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BARENTS SEA COASTS

ABSTRACT

Barents Sea is an area of great geopolitical and economical importance, as well as an indicator of sustainable development of the Russian Federation in Arctic region. The article presents generalization made for the Barents Sea coastline. For each area a brief description of distinct geomorphologic features and coastal dynamics is outlined. The environmental forcing factors and conditions, which determine the development and present coastal dynamics at Barents Sea, are examined.

KEY WORDS: Barents Sea, environmental conditions, coastal geomorphology and dynamics

INTRODUCTION

The Barents Sea is the largest sea in the Arctic Ocean with an estimated surface area of 1,424 km^2 and a volume of 316 thousand km^3 [The Atlas of the Arctic, 1985]. In terms of its morphological structure the whole of this sea lies on the shelf – the underwater extension of the Eurasian continent. The average depth of the Barents Sea is 222 meters, and at its deepest, 600 meters. Its waters wash the shores of two countries – Russia and Norway – as well as several large islands and archipelagoes, e.g. Svalbard, Franz Josef Land (FJL), Novaya Zemlya, Vaigach, Kolguev, Medvezhii.

Amongst the seas of the Arctic it is the Barents Sea which has been used most intensively by people. Its coast is home to Murmansk – the only year round ice-free port along the Russian Arctic coast, with paramount importance for the Russia's transportation, fishery and military. Several oil and/or gas bearing structures, including the Shtokman gas condensate field, one of the richest in the world, have recently been discovered and tested for operation on the Barents Sea shelf. A number of submerged oil pipelines and onshore oil storage sites and terminals have been either designed for or built in this area, for example, the oil loading facility on Varandei Island. This facility, up and running since year 2000, operates 24 hours a day and is reached a throughput of 15 million tons a year 2010. In this context of coastally situated facilities and industrial sites the dynamics of the coast and the intertidal and shelf zones take on an important safety dimension.

In the Late Pleistocene the Barents Sea was surrounded by icecaps, lobes from which extending down to the water from northern Norway, Kola Peninsula, Novaya Zemlya, Svalbard and Franz Josef Land [Pavlidis et al., 1998]. Traces of that process can be found on the bottom of the sea in the form of numerous terminal moraine ridges. At that time the whole if the sea, where it was not occupied by the glaciers of the ice cap, was covered by floating pack ice. Towards the end of Late Pleistocene and in the beginning of Holocene this area went through a deglaciation process whereby all areas recently exposed by retreating glaciers were flooded. Currently, a few individual and comparatively small glaciers on Novaya Zemlya, Svalbard and Franz Josef Land (FJL) reach the shoreline and the sea is ice-free most of the year. Since being freed of ice cover, the glaciated shores have undergone rapid isostatic rebound. On the continental coast east of Kanin Nos Peninsula there are relics of Late Pleistocene frozen deposits [Ershov, 1988]. These two factors play a significant role in determining the specific features of the Barents coastal development observed today.

ENVIRONMENTAL CONDITIONS

The climate of the Barents Sea, which may be broadly characterized as "polar marine", is determined by its latitude, proximity to the bulk of the Asian continent, and by the direct influence of both the Arctic and the Atlantic Oceans. The Barents Sea region, and this latitude in general, experience long winters and short summers. The marine influence moderates temperatures, giving relatively warm winters (average monthly temperatures from –1°C in the West to –20°C in the East (January and February)) and cool summers (T range from +10°C in the South to +2°C in the North (August)) for its latitude, and maintains consistently high atmospheric moisture content (Fig. 1). As for many arctic regions, many aspects of the climate in this region are variable, and seasonal temperatures can exhibit large swings from one year to the next.

In terms of air temperatures, the local climate becomes increasing harsh towards the north and east, as indicated by the mean annual air temperatures on the islands, which are as follows: above zero in the south-western part of the sea south of 74° N latitude, -1,6°C on Medvezhii, -5,2°C on Svalbard, and -10,5°C on Franz Josef Land. During the most climatically severe years the temperature may stay below zero throughout the year.

The earliest, continuous records of systematic hydrometeorological observations date to 1927 at Naryan-Mar and 1936 at Murmansk. Over the period of record at these stations a statistically significant trend in temperature has not been observed; instead the series are dominated by periodic oscillations of 11, 5, and ~2.5 years. It is of interest to note that the Scandinavia Pattern, an index of periodic atmospheric pressure variability with a center of activity in the Barents region, also has a spectral power peak at ~2.5 years.

One of the most prominent cyclone tracks in the northern hemisphere moves along the north Atlantic and into the Norwegian/Barents Sea region. Cyclonic systems moving into the region from the Atlantic represent an important influx of energy into this region. The juxtaposition of the Barents Sea region, between two relative extremes of a warm air source from the west and cold air sources from the Arctic Ocean and the continental region to the south in winter sets up strong baroclinic (steep temperature gradient) conditions that contribute to pronounced temperature and weather variability.

The wind situation on the Barents Sea, as anywhere, is determined by the pressure field. It exhibits large seasonal variation; in general, however, typical hourly wind speeds over the winter period are in the 6 to 10 m/s range. Light winds (<5 m/s) occur 25–30% of the time, and strong winds (>11 m/s), 15%. It is important to note that strong winds occur in clusters defined by episodic events (storms) and, although they represent a relatively low fraction of observed winds, (2.0–2.5% of winds occurring in events lasting 24 hours or more), this wind speed range constitutes an important coastal process driver. The fact that they tend to be episodic means these strong winds are sustained, which adds to their impact potential.

Further details of environmental parameters are provided below, grouped by season.

In winter (December-April) the central part of the sea is the locus of intensive cyclonic activity, which brings windy conditions, air temperature oscillations and abundant precipitation. Overall, wind directions are typically south-westerly, with the broadest patterns of mean wind direction being governed by the presence of a trough of low pressure that extends off the Icelandic low pressure feature, reaching over to the Barents Sea region. In the southern mainland coastal region wind directions are from the

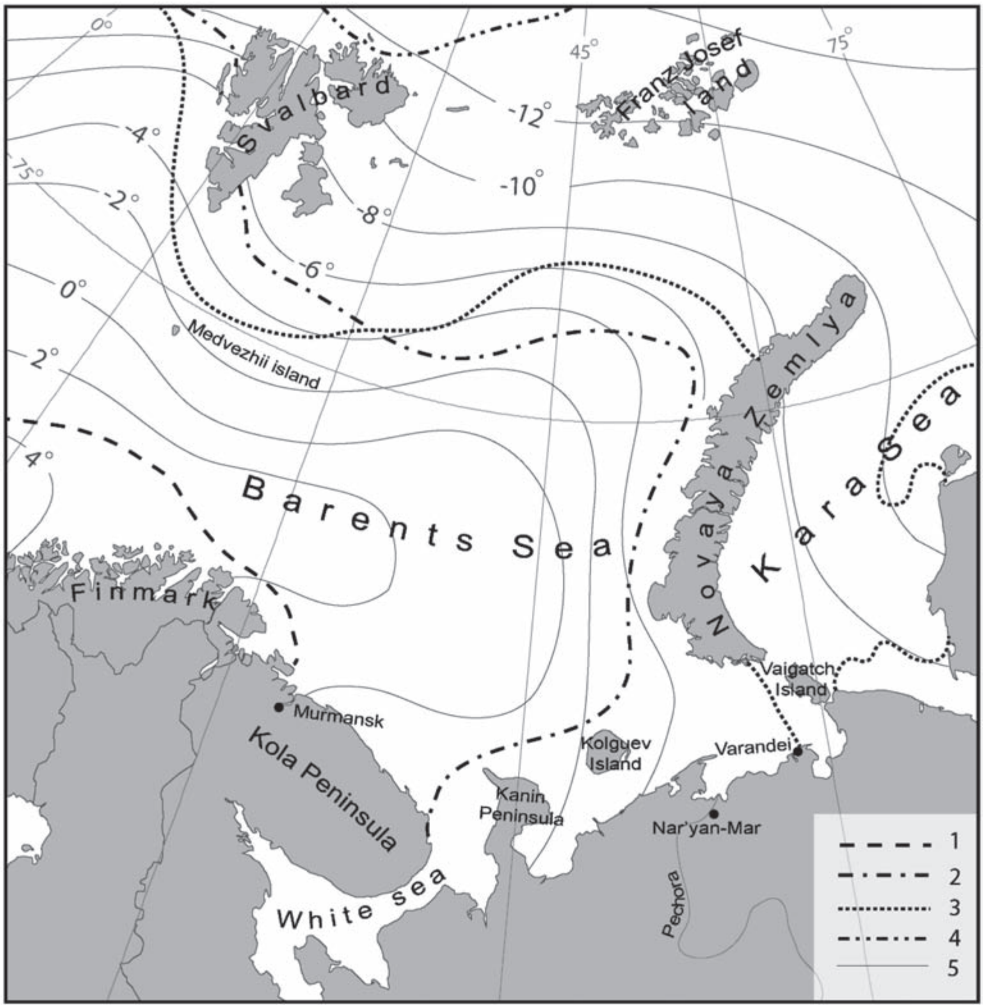

Fig. 1. The distribution of brine ice and average annual air temperature in the Barents Sea [The Atlas of the Oceans. The Arctic Ocean, 1980]:

1 – Boundary of the largest ice coverage during its maximum development (March-April); 2 – Boundary of the minor ice coverage during its maximum development (March-April); 3 – Boundary of the largest ice coverage during its minimum development (September); 4 – Boundary of the minor ice coverage during its minimum development (September); 5 – Average annual air temperature

south and the south quarter ~50% of the time. North of the coast, over the Barents Sea and near Novaya Zemlya, mean wind direction shifts towards the east/southeast; these directions account for 60% of wind observations in this area. Primary wind direction in the northern Barents Sea is from the northeast and east.

When winds are from the south they bring cold continental air. During the coldest month – March – the average temperature is –22°C on Svalbard, –2.4°C, in the west and centre, –4°C by Kolguev, –7°C in the southeast. Wind speeds during winter storms can exceed 25 m/s, but are more typically 10 to 15 m/s.

The spring is a transition season in the Arctic; the mainland coastal zone of the Barents Sea region (May – June here) is no different. During this short period the stable pressure fields of winter break down; accompanying this is an associated drop in wind persistence, with frequent storm systems, variable winds, precipitation, and cloud cover. A northerly/ northeasterly component to the winds becomes more frequent over the majority of the Barents Sea. The repeatability of weak winds (<5 m/s) is 40–50%, and up to 60% in the south. Strong winds (>15 m/s) occur no more than 1–4% of the time.

Further north, however, the weather remains stable and cold, with moderate north-eastern winds, because the sea ice cover in this area has not begun to break down at this time. The air above the entire sea has low temperatures. The average value in May is –4°C near the southern coast of Svalbard and 0.2°C near Murmansk coast.

In summer (July through September) a stable zone of high pressure (anticyclone) forms over the Barents Sea bringing fairly warm and dreary weather. Winds tend to be weak and dominated by northern/northeastern components, with frequencies of 50–60% for light winds, 5–10% for strong winds and 1–2% for gales (>15 m/s). In western and central Barents air temperatures in July and August reach 8–9°C, in the south-eastern part it is 7°C, and in the northern – 1–5°C.

Influxes of air from the Atlantic bring clearer skies, higher wind speeds and a change in wind direction to the southeast. These occurrences, which contribute to weather and temperature variability, are limited to the western and central Barents Sea. In the north the weather is less variable.

In September the frequencies of stronger wind speeds increases, and the ambient air temperature above the sea becomes lower than the temperature of the water all across the sea. This reduces atmospheric stability and increases weather variability and occurrences of precipitation.

In autumn (October through November) the summertime stability of the weather breaks. The early part of the season is a period of transition characterized by pronounced wind direction variability; by later in the season a southwesterly regime has been established. Strong winds then bring cold, continental air into the region. By as early as October the air temperature in the northern part of the sea has dropped below 0°C. In other areas of the sea this happens by November. The gradual shift from autumn to winter conditions accelerates in the second half of the season.

In autumn the growing number of cyclones that move into the Barents Sea triggers wind activity. The repeatability of winds of northern directions decreases. The average wind speed grows to 7 m/s. In the western part of the sea the average is 8 m/s and more. The repeatability of the winds of over 11 m/s reaches 20–30%. Of these the strong winds take up 5–10%.

The general pattern of ocean currents, consisting of warm water from the Atlantic flowing to the southwest and the cold Arctic water moving into the region from the north, strongly influence the climatic differences between the various parts of the Barents basin. Some 76 thousand km^3 of water a year, i.e. about one fourth of the total volume, comes into Barents Sea from elsewhere. In this region prevailing ocean currents don't affect the near-shore currents sediment transport.

The main constituents of the observed current regime in the Barents Sea include non-periodic (wind- and gradient-induced) and tidal currents. The most powerful and stable current in the Barents Sea is the warm North Cape Current, which is an offshoot of the Norwegian Current. From the Kara Sea comes the cold Litke Current, which goes along the southern and western coast of Novaya Zemlya. Tidal currents play a significant role in the Barents Sea water dynamics along the Murmansk coast, at the entrance into the White Sea, and in the Kanin-Kolguev area, at Cheshskaya Bay.

The distribution of water temperatures across the surface and depth of the Barents Sea depends on the distribution of warm and cold currents, on the strength of winter cooling and summer warming, as well as bottom morphology. South of latitude 75°N, except for the south-eastern part of the area (the so-called Pechora Sea), the water column from surface to bottom has positive temperatures throughout the year. In winter the temperature of the water surface in the southwestern part is at 4–5°C, but in the northern part and in the southeast it is below zero (which is close to the freezing point given the local water salinity). The spring warming of the sea surface begins to appear in May. The water temperature in June increases to 8°C in the southwest and 3°C in southeast. In summer the water surface has a temperature close to the near-surface air temperature. In the south-western basin of the sea the temperatures are 9–10°C; in the shallow southeastern area – around 7°C and occasionally upward to 10°C and higher; in the central part – 3–5°C; and in the northern, ice-free basins, 2–4°C.

The Barents Sea, much of which stays ice-free year round and which is exposed to an intensive cyclonic activity, is one of the stormiest seas in the Arctic Ocean. In addition to purely wind-induced wave activity, the southern and southwestern parts of the sea exhibit a swell regime, similar to that observed in southern oceans, that results from swell imported via the Norwegian and Greenland Seas.

The most pronounced wave activity is observed in the western section of the Barents Sea. The largest are observed in November through March, when the frequency of gale-force winds is largest. Typical large wave expedience values reach 5% for wave heights of 3.0–4.5 m during this period. Waves exceeding 8 m are uncommon and require specific conditions of steady westerly or northwesterly winds. In spring the frequency of large waves decreases. The period of smallest wave heights is July and August, which corresponds to the time of weakest winds, noted above. During this period uninterrupted duration of calm weather (e.g. 5% significance level waves <1.5 m) is the largest.

The wave climate of the open Barents Sea (the remote areas of the sea) differs noticeably from the partly closed and relatively shallow south-eastern sector – the Kanin-Pechora – which typically has a complicated and unstable ice cover during the stormiest period in the year, the pre-winter one (Fig. 2). In such conditions any waterside/intertidal construction would require detailed wave calculations, based on high-resolution bathymetry and coastal orientation, for the specific point under consideration for the building activity (Table 1). Working up a detailed wave parameter suitable for engineering purposes requires precise information about the local physical environment. It must be noted that the isolines shown in Fig. 2 refer only to deepwater areas of the sea (over 25 m deep), which are not protected by islands or coastal curves or shallow water from the propagation of the waves of open sea should the most dangerous winds attack them. Such dangerous winds, i.e. winds with the greatest wave-generating potential, are north-western for the south-eastern part of the sea and western and south-western for the central, eastern and western areas of the Barents Sea. For the sea adjacent to the southern coast a northern wind would also be wave-hazardous. For the sea adjacent to the edge of the Arctic ice cap (during the stormiest months) winds of not only western and south-western directions but also southern ones can be wave-generating.

Tide in the Barents Sea is caused by propagation of tidal waves from the northern Atlantic, combined, in the northern Barents Sea near northeast coast of Svalbard and FJL, with the tidal regime of the Arctic Ocean.

Tides in the southern Barents Sea are of regular, semi-diurnal cycle but of large amplitude unusual for Arctic waters. On the Murmansk Coast tides over 3 m high have been observed. The highest tides have

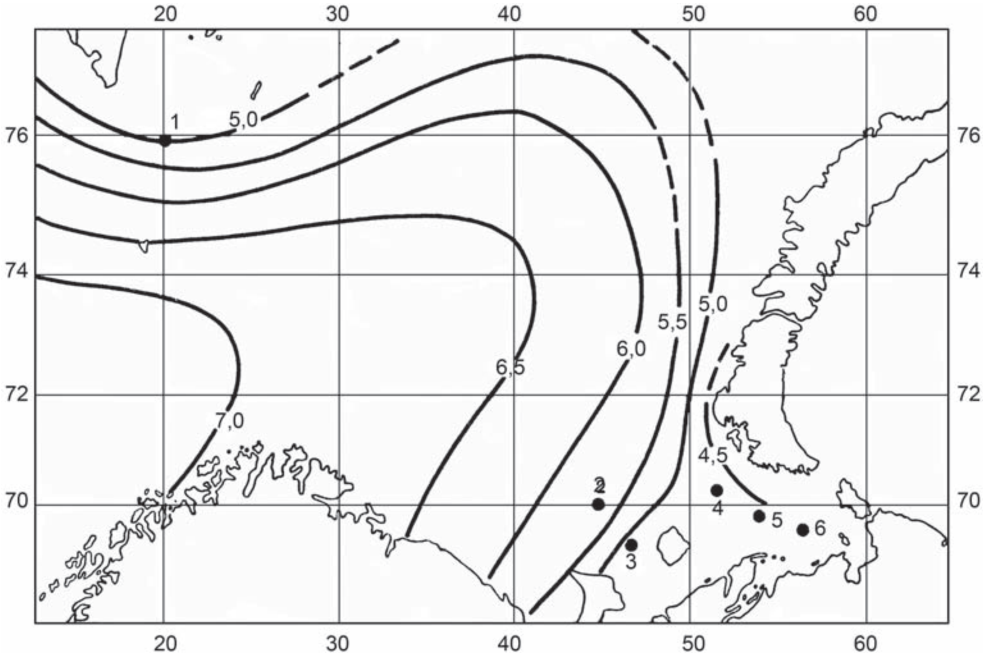

Fig. 2. The most probable fifty year maximums of average wave heights

[The Hydrometeorological Conditions of the Shelf Seas of the USSR. Barents Sea, 1985]

been registered in Cheshskaya Bay where the average syzygial tide value reaches 6 m. In the north, north-east and east tides are much smaller: 1 to 2 m near Svalbard or near Varandei Island and only 0.4 to 0.7 m by the southern coast of FJL.

The entire length of the Barents Sea coast is exposed to surges in sea level caused by strong, persistent winds accompanying strong cyclones. The resultant height of a surge observed at a specific location depends on the interplay between the direct action of

Table 1. Estimated wave parameters for deepwater areas and wind speed of different significance level for point 6 (see Fig. 2)

[The Hydrometeorological Conditions of the Shelf Seas of the USSR. Barents Sea, 1985]

Parameter	**Significance level *F*, %**				**Repeatability, once in *n* years**				
	50	**20**	**5**	**1**	**1**	**5**	**10**	**20**	**50**
July-September									
h, m	0.6	1.1	1.5	2.1	2.2	2.5	2.8	2.9	3.2
τ, s	3.6	4.8	6.0	6.9	7.1	7.8	8.0	8.2	8.5
v, m/s	6.9	10.0	13.5	16.6	17.2	19.5	20.5	21.2	22.1
October-December									
h, m	0.8	1.4	2.2	2.8	3.3	3.7	4.0	4.3	4.5
τ, s	4.4	5.6	6.6	7.2	7.5	8.0	8.2	8.3	8.4
v, m/s	7.5	12.0	17.2	20.0	25.0	28.5	31.0	32.0	33.0

the wind, the surge wave it has set up, and the specific nature of the local bathymetry, off-shore slope, and coastal orientation. Note that in Pechorskaya Bay water level height is also affected by seasonal variations in the discharge of the Pechora River.

The average salinity of the Barents Sea is close to the average World Ocean salinity. Its distribution depends on the influx of Atlantic water, sea-ice formation and melt, and terrestrial freshwater discharge into the sea. In the year-round ice-free zone in the southwestern part of the sea salinities of 35‰ have been observed, which is typical for Atlantic water in general. In the southeastern sea it drops to 30‰.

The Barents Sea is the only Arctic sea which never freezes entirely (see Fig. 1). Sea ice present in this region is mainly of local formation, although in the northern part there may be ice carried in by wind and currents from the Arctic Ocean and the Kara Sea. In the central and southeastern areas of the sea the ice is one year old ("first-year" ice), i.e. ice formed during the coldest period of the year. Multi-year ice can be found only in extreme north and northeastern reaches of the sea. Icing starts in September in the north, in October in the centre and in November in the south-east. Most of the ice is of the drift type. Amidst these floes small icebergs (less than 25 m height and less than 500 m length) can be seen. Fast ice forms at Novaya Zemlya, in Kanin-Pechora area and in some inlets of Murmansk Coast. As it forms, the fast ice often breaks up and crawls onto shore. Melt starts in May (sometimes as late as July) in the southeast and in June to July in the central basin.

The historical average boundary of floating ice in the western sea is at a 350–500 km distance from Kola Peninsula. At meridian 45°E the ice edge protrudes sharply south, coming right up to Kola Peninsula near Svyatoii Nos Cape. The permanent ice pack retreats to its northernmost edge in September and grows to its maximum coverage in April. Ice cover in the Barents Sea, which is strongly dependent on atmospheric circulation and the influx of Atlantic water, is characterized by significant interannual and interseasonal variations (see Fig. 1).

SHORELINE TYPES

The look of the coastal zone is a result of its sequential development in Late Pleistocene and Holocene against the background of the sea level rise after the Ice Age and the subsequent stabilization. The coastal zone of the Barents Sea in the limits close to modern situation was formed about 6 thousand years ago [Kaplin, 1973], when the sea stabilized at today's level. Over the time ensued the sea level has undergone several small oscillations and the thermal and wave processes have grown to be the major factors of terrain-forming developments.

The shoreline of the Barents Sea can be split into two unequal stretches: south-eastern (Kanin-Pechora), where the coast is composed mainly of frozen dispersive sediments, and the rest of the littoral, including Murmansk Coast of Kola Peninsula, the fjords of Norway and all the large islands and archipelagoes trimming this sea (Svalbard, FJL, Novaya Zemlya, Vaigach), where the material exposed to the seafront consists mainly of solid crystallized rock.

The Northern Norwegian Coast (Nordland and Finnmark) has a great variety of fjords due to heterogeneity of the local bedrock [Kaplin, Leont'ev et al., 1991]. Their alignment has also been influenced by the course of the local metamorphized sediment rock layers and fractural tectonics. Within the limits of the fylke of Nordland typical fjords are those with unclear traces of wave action and mainly ones that follow sublatitudinal faults. Lungsfjord is an exception here. This water body follows a fault of submeridional course. The differences in the lithology of the rock that compose the western and eastern shores of this gulf tell directly on its morphology.

In Finnmark – Norwegian northernmost continental region – the fjords are much wider; they have very well developed cliffs and coastal benches adjacent. The glacial forms here have remained in a much clearer state than those of Nordland. Apparently the development of the coasts of these gulfs here has been significantly influenced, along with other factors, by tides. Along with that, the very outline of the local coastline suggests an influence of the fractural tectonics and the local bedrock orientation.

East of Finnmark, ***Kola Peninsula*** is part of the Baltic Crystalline Shield in its geology. This has not ruled out the chance of two geologically absolutely different areas, very unequal in sizes, to have formed. There is the north-western corner of Murmansk Coast (Rybachii and Srednii peninsulas and the Kil'din and the rest of the shore. The first area lies on sediment rock, still rather solid, of Upper Proterozoic. The other, much longer, part of Murmansk Coast is composed of crystalline shale rocks and gneisses, as well as supersolid Archean granites.

The mentioned north-western corner preserves the tradition of fjordic disjointing of coastal land, very similar to what we saw on Norwegian shores. Such gulfs as Pechenga, Litsa, Ara-Guba, Ura-Guba, Kolskii are typical fjords of tectonic-erosion-glacial genesis, akin to Norway's. The shores of these gulfs have high denudation scarps, all of which have relation to concentric faults.

The most typical and the largest fjord here is the Kolskii Gulf. The outline of its coast is characterized by straight-angle turns, which have been born to the participation of radial faults, and not only concentric ones, in its genesis. The depth in the middle, deepest section of the fjord exceeds 300 m. Scarps on the coast may be over 100 and even 300 metres high. Forms that have influenced the shape of the coastal scarps here include not only glacial exaration but also fissures, which have fractured the rock here into separate blocks and chumps due to numerous tectonic disturbances.

Underwater slopes of the fjords of Kola area are steep and in most cases are actually continuations of the fault surfaces, which form the coast above water. Just like in Finnmark, in all the fjords here the underwater sills are very clearly seen as results of flooding by end moraines.

East of Kolskii Gulf the pattern geological morphology and coastal disjunctions changes radically. Given the enormous solidity of crystalline rock, the local coast, of fault / tectonic shapes here, with very well expressed traces of a glacial exaration action on slopes, has practically yielded itself to no change by sea waves. The curvature of the coastal line here has not altered. It has stayed still in its development since the remote glaciation era. Only in some very few cases we can encounter here scarps, grottoes and tidal niches all formed by a cumulative action of waves, tides, and physical denudation. Occasionally we may come across small islets of the type of skerries – the so-called "ludy". The various small fjords (Fig. 3), which here are met sporadically, without forming a continuous fjordal coast, have traces of tectonic origin [Kaplin, 1962].

Svalbard – archipelago consisting of four large islands and a number of small ones – has a tectonic structure composed, all of it, by large faults of meridional and submeridional courses.

Fifty eight per cent of Svalbard is covered by glaciers. Most of them form ice caps. There are also a number of valley glaciers, a great majority of which serves as outlet glaciers. Many glaciers reach the sea. In some places along the coast there is a stretch of step-shaped shore-long narrow flatland, of the type of strandflat. There are also accumulation and abrasion-accumulation marine terraces here. A peculiar feature of these terraces here is that even the highest of them (50–60 m) are of Holocene Age [Kaplin, Leont'ev et al. 1991]. This betrays a very intensive uplift of the archipelago in Modern Age. Pleistocene marine sediments get denuded also in the socle of Holocene terraces [Lavrushin, 1969].

The most typical kind of coast for Svalbard is fjordic (Fig. 4). The fjords of Svalbard are

Fig. 3. A small fjord at Murmansk coast (photo by S.A. Ogorodov)

different from Norwegian ones. They are wider, straighter and have fewer side fjords in them. In the fjords, especially along stretches facing the sea frontally on the peninsulas between them, the prevailing type of coast is the one that has not been changed by any sea action but which has clear indications of a glacial processing of bedrock outlets. The other predominant type of coast here is the abrasion-denudation one. At places, in areas where there are narrow strips of lowland, made of marine and glacial sedimentation, along the shore, the coast is of thermal-abrasion type due to a broad coverage of multi-year frost here throughout the land. The few and short accumulation coasts with their rudaceous beaches recharge mainly from physical (frost-driven) weathering as

Fig. 4. Coast of Isfjord, Svalbard, near Kapp Linne (photo by D.E. Kuznetsov)

products of this action arrive from mountain slopes. The coast of Edge Island has coastal accumulation forms and surge flood plains (laida).

Ice coast is quite typical here too. This is formed by fronts of outlet glaciers and ice cap that reach the sea. In most cases they are actually high scarps of ice that look like walls, in which we can observe various forms of glacier ice structure. All the glaciers of Svalbard that reach the sea give birth to icebergs so the ice walls are constantly renewed. The bottom of the fjords would normally be covered with glacial-marine sediments with a poor sorting and an uneven terrain both so typical of it.

The islands of ***Novaya Zemlya*** and ***Vaigach*** are a prolongation of the Urals mountain system. Geologically they are built of the rocks of Herzynian folding. Along most of the western coast of the islands relatively solid crystalline rocks reach the shoreline. Another influence on the shaping of the local coasts comes from Glavny Razlom Fault. This fault circumvents the western shores of Vaigach and the southern tip of Novaya Zemlya [Kaplin, Leont'ev et al. 1991]. The major fault lines are crisscrossed by numerous minor ones, going athwart. These smaller disturbances have been used by watercourses, which have developed their river valleys in them, and by glaciers, which have reshaped these valleys into troughs.

Most of the shore on the ***Novaya Zemlya*** archipelago belongs to the coast of ingression primary disjointed type. The ruggedness of relief is related to different factors, e.g. glacial-tectonic, exaration-tectonic, erosion-tectonic, and denudation-tectonic. So this gives the ingression primary disjointed coast diversity. One of the varieties in this diversity is fjords, which have been formed as a result of a glacial-tectonic dissection of the shoreline. Fjords are more numerous along the western coast of the more northerly Severnyi Island. Between Stolbovoi Cape and Borisov Cape fjords often have ice banks (Fig. 5).

Along the western coast of the southerner Yuzhnyi Island most of the shore dissection is of the fiardic or fiardic-skerry type. The Novaya Zemlya fiards are relatively shallow

Fig. 5. Ice coast in the north of Novaya Zemlya (photo by D.D. Badyukov)

and wide. They are cone-shaped and deeply cut into land, surrounded by smooth subdued terrain. The coast of Yuzhnyi Island cannot be referred to the class of coast not affected by sea action [Kaplin, 1962], for here, due to a benign geological setting, such shore-forming processes as abrasion and accumulation have been in active development under the action of waves, given that this coast is washed by a warm sea current and is free of ice most of the time. A wide range of all sorts of accumulative terrain forms can be met here in the bays, such as bay-bars, spits, crescent-shaped bars and tomboloes. Occasionally strandflats under and above water can be seen. Here they mainly have abrasion origin.

Almost the entire coast of ***Vaigach Island*** drops at the sea with an abrasion cliff composed of pre-Quaternary rock. The relatively poor dissection of Vaigach western shoreline is explained by the local rock positions, which coincide with the direction of the coast here. Quite often the foot of the abrasion cliffs would be rimmed by beaches composed of rudaceous material. The western and north-western shoreline is disjointed due to groundwater flooding of synclinal folds and downthrown block, which makes this coast a relative to Dalmatian one [Kaplin, Leont'ev et al. 1991] or to fiardic type of separation. Abrasion bays have been formed where more yielding rock has come to surface. This can be referred to the type of abrasion-bay coast.

Normally the coast of ***Franz Josef Land*** is referred to fjordic type, however. As P.A. Kaplin notes [1962], it is remarkably different from the types of fjords reviewed previously. First of all, most of the fjords here are not gulfs or bays but sea straits between islands. There are some gulf fjords but they are few and small. The other distinguishing trace of FJL fjordic pattern is that here the ice action on the slopes of the fjords has not been as massive as elsewhere we described above.

Fronts of ice cap descending right into the sea have taken up more than 60% of the total coast length. A typical FJL coast would be a wall of ice – flat or concave – several dozens of metres high. The coast-adjacent part of the JFL Islands in terms of its geomorphological structure is a terraced or inclined sloping surface of littoral-marine accumulation. As a rule, in its lower part it is built of well-rolled boulderet material, with inclusions, more here less there, of materials of smaller grading. The upper part consists of cobble roundstone filled with fine ochreous material. Traces of earlier sea level position are normally clearly visible across the terrain in the form of beach ridges up to 1.5–2 m high and terraces several dozens of metres wide; sometimes, less often, hundreds of metres, depending on the general gradient of the island's surface. The joint of the uppermost terrace on the central JFL Islands is located at the absolute altitude of about 35 m. On Bell Island the joint of the uppermost terraces, out of the 7 existing there, is at the absolute altitude of some 50 m.

As noted above, the south-eastern shallow water sector – the ***Kanin-Pechora sea region*** (including the ***Kolguev Island)*** – is fundamentally different from the rest of the Barents Sea in terms of both its structure and coastal dynamics. Kanin Peninsula and the north-eastern coast of Cheshskaya Bay are referred to the ancient Orogenic zone of Timan ridge, which has in its foundation metamorphic Proterozoic shales and sediment rock of Lower and Middle Paleozoic. The rest of the coast, up to Haypudyrskaya Bay, lies within the limits of Pechora Plate, which bedrock is capped by a thick mantle of sediment rock, overarched by a thick layer of glacial and marine Quaternary deposits. The coast of Haypudyrskaya bay and further east up to Yugorskii Shar Strait is referred to Pre-Uralian sag, made of Upper Paleozoic molassa and overlapped from surface by marine and glacial Quaternary deposits. This means that along most of the coast under review the rock that is denuded here includes dispersive Quaternary deposits, which have stayed in a frozen condition since Late Pleistocene given the severity of the climate, and the later frozen rock, which has stayed since the second half of Holocene and in the bodies of large river barriers and spits.

The northern and western shores of ***Kanin Peninsula*** are under intensive destruction [Kaplin, Leont'ev et al. 1991]. The loose sand-clayey marine sediments that build local shores are occasionally gripped by permafrost, which triggers thermal abrasion developments. The speed, at which Kanin thermoabrasion shore recedes from the sea, reaches a value of 2 m/year [Gorbatskii, 1970]. There are two exceptions to this general trend. The capes of Kanin Nos and Mikulkin represent cusps of metamorphic bedrock. Near Naydenny cape shore accumulative forms are developed. The latter include here the cape's nearby spit and a ridge of accumulation islets called Kambalnitskiye Koshki, which are a continuation of the spit.

The morphology of ***Cheshskaya*** and ***Indigskaya*** bays is comparatively diverse: it includes laidas up to 2–3 m high, a complex of terraces (from 4–6 to 30–40 m) and bedrock outcrops, not numerous. Despite the two bays' limited exposure to the sea, destruction is quite active here. According to some data sources [Kaplin, Leont'ev et al. 1991], thermal abrasion of coast is also developed here. According to aerial photography evidence confirmed by morphological signs, the maximum average historical speed of shore cusp recession has been assessed at 3.5 m/year (as at the cape of Zapadny Ludovaty and near the mouth of river Prischatinitsa). High tides have led to the general pattern of wide and mainly sandy tide flats – starting from 2.5–3.0 km near the mouths of Oma and Vizhas rivers and ending with up to 100–150 m in the direction of Mikulkin and Svyatoy Nos capes. The sand sedimentation in such tide flats and beaches usually does not exceed 2 to 4 m. The underwater coastal slope does not have a clearly identifiable boundary and smoothly transforms itself into the sea bed of a shallow bay. Submarine bars dot the entire surface of the underwater slope, with heights between 2 and 3 m.

The Island of ***Kolguev*** is made up of a mass of sedimentary Neogene-Quaternary sandy-agrillaceous permafrost formation. The year-averaged temperature of the frozen deposits varies between –0.8 and –3.0°C depending on the hypsometric levels [Ershov, 1988]. Consequently the thickness of the permafrost formation increases from 30 to 150 m. There are also masses of layer ice 0.5 to 2.0 m thick [Velikotskii, 1998].

On the western and northern coast of Kolguev a gently sloping hilly flatland with heights between 30 and 65 m comes to the shore where it drops abruptly leaving steep coastal cliffs 40 to 50 m high, sheer walls plumb in their middle profile (Fig. 6). In plane the edge of the coastal bluff is irregular, scalloped, the cliffs indented with numerous ravines and scours. Where layered ice is striped, there are large coastal thermocirques, 200 to 400 m long along the shore and cutting in up to 200 m upland. During the last half a century the thermoabrasion coast of western Kolguev has been retreating at an average of 0.6 to 2.6 m/year [Perednya et al, 2003].

Fig. 6. Thermo-abrasion coast in the east of Kolguev Island (photo by A.I. Kizyakov)

Continental land massif protects the southern and southeastern parts of the island from direct wave impact. At this part of the Kolguev Island that is opposite to the main wave-inducing winds, the wave energy flux weakens, and sediment flows forms accumulative landforms such as the Western and Eastern Tonkie Koshki spits and a big spit-barrier separating the Peschanaya lagoon from the sea.

The Timanskii Coast stretches from Svyatoii Nos Cape to the peninsula called Russkii Zavorot. Svyatoy Nos Peninsula is an accumulation form of double recharge of tombolo type created by drifts, brought in from the direction of the abrasion coast of Indiga Bay and the counterflow from Gornostalya Bay [Suzdalskii, 1974]. The tombolo links the coast to a bedrock deposits outlier. Further north-east there is a relatively strait section of the coast, almost 200 km long, called The Timanskii Coast. Between Svyatoii Nos Cape and Sengheyskii Island the coast is abrasion-accumulative. The coasts washed by Gornostalya Bay are mainly thermoabrasional (in the frozen formation, which underlies the local marine terrace, 25–35 m high). Further east there are some sections of accumulative coast. Sengheyskii Island, up to 50 m high in absolute altitude, has bedrock deposits in its foundation and is probably outlier of a denudation plain of Middle-to-Late Pleistocene age. On the surface of this island there is an ongoing eolation. The fact that there is a big amount of sand material on the island is explained by a discharge of a flow of drifts coming here both from the west and from the east. North-east of Sengheyskii Island there is a well-developed Holocene barrier 5 to 10 m high. In today's conditions the barrier is open to scours so as a result of that in some areas – for instance, east of Kolokolov Bay – a lacustrine-alluvial terrace 10–15 m high, of Late Pleistocene to Holocene age comes to shoreline. The coast here is thermoabrasional. No study of the coast recession speed has been done for this area, but judging by the morphological features of the local abrasion bluffs it should be at least 1 m/year.

The Pechora coastal region includes the accumulative forms of Russkii Zavorot and Gulyayevskiye Koshki [Popov, Sovershaev et al. 1988]. These forms are a Holocene bar. Gulyayevskiye Koshki is the barrier, partly under water, partly islets, that continues Russkii Zavorot for well over 50 km fencing off Pechora Bay from the north. That this chain is really a barrier can be verified by absence of any serious sources of recharge, which could have ensured here a massive longshore transport of drift material, and by presence of layered ice of subaerial origin [Velikotskii, 2001]. Russkii Zavorot Peninsula is made up of a well-sorted sand material, wherefore there is an intensive eolation going on the surface that has already brought about a massive belt of dunes.

Gulyayevskiye Koshki is a chain of nine barrier islands dividable into Western and Eastern ones. The Western islands are larger than Eastern ones and they move to the south and east. Tides and drifts generate deltas as straights between islands. Waves generate spits at the tips of the islands. Overall these forms, fed by drifts both from seabed and Pechora bay, are relatively stable. Due to some local peculiar hydrodynamic features the position and sizes of the Western islands in the chain keep changing all the time [Suzdalskii, Kulikov, 1997]. These forms are not stable and are not suitable for any construction of long-term buildings on them. In the old 16^{th}–17^{th} century maps of the Russian Pomors the chain of Gulyayevskiye Koshki is shown to have larger islands, than today, and more numerous at that [Ogorodov, 2003]. Probably, Russkii Zavorot and Gulyayevskiye Koshki used to be a single accumulative form in old times.

Within ***Pechora Bay*** we register a succession of abrasion-thermodenudation coasts (developed in frozen post-ice-age marine, alluvial-lacustrine and biogenic sediments) and accumulative laida-type plus lagoon-bay type coasts. The delta of the Pechora occupies the southern part of the bay. Morphologically this delta is of the type of multi-branch deltas.

Much of the total length of the coast here is taken up by fossil abrasion bluffs, rimmed up by an adjacent lacustrine-alluvial-marine young terrace, i.e. a laida. Laidas appear in the back parts of barrierss, spits, shore in-bends and innermost apex corners of gulfs under an influence of high storm-driven sea surges, which here can be up to 2.5–3.0 m high. The generation of a laida is related to an intensification of the accumulation process as a result of a Holocene stabilization of the level after a long Flandrian Transgression, during which an abrasion process dominated the scene. Laidas are drained by creeks and numerous laidic channels, which are generated under the influence of surges and tides.

According to available data [Suzdalskii, Kulikov, 1997], the average rate, at which the abrasion-thermodenudation coast in the south-eastern part of the bay (near Vangurei village) retreats, is between 0.8 and 1.2 m/year, 0.4 m/year or even less in the bays. The relatively small abrasion values are due to the dynamically active period being shorter here than along the open coast of Pechora Sea and the wave power here, in a partly closed water sector of the bay, being low. According to the same authors, the littoral offshore zone of the bay receives some 1,000 m^3 of sedimentary material, which is more than 4.5 times less than the solid runoff of the Pechora, through abrasion of the coastal bluff and the adjacent continental slope. Apparently most of the fine-dispersed material is borne beyond the limits of the bay, including through the flooded channel of the paleo-Pechora and through the numerous runoff channels used by the tidal and surge water. In Pechora bay tides may be up to 1.2 m high. This ensures that in the concavities of the shore and in the wave shade of the accumulation islands here a regular tide-flats are quite common.

Varandei coastal region encompasses the section from Pesyakov Island in the west to Medynskii Zavorot peninsula in the east. Pesyakov and Varandei Island are coastal Holocene bars of sand material. In structure they are similar to Russkii Zavorot Peninsula [Popov, Sovershaev et al. 1988]. The frontal segments of these barriers are exposed to scouring at the modern stage. At their distal tips the coast is accumulative. To the east from Varandei Island there is an outlet to the shoreline of a 5–15 m terrace; here the coast is thermoabrasion: there is an exposure to abrasion of a frozen mass of Middle Pleistocene bouldery loams and clays surfacing in the socle of the terrace. Medynskii Zavorot Peninsula has a complex genesis – a halfway option between a spit and a barrier.

Under the defense offered by the barriers and spits some windy-tide-flats and laidas have developed. Although the average tide height in Pakhancheskaya and Perevoznaya bays is pretty moderate (0.8 to 1.2 m), the fact that the bias of both the onshore coast-adjacent land behind the bars and the underwater coastal slope is very gentle contributes to the development of such forms. South of Perevoznaya Bay up to the mouth of Haypudyrskaya Bay a vast accumulation form has shaped up under the action of the surge oscillations of the level. The part above water is represented by a large laida dissected by a network of channels, whereas the part under water is a surge-cleared dereliction example.

The dynamics of Varandei Coast is well documented. Since 1981 several laboratories of various institutions, including the Laboratory of Geoecology of the North of MSU Geography Faculty, have conducted stationary monitoring here. In areas relatively little affected by human activity the coast retreat speed is 1–2.5 m/year on Pesyakov [Ogorodov, 2001] and 1.8–2.0 m/year [Novikov, Fedorova, 1989] within the limits of the local thermoabrasion coast. The coastal bluff of Varandei Island undergoes a destruction of about 3 m/year [Ogorodov, 2005] (Fig. 7) on average, under the impact of human activity in the area.

The chain of islands to the north-east from Varandei Coast, although near, has a

Fig. 7. Coastal erosion on Varandei Island, June 2000 (photo by S.A. Ogorodov)

different origin. The Islands of Matveyev, Golets, Dolghii, Zelentsy from a single linear elongated out shot of crystalline deposits reworked by wave processes and physical weathering. The coast here is from abrasion to abrasion-bay. The attached and the pocket beaches consist of shingle and rock debris. The beach barrier marks remaining in the modern terrain go further and further up towards the centre of Dolghy Island, which nay testify to its tectonic uplift. The presence of crystalline rock, the considerable altitudes (10–18 m) make the coasts of these islands and the islands themselves, especially Dolghii, quite stable and suitable for practical use.

The shores of ***Haypudyrskaya Bay*** are represented by all the structural varieties characteristic of the south-eastern Barents Sea. Such diversity is explained by the fact that many different morphogenetic complexes make it to the shoreline of the bay. These include types from deltas of small rivers to high marine terraces, 50–60 m in altitude. High (up to 50 m) abrasion-thermodenudation bluffs rim the bay from south-south-west. Typical thermoabrasion coasts occupy the northern and western sectors. Accumulative beach and delta coasts appear in the south-east. In the southern inner cove of the bay large wind tide-flats are formed. These are similar to those of Cheshskaya bay.

Zapadno-Yugorskii coastal region stretches from Sin'kin Nos Cap to the sea strait of Yugorskii Shar (Popov, Sovershaev et al., 1988). Unlike the areas described above, here the rock mass that makes the coast is largely a boulder-and-pebble material. In the northern part there is an example of hard rock coming out to meet the sea. Sin'kin Nos Cape is actually a bedrock outcrop with a mantle of mainly loose rudaceous material on top. In the concavity of the shore to the east of the cape an accumulation process prevails in general. Near the mouth of the Korotaikha River a large fan builds, i.e. the avandeltas of the stream. To the south of Yugorskii Shar strait there is a large accumulative form (Bel'kovskii Nos Cape), which unlike most of the barrier-spits of the south-eastern sector of the Barents Sea, is made up of chiefly macrofragmental material.

CONCLUSION

In summary, there are coastal dynamics features, which make Barents Sea totally different from other Arctic seas.

Barents Sea has an extraordinary wave power potential, which is due to an intensive activity of cyclones on the one hand and to a considerable length of the dynamically active period on the other hand, e.g. a large part of this sea cannot be capped by ice even in winter.

The structure and dynamics of the coast in the Norwegian-Murmansk sector of the Barents Sea as well as the numerous islands and archipelagoes are determined by a high solidity of the local rock and by the fact that it has developed against the background of a glacioisostatic land elevation.

Unlike the above, the structure and dynamics of the Kanin-Pechora sector of the sea, including the island of Kolguev are determined by the wide spreading of dispersive coastal deposits, mostly frozen, which preconditions the development of the thermo-abrasion effect. The large amount of sediments in the area and the intensive wave action triggered the development, in Holocene transgression, of big accumulative forms so typical to this part of the Arctic, such as spits and barriers.

Over the last few years the coast and shelf of Barents Sea have become a priority area for oil-and-gas development in the Russian Arctic. In this context it is important to realize that making truly responsible strategic decisions towards the development of this part of the country and construction of new facilities is to be supported by a comprehensive knowledge the local environmental processes, e.g. coastal dynamics. Ignoring this issue can mean irreversible implications both for the coastal geosystems and the facilities themselves, up to their destruction, which can bring in unpredictable environmental repercussions.

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