COASTAL FORMATION IN THE WESTERN SECTOR OF THE RUSSIAN ARCTIC REGION DURING THE PLEISTOCENE-HOLOCENE

N.A. Shpolyanskaya, Yu.B. Badu and I.D. Streletskaya

Geographic Faculty, Moscow State University, Vorob'evy gory, Moscow, 119992 Russia

The recent position of the Arctic shelf and the Arctic Ocean coastline is the result of their evolution in the Late Cenozoic under the action of two groups of natural processes. The first group includes global processes caused by tectonic and climatic factors, which resulted in considerable changes in sea level and in the appearance of wide glacier covers (Velishko 1998; Kaplin and Selivanov 1999). The second group combines permanent exogenous processes, complicated by permafrost mostly including large underground ice fields (Rozenbaum and Shpolyanskaya 1998, 2000; Trofimov 1986).

We have traced the dynamics of the coastal zone of the western sector of the Russian Arctic region (northern Europe and Western Siberia) during approximately the last 250 kyr.

At the end of the Pliocene-beginning of Pleistocene, climate became more severe and the sea transgression began along the entire Arctic coast of Eurasia. The vast cold-water sea basin gradually occupied the northern regions of the Russian Plain and Western Siberia, and glaciers covered the land. Both glaciation and sea transgression were maximal in the Middle Pleistocene (II_{2-4}) approximately 250 to 150 ka ago. The sea depth at the Barents and Kara shelves was not more than 100 m. The western part of the northern Russian Plain, including the Kola and Kanin peninsulas, mountain system of Novaya Zemlya and the Urals, and mountains of Central Siberia were covered by glaciers.

Air temperature decreased by 6-7^0 as compared to the present-day temperature. Nevertheless, the conditions were not favorable for development of permafrost, since the entire land was covered by either sea or glaciers. This created specific conditions for coastal processes. Coasts were formed under the action of glaciers (Fig. 1a).

The Late Pleistocene, Mikulino (Kazantsevo) Interglacial (III_1) - warm interglacial period replaced the period of glaciation. The sea transgression was considerably less intense. The sea occupied only northern lowlands (Fig. 1b). During the peak warming (125 ka ago), the air and ground temperatures exceeded the present-day temperature by 2.5-3.5^{0}C and were positive over the major part of the land. The cryolithozone with a temperature of -2 to -6^{0}C and a thickness of up to 400 m existed only in the Polar Urals and Pai-Khoi and at latitudes higher than 65^0 N in Western Siberia. The cryolithozone with thick tabular ice could form at depths of more than 40 m on the Kara shelf; and with tabular ice and fossil ice vein in the shallower shelf regions.

In this epoch, the coastal processes were more diverse than in the previous period. The coasts of Scandinavia and the Kola Peninsula were highly dissected (the fiord type) and showed the features of not only glacial erosion but also fracture tectonics. Offshore slopes of a fault origin were steep. Protrusions of land in place of the recent Kanin Peninsula, Timan Range, Pai Khoi, Polar Urals, and ancient Taimyr Island were similar to the Kola Peninsula coasts. The remaining land was the sea plain composed of very dense Middle Pleistocene glacial-marine silty clays (perennially frozen on Kara Sea islands). Abrasion and accumulation (thermal abrasion and accumulation on Kara Sea islands) proceeded here, and flattened coasts with high cliffs and deepened submerged slope were formed in this region. The zone of active coastal accumulation with bars, spits, etc. was formed in shallow straits.

Late Pleistocene, Valdai (Zyryan-Sartan) epoch (III_{2-4}) - prolonged cold stage replaced the epoch of warming. The regression of the Arctic Basin continued and terminated as a deep regression in the Late Valdai (Sartan) period (III_4). This epoch, which began 18-20 ka ago, is considered as the most cold period in the Pleistocene. The sea regression resulted in the Arctic ocean receding to a bottom contour of 110-140 m (Fig. 1c). The climate was pronouncedly continental, and the air temperature was lower than the present-day temperature by 7 - 10^0C; the epoch was characterized by a very dry climate. Ice caps generated again, although they were considerably smaller than in the Middle Pleistocene. Glaciers did not approach the coasts.

The low-temperature cryolithozone existed on land; its thickness was up to 700 - 800 m within plains and 1000 m and more in mountain regions. Within shelves, the cryolithozone also existed, especially at water depths of 0-2.5 m (below fast ice), with a temperature of -11 to -14^0C and thickness of 30 to 400 m.

Under such conditions, the coastal processes could not be active. The high ice coverage of the sea (which restricted wave activity), very short warm period (when coasts were almost not clear of fast ice), and frozen coasts hardly promoted the development of abrasion and thermal abrasion. The material of eroded coasts settled not far from the coast because of rather stagnant water. During this period, the main type of the coasts was insignificantly thermoabrasional and accumulative. The processes of thermal erosion developed in the large valleys of ancient rivers, which were similar to narrow extended bays, and formed thermoerosional accumulative coasts.

The Holocene (IV) - the warm interglacial period, which began 10.5 ka ago and still continues. The post-glacial (Flandrian) sea transgression proceeded at that time and formed the present-day coastline configuration 6 ka ago. From that time, sea level fluctuated only insignificantly. The period of climatic optimum - the epoch of warming when the normal annual air temperature exceeded the present-day temperature by 2^0 - began precisely in that period. Frozen rocks thawed in this region. The cryolithozone remained only in the northeastern European region and northward of the Arctic Circle in Western Siberia (Fig. 1d). At the shelf of the southeastern Barents Sea and of the Kara Sea, the relic cryolithozone existed in the area flooded by the sea.

Among the coastal processes of that time that are still significant, abrasional -abrasional-accumulative and thermoabrasional - thermoabrasional-accumulative processes were most frequent (affected 80% of the coastline length) in the regions without permafrost and in the cryolithozone, respectively. The thermal abrasion of the Kara and Barents sea coasts is very rapid. A constantly heavy sea of 1-3 points over one summer season results in an average erosion rate of 1 – 2 m/yr in the Yamal, Gydan, Yugor, and Taz coasts, that are composed of icy silty-clayey sediments (Vasiliev et al. 2001). At the eastern Yamal and northern Gydan coasts, the silty-sandy sediments with very high ice content (up to 70-80%) are eroded at a higher rate (2-5 and up to 10–15 m/yr in individual years). Frozen rocks with a low ice content, which compose, for example, the western coast of the Taz Peninsula and the Kolguev Island coasts, are eroded slowly (0.1 – 0.3 m/yr).

In conclusion, we should note that the Pleistocene-Holocene dynamics of the Arctic coastal zone formed the clearly defined steps of marine interfluvial plains separated by ancient cliffs, which once were the boundary of the maximal transgression of the sea basin, near which took place thermoabrasion and accumulation of coastal sediments. Virtually a constant position of the present-day coastal zone during the last 6 kyr indicates that, during this period (in the climatic optimum and later), the coasts have changed mainly due to the processes of thermal abrasion (with thermal denudation and thermokarst), and thermal abrasion-accumulation at the coasts composed of rocks with high ice content and underground tabular ice. The same process will proceed everywhere at the Arctic coasts under consideration.

The present study was supported by INTAS, grant 01- 2329, and the Russian Foundation for Basic Research, project no. 02-05-64263.

Reference

Kaplin, P.F. and A.O., Selivanov (1999) Sea-level changes and coasts of Russia: past, present, future. GEOS, Moscow. (in Russian).

Rozenbaum, G.E. and Shpolyanskaya, N.A. (1998) Late Cenozoic permafrost history of Russian Arctic. In Permafrost Periglacial. Processes, 9, 247-273.

Rozenbaum, G.E. and Shpolyanskaya, N.A. (2000). Late Cenozoic permafrost history of Russian Arctic and the tendency for the future evolution. Nauchnii Mir, Moscow. (in Russian).

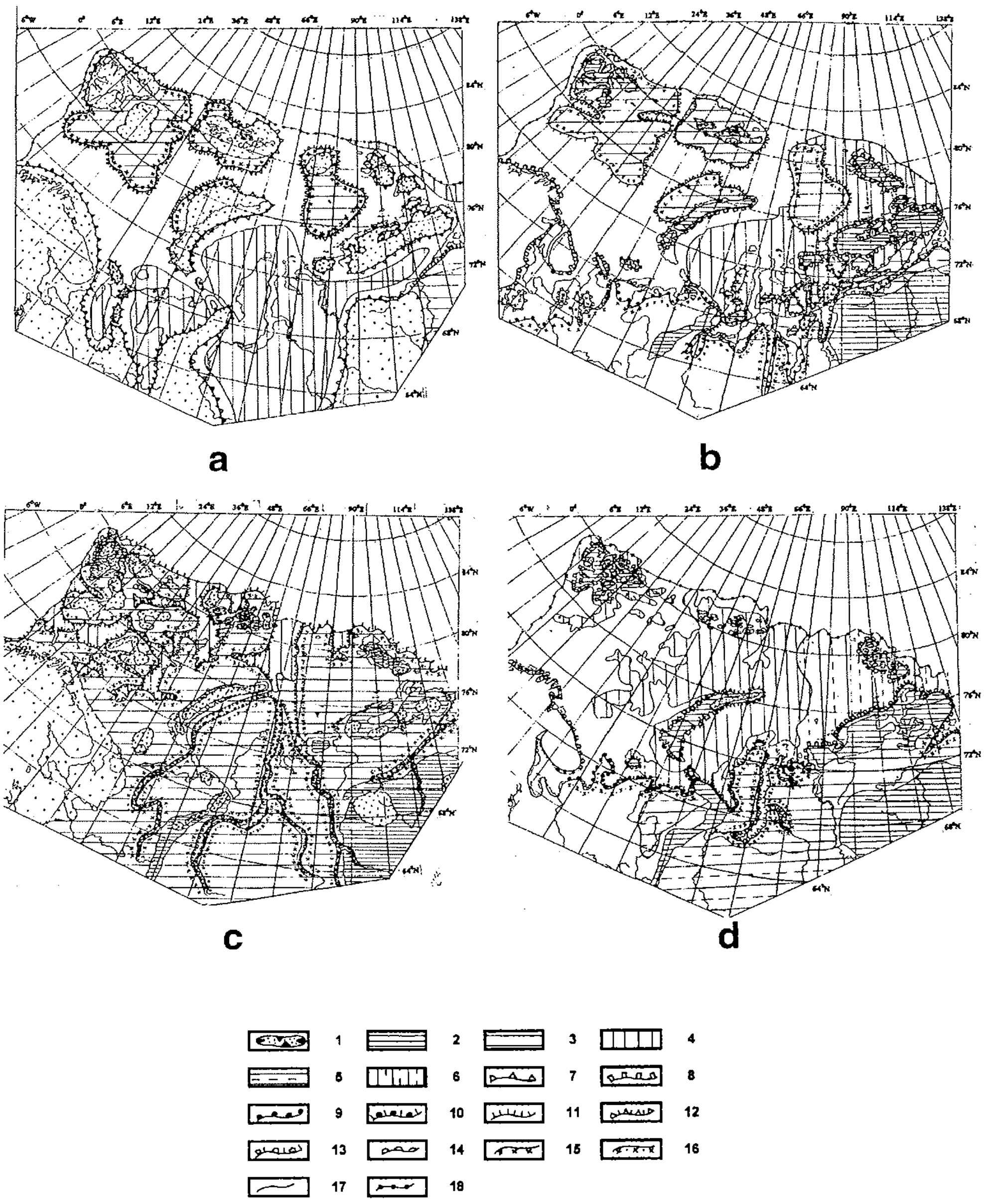
Trofimov, V.T. (ed) (1986) Exodynamic of West Siberia platform. Izdatelstvo Moskovskogo Universiteta. (in Russian).

Vasiliev, A.A., Pokrovsky, S.I. and Yu.L. Shur (2001) Dynamics of the coastal thermoerosion of West Yamal. Kriosfera Zemli, 5 (1), 44-52. (in Russian).

Velishko, A.A. (ed) (1998) Climate and environment changes during the last 65 million years (Cenozoic: from Paleocene to Holocene). GEOS, Moscow. (in Russian).

Legend for Figure 1 (next page)

a. The West Arctic Ocean coastline position in the Middle Pleistocene. Maximal glaciation and sea transgression (II_{2-4}).
b. The West Arctic Ocean coastline position in the Late Pleistocene. Mikulino (Kazantsevo) Interglacial (III_1).
c. The West Arctic Ocean coastline position in the Late Pleistocene. Late Valdai (Sartan) epoch (III_4).
d. The West Arctic Ocean coastline position in the Holocene (IV). The warm interglacial period (6 ka ago).
1 - The sheet glaciation and caps.
2 - The subaeral cryolithozone in the mountains.
3 - The subaeral cryolithozone in the plains and valleys.
4 - The frost penetration shelf deposits.
5 - The relict subaerial cryolithozone.
6 - The relict submarine cryolithozone.
7-14 - The types of coasts:
7 -the thermo-abrasional glacial shores, 8 - glacial trough coasts, 9 - abrasion shores, 10 - abrasion-accumulative shores, 11 - thermo-abrasional shores, 12 - thermo-abrasional and accumulative shores, 13 - thermo-erosional and accumulative shores, 14- accumulative shores.
15 - 16 - The types of deposits:
15- loam and clay, 16 - sand, sandy loam and loam.
17-18 - The boundaries:
17- land , 18 - shelf.


a
b
c
d
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18