waters with a quiescent hydrodynamic regime that existed in different parts of the paleobay (areas of lakes Lotos and Zarechnoe). Tropical–subtropical species of mollusks of the genera *Anadara, Dosinia,* and *Trapezium* testify to the good warming of the paleobay in summer, which exceeded the modern conditions, probably due to shallow water, The composition of the fauna indicates weak desalination of the waters of the paleobay [16], which contradicts the data on diatoms and location near the mouth of such a large river. This can be reconciled, assuming that significant desalination of the paleobay was not constant, but sporadic, during severe floods in the Tumannaya River basin as a result of typhoons. Mollusks are subjected to such periods of desalination almost every year, which is clearly visible from their modern distribution at the head of Amur Bay. It is possible that during catastrophic floods, mass deaths of mollusks could have occurred, along with other representatives of the marine fauna, as sometimes (the last time about 70 years ago) happens in Expedition Bay, where the waters of the Tumannaya River break through. The rest of the time, with a quiescent hydrometeorological regime, desalination was much less, and the salinity of waters may have increased to 27–29‰, as in modern bays of the river runoff zone of influence. The vegetation on the southwestern margin and adjacent territory was close to the modern, differing by a greater forest cover, reflected in the overall composition of the SPA by the high role of pollen from trees and shrubs (average content 75%, versus 63% in subfossil spectra). Multispecies broadleaved forests, dominated by oak, became widespread. The high content of oak pollen, on average 1.5 times higher than the subfossil level, most likely indicates the development of dense forests rather than oak woodlands, as is now the case in the coastal area. The pollen contents of most other broadleaf species (most notably the thermophilic hornbeam) indicate that their role in stands was consistent with their modern role in the vegetation, in contrast to the lesser contribution of birch. Beech was absent from forests of the southwestern margin; the insignificant presence of its pollen in sediments is explained by distant wind drift. Coniferous–deciduous forests growing in the Black Mountains also had the current participation level of vegetation, which indicates the development of relative climate cooling close to modern conditions [21].

The middle stage of sedimentation is recorded by a member of fine silty sediments (6.70–1.75 m interval), which accumulated on under conditions of greater hydrodynamic activity compared to the previous situation. It could only have been caused by disturbance of the southern points, which were able to penetrate the waters of the paleobay after the erosion of the southern accumulative barrier, probably caused by an accelerated rate of postglacial oceanic transgression. At least half the volume of the clay fractions transported by the Tumannaya River began to drift out into the open sea. The composition of diatoms (subassemblage 2.2) confirms the trend of increasing openness and depth of the water area: the participation of planktonic neritic species increases almost 1.5 times; the importance of subtidal benthic algae is correspondingly reduced to the minimum level. The salinity of waters has increased, reflected by the weakening role of the mesohalobe *Diploneis smithii.* Periodic desalination of waters of the paleobay continued, as evidenced by the high abundance of the above-mentioned taxon and some estuarine species in a number of horizons (6.65, 4.45, 3.70, and 2.20 m). An increase in water salinity during interflood periods did not change the composition of the mollusk fauna. Among them, the same representatives of the oyster assemblage and warm-water species are recorded: witnesses of good warming of waters in summer. The latter, however, cannot serve as evidence of a warmer climate, which, judging by the lack of changes in the vegetation cover of the southwestern margin, still remained close to modern conditions (the high water temperature is confirmed by the composition of the diatom flora for the final stage, but warm-water species of mollusks did not develop then). At the end of the middle stage, on the windward shores of the paleobay (northern shore of Lake Ptichye, a section of plain between it and Lake Rodnikov) as a result of a powerful storm (tsunami?), high coastal bars were formed, composed of boulder–pebble deposits with an inclusion of numerous shells of the tropical *Anadara*. A series of dates from them indicate a Late Atlantic age for the event, around 6000–5300 BP/6400–5700 cal BP (Table 2). The dates are rejuvenated, proven by the very presence of shells of warm-water mollusks that went extinct at the end of this stage [16]. The actual age of the coastal ramparts most likely does not exceed 6200 BP/7100 cal BP. Leveling showed that their height is 3 m, not 5 [1, 2]. With the height of the beach in the open bays of the coast being 2.5 m [5], it is obvious that the level of the Sea of Japan at the time of formation of the bars was close to its present position.

The completion of marine sedimentation occurred at the end of the middle phase of the Atlantic Holocene period, around 6200–6000 BP/7100–6800 cal BP, recorded in the section by layers of siltstones, including sandy ones, and fine-grained silty sands. The appearance of sand in the sediments was most likely associated with the approach of the river mouth zone. Tumannaya to the area of the modern water area of the Ptichye lagoon-lake. The last stage was characterized by the lowest rate of sedimentation, on average about 9 mm/year, which, nevertheless, led to the shallowing of the paleobay, which is explained both by the small initial depth, not exceeding 3 m in the area of the section, and by the slowdown in the rate of transgression of the Sea of Japan . Judging by the low height of the accumulative form (1.5 m) on the isthmus of the Lagerny Peninsula (Fig. 1, section 6), formed under conditions of weakened wave activity, the sea level rise was no more than 1 m above the current position. The coastal form is composed of coarse-grained sands with a large content of oyster shells, which entered the coastal sediments, probably from oyster banks that had died by that time [16]. Changes in the composition of diatoms (assemblage 3), expressed in a sharp decrease in the proportion of neritic species and an increase in the role of subtidal benthic taxa, indicate a decrease in the depth of the paleo-reservoir, and the presence of the tropical epiphyte *Terpsinoe americana* – for good summer warming of water. The increased influence of desalinated river waters on the process of sedimentation is recorded by a twofold increase in the value of mesohalobe *Diploneis smithii* and the maximum, on average, content of freshwater diatom valves. The nature of the vegetation cover clearly indicates warmer (optimal) climatic conditions than modern ones, in which the final phase of marine sedimentation developed. In the territory adjacent to the paleobay, multispecies broadleaved forests with a predominance of oak have spread, in which the participation of thermophilic hornbeam and various species of birch has increased. Coniferous-deciduous forests, which had significantly weakened their positions in vegetation, were preserved only in fragments, in the watershed of the Black Mountains.

CONCLUSIONS

A comprehensive study of Holocene marine sediments in the Talmi well section made it possible to examine in detail the paleogeography of the coast of the southwestern margin of Primorye in the second half of the Atlantic period of the Holocene, about 6500–6000 BP/7400–6800 cal BP. On the accumulative plain of the coast at that time, there was a shallow marine bay that arose as a result of postglacial transgression of the ocean. Sedimentation in it was completely governed by the Tumannaya (Tumangan) River, the largest in the Sea of Japan Basin. The mouth area of the river, from which huge masses of suspended detrital material were carried out, created an environment of avalanche sedimentation with an average rate of 16–24 mm/year, causing the shallowness of the paleobay. Over the entire 500-year history of its existence, up to 8–12 m of clay sediments accumulated at its bottom. There are three stages in the evolution of the marine sedimentation environment. The earliest of these, beginning around 6500 BP/7400 cal BP, when the waters of the Sea of Japan, having flooded the Upper Pleistocene accumulative plain, formed a semiclosed bay into which waves from the open sea did not penetrate. Low wave activity is confirmed by the accumulation of a thick (up to 5 m) layer of fine detrital clays. The composition of diatoms indicates shallow depths and periodic desalination of the paleo-reservoir caused by floods in the Tumannaya River basin. The development of warm-water mollusks in them testifies to the good warming of waters in the summer, which exceeds the modern level. The middle stage, which began perhaps 150–200 years after the onset of the marine environment, was characterized by open bay conditions with increased wave activity, as evidenced by the formation of a layer of fine silty clays. Up to half of the finest, clayey component of suspended sediment began to go into the open sea, which led to a decrease in the rate of sedimentation and, probably, an increase in the depth of the reservoir. Judging by the lack of changes in the mollusk fauna (the same presence of warm-water species), it was small and did not lead to a significant decrease in the summer warming of waters. The composition of diatoms supports the trend of increasing openness of the paleowaterbody and greater depth and salinity of its waters: the participation of planktonic neritic species increased almost 1.5 times, while sublittoral benthic species greatly decreased. At the end of the stage, around 6200 BP/7100 cal BP, when the sea level approached the modern position, on the windward shores of the paleobay from the south, as a result of a powerful storm, high coastal bars formed, composed of boulder–pebble deposits with abundant inclusions of *Anadara* shells. The nature of the vegetation, which did not change during both sedimentation stages, indicates the development of relative climate cooling, with parameters close to modern conditions (it also evidences the short duration of the event). Multispecies broadleaved forests with a greater role of oaks than in current tree stands became widespread. Park oak forests with a well-developed herbaceous cover characteristic of modern landscapes were absent on land adjacent to the seacoast. The late stage of marine sedimentation, after 6200 BP/7100 cal BP, took place when the transgression of the sea slowed, the level of which reached the maximum height, 1 m, for the entire Middle Holocene on this section of the coast. A significant increase in the depths of the paleowaterbody, which did not exceed a few meters at the beginning of this stage, did not occur, i.e., compensated by an increased sedimentation rate. Changes in the composition of diatoms, expressed in a sharp decrease in the proportion of neritic species and an increase in the participation of subtidal benthic taxa, indicate shallowing of the paleo-reservoir; the presence of a tropical epiphyte in their composition - for good warming of the waters. The increased importance of mesohalobe diatoms indicates increased desalination of the reservoir caused by the influence of river waters. Approaching the mouth zone of the river. Tumannaya to the eastern shores of the paleobay, a rapid increase in the proportion of fine sand in the sediments of the section was also recorded. The distribution of multispecies broadleaved forests with a predominance of oak and an increased participation of thermophilic hornbeam in the territory adjacent to the coast clearly indicates optimal climatic conditions. The completion of marine sedimentation occurred around 6000 BP/6800 cal BP. After this, up to the middle of the Sub-Atlantic period, it did not resume here.

ACKNOWLEDGMENTS

The authors thank Ya.V. Kuzmin (Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Sciences) and S.A. Gorbarenko (Pacific Oceanological Institute, Far East Branch, Russian Academy of Sciences) for assistance in radiocarbon dating of samples using accelerator mass spectrometry at US laboratories, as well as T.S. Ivashinnikova, Coastal Research Center, Far East Federal University, for granulometric analysis.

FUNDING

The study was carried out within the state assignment of the Far East Geological Institute, Far East Branch, Russian Academy of Sciences (topic no. 122048000201-8).

CONFLICT OF INTEREST

@@@@@@@

ADDITIONAL INFORMATION

The article is from a collection on the 65th anniversary of the founding of the Far Eastern Geological Institute, Far Eastern Branch, Russian Academy of Sciences.

REFERENCES

1. M. N. Alekseev, *Anthropogen of East Asia* (Nauka, Moscow, 1978).
2. M. N. Alekseev and L. V. Golubeva, “Upper Pleistocene Stratigraphy and paleogeography of southern Primorye,” Byull. Komissii Izuch. Chetvertichn. Perioda **50**, 96–107 (1980).
3. Kh. A. Arslanov, V. A. Dergachev, F. E. Maksimov, and I. V. Kudryavtseva, “Chronology of Holocene short-period climatic variations in northwestern Russia and correlation with solar activity variations,” Uch. Zap. Kazan. un-ta. Ser. estestv. nauki **164** (1), 135–165 (2022).
4. S. S. Barinova, L. A. Medvedeva, and O. V. Anisimova, *Biodiversity of Environmental Indicator Algae* (Pilies Studio, Tel’-Aviv, 2006).
5. B. I. Yu, M. T. Gorovaya, and V. K. Annin, “Quaternary sediments and paleogeography of the Posyet Bay (Sea of Japan),” in *Paleogeographic Analysis and Stratigraphy of the Far East Anthropogen* (DVNTs AN SSSR, Vladivostok, 1983), pp. 144–169.
6. O. K. Borisova, “Landscape and climatic changes in the Holocene,” Izv. RAN. Ser. geogr, No. 2, 5–20 (2014).
7. N. B. Verkhovskaya and A. S. Kundyshev, “Vegetation of the Peter the Great Bay coast in the optimum phase of the Holocene,” in *Comprehensive Study of Holocene Sediment Sections of the Peter the Great Bay Coast* (Bagira-Press, Moscow, 1995), pp. 8–17.
8. I. G. Gvozdeva, S. A. Gorbarenko, V. A. Rakov, K. A. Lutaenko, E. I. Shornikov, and Yu. A. Mikishin, *Paleoenvironment of Primorye in the Middle and Late Holocene according to Complex Data from the Shkotovo Section* (TOI DVO RAN, Vladivostok, 1997).
9. *Diatom Algae of the USSR (Fossil and Modern). Vol. 1. Practical Guide* (Nauka, Leningrad, 1974).
10. G. A. Dzhons and K. Ya. V, “Radiocarbon dating of shells of "warm-water” mollusks from the coast of Peter the Great Bay by gas pedal mass spectrometry,” in *Complex Study of Holocene Sediments of the Peter the*

Great Bay Coast (Sea of Japan), Ed. by M. (Bagira-Press, 1995), pp. 34–38.

11. L. P. Karaulova, A. M. Korotkii, and E. I. Tsar'ko, "Marine Holocene of Primorye," in *Holocene Palynology and Marinopalinology* (Nauka, Moscow, 1973), pp. 137–141.
12. A. M. Korotkii, L. P. Karaulova, and T. S. Troitskaya, *Quaternary Sediments of Primorye: Stratigraphy and Paleogeography* (Nauka, Novosibirsk, 1980).
13. A. M. Korotkii, "Sea level fluctuations in the Sea of Japan and coastal landscapes (developmental stages and trends)," Vestn. DVO RAN, No. **3**, 29–42 (1994).
14. K. Ya, "Paleogeography of the coast of Peter the Great Bay during the Holocene optimum (5000-8000," in *Integrated Study of Holocene Sediment Sections of the Coast of the Peter the Great Bay (Sea of Japan)* (Bagira-Press, Moscow, 1995), pp. 44–70.
15. A. P. Lisitsyn, *Avalanche Sedimentation and Breaks in Sedimentation in the Seas and Oceans* (Nauka, Moscow, 1988).
16. K. A. Lutaenko, "Mollusks from Holocene deposits of Khasansky Raion (Southern Primorye)," Stratigrafiya. Geol. Korrelyatsiya **1** (6), 89–91 (1993).
17. Yu. D. Markov, *Southern Primorye shielf of the Japan Sea in the Late Pleistocene and Holocene* (Vladivostok, 1983).
18. Yu. A. Mikishin, I. G. Gvozdeva, and T. I. Petrenko, "Spore-pollen spectra of modern sediments of the coast of southwestern Primorsky Krai," in *Methodical Aspects of Palynology: Proceedings of the X All-Russian Palynological Conf.* (IGiRGI, Moscow, 2002), pp. 154–156.
19. Yu. A. Mikishin, Ya. V. Kuz'min, and S. A. Gorbarenko, "New data on the evolution of the relief of the accumulative plain of southwestern Primorye in the Holocene," in *Abstracts of the International Workshop on the Study of Global Changes in the Far East* (Dal'nauka, Vladivostok, 2002), pp. 69–73.
20. Yu. A. Mikishin, A. N. Popov, T. I. Petrenko, V. A. Rakov, and E. I. Tsar'ko, "Biostratigraphy of Holocene sediments of the Boisman-2 monument," in *Archaeology and Cultural Anthropology of the Far East* (DVO RAN, Vladivostok, 2002), pp. 41–56.
21. Yu. A. Mikishin, T. I. Petrenko, I. G. Gvozdeva, A. N. Popov, Ya. V. Kuzmin, S. A. Gorbarenko, and V. A. Rakov, "Holocene of the southwestern Primorye coast," Nauchn. obozrenie, No. 1, 8–27 (2008).
22. M. Yu. A and I. G. Gvozdeva, "Paleoenvironment of Russkii Island (southern Primorye) in the middle–late Holocene," Fundament. Issled., No. 3, 516–522 (2014).
23. Yu. A. Mikishin, T. I. Petrenko, and I. G. Gvozdeva, "Late phase of the Atlantic period in the southern Primorsye," Usp. Sovrem. Estestoznan., No. 12, 96–107 (2019).
24. B. I. Pavlyutkin and N. I. Belyanina, "Quaternary sediments of Primorye: some results of systematization and future prospects of study, " Tikhookean. Geol. **21** (3), 80–93 (2002).
25. Paleopalinologiya, *Methodology of paleopalynological studies and morphology of some fossil spores, pollen and other plant microfossils* (Nedra, Leningrad, 1966), **Vol. 141**.
26. V. P. Petelin, *Grain-size Analysis of Marine Sediments* (Nauka, Moscow, 1967).
27. V. S. Petrenko, "The main Holocene–Mellocene processes of coastline development of the Rias coast of Primorye," in *Climomorphogenesis and Regional Geographic Forecasting* (DVNTs AN SSSR, Vladivostok, 1980), pp. 119–125.
28. I. A. Prushkovskaya, *Extended Abstract of Candidate's Dissertaiton in Geology and Mineralogy* (Tikhookean. Okeanol. Inst. im. Il'icheva DVO RAN, Vladivostok, 2022).
29. M. Korotkii, S. P. Pletnev, V. S. Pushkar, T. A. Grebennikova, E. D. Sakhebgareeva, and L. M. Mokhova, *Development of the Natural Environment of the Southern Far East (Late Pleistocene–Holocene)* (Nauka, 1988).
30. V. A. Rakov, "Malacofauna of Neolithic "shell heaps" of the coast of the Peter the Great Bay," in *Integrated Study of Holocene Sediment Sections of the Peter the Great Bay Coastline* (Bagira-Press, Moscow, 1995), pp. 38–44.
31. T. S. Troitskaya, L. P. Karaulova, and E. I. Tsar'ko, "The first experience of detailed dissection of the marine Holocene of the southern Primorye Krai based on the complex paleontological data," in *Bulletin of the Commission for the Study of the Quaternary Period* (Nauka, 1978), **Vol. 48**, pp. 66–78.
32. N. A. Khotinskii, "Radiocarbon chronology and correlation of natural and anthropogenic Holocene boundaries," in *New Data on the Geochronology of the Quaternary Period. On the XII Congress of INQUA, Canada* (Nauka, Moscow, 1987), pp. 39–45.
33. M. V. Cherepanova, E. V. Lepskaya, P. Anderson, and A. V. Lozhkin, "Diatom algae from Holocene sediments of Lake Nerpichie (Kamchatka)," in *Studies of Aquatic Biological Resources of Kamchatka and the Northwest Pacific Ocean* (2013), Vol. 31, pp. 89–106.
34. P. Alhonen, A. Heino, and R. Tynni, "Über Vorkommen und Bedeutung von Terpsinoe americana (Bail.) Ralfs in den Ablagerungen des Litorinameeres," Bull. Geol. Soc. Finland **56** (1-2), 117–133 (1984). https://doi.org/10.17741/bgsf/56.1-2.008
35. L. M. Bertolli, D. M. Talgatti, T. M. D. S. Nascimento, and L. C. Torgan, "The genus Tryblionella W. Smith (Bacillariaceae, Bacillariophyta) in southern Brazil salt marshes," Biota Neotropica **20** (1), 1–18 (2020). https://doi.org/10.1590/1676-0611-bn-2019-0774
36. K. A. Hughen, M. G. L. Baillie, E. Bard, A. Bayliss, J. W. Beck, C. Bertrand, P. G. Blackwell, C. E. Buck, G. Burr, K. B. Cutler, P. E. Damon, R. L. Edwards, R. G. Fairbanks, M. Friedrich, T. P. Guilderson, B. Kromer, F. G. Mccormac, S. Manning, C. Bronk Ramsey, P. J. Reimer, R. W. Reimer, S. Remmele, J. R. Southon, M. Stuiver, S. Talamo, F. W. Taylor, J. Van Der Plicht, and C. E. Weyhenmeyer, "Marine04 Marine Radiocarbon Age Calibration, 0–26 Cal Kyr BP," Radiocarbon **46**, 1059–1086 (2004).
37. K. Krammer and H. Lange-Bertalot, *Bacillariophyceae, Sübwasserflora von Mitteleuropa. 1. Teil: Naviculaceae* (VEB Gustav Fischer Verlag, Jena, 1986), **Vol. 2**.

38. K. Krammer and H. Lange-Bertalot, *Bacillariophyceae, Sübwasserflora von Mitteleuropa. Teil: Bacillariaceae, Epithemiaceae, Surrillaceae* (VEB Gustav Fischer Verlag, Stuttgart—New York, 1988), **Vol. 2**.

39. K. Krammer and H. a. Lange-Bertalot, *Bacillariophyceae, Sübwasserflora von Mitteleuropa. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae* (VEB Gustav Fischer Verlag, Stuttgart—Jena, 1991), **Vol. 2**.

40. K. Krammer, *The Genus Pinnularia, Diatoms of Europe. Diatoms of the European Inland Waters and Comparable Habitats* (A.R.G. Gantner Verlag K.G., Ruggell, 2000), Vol. 1.

41. K. Krammer, *Cymbella. Diatoms of Europe. Diatoms of the European Inland Waters and Comparable Habitats* (A.R.G. Ganter Verlag K.G. V, Ruggell, 2002), Vol. 3.

42. K. Krammer, Cymbopleura, and N. Delicata, *Gomphocymbellopsis, Afrocymbella, Diatoms of Europe. Diatoms of the European Inland Waters and Comparable Habitats* (A.R.G. Gantner Verlag K.G. V, Ruggell, 2003), Vol. 4.

43. R. O. Mclean, J. Corrigan, and J. Webster, "Heterotrophic nutrition in*Melosira nummuloides*, a possible role in affecting distribution in the Clyde Estuary," Br. Phycological J. **16** (1), 95–106 (1981). https://doi.org/10.1080/00071618100650081

44. M. A. Yu, T. I. Petrenko, I. G. Gvozdeva, and A. N. Popov, "Evolution of landscapes in Khasansky district (southwest Primorye) in Late Pleistocene-Holocene," in *Proceedings of International Symposium "Human Ecosystem Changes in the Northern Circum Japan Sea Area (NCJSA) in Late Pleistocene"* (Tokyo, 2008), pp. 82–94.

45. N. Razjigaeva, L. Ganzey, T. Grebennikova, L. Mokhova, T. Kopoteva, E. Kudryavtseva, P. Belyanin, A. Panichev, Kh. Arslanov, F. Maksimov, A. Petrov, V. Sudin, M. Klimin, and T. Kornyushenko, "Holocene mountain landscape development and monsoon variation in the southernmost Russian Far East," Boreas **50** (4), 1043–1058 (2021). https://doi.org/10.1111/bor.12545

46. B. Weninger, O. Jöris, and U. Danzeglocke, *Cologne radiocarbon calibration paleoclimate research package. CALPAL_A (Advanced) in the Ghost of Edinburgh Edition* (Universitat zu Köln, Institut fur Urund Fruhgeschichte, 2002), **Vol. 125**.

47. A. Witkowski, H. Lange-Bertalot, and D. Metzeltin, "Diatom flora of marine coasts I," in *Iconographia Diatomologica Annotated Diatom Monographs*, Ed. by H. Lange-Bertalot (ARG Gartner, Ruggell, 2000), pp. 1–925.

48. Yo. Zong, "Mid-Holocene sea-level highstand along the Southeast Coast of China," Quat. Int. **117** (1), 55–67 (2004). https://doi.org/10.1016/s1040-6182(03)00116-2

SPELL: OK