DYNAMICS AND EVOLUTION OF BARRIER BEACHES IN THE PECHORA SEA

S.A. Ogorodov and Ye.I. Polyakova

Faculty of Geography, Moscow State University, Moscow, Russia, ogorodov@aha.ru

Abstract

The article discusses the main results of the complex investigations of barrier beaches in the Pechora Sea including coastal dynamics and accompanying exogenic processes (eolian transportation), lithological and micropaleontological studies of the sediment sequence and radiocarbon dating. We were the first to reconstruct sedimentation conditions and evolution of these big accumulative forms in the Pechora Sea. Stationary observations on coastal dynamics and the rate of eolian sedimentation allowed estimating the rate of barriers retreat. The mechanism of formation and evolution of dune belts on these barriers is described. The composition of diatom associations and lithological data give evidence for facial-genetic conditions of sedimentation during the accumulation of barriers. Radiocarbon datings corroborate the "young" age of the modern avandune ridges of the barrier beaches.

Introduction

Coastal accumulative landforms (spits, barriers, bay-bars) are widespread in the Pechora Sea among them big barrier beaches and barrier islands – Varandei Island, Pesyakov Island, Gulyaevskie Koshki Islands (Popov et al. 1988). These landforms are thought to be accumulated during the period of climatic optimum at the final stage of the Holocene transgression, when both the duration of the dynamically active period and the hydrodynamic activity were highest (Zenkovich 1957; Badyukova and Kaplin 1995). Clastic material from the upper shelf involved in onshore movement was accumulated in big coastal landforms. Where the wave resultant is nearly normal to the coastline, the typical barrier beaches and barrier islands were formed. Other accumulative forms of Holocene age, like the Russkii and Medynskii Zavorot Peninsulas, are usually considered as barriers-spits by specialists (Popov et al. 1988). Besides the transversal movement of load, alongshore sediment flows also plays an important role in their formation. A further lengthening of the barrier-spits results from the decrease in the alongshore wave energy flux and corresponding sediment discharge.

Where the waves are high enough to overflow the coastal accumulative forms, the latter are lower than 2.5-3.0 m. Over considerable stretch of the shoreline, eolian processes have built a thick dune belt (avandune) over barrier beaches and barriers-spits. Their absolute height averages 4-7 m, but some dunes are up to 10-12 m high. Some researchers take the average height of the dune belt as the height of the ancient coastal ridges formed during maximum of the Holocene (Flandrian) transgression (Avenarius 2001). Based on this assumption, the Middle Holocene sea-level highstand is estimated as 5-6 m above its present position, and the high fragments of accumulative forms are referred to as the Middle Holocene ones (Avenarius et al. 2001; Avenarius and Repkina 2001). Therefore, according to this hypothesis, the dune belt represents "fragments of paleo-barriers", that could hardly be a justified assumption.

Detailed geological and geomorphological investigations of Varandei and Pesyakov islands carried out by the authors included observations on coastal dynamics and accompanying exogenic processes (eolian transportation), lithological and micropaleontological studies of the coastal sections and radiocarbon dating. This allowed us to carry out the first reconstructions of sedimentation conditions and evolution of big coastal accumulative forms in the Pechora Sea.

Results and discussion

Barriers of Varandei and Pesyakov islands have similar structure (Fig. 1). The shoreface of these accumulative forms is covered with the dune belt (avandune) up to 4-10 m high. In the zones of divergence of wave energy, an abrasion bluff formed on the marine slope of avandune evidences a relatively high rate of coastal retreat. At the places of sediment transit, the marine slope of avandunes is relatively gentle (about 20-50^{o}) due to less intensive wave activity and the influence of slope processes. However, during years of extremely strong storms it could become steeper for a period of time due to abrasion. A relatively narrow beach (20-100 m) leaning against the marine slope of the avandune gradually turns into the tidal flat.

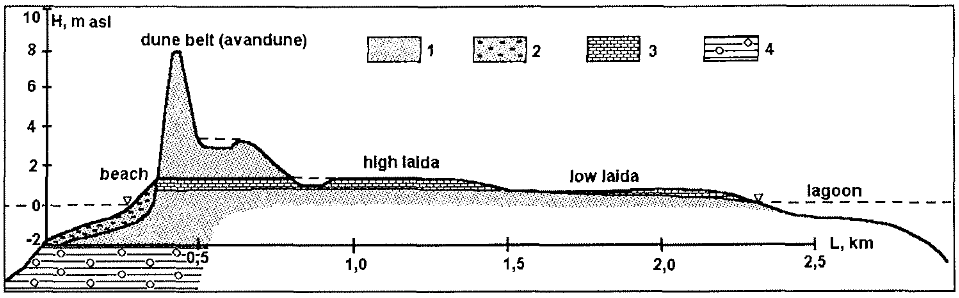

Figure 1. Geologic-geomorphologic transect of the barrier beach, Pesyakov Island. Key: 1 – fine-grained sands; 2 – sands with pebbles; 3 – "peat-grass pillow"; 4 – boulder clays and loams.

At the distal parts of barriers, the avandune becomes lower and is replaced by a series of inactive coastal ridges marking certain stages in evolution of accumulative landforms. Coastal ridges have been considerably reworked by eolian processes. Where the storm surge overwashes the barrier, the well-developed active coastal ridge is formed.

Laidas or high-water surge berms occupy the inner part of the barrier beach behind the dune belt. They are located at 2.5-3.0 m asl. Two morphological levels correspond to wind surges of low and high recurrence (Fig. 1).

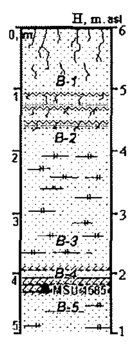

Figure 2. Composite section of the barrier beach, Varandei Island: **0-1,1 м** – sands, fine-grained, well-sorted, greyish yellow, with thin sub-horizontal layering, numerous plant roots. Spots of ferruginization and a thin organic-rich layer at the boundary with the underlying layer; **1,1-1,3 м** – sands, fine-grained, well-sorted, whitish yellow, with thin horizontal layering, inclusions of slightly decayed grass stems; **1,3-1,7 м** – intercalation of sub-horizontal undulated brown and black interlayers of "grass pillow" with interlayers of whitish yellow fine-grained and dusty sands, thickness of interlayers up to 5 cm; **1,7-3,9 м** – intercalation of whitish yellow and brownish yellow sands, fine-grained, well-sorted (sub-horizontal layering). Layering expresses itself by thin dark interlayers with semi-decayed plant debris and spots of ferruginization; **3,9-4,4 м** – "peat-grass pillow": semi-decayed remains of grasses and bog plants together with brownish sandy-clay material with greyish yellow interlayers of clayey fine-grained sands; **4,4-5,0 м (apparent)** – fine-grained sands, grey, with plant debris, layering is absent; ***B-3*** – samples for diatom analysis; **MSU-1585** – sample for radiocarbon dating.

In general, barrier beaches of the Pechora Sea are relatively rapidly moving onshore because of shoreface abrasion, wave and eolian transportation of sand from the windward to leeward slope. Field observations on coastal dynamics carried out from 1969 till 2000 showed that the coastal retreat rates on Pesyakov Island, which is practically unaffected by human activity, equaled 0.5-2.5 m per year (Ogorodov 2001b). As a result, the so-called "fragments of paleo-barriers" with a width of 50 to 350 m must be completely reworked during 100-400 years. Thus, they could hardly be of Middle Holocene age even if assuming that the rates of coastal retreat have increased during the last century. Radiocarbon dating of wood (MSU-1585) from the lower part of the "peat-grass pillow" of the laida exposed in the basal part of coastal bluff (Figs. 1, 2) corroborates the extremely "young" age of the overlying sand layer.

Eolian processes play an important role in formation and evolution of barrier beaches in the Pechora Sea. This role has been previously underestimated. In case wind speed exceeds 12 m/s fine-grained sand material is evacuated from beaches and tidal flats. Observations revealed that during one storm a 3-5 cm thick sand layer could be blown away from the open beach surface (Ogorodov 2001a; Fig. 3). During the dynamically active period, deflation removes not less than 1 m^3 of sediments from one square meter of beach surface. Most part of eolian material removed from beaches and tidal flats is accumulated within the dune belt (avandune). Specific vegetation growing on avandunes protects it from deflation and favors intensive accumulation of eolian material. It should be noted, that the extent of the opposite eolian transportation – from the dune belt to the beach and tidal flats – is considerably less due to high anti-deflation stability of the dune belt.

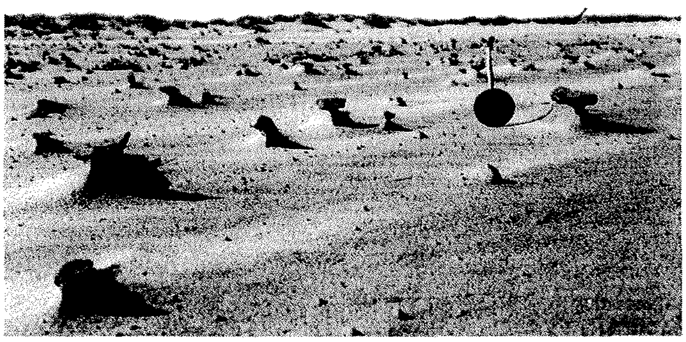

Figure 3. Beach surface after severe storm wind, Pesyakov Island (photo of N.N. Lugovoi).

During fieldwork in 2000 we measured the rates of eolian sedimentation at specially equipped monitoring stations. Averaged data on repeated measurements carried out at more than 50 reference marks showed that the thickness of the sand layer accumulated during the two summer months ranged from 3-16 cm at a distance of 10 m from the avandune edge to 0.5-4 cm - at 100 m. These high rates of eolian accumulation are responsible for the considerable height and width of the dune belt previously mistaken for as "fragments of paleo-barriers".

Actually, the sediment sequence exposed in coastal bluffs of the barriers above 1.0-2.0 m is entirely represented by subaerial complex (Fig. 2): fine-grained sands with abundant grass remains and traces of soil processes. They are devoid of any pebbles, gravel and other coarse-grained debris. On the contrary, deposits of beaches, active coastal ridges and high-water surge berms in the Pechora Sea consist of less sorted sands with numerous pebbles, gravel, rock debris and single bivalve shells. Coarse-grained material originates from numerous exposures of boulder clays and loams on the submarine coastal slope (Fig. 1). No coarse debris was found in the barrier beach sediments from the cores recovered at considerable distance from the coastal bluffs. Laida deposits with characteristic peat-grass pillow are usually exposed below 1-2 m level. Laida deposits accumulated in the inner parts of the barriers under the influence of storm surges up to 2.5-3.5 m high do not give any evidence either for higher than modern sea-level position or the Middle Holocene age of the overlying sand unit.

Diatom analysis of the barrier beach sequence from the Varandei Island (Fig. 2) revealed the gradual succession of fossil associations indicating changing sedimentation conditions.

Fine-grained grey sands with grass remains exposed at the base of coastal bluff (**sample B-5**) contain ecologically diverse diatom association including both marine and freshwater species. Taxonomically diverse marine benthic diatoms inhabiting littoral and sublittoral zones of the arctic seas *(Diploneis interrupta, D.bombus, D.smithii, D.litoralis, Paralia sulcata)* along with euryhaline species *(Achnanthes delicatula v.hauckiana, A.lemmermannii, Fragilaria pinnata)* typical of the arctic brackish waters (Polyakova 1997) predominate in this association (~ 80%). Freshwater diatoms are rare. They are represented by species dwelling in bottom sediments and on overgrowths in the Arctic inland basins *(Navicula bacillum, Pinnularia leptostauron, P.microstauron, P.viridis)*. The composition of diatom associations allows assuming that sedimentation went on either in the inner sublittoral or littoral zone under changing marine and subaerial conditions.

The overlying peat-grass layer (**sample B-4**) is distinguished by the highest species diversity and abundance of diatoms. Like in the underlying layer, the diatom association includes different species in terms of salinity preferences with predominance of typical freshwater lacustrine-bog forms primarily of *Eunotia, Pinnularia* and *Cymbella* genera. Halophobic species are also present. *Pinnularia microstauron, P.divergentissima, P.viridis, P.subcapitata, P.borealis, P.stomatophora, Eunotia fallax, E.praerupta, E.pectinalis, Cymbella hilliardii, Encyonema minutum, Neidium bisulcatum* dominate the association. However, species diversity of halophiles and brackishwater species is also high. These include *Nitzschia hybrida, Diploneis interrupta, D.bombus, D.litoralis, Amphora ovalis, Navicula cryptocephala, Cavinula pseudoscutiformis*. Their presence gives evidence for possible infiltration of seawaters or periodic flooding of the swamped coastal lowland during high tides or wind surges.

The abundance and diversity of diatoms sharply decrease in the overlying, mainly fine-grained, sands (**sample B-3**). The diatom association is represented by freshwater species typical of the bottom grounds of the northern shallow water basins *(Pinnularia viridis, P.molaris, P.streptoraphe, Neidium bisulcatum, Navicula importuna, N.semen)*. Rare freshwater planktic and rheophile species *(Stephanodiscus hantzschii, Luticola mutica)* are present, as well as fragments of marine Paleogene diatoms. The composition of diatom associations suggests the sediments were accumulated under relatively active hydrodynamic environment, probably, in temporary streams.

Upward the section (**sample B-2**), the composition of diatom associations changes. Planktic and rheophile species disappear, but aerophile diatoms *(Hantzschia amphioxys, Navicula contenta)* become abundant. These are typical for edaphic (soil) coenoses of diatoms. Subsurface deposits (**sample B-1**) represented by fine-grained well-sorted sands with grass roots contain diatom association entirely dominated by subaerial bog-soil species, mainly of *Eunotia* and *Pinnularia* genera *(P.brevicostata, P.microstauron, Eunotia parallela, E.lunaris, Hantzschia amphioxys* and others).

Thus, the composition of diatom associations indicates changes in sedimentation environment during accumulation of the barrier beach – from nearshore marine, littoral, probably marsches, to swampy laida and, finally, subaerial avandune. Temporary streams played an important role in the formation of the lower part of subaerial unit lying above 2.0 m asl. These streams redistributed abundant eolian material and supplied plant debris into shallow lakes and puddles during flood. The plant debris was accumulated in the form of thin interlayers. At present, similar conditions exist in the inner part of the dune belt between the avandune ridge and laida (Fig. 1). The uppermost part of the subaerial unit was accumulated due to active eolian-soil sedimentation typical for the topmost part of the dune belt on the barrier beach.

Conclusions

As a result of the complex investigations we came to the following conclusions. Barriers of the Pechora Sea were formed in the coastal zone by accumulation of coarse debris derived from the submarine coastal slope. In the course of coastal evolution, the barriers were moving onshore overlapping coastal laidas formed behind them. Eolian processes played an important role in shaping the shores. Eolian transportation of sand from beaches resulted in the accumulation of big dune ridges. The latter rework and overlap barriers. That is why the absolute height of the barriers in the Pechora Sea could not serve as an indicator of the sea-level position in the Holocene. Diatom associations evidence upward changes in sedimentation environments during the formation of coastal accumulative forms in the Pechora Sea, from nearshore marine, littoral, probably marsches, to swampy laida and, finally, subaerial avandune. According to radiocarbon datings, the modern avandune in the studied region began to form not earlier than 350-400 years ago.

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