

# Submerged Shorelines on Continental Shelves of the Sea of Japan and Sea of Okhotsk, USSR<sup>1</sup>

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## ABSTRACT

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This paper describes old shorelines formed on the shelves of the Sea of Japan and Sea of Okhotsk during the latest postglacial transgression. A complex of features detected during geological surveying on the shelf areas are employed in the identification and mapping of old shorelines. The irregular but progressive development of the latest postglacial transgression contains several well-defined stages and phases that are recorded by shoreline features that include distinctive relief forms and complexes of littoral, marine, and lagoonal sediments. Comparison of submerged shorelines lying on the continental shelf in this region suggests that their common formation is related to an irregular (pulsating) rise of global sea level at the end of the late Pleistocene and continuing into the Holocene. Differences in hypsometric positions of similarly aged shorelines in different regions and the formation of additional shorelines at intermediate levels in certain areas are assumed to be associated with neotectonic movements.

**ADDITIONAL INDEX WORDS:** *Abrasion bench, abrasion platform, lagoonal sediments, marine bench, Peter the Great Bay, postglacial transgression, Sea of Japan, Sea of Okhotsk, submerged shoreline.*



## INTRODUCTION

Characteristic features allowing identification and mapping of submarine shorelines were determined from a geological survey of the continental shelf in the Sea of Japan. A method of integrated analysis, based on geological and geophysical data obtained during marine geological surveying, provided criteria for the identification and mapping. The features recognized include: (1) marine abrasion benches and adjoining abrasion platforms, (2) characteristic off-shore aggradation forms (beach barriers, bars, and spits), and (3) lagoonal depositional fields. Occasional strips of coarse-grained sediments (pebble or gravel beds) or sands occur along old shorelines, which themselves are notable for their higher grading coefficient compared to surrounding sediments. As a result of this study, a

number of old shorelines, including those of the latest transgression, were discovered.

Identification and mapping of submerged coastal formations on the shelf is of practical importance. Almost all known marine placers are, for example, associated with wave-cut deposits that contain pebble and gravel beds suitable for concrete aggregates in construction. Lagoon silts on the other hand often possess palynological properties useful for dating purposes.

## NORTHWESTERN SECTOR OF THE SEA OF JAPAN

Surveys of the northwestern shelf of the Sea of Japan were conducted using a broad complex of geological and geophysical research techniques that involved, for example, continuous seismic-acoustic profiling, echo-sounding, floating platform and ship-side drilling. As part of the general program for mapping of Quaternary deposits on the shelf, detailed stratigraphic studies were also conducted. As part of this latter effort, sediments were identified within stratigraphic subdivisions.

<sup>1</sup>[Editorial Note: We are pleased to publish the English version of papers presented at the 1982 INQUA Symposium (Shorelines Commission) held in Moscow. Russian versions were previously published in collection by "Nauka" and Moscow State University publishers but this is the third installment in a series of reports that will appear in subsequent issues of the journal.] Received 15 January 1984.

In order to determine the genetic features of the Quaternary sediments being mapped, microfaunal and diatom analyses had to be used in addition to data from visual field studies. Sedimentary age was determined from palynological data and by radiocarbon dating of plant remains. Analysis of these materials permitted us to not merely identify older coastal zones now submerged on the shelf but also to infer some general developmental features of the latest postglacial transgression, beginning with the lowest level prior to initiation of the transgressive phase.

The overall transgressive phase was repeatedly interrupted by short-term still stands or occasional low-amplitude regressions. Characteristic coastal relief forms such as beach barriers and abrasion platforms did, however, have enough time to form as did the development of sedimentary features typical of coastal zones *e.g.* beaches, lagoons, estuaries. Their position on the continental shelf was determined from generalized geological sections compiled for the central part of Peter the Great Bay (Figure 1). On these sections the numbered arrows indicate the positions of old shorelines formed during the latest postglacial transgression, that is, from the oldest (1) to the youngest (8).

The lowermost shoreline (1)<sup>1</sup>, which formed prior to the beginning of the latest postglacial transgression, occurs at a variable depth between the -100 to -110 m isobaths. It is identified against a strip of surf zone pebble beds and sands containing fragments of thick-walled mollusc shells (Q<sub>III</sub><sup>a</sup>). These deposits comprise offshore bars that are clearly identifiable on precision echo sounding records. The back zone often receives adjoining aleurolites comprising vegetal remains and intact thin-walled shells of brackish-water molluscs. This association suggests the development of a chain of coastal lagoons isolated from the sea by offshore bars and spits. Offshore marine and lagoonal deposits of this shoreline adjoin an abrasion bench cut into deposits of the 1st and 2nd late Pleistocene transgressions.<sup>2</sup> This bench can be clearly identified from echo sounding and seismo-acoustic profiling data. On the basis of spore-pollen analysis it is considered that the offshore marine and lagoonal deposits of this shoreline were formed at the end of the Pleistocene.

<sup>1</sup> Bracketed figures indicate shoreline positions on summary geological sections.

<sup>2</sup> 1st and 2nd late Pleistocene transgressions in the Sea of Japan are correlated, respectively, with the Kazansk and Karginsk transgressions of Western Siberia or with Alaska's Peluk and Vorontsov transgressions.

Radiocarbon (C<sup>14</sup>) age determinations of a peat sample taken from lagoonal deposits at 0.75 m depth beneath the seabed surface in the eastern part of the Gulf of Peter the Great at the 101 m isobath gave the result 14,199±120 years (VNIIMORGEО, Riga, 1976). The shoreline appears to record a turning point in late Pleistocene and Holocene times.

The initial (late Pleistocene) stage of the last postglacial transgression is characterized by a rapid rise of sea level and its advance onto the land. From the onset of transgression (17,000 years ago) to the end of the late Pleistocene (10,200 years ago), sea level rose 40 to 50 m (from about -100 or -110 m to -60.). At -60 m elevation, sea level temporarily stabilized and a shoreline (3) formed with an abrasion bench (see Figure 1). This marine bench was cut in deposits of the 2nd late Pleistocene transgression. A complex of wave-cut and lagoonal sediments adjoin this bench (Q<sub>III</sub><sup>c</sup>). Brief delays in the transgression appear to have occurred also at lower sea level stands (*i.e.* at -90 to 95 m, -85 to -90 m, and -75 to -80 m). Therefore, old shorelines are mapped from relict off-shore aggradational forms, *e.g.* bars and conjugate deposits of old lagoons. Of these intermediate shorelines, dating to the late Pleistocene stage of the latest postglacial transgression, the one most consistent in strike and clearly identifiable is the shoreline (2) bounded by the 75 to 80 m isobaths (Figure 1). Associated with this shoreline is a specific strip of wave-cut and lagoonal sediments (Q<sub>III</sub><sup>b</sup>). The age of the peat sampled from the lagoonal deposits lying 1.2 m beneath the seabed near the 67 m isobath and dated with 14<sup>14</sup> was 13,900±130 years (VNIIMORGEО, Riga, 1976).

Three stages are prominent in the Holocene phase of this transgression: early Holocene (from 10,200 to 8,000 years ago), middle Holocene (from 8,000 to 2,500 years ago), and late Holocene (from 2,500 years ago until the present). The early Holocene stage is notable for two still-stands in the progressive transgression (at the 50 to 55 m and 33 to 35 m isobaths). The still-stands are recorded in the form of abrasion benches in older deposits and coarse-grained wave-cut deposits adjoining the benches. Palynologic evidence from the wave-cut deposits are dated as pre-Boreal and Boreal. Thus, the early Holocene stage of the latest postglacial transgression is manifested on the continental shelf of the Sea of Japan (north-western sector) by two shorelines (4 and 5). These shorelines, with their associated abrasion benches and offshore-marine deposits of early Holocene, are capped by middle

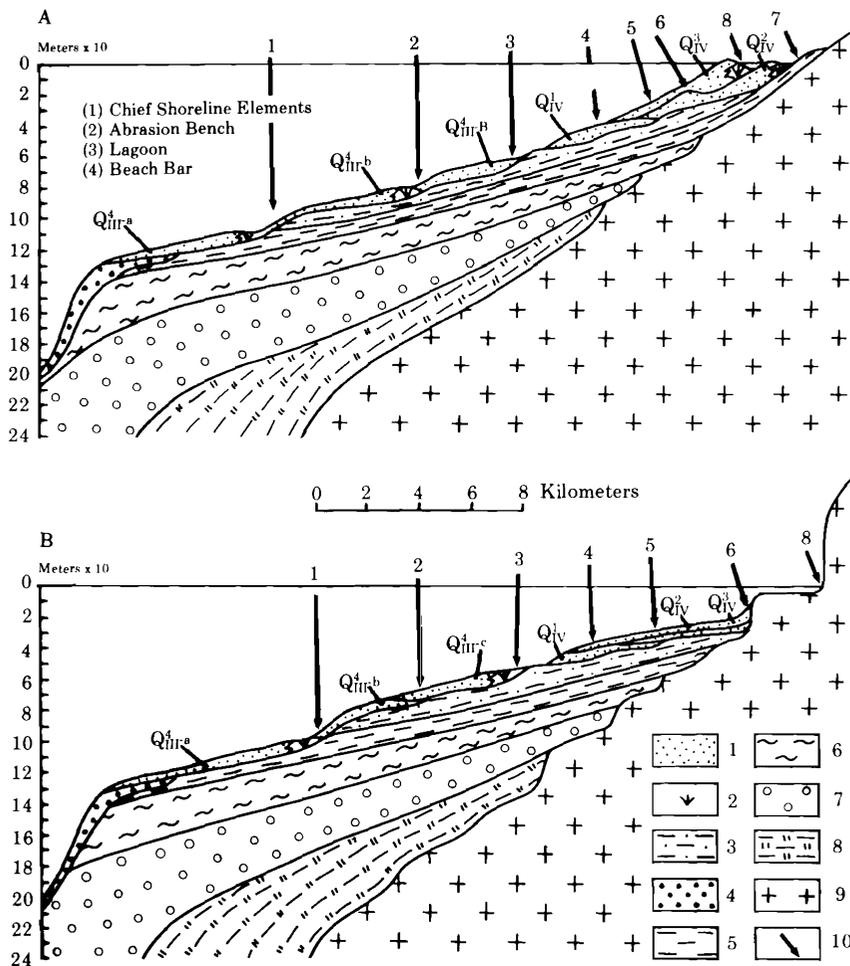


Figure 1. Generalized geological cross sections for the central part of Peter the Great Bay (A. Aggradation coastal area; B. Abrasion coastal area). Deposits of the latest postglacial transgression ( $Q_{III}^4 - Q_{IV}^4$ ) where: (1) wave cut and (2) lagoonal. (3-5) Late Pleistocene transgression deposits ( $Q_{III}^3$ ), (4) Deposits dating to the epoch of the lowest sea level stand prior to the beginning of the 2nd late Pleistocene ( $Q_{III}^2$ ), and (5) first late Pleistocene transgression deposits ( $Q_{III}^1$ ). (6) Early to middle Pleistocene marine deposits ( $N_2$ ); (8) Miocene marine deposits ( $N_1$ ); (9) shelf basement and (10) shorelines and their numbers.

Holocene and late Holocene sediments (Figure 1). The middle Holocene stage comprises two shorelines. One is identifiable between the 18 and 22 m isobaths. Located on an aggradation coast (Figure 1A), this shoreline (6) follows the base of a marine abrasion platform that breaks off into the sea as part of the present bench.

The other shoreline (7) records the transgressive maximum and is represented along aggradational coastal stretches by a low marine terrace comprising wave-cut and lagoonal deposits of Atlantic and Subboreal age (based on dates from spore-pollen

analysis). The low marine terrace rises above present sea level by 4 to 5 m along coastal stretches. In protected closed bays the terrace stands 2 to 3 m above sea level. The top of middle Holocene lagoonal deposits that contribute to the structure of the low marine terrace is 1.5 to 2 m above present sea level. We conclude that the maximum elevation of the latest postglacial transgression in this region coincided with the middle Holocene and that sea level at that time was 2 to 2.5 m above recent MSL.

Within the Recent coastal zone (8) both abrasion and aggradation relief forms are widespread. Analysis

of spore-pollen data show that aggradation forms are Sub-Atlantic in age.

### THE SOUTHWESTERN SAKHALIN ISLAND SHELF

The loose sedimentary cover on the Sakhalin shelf is complexly structured due to shoreline migrations that resulted from Quaternary transgressions and regressions.

A characteristic feature of the southwestern Sakhalin shelf is the presence of benches completely devoid of drifts. Their width (determined by aerial photography, lateral survey ranging, and seismo-acoustic profiling) varies from 300 to 2000 m. In many areas the benches occur 5 to 6 m seaward from the coastline, *e.g.* beyond the loose sedimentary strip. These benches can be recorded using seismo-acoustic profiling and echo-sounding methods. Practically all profiles computed for the southwestern Sakhalin shelf in the 10 to 30 m depth range have recorded bedrock protrusions completely devoid of drifts and bearing traces of marine abrasion. Frequently they extend shoreward to the present shoreline or are buried along the shore by a thin layer of Recent sediments. Drill cores (obtained by ship-side drilling) also contain identifiable abrasion forms, *i.e.* bedrock protrusions at 10 to 25 m depths. Some profiles show that the bench surfaces

are buried beneath thin (less than 1 m thick) loose sediments. Drilling seaward from these protrusions showed, in the majority of cases, typical offshore sediments composed of well-sorted sand and gravel beds. This indicates the presence, at 20 to 30 m depths, of a shoreline (5) coincident with the distal boundary of the benches (Figure 2). In all probability, this boundary corresponds to the early middle Holocene stage of the latest postglacial transgression. The maximum transgressive phase is marked by a low marine terrace (+3 to +4 m), shoreline (6), formed during the close of the middle Holocene. The depositional surface of this terrace lies 2 to 3 m above the surface of beach deposits on the Recent shoreline (7).

Geophysical methods and drilling on the southwestern Sakhalin shelf recorded an additional old shoreline (at 50 to 60 m depths) that is presumably of early Holocene age (4). Abraded bedrock protrusions that terminate seawards are also clearly recorded. This shoreline is comprised of a conjugate complex of lagoonal and beach sediments, represented by aleurolites and pelites with vegetal remains and peat interlayers, to beach sediments (graded sands, gravels, and small pebble beds). When viewed from above, the southwestern Sakhalin shelf shows the early Holocene as a strip of coarse sediments running parallel to the shore. In addition, echo sounding at 50 to 60 m depth occasionally

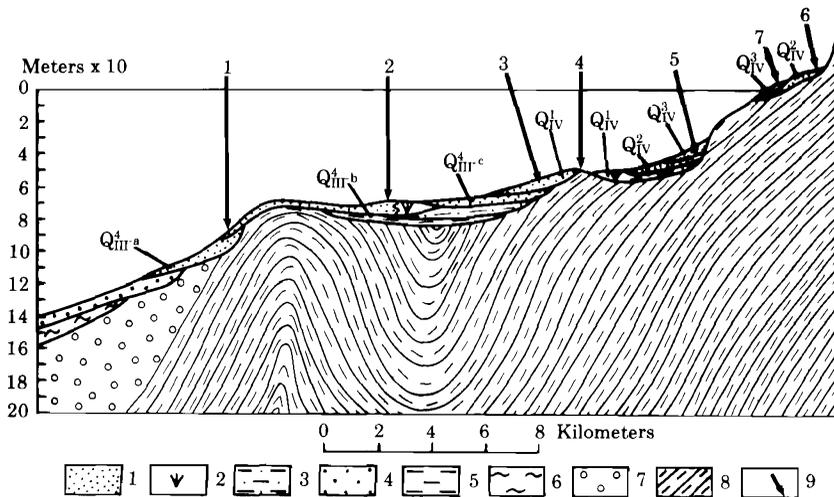


Figure 2. Generalized geological cross section for the southwestern shelf area of Sakhalin Island. (1-2) Deposits of the latest postglacial transgression where: (1) wave cut and (2) lagoon (3-5) Late Pleistocene marine deposits where: (3) 2nd late Pleistocene transgression deposits; (4) deposits dating to the lowest sea level stand prior to the 2nd late Pleistocene transgression; and (5) 1st late Pleistocene transgression deposits. (6) Early-middle Pleistocene marine deposits; (7) late Pliocene to early Pleistocene marine deposits; (8) Pliocene to early Pliocene marine deposits; and (9) shorelines and their numbers.

records aggradational forms, *i.e.* offshore barriers that run parallel to the coast.

Old shorelines formed during the initial (late Pleistocene) stage of the latest postglacial transgression were recorded at great depths (–80 to –100 m). Particularly clear was a buried shoreline at 85 to 95 m depth (1). It is characterized by a coastal strip of offshore sediments ( $Q_{II}^{4-a}$ ) and an abundance of abrasion outliers running along the shore, their surfaces bearing traces of abrasion.

Seismo-acoustic profiling highlighted relics of late Pleistocene river valleys that lie between the 50 to 80 m isobaths. At 85 to 95 m depth, these valleys open up onto the old coastal slope. No valleys as yet have been detected between the 30 and 50 m isobaths. They were presumably completely destroyed by abrasion processes. Above the 30 m isobath, river valleys reappear (based on seismo-acoustic profiling) and can be traced as far as the mouths of present river valleys. Within the 20 to 30 m isobaths these valleys open onto a coastal slope and rest on the middle Holocene shoreline (5).

Two other older shorelines were identified between the 60 and 80 m isobaths. Each shoreline was marked by its own complex of lagoonal and wave-cut sediments:  $Q_{III}^{4-b}$  between the 70 to 75 m isobaths (2) and  $Q_{III}^{4-c}$  between the 55 to 60 m isobaths (3). Both shorelines (2 and 3) are related to the

Pleistocene stage in the latest postglacial transgression (*c.f.* Figure 2).

## THE SOUTHWESTERN SEA OF OKHOTSK

The western Priokhotic shelf, which occupies a vast area of shallow water in the Shantar Sea, Sakhalin Bay, and Udskaya Guba, is about 100 km in width. Generally, the shelf in the western part of the Sea of Okhotsk represents a gently-sloping plain with low gradients that range from 0.001 to 0.005. The plain terminates at 180 to 200 m depth in a fairly steep bench that merges into the old submerged shelf.

In the part of the Sea of Okhotsk under discussion there are aggradation-abrasion and abrasion-aggradation types but the latter is predominant. The upper part of the shelf, which extends as far shoreward as the 30 to 40 m isobaths, appears to be an abrasion plain overlain by a thin veneer of marine sediments. The lower part of the shelf represents the zone of intensive sediment accumulation.

Morphologically the present shelf surface appears as a submarine plain comprising, at different hypsometric levels, a series of smooth steps that make up the seabed relief. Evidence derived from geological and geophysical studies suggest that these

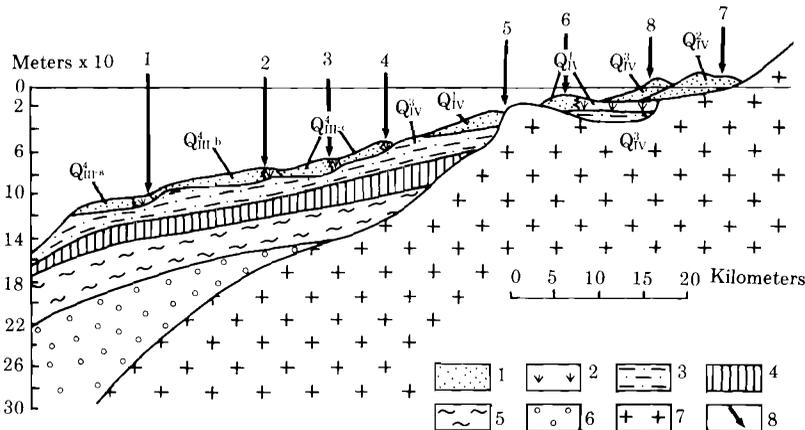


Figure 3. Generalized geological cross section for the southwestern shelf of the Sea of Okhotsk. (1-2) Deposits of the latest postglacial transgression where: (1) wave cut and (2) lagoonal. (3-4) Late Pleistocene deposits where: (3) 2nd late Pleistocene transgression deposits ( $Q_{III}^{4-c}$ ) and (4) a transgressive-regressive complex of marine deposits dating to the first half of the late Pleistocene ( $Q_{III}^{4-b}$ ). (5) Middle Pleistocene deposits ( $Q_{II}$ ); (6) Pliocene to early Pleistocene deposits ( $N_2 Q_1$ ); (7) shelf basement; and (8) shorelines and their numbers.

smooth steps are old shorelines that record temporary sea level stands during the latest postglacial transgression. A generalized geological section of the western shelf of the Sea of Okhotsk is shown in Figure 3. Between the offshore shoal and the shore there are eight pronounced benches that are covered by adjoining late Pleistocene and Holocene deposits of the coastal and lagoonal facies of the latest postglacial transgression. Absolute elevations of the benches are -110 m; -78 to -80 m; -68 to -70 m; -59 to -61 m; -21 to -24 m; -15 to -17 m; +5 to +7 m, and 0 m.

Analysis of seismo-acoustic profiling, drill cores, and bottom sampling data suggest that the lower (bathymetrically) lying bench (-110 m) corresponds to a shoreline, marking the lowest sea stand, which formed during the initial transgression (1). Seismic records and echo-sounding profiles show a steep bench cut in Karginisk age deposits ( $Q_{III}^3$  with 0.03 to 0.05 gradient) which received the adjoining laminated offshore-marine deposits dating to the late Pleistocene ( $Q_{III}^3$ -a). This shoreline can be confidently traced at -110 to -112 elevations, isometrically curving around sharp outlines of the present western Okhotsk coast. At certain places trunk valleys of the old drainage network join it providing indirect evidence of a long delay in the general transgression at this elevation.

Higher in the profile there are partly overlapping deposits which correlate in age with the beginning of the postglacial transgression ( $Q_{III}^4$ -a). Sediments of the next stage ( $Q_{III}^4$ -a) mark a slow-down in the transgression at -78 to -80 m elevations. Morphologically, this shoreline is represented by a small bench cut in deposits of the underlying Karginisk horizon. This horizon is frequently overlapped by the aforementioned sediments ( $Q_{III}^4$ -b) forming an aggradational strip composed of offshore barriers and beach bars. Also associated with this old shoreline are the mouths of ancient trunk valleys that originated in the headward reaches of Udskeya Guba and Akademiya Bay. Viewed in plan, this shore is a concentric replica of coastal outlines formed during the previous stage. This younger shoreline adds 10 to 15 km to the radial curvature. In contrast to the previous (older) shoreline, both the bench and coastal forms are less prominent. This diminution of form seems to suggest a relatively brief hiatus in transgression.

Bathymetrically higher on the shelf at -59 to -61 m is a pronounced bench (4) with a gradient of 0.03 to 0.08. It reflects the adjoining major positive forms that make up old aggradation shores. This

bench is particularly prominent on seismo-acoustic profiling records. Associated with this bench in Sakhalin Bay, Akademiya Bay, and Udskeya Guba are trunk river valleys, as well as some other tributary paleovalleys. At the mouths of these valleys along the shoreline there is a chain of barriers, spits, and bars composed of sediments of the late Pleistocene terminal stage ( $Q_{III}^4$ -c). The aggradation forms are of large dimensions ranging from 30 to 50 km in length, from 1 to 3 km in width, and up to 10 m in relative height. These aggradational bodies are composed of coarse-grained sediments of offshore facies. On the backside, the boundaries between individual layers disappear indicating a changeover into lagoonal facies. This shoreline is marked by persistent elevations that trend westerly and north-westerly with a partial decline to -65 m. North and northeast of Sakhalin Island this submerged shoreline lies slightly below this stage at -68 to -70 m (3). Some minor aggradation forms presumably characterized a temporary stabilization of sea level at these elevations prior to the end of the latest transgression ( $Q_{III}^4$ -c). Higher up, across the shelf is a smooth, gently-sloping plain covered with deposits that are overlapped by Recent sediments. Spore-pollen complexes peculiar to thermophilic plants of the Karginisk interstadial epoch were used to date the plain. Seismo-acoustic profile data and drilling results indicate that the Holocene sedimentary thickness starts to increase at 45 m depth towards the Recent shore, presumably recording the beginning of the Holocene transgression. Early Holocene offshore marine deposits are relatively thin and form a continuous coastal strip. At 20 to 25 m depths they join a steep abrasion bench forming a shoreline at -21 to -24 m (5). In the western part of the region where the offshore shelf zone lacks a sedimentary cover, the offshore zone developed an abrasion plain. There are thin gravel-pebble deposits of an old beach at the foot of the abrasion bench. At the head of Sakhalin Bay there is an old offshore barrier, its deposits containing early Holocene spore-pollen complexes. The shoreline has a tortuous configuration that incorporates mouths of submerged rivers in Tugursk, Ul'bansk, and Sakhalin Bays.

Study of drill cores indicates relics of cyclically structured coastal bars (6) at -17 to -18 m that rest on bedrock or on underlying loose sediments. Radiometric analysis of a wood sample taken from these sediments at 21.7 m depth was dated at  $30,503 \pm 260$  years (VNIIMORGEО, Riga, R-54). This age corresponds to the Karginisk interstadial. On the backside of the bar there are lagoonal deposits

that contain spore and pollen spectrum that indicate an early Holocene age. The shelf can be traced in plan only at the heads of the Udskeya Guba and Sakhalin Bays. In other places it merges with the abrasion bench of the preceding (5) shoreline.

The next important shore development during the latest postglacial transgression involved the formation of a low-lying marine terrace at 5 to 7 m (7). Middle Holocene in age (LEONTIEV *et al.*, 1963; VEINBERG *et al.*, 1976), this marine terrace occurs only at the heads of large bays and near the mouths of major rivers. Absolute elevations of the low terrace surface range from 2.5 to 15 m above sea level. This range of elevation seems to be associated with large tidal amplitudes.

Erosional forms such as cliffs, niches, and grottos are widespread on the Recent coast (8) in the southwestern part of the Sea of Okhotsk. Depositional shores have only been recorded at the heads of the bay and are characterized by the occurrence of beaches, bars, barriers, and spits. Absolute surface elevations range from 0 to 7 m and are associated with large tidal oscillations and subject to high storm surge.

#### SEA OF OKHOTSK, SOUTHEASTERN SHELF

Geological and geophysical surveys conducted on Kamchatka's southwestern shelf and coast provided data that permitted the mapping of old shorelines. The results of these surveys are summarized in a generalized geological section (Figure 4) which shows old shorelines at the following absolute elevations: -132 to -134 m; -80 m; -62 to -64 m; -43 to -46 m; -19 to -20 m, and 3 to 5 m. Formation of these shorelines dates back to the time of the latest postglacial transgression.

One of the oldest and most prominent of the shorelines is the one occurring at a depth of 132 to 134 m (1). It is identified on seismo-acoustic profiles and echo sounding records by a clear-cut break in the seabed relief. Tapering out from the base of this break is a seismo-acoustic horizon interpreted by us as a prism of wave-cut sediments which change into lagoonal deposits higher up on the slope. Tectonic movements in this part of the West Kamchatka Trough adjoining the Sea of Okhotsk basin show a negative (downward) movement. We associate the formation of this shoreline with sea level stabilization prior to the latest postglacial transgression (MARKOV and SUETOVA, 1964) which began 17-18,000 years ago when global sea level was 110 m

below its present position. The location of the old shoreline at a depth of 132 to 134 m leads us to conclude that the shelf has been subject to tectonic settling at an average rate of 1.4 mm/yr over the past 17,000 years.

We used similar features to identify old shorelines at depths of 80 m (2) and 62 to 64 m (3). Using seismo-acoustic profiling records, we identified a system of two close-lying submerged beach barriers at the 45 m isobath. They run parallel to the Recent shoreline for a distance of 12 km in the form of an arc facing convex to the west. Deposits in these barriers and the corresponding shoreline (4) have been dated by us as early Holocene (Q<sub>Iv</sub><sup>1</sup>). Drilling behind this system of old barrier beaches within the 43.5 to 29.5 m depth interval at 8.7 to 18.2 km distance from the shore, indicated the presence of a 4.5 m thick horizon of lagoonal sediments beneath a thin layer (less than 1.5 m) of marine sandy-gravel.

Analysis of diatoms from one of the boreholes showed that this was a shallow water lagoon approximately 8.5 km in width. A horizon of swamp-type autochthonous peat begins at 27 m depth and spreads out down slope. Its C<sup>14</sup> determination of 24,200±100 years (GIN-1667) means that the overlying lagoonal deposits can be no older than late Pleistocene. At a shallower depth of 19 to 20 m, there occurs a shoreline (5) which was dated as middle Holocene. Therefore, we believe the likeliest age of this shoreline (4) to be early Holocene.

At shallow depths of 23 m and less, drilling exposed lagoonal formations which, due to their thickness and areal extent, are dimensionally inferior to those previously described. After preparing the bottom depositional maps it became clear that their "string-like" form and dimensions are similar to contemporary lagoons. In length the lagoons are about 10 to 13 km with an average width of 250 m. A group of buried lagoons form a single arc that is slightly convex westwardly and which is parallel to the Recent shore. Along with its corresponding relict submerged beach bar of well-rounded shingle, it marks the outline of a middle Holocene shoreline (5), the age of which was established in the following manner. The horizon of lagoonal sediments, occurring between 23 to 6 m depth, is overlain by late Holocene marine deposits and underlain by autochthonous swamp-type peats. The C<sup>14</sup> dates of these peats range between 7,800±150 years to 9,200±100 years (GIN 1668-1669). The peats were found by drilling the 7 to 8 m isobath strip beneath the lagoonal deposits. These data suggest to us that the age of these lagoonal deposits and the shoreline

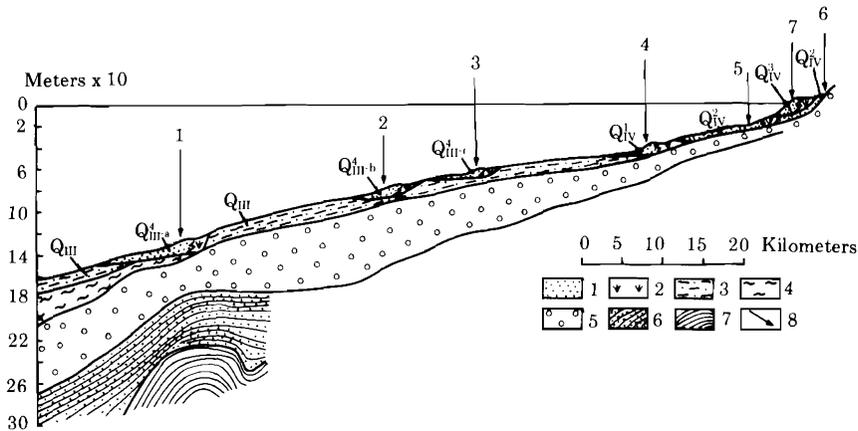


Figure 4. Generalized geological cross section for the southeastern shelf of the Sea of Okhotsk. (1-2) Deposits of the latest postglacial transgression ( $Q_{III}^1$ - $Q_{IV}^1$ ) where: (1) wave cut (2) lagoonal; (3) late Pleistocene marine deposits; (4) early to middle Pleistocene marine deposits; (5) undifferentiated Neogene rock complex; (6) Paleogene complex of rocks; (7) Mesozoic basement rocks, and (8) shorelines and their numbers.

marked by them is middle Holocene.

The shoreline marking the highest sea level in the postglacial transgression (6) is coincident with the shoreward juncture of a low (3-5 m) middle Holocene ( $Q_{IV}^2$ ) marine terrace. It is fairly prominent on aerial photos, occurring as a narrow strip (within 1.5 km) along the Recent shoreline. Its deposits adjoin, on the landward side, a gently sloping but pronounced Recent bench that is composed of Pliocene shingles. Seaward the shingles disappear beneath the level of Recent lagoonal and beach sediments. Terrace deposits contain well-rounded cobbles, gravel beds, and sands with lagoonal sedimentary lenses.

Corresponding to the Recent shoreline (7) is a complete beach profile that ranges from 80 to 500 m wide. This beach is characterized by the presence of a continuous chain of pronounced halos of natural magnetite-garnet concentrate up to 30 m wide.

## CONCLUSIONS

Comparison of data from old shorelines lying as shelves of the Seas of Japan and Okhotsk indicates that, notwithstanding certain (occasionally quite significant) differences in their structure and morphology, the shorelines formed at different stages during the latest postglacial transgression. It is possible to correlate the shorelines in different regions. In all of these regions there are two groups of

shorelines that can be related to two specific stages in the latest postglacial transgression, late Pleistocene and Holocene. In both stages there are at least three phases; each shoreline is marked by a specific morphology and by complexes of offshore marine and lagoonal sediments (see Figures 1-4). The evidence marshalled here suggests that the emergence and development of the old shorelines on the shelf must have been related to an irregular (fluctuating or pulsating) rise of global sea level towards the end of the late Pleistocene and Holocene. Thus, the latest postglacial transgression seems to have been an irregular but progressive process. Differences in the hypsometric position of individual shorelines and the emergence of additional shorelines at intermediate levels may be accounted for in terms of neotectonic movements.

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