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GROUND ICE AND RELIEF EVOLUTION ON THE ISLANDS AND COASTS OF THE RUSSIAN ARCTIC

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Abstract

Analysis of long-term field observations (1985-1997) of geomorphic processes indicate that the intensity of the relief-forming processes depends on ground ice and ice-rich deposit distribution and on modern relief features. The most intensive erosional processes are characteristic of plains with massive ground ice bodies (Central Yamal, the northern part of Anabar-Olenek interfluve; Novosibirsky Islands) while erosional plains are characterized by a prevalence of sediments with low ice contents and erosional processes are correspondingly less active. Thermal erosion, thermal abrasion and "thermal denudation" are the most important and widespread processes in regions which are formed out of ice-rich deposits: the volume of transported material is up to 100,000 m^3/km^2 per year and more. A comparison of the intensity of erosional processes in the various Arctic regions is presented.

Introduction

The patterns of formation of modern relief in Russian Arctic Region are poorly understood. The relief and surficial sediments of small islands in the cold seas which are covered by ice during almost the whole year are practically unknown. There are few data on modern relief development and on the mechanisms, distribution and intensity of erosional processes on the plains of the North. Long-term (1985-97) fieldwork in various areas of the Russian Arctic Region (Figure 1) allowed us to reveal some features of modern relief formation and to examine the connection between the intensity of geomorphic processes and ground ice distribution. We used the following methods: field observations, geomorphological mapping, survey observations of erosional rates and analysis of aerial photos.

Landforms and surficial deposits in the study area

There are two types of landscapes within the study area: (1) coastal lowlands and (2) erosional plains. Within the former group, there are territories composed mainly of surficial sediments with low ice contents (Sverdrup Island) and areas with massive ice layers and ice-wedges (Central Yamal, northern part of Anabar-Olenek interfluve; main part of Novosibirsk Islands). The second landscape type includes erosional plains of Taymyr, as well as the islands in the Kara and Laptev Seas.

Sand-clay sediments with peat and rare thin (up to 1-1.5 m) ice wedges are mainly characteristic of the Yamal coast. Marine and lacustrine-fluvial terraces with the heights of 10-18 and 4-9 m, respectively, formed in the late Pleistocene-Holocene, are composed of these deposits. Massive ice bodies of Central Yamal, with heights up to 45 m are found beneath almost all landforms (from III-d terrace with a height 22-35 m up to lower terraces of the Mordyyakha River with a height of only 1-7 m) and are well known (Machaney et al., 1995). The surface area of some of these ice bodies reaches 10 km^2 (Solomatin et al., 1993). The genesis of these ice bodies is debatable. The hilly plain in the northern part of the Anabar-Olenek interfluve with a height of 10-40 m is formed by consecutive alternation of lacustrine-fluvial sandy-clay sediments, peat layers, and syngenetic ice veins with a height of up to 20-25 m. The thermokarst-erosional plains of the Novosibirsk Islands with heights up to 50 m have a similar structure. Here massive (up to 10 m) ice wedges are widely distributed in loessic sediments.

In contrast, the thickness of surficial sediments with the low ice contents located on the elevated plains of the Northern Taymyr, usually does not exceed several meters. Here, even underground ice veins are relatively rare. The dome-shaped Izvesty TSIK and Russky Islands are composed of Proterozoic slates and sandstones. The structural-erosional plains with heights up to 40 m are covered by eluvial-deluvial loams with gravel up to 2-3 m in thickness. On rocky Preobrazheniya Island (Laptev Sea), ground ice veins

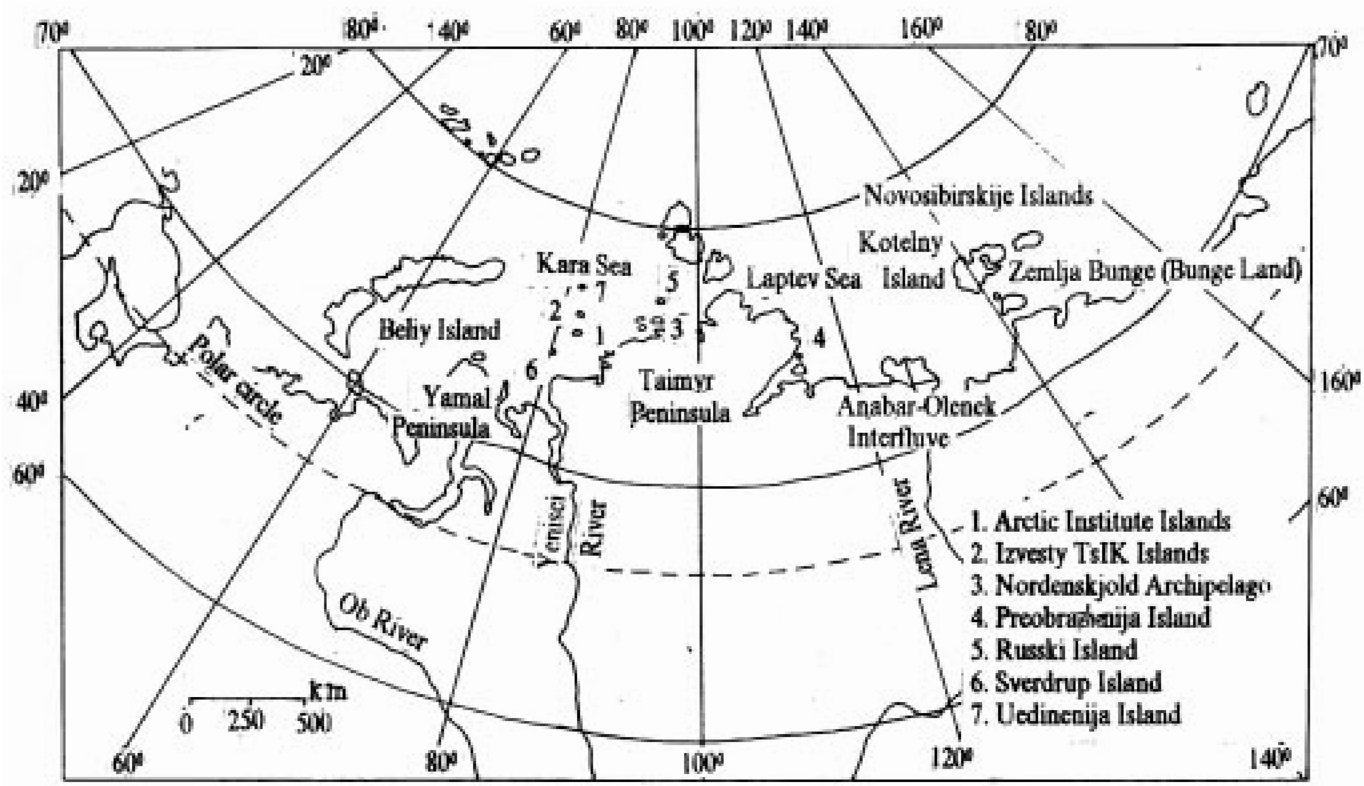

Figure 1. Field study areas: 1. Arctic Institute Islands; 2. Izvesty TZIK Islands; 3. Nordenskjold Archipelago; 4. Preobrazhenija Island; 5. Russky Island; 6. Sverdrup Island; 7. Uedinenija Island.

are located in sandy-clay-gravelly sediments at heights of 10 to 80 m above sea level. The Eastern coast is a vertical scarp with a height of up to 90 m. The Sverdrup and Arctic Institute Islands are erosional plains, up to 40 m height, composed mainly by sand with a great number of erratic boulders. Segregation ice lenses and ice-cement bodies are mostly distributed in the islands near the Taymyr shore and ice-wedges are uncommon here. There are no injected ice and massive ice bodies. At the coastal cliffs of rocky islands, ground ice layers occur that have formed as a result of compaction and recrystallization of marine ice and snow-patches.

Modern exogenic processes

An important group of erosional landforms on the Arctic islands are linear depressions without well-defined channels, up to 100 m wide, sloping at angles of 3-5° and possessing stony beds. The valley depth is no more than 1 m. Canyon-shaped river gorges in bedrock on the Izvesty TSIK Islands and a large (0.5-0.8 km) valley with well-developed fluvial morphology on the Russky Island are exceptions. The fluvial regimes are nival, and discharge ceases and the islands become desert-like in the middle of summer.

The large relief amplitude of an extensive drainage area and the presence of a large polar station on Preobrazheniya Island have led to the development of active thermo-erosional processes (up to 20,000 m^3/km^2). Almost all gullies with V-shaped transverse sections have developed within the traces of tractor vehicles and have intersected underground ice at elevations of 25-40 m above sea level.

The active displacement of meanders causes the intensive drainage of lakes. For example, some 10 lakes with a total surface area of more than 6.7 km^2 were drained in the lower terraces of the Seyakha and Mordyyakha Rivers (Central Yamal) between 1949-1993. The surface area of one of the largest lakes of Kotel'ny Island (Novosibirsky Islands) decreased by approximately by 30% between 1951-1985.

The intensity of landslide processes is high at all coastal cliffs (Table 1). Rockfalls on Prebrazheniya Island occur every 10-15 minutes during the summer time. Erosion rates are high because of freeze-thaw processes. Classical solifluction terraces are extremely rare on the islands (Russky Island). On the Novosibirsky Islands, the displacement of small blocks of soil (width up to 0.15 m) strengthened by lemming activity is highly developed. Within the small ground fissures, the mass movement of soil starts because of their widening by lemmings.

Slopewash is common on Russky, Sverdrup and Izvesty TSIK Islands because the vegetation cover does

Table 1. Intensity of principal exogenic processes (in m³/km² per year)

region	slope processes		slopewash	thermal erosion		cryogenic		thermal abrasion
	rockfall and talus	solifluction		gully	stream	detachment slides	retrogressive thaw slumps	
Central Yamal	100-150	5-10	1-2	10000-12000	500-600	40000-50000	600-700	-
Western Yamal	50-100	1-2	0.5-1	30-40	50-100	10-20	10-20	12 000 - 17 000
Western Taimyr	30-40	12-15	2-3	50-70	150-200	100-200	150-250	10000-15000
North-Western Taimyr	80-100	40-50	0-1	5-10	10-20	0-5	0-5	1000-2000
Eastern Taimyr	5-10	4-7	4-7	60-80	10-20	400-500	200-300	-
North-Eastern Taimyr	0-1	0-1	4-7	5-10	10-20	0-5	5-10	100-200
Sheluskin Peninsula	0-1	1-2	3-4	2-5	10-20	0-5	5-10	-
Arctic Institute Island	0-1	0-1	10-15	200-300	-	5-10	5-10	4000-4500
Izvestij TSIK	400-450	0-1	8-10	50-70	5-10	0-1	60-100	200-300
Russky Island	1-2	3-4	8-10	2-5	5-10	0-1	30-50	300-400
Sverdrup Island	3-5	0-1	10-15	300-400	-	1200-1500	5-10	8000-10000
Kirova Island (roughly)	150-200	0-1	8-10	400-500	10-15	0-5	5-10	15000-20000
Uedineni-ja Island (roughly)	200-300	1-2	15-20	300-400	10-15	5-10	10-15	80000-100000
Preobra-zhenija Island	up to 100 000	0-1	4-6	15000-20000	-	0-5	5000-6000	8000-10000
Anabar-Olenek Interfluve	0-1 (200-250 in coast)	3-4	2-3	200-500	200-400	1000-2000	2500-3000	75000-80000
Kotelny Island	300-400	10000-12000	10-15	400-500	150-200	1000-2000	50000-60000	1500-2000

not exceed 50 %. However the intensity of this process is not high (Table 1) because the precipitation is mostly low intensity rain.

"Thermal denudation" acts together with solifluction and (often) thermal abrasion. Retrogressive thaw slumps are located at sites with significant ground ice (up to 10-15 per 1 km of shore). The underground ice at the seashore leads to their formation. Melting of ice at the headwalls of the thaw slumps leads to the sliding of turf blocks down the scarp. The height of the headwall depends on the thickness of the active layer and blocks of soil travel down along the permafrost boundary. Thaw slump widths reach 150 m or more and depths are 10-25 m. On Russky Island, their formation is not connected with massive ice deposits but with the presence of horizontal ice layers of 2 - 3 cm thick in the ground at the base of the active layer.

In some areas of Central Yamal, active-layer detachment slides, which are a second type of "thermal denudation", occupy up to 60 % of the slope area. Periods of intensive active-layer detachment slides (as on Yamal in 1989) are very dangerous for engineering structures. In one area of about 25 km^2, active-layer detachment slides moved approximately 500,000 m^3 of soil during July-September 1989. The main causes of their formation are the following: presence of ice-rich deposits (in this case, thick layers of ice), warm summers causing an increase in active layer depth and abundant precipitation in August-September. Sometimes only ice layers 1-2 cm thick (heavy loam on Sverdrup Island) are enough for the formation of active-layer detachment slides. Usually each form has a well expressed back-wall, a track without vegetation and a depositional zone containing the transported blocks. Ice deposits are frequently exposed in the scar back-wall which leads to retreat and the formation of retrogressive thaw slumps.

Measurements of retrogressive thaw slump expansion on Central Yamal Peninsula and Novosibirsky Islands were made by periodically mapping the position of the headwall in relation to fixed bench-marks. On Yamal Peninsula during 1990-91 it receded by an average of 3.3 m (maximum 6.4 m), and during 1992-96, by 9 m on average; on Novosibirsky Islands during the summer of 1985, by 0.3-0.5 m; during 1986-94, by 5-8 m.

Thaw slump formation involves active thermal erosion, surface wash, mudflow, block-fall and other processes. Slumps thaw deeply and a rill (and then gully) develops during the summer. When ice-rich deposits thaw, the liquid material is transported downslope. These processes begin in April when air temperatures are below 0°C. In the summer, the intensity of "thermal denudation" is so high that a continuous noise of falling material is usually heard near the scarps.

Deflation acts intensively only on Russky and Zemlya Bunge Islands which are composed mainly by sands, and because of the absence of vegetation cover. In other areas, wind erosion is significant only in dry years (1986).

The rate of thermal abrasion at the coast depends on the scarp height, ice content and grain-size composition of the exposed sediments, as well as on the climatic conditions in a particular year. On the western shore of the Yamal Peninsula, the rate of abrasion ranges from 0.3 to 4.9 m/year (maximum of 11.8 m/year) (Sovershaev, and Kamalov, 1992); in the North of the Anabar-Olenek interfluve, 4-5.5 m/year; on Kotel'ny Island, 0.3 m/year. During 1935–1993, the shore-line near the polar station on Russky Island, formed of early Proterozoic slates, had receded by 18 m. Shore sections where ground ice is exposed at the surface (e.g., Bely Island and coast of the Yenissey Gulf) can recede 18-20 m during a single storm.

Conclusions

1. Thermal erosion, thermal abrasion and "thermal denudation" (basically thermokarst development) are the most widespread geomorphic processes on the islands and coasts of the Arctic seas. The main factor which determines their location and activity is the presence of significant ground ice and ice-rich deposits (Table 1).

2. The most active erosional processes characterize coastal plains containing massive ground ice. In contrast, relief-forming processes on erosional plains operate at low intensities;

3. Thermal erosion and thermal abrasion become catastrophic in intensity and in the volume of material removed over relatively small areas in unconsolidated sediments containing significant amounts of ice. If there are no ground ice deposits, permafrost factors do not play the main role. When massive ground ice or ice-rich rocks are present adjacent to a river channel in the coastal slope, other influencing factors become of minor significance;

4. The "thermal denudation" rate is high because of the strong influence of positive air temperatures and solar radiation. Even in severe climatic conditions during the summer, ground thawing continues;

5. Thermal erosion and "thermal denudation" are connected very closely. The sites of most intensive "thermal denudation" development are located mainly in areas highly dissected by erosion.

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