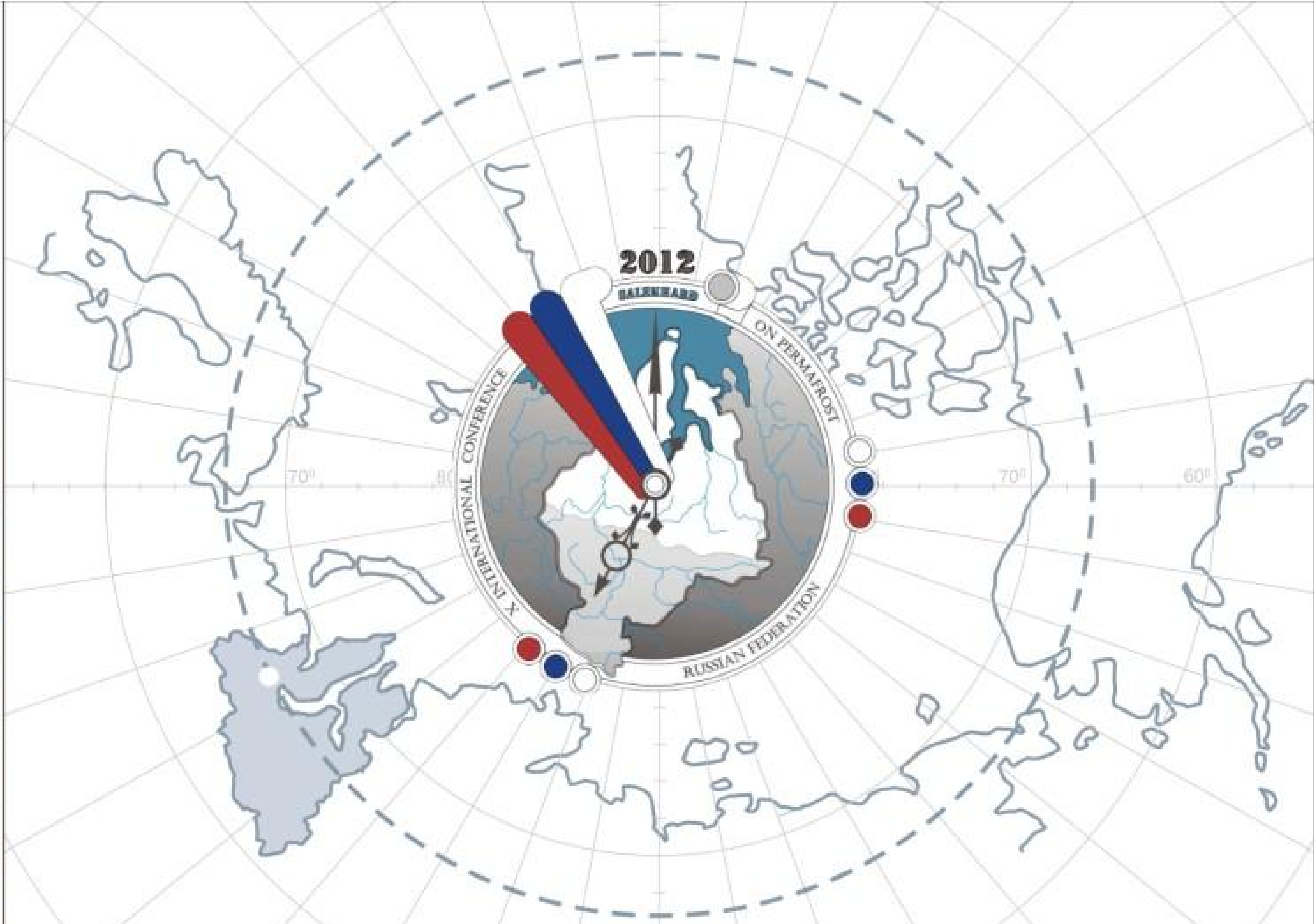

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Quaternary Deposits and Geocryological Conditions of Gydan Bay Coast of the Kara Sea

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Abstract

A description of the geological and geocryological structure of coastal exposures of Gydan Bay is presented. The data on isotopic and chemical composition of ground ice, texture, and age of deposits are presented. Two generations of polygonal wedge ice are distinguished: the Late Pleistocene and the Holocene. The conditions of sedimentation, freezing, and denudation of deposits during the last glaciation and the Holocene optimum are determined.

Keywords: Gydan Bay; permafrost formation; Quaternary deposits.

Introduction

Gydan Bay of the Kara Sea is one of the least accessible areas of the northern parts of Western Siberia. The data on geomorphology, Quaternary sediments, and modern processes in the north of Western Siberia were discussed by Saks (1951). The Quaternary deposits of the area were studied and mapped during geological mapping by the Arctic Geology Research Institute (Sokolov & Znachko-Yavorskiy 1957).

The permafrost conditions and Quaternary deposits of the Gydan Peninsula were thoroughly studied in 1973–1985 by the Tyumen expedition of the Department of Soil Science and Engineering Geology, Geology Department of Moscow State University (Trofimov et al. 1986). As a result of these investigations, the regional stratigraphic scheme of Quaternary deposits was developed; tabular massive ice, wedge ice, and modern processes of thermokarst and thermal erosion were studied.

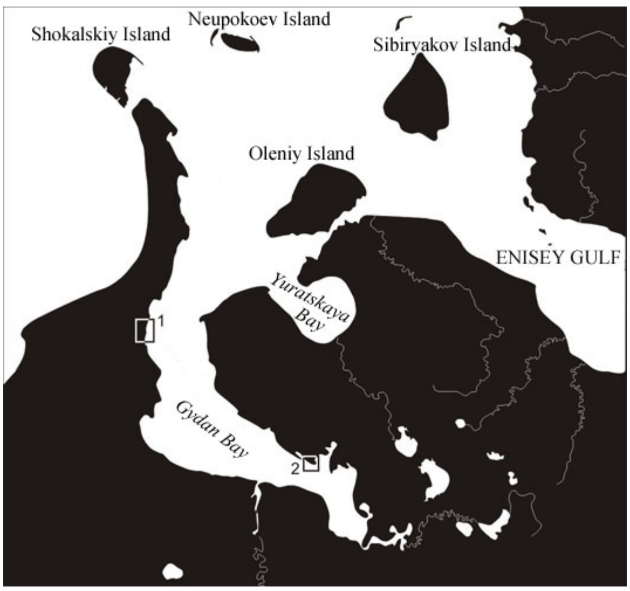

Figure 1. The research areas location: 1 - Era-Maretayakha River estuary; 2 – Cape Pakha-Sale.

Based on the section of the organo-mineral complex in the Mongatalyangyakha River estuary, which is located near the section in the Era-Maretayakha River estuary studied by the authors, Vasilchuk (1992) obtained a series of radiocarbon Late Pleistocene datings at different elevations above sea level: at 3.5 m, 30,200 ± 800 years BP (GIN-2470); at 4.5 m, 28,600 ± 800 years BP (GIN-2638); at 5 m, 25,100 ± 220 years BP (GIN-2471); and at 5.9 m, 21,900 ± 900 years BP (GIN-2469). Peatland at the elevation of 9.3 m had a radiocarbon age of 3,900 ± 100 years BP (GIN-2468).

The fieldwork conducted in 2010 by MSU, the Earth Cryosphere Institute, and the All-Russia Research Institute for Geology and Mineral Resources of the World Ocean covered the western and eastern coasts of Gydan Bay (Fig. 1). The description of the geological and geocryological structure of the Quaternary deposits and the data on isotopic and chemical composition of ground ice, texture, and age of deposits are presented in this paper.

Results and Discussion

Era-Maretayakha River estuary

The studies were conducted near the Era-Maretayakha River estuary located on the eastern coast of the Gydan Peninsula. The structure of the coastal bluff consists of inclined eroded surfaces with elevations of 10–25 m and a steep thermal erosion bluff descending to the modern beach (Fig. 2.1).

To the depth of 4.7 m (Fig. 2.1, section 1006), the upper part of the section is represented by frozen lacustrine and peat deposits with a significant ice content. Thick layers of almost pure ice are interbedded with poorly decomposed peat. Radiocarbon dating of a peat sample from the depth of 3.8 m provided an age of 8,500±90 yr BP (LU-6535).

Lower silty sediments are exposed (the silt particle content is more than 54%; Fig. 2.1, section 1007). The

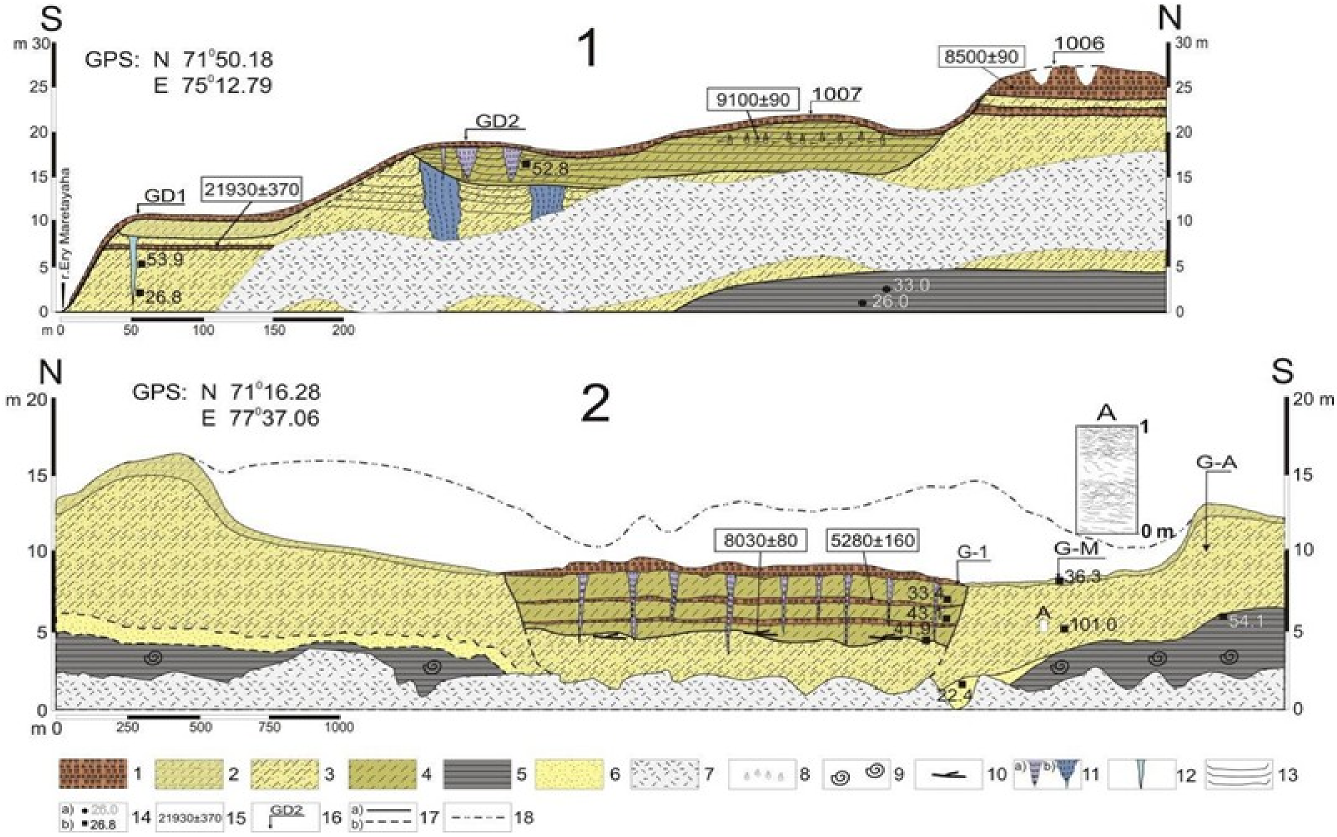

Figure 2. The scheme of the structure of the coastal exposures of Gydan Bay: 1 – Era-Maretayakha River estuary; 2 – Cape Pakha-Sale. Legend: 1 – peat; 2 – interbedded sandy silts and sands; 3 – silts; 4 – peaty silts; 5 – clays; 6 – sands; 7 – slump; 8 – fresh-water lacustrine shells; 9 – sea mollusks; 10 – wood debris; 11– wedge ice: a) Holocene, b) Late Pleistocene; 12 – ice in fractures; 13 – belt-like cryostructure; 14 – gravimetric moisture content (in %): a) total, b) of mineral interlayers; 15 – radiocarbon age of organic inclusions, years BP; 16 – number of section; 17 – lithologic boundaries: a) identified, b) assumed; 18 – position of the surface that did not undergo thermal erosion.

sandy silts contain peat, plant roots (the organic carbon content reaches 0.9%), and freshwater mollusk fragments. The deposits are ice-rich. The total gravimetric moisture content is about 53%. The cryostructure is belt-like. The cryostructure between the belts is reticulate. Radiocarbon dating of plant roots obtained from the depth of 4 m showed the age of 9,100±90 yr BP (LU-6534). The amount of sand particles in soil increases with depth, while the organic content decreases (organic carbon content reaches 0.2%). Closer to the Era-Maretayakha River estuary, in the section of a surface about 10 m high, silts are interbedded with fine sands and peat interlayers. The cryostructure of deposits is porous (structureless). The total gravimetric moisture content decreases with depth from 54 to 27%. High ice content of the deposits allows us to assume their syngenetic nature. The peat interlayer in sandy deposits at the depth of 2.2 m has the radiocarbon age of 21,930±370 yr BP (LU-6542). In the northern part of the exposure, the silts from the depth of 20 m are underlain by ice-rich clays with a reticulate cryostructure. The upper contact of clays and silts is sharp and goes under the sea level at the southern part of the exposure. In clays, the mineral blocks with the dominating size of 10 x 10 cm are divided by ice lenses up to 1 cm thick. The moisture content of mineral blocks is 26.0–33.0%. The isotope analysis of segregated ice (-8.48‰ for $\delta^{18}O$ and -63.4‰ for δD) and the cryogenic structure point to the epigenetic nature of frozen deposits. The clays have a high content of organic carbon (0.89%). Most likely, the clays were accumulating in a shallow, relatively warm sea.

Two generations of polygonal wedge ice (PWI) (Fig. 2.1, section GD2) are exposed in the section: the upper PWI with the width of 1.2 m on top and the height of 3.6 m and the large lower PWI with the width of 2.5 m on top and the height of more than 10 m. The silts containing PWI have a high ice content. The gravimetric moisture content at the depth of 1.3 m is 52.7% (Fig. 3).

The isotope composition of the upper PWI varies from -23.6 to -18.3‰ for oxygen ($\delta^{18}O$) and from -179.9 to -134.3‰ for hydrogen (δD); the deuterium excess (d excess) varies from 9 to 12‰. Unfortunately, we were unable to sample the PWI of the lower generation. These wedges are observed in deposits with the age of more than 10,000 years, and the isotopic composition of most wedge ice is rather low. This suggests that the ice wedges were formed mostly during the Late Pleistocene.

Large syngenetic ice wedges were not observed in the southern part of the exposure. It is possible that they were eroded by slope processes or partly thawed. Here, thin (width of up to 0.4 m) ice wedges with the average vertical extent of 4.5 m (section GD1) penetrate into sands and silts. The content of oxygen and hydrogen stable isotopes in the ice does not change with depth and varies from -24.6 to -22.6‰

Figure 3. Silts containing two generations of polygonal wedge ice.

for $\delta^{18}O$ and -193.1 to -176.5‰ for δD; the deuterium excess does not exceed 6–7‰. The noticeably high content of chlorine ions (8.8 mg/l) was detected in the ice wedges. The isotope composition of wedge ice most likely indicates the Late Pleistocene age of the ice.

Based on the simple linear relation between the average January temperature (t_j) and the isotope composition of oxygen ($\delta^{18}O$) in the PWI that was suggested by Vasilchuk (1992), the average January temperature during the PWI formation was determined: $t_j = -1.5\delta^{18}O$ (±3°C), which equates to -36.0 ±3°C.

Cape Pakha-Sale

The northern coast of Gydan Bay near Cape Pakha-Sale was another area of our research (Fig. 2.2). Here, marine and coastal-marine sand and silt deposits were exposed in coastal bluffs with the height of 15–20 m. More ancient marine deposits are overlain by the Late Pleistocene-Holocene continental sediments with plant detritus. Numerous bone fragments that were washed out of coastal bluffs are scattered along the beach.

A lens of lacustrine deposits with the thickness of 4 to 6 m and the visible length of 1200 m contains laminated silts with organic matter (organic carbon content reaches 1%). Sandy silts transform into silts with some clay at the depth of 2 to 4 m. The amount of organic debris decreases. The content of silt particles increases from 35% at the depth of 1.4 m to 56% at the depth of 3.7 m. Ice content increases with depth. The total moisture content of silts increases from 33% at the depth of 1.4 m to 64.7% at the depth of 3.2 m. The cryostructure of sandy silts is layered. The age of wood inclusions at the depth of 2.6 m at the contact of sandy silts and silts with some clay is 5,280+/-160 yr BP LU 6540. At the depth of 6 m, sandy silts with high organic content are replaced by dusty sandy silts. In particle size distribution and in the content of organic carbon they are similar to sandy silts that contain the lens of lacustrine sediments. The total moisture content at the layers contact was 41.9%. The radiocarbon age of wooden inclusions at the contact was 8,030+/-80 yr BP LU 6541. The cryostructure of the lower silts is reticulate. Most likely, these are lacustrine talik deposits.

The lens of lacustrine deposits is embedded into a layer of silts that form the slopes of thermokarst depression and 15 m high surface. Sediments include 83% silt. Up to the depth of 4.0 m, the 15 to 20 cm thick layers with a higher ice content alternate with 80 to 90 cm thick layers containing less ice. The cryostructure is belt-like, and between the belts it is micro-lenticular (Fig. 2.2, inset A). The gravimetric moisture content of silts reaches 101%. Silts are underlain by grey, fine-grained sands. The sand layer thickness reaches 3 m (Fig. 2.2, section G-1). The sand cryostructure is porous (structureless). The gravimetric moisture content is 22.4%. The sand interlayer wedges out in the southern part of exposure. Sands in the northern part and silts in the southern part of the exposure are underlain by clays containing abundant fauna of marine mollusks. Moisture content at the contact of clays and silts is 64.1%.

Lacustrine deposits include a PWI complex. The ice wedges form a polygonal network on the surface with the polygons of 18 to 55 m across. Ice wedges have a width of 20–50 cm on top and a vertical extent of 2–5 m. The polygonal wedge ice is brownish white, vertically foliated, and oxidized at the contact with hosting soils. The PWI isotope composition is -19.1‰ for oxygen ($\delta^{18}O$) and -146.2 ‰ for hydrogen (δD), the deuterium excess (d excess) is 7.2‰. A relatively low chlorine ion content (5.0 mg/l) is typical of ice wedges that were formed without the influence of sea water. According to the data by Vasilchuk (1992), PWI from the north of the Gydan Peninsula is characterized by average values of $\delta^{18}O$ about -18‰.

The filling of thermokarst depression occurred in two stages. During the first stage in the beginning of the Holocene, deposits accumulated in the lake during the destruction of coasts that consisted of ice-rich silts. Coarser sand sediments accumulated at the end of the filling of the lake basin. A horizon with relatively low ice content and post-cryogenic cryostructure indicates the existence of a talik under the lake.

Conclusions

The deposits studied in coastal cliffs of Gydan Bay are of the Holocene and Late Pleistocene age. The two generations of PWI that we distinguished are also of different ages: the lower one is the Late Pleistocene, and the upper one is the Holocene. The formation of the lower generation of syngenetic PWI (polygonal wedge ice) occurred during the last glaciation, when the sedimentation in a shallow and relatively warm sea was replaced by continental sedimentation. Similar conditions existed in the Sopochnaya Karga area in the Enisey River estuary, where the sediments of the second fluvial terrace were accumulating at that time (Streletskaya et al. 2007). A drastic landscape change occurred during the climatic optimum of the Holocene. At this time, shrubs and even trees existed here. A large number of freshwater mollusks lived in the lakes, and these are not present in the modern lakes of the Gydan tundra. After the optimum, sediments, including peaty strata, froze. During the climatic optimum, the Late Pleistocene PWI of the lower generation partly or completely degraded. Thermokarst depressions were formed, and an active formation of gullies along degrading ice wedges occurred. The Holocene cooling that occurred 5,000 to 4,000 years ago (according to the estimates, January temperatures at that time dropped to -27±3°C) caused frost cracking and the formation of the upper generation of ice wedges. They show higher isotope content compared to the Holocene PWI in the areas of Dikson, Sopochnaya Karga (Streletskaya & Vasiliev 2009, Streletskaya et al. 2011, Siegert et al. 1999), Sibiryakov Island, and in other arctic regions (Pavlova et al. 2010). Syngenetic Holocene ice-rich deposits containing PWI blanket a high surface and adjacent slopes. They fill thaw lake basins and old thermokarst cirques, which formed due to thawing of tabular massive ice bodies.

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