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TRANSFORMATION OF THE RELIEF OF THE AREAS OF DEVELOPMENT OF GAS FIELDS OF THE TAZ PENINSULA

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The article discusses the natural conditions of the Taz Peninsula in order to identify the main natural factors for the transformation of the relief. Special attention is paid to the characterization of permafrost and cryogenic processes and phenomena observed in this area. The geological structure of the territory is characterized. The influence of the hydrometeorological conditions of the Taz Peninsula is estimated. The contribution of the anthropogenic factor to the transformation of relief is substantiated. The most common geomorphological processes on the territory of the Taz Peninsula triggered by the anthropogenic factor are cryogenic swelling of soils thermokarst, landslide processes and erosion, less common deflation. Geological engineering zoning of the area for the development of gas pipeline routes is proposed.

Key words: Dynamics of the environment; relief; permafrost; anthropogenic transformation; geocryological engineering zoning.

В статье рассматриваются природные условия Тазовского полуострова с целью выделения основных природных факторов трансформации рельефа. Особое внимание уделяется характеристике многолетнемерзлых пород и криогенных процессов и явлений, наблюдаемых на этой территории. Дается характеристика горных пород слагающих данную территорию. Оценивается влияние гидрометеорологических условий Тазовского полуострова. Обосновывается влияние антропогенного фактора в трансформации рельефа. Самыми распространенными на территории Тазовского полуострова геоморфологическими процессами, которые активизирует антропогенный фактор, являются морозное пучение грунтов и термокарст, вызванные криогенными процессами, оползневые процессы и эрозия, менее распространенным — дефляция. Предлагается инженерно-геокриологическое районирование территории для разработки трасс газопроводов.

Ключевые слова: Динамика окружающей среды; рельеф; многолетнемерзлые породы; антропогенная трансформация; инженерно-геокриологическое районирование.

INTRODIUCTON

The high-latitude position of the Taz Peninsula, along with the robust Arctic climate, determines a wide distribution of permafrost. Frozen rocks widely occur both on the coast of the Ob and Taz bays, and in the central parts of the peninsula. The heterogeneity of the permafrost-geological situation due to the diversity of natural conditions in the Pleistocene, as well as significant cryogenic and post-cryogenic sediment transformations in the modern period create difficult conditions for conducting gas production.

The main objective of the study was to develop a rationale for routes of gas pipelines. To achieve this goal, a number of tasks were performed: a study of the peculiarities and transformations of the relief of the Taz Peninsula was carried out, a characteristic of the geological structure was compiled, hydrometeorological conditions were assessed, permafrost, described the observed cryogenic processes and phenomena. The result of the geological and geomorphological study of the territory was the development of a scheme of engineering and geocryological zoning.

MATERIALS AND METHODS

A comprehensive study of the Ob-Taz region was started in 1940–1950. Since 1995, the trust "Sevmorneftegeofizika" conducts seismic exploration in the Ob and Taz bays. The gas prospect of the region served as the beginning of a systematic geological engineering survey in the Ob and Taz Bays. Since 1995, engineering geological surveys have been carried out at gas drilling sites.

The main methods of engineering and geological surveys in the study area are: continuous seismoacustic profiling in combination with echoing and sound-looking sonar (SLS), drilling of geotechnical wells, sampling and laboratory studies of soil samples [ГОСТ, 1996], own observations and studies of the authors. Field studies were conducted in 2018 and consisted of selected mapping routes along the Yamburg-valley river. Poylavayah — the valley of the Nargayah River.

As a result of the survey, the necessary information was obtained on the engineering-geological section of the sites, the physical and mechanical properties of the soils were studied, the bearing capacity of the soil foundation was calculated, and the operating characteristics of hydrometeorological conditions were determined.

For the development of engineering and geocryological zoning of the Taz peninsula, a paired cartographic analysis of thematic maps was carried out, and then areas were described and boundaries were clarified based on actual observations in the areas of engineering geological surveys. In addition, materials from previously published papers and technical reports were used (thematic report: "Study of engineering-geological information and issuance of initial technical requirements for the development of technical means for arranging potential deposits in the Ob and Tazskaya bays", report of VNIIGAZ LLC., „Stage 1" Analysis of engineering-geological conditions and their detailing for the fields „North-Kamennomysskoye", „Kamennomysskoye-sea", „Obskoye").

CHARACTERISTICS OF NATURAL CONDITIONS OF THE STUDY AREA

Geographical location of the study area

Administratively, the Taz Peninsula is located in the Yamalo-Nenets Autonomous District (district center — Salekhard) of the Tyumen Region of the Russian Federation. From the north and east, the peninsula is surrounded by the Taz Bay, from the west — by the Ob Bay, in the south the border passes approximately in the valley of the river Hadutte along the parallel 67°30′n. Currently under development, the Yamburg gas condensate field is located on the Taz Peninsula, between the rivers Ob and Taz, and the Yamburg-Center gas trunkline and the Yamburg-Urengoy condensate pipeline are located.

Tectonics and geology

In structurally tectonic terms, the peninsula is located within the limits of tectonic elements of the first order of the Medvezhye-Nerutinskaya structural stage and the Yamburg-Urengoy projection, complicated by structures of a higher order. The increase in the amplitudes of tectonic movements during the Neogene-Quaternary time within the limits of Nydinsky, Medvezhy, Urengoi, Yamburg shafts was 40–80 m.

The research area is located in the northern part of the West Siberian Plate. In its geological structure there are three structural and tectonic levels:

- the lower structural floor is a heterogeneous foundation represented by hercynian formations;
- the upper one is a platform cover composed of sedimentary Meso-Cenozoic rocks;
- intermediate para-platform structural level, represented mainly by volcanogenic-sedimentary Triassic and Lower Jurassic rocks.

The surface of the basement, which coincides with the base of the Mesozoic-Cenozoic cover, plunges from the sides of the West Siberian Plate to its central and northern regions. This general regularity happens sharply in some places in the form of ledges, or, in sections, smoothly at the sides. The foundation lies at depths of 2.6–4.0 km, and to the north it sinks to 9–11 km.

Tectonically, the research area is located in the territory of the Northern tectonic region. The northern region is represented by a series of large linear structures such as megaridges, ridges and deflections in the submeridional direction. The difference in depth between the uplifts and depressions is usually 2–3 km, sometimes increasing up to 4 km. The amplitudes of large structures, both positive and negative, range from 1 to 1.5 km. In places, the structures are complicated by faults. The amplitude of displacement along the ruptures is as high as 200–300 m, disturbances are traced up to the Cenomanian and Turonian sediments.

The main part of the plate complex is made up of Mezo-Cenozoic deposits, which are virtually continuous and full section, starting from the Triassic. The thickness of the Meso-Cenozoic sedimentary cover in the northern part of the West Siberian Plate varies from 1 to 5 km.

The Oligocene-Neogene complex has a thickness of 200–400 m. Its deposits form the lower part of the neotectonic structural floor. Within the limits of the Ob and Taz Bays, within the structure of this complex, rock formations for the most part are presented by a kaolin formation with a thickness of about 150 m.

Its composition is dominated by lake-alluvial white and light gray sands with inclusions of gravel and pebbles, with layers of brown clay and with accumulations of plant debris. The deposits are saturated with kaolinite, filling the porous space between the individual particles and isolated in the form of aggregates, lenses and layers.

The Upper Pliocene-Quaternary complex is developed in the Ob and Taz Bays region as a continuous cover with a capacity of up to 100–360 m. The rocks of this complex make up the upper part of the neotectonic structural floor. These deposits are distinguished by the diversity of their composition, expressed in the presence of a practically complete lithological spectrum, ranging from gravel-pebble soils to thin clays [Воскресенский, 2001].

Upper Pliocene-Eopleistocene deposits in the area under consideration perform over-deep valleys. This complex in the north of the West Siberian Plate is combined to form the strata of the Yamal series.

Upper Pliocene (N_2a) rocks are represented by predominantly ice-marine formations. In the composition of the Upper Pliocene complex, the following deposits Novoportovskoy stratum (N_2 np), Myskamensk layers (N_2 mk) and Tiuteisky suite (N_2 tt).

The Eopleistocene (QE) in the study area is formed mainly by diamictons with packs of gravel sand. The complex includes two formations: Soruento and Salemala, combined into the Salekhard series.

The Neopleistocene (QNP) in the study area is mainly represented by ice-sea formations. The deposits of the lower level (Marresala formation) is placed on the eroded buried surface of the Salekhard series and are poorly developed within the region.

The Upper Neopleistocene — Holocene. Upper Neopleistocene-Holocene formations are the best studied deposits and, from the point of view of engineering geological conditions, are characterized by the greatest complexity. The geotechnical features of these sediments, in turn, are a reflection of the lateral Pleistocene facies and climatic conditions and their changes over time.

In the territory under consideration, the confluent type of permafrost usually occurs. The continuity of the permafrost (PERMAFROST) is interrupted from the surface only under the river beds and lakes, as well as in depressions of the relief with dense thickets of bushes, where snow accumulation is increased. The thickness of under-floor and suspect taliks can vary from 3 to 30 m. In the bottoms of logs, kasyreev and lower parts of slopes covered with shrubs talik depth is 2–10 m. Radiation-thermal taliks are found exclusively in sub-pit conditions under lakes of at least 1000–1200 m. and depth exceeding 1–1.8 m, as well as under the beds of the largest rivers.

The PERMAFROST capacity in the watershed plains is 300–350 m, less often 400 m, within the limits of floodplains and lagoon-sea terraces it is reduced to 150–250 m, and on the floodplains of large rivers — to 50 m.

A characteristic cryogenic feature of the Quaternary sediments is a high ice content. The high ice content is due to lower temperatures and desalinated composition of the formation waters, in connection to the existence of quaternary rocks in the section before the free water of exchange zone freezes. The surface ice deposits have the greatest ice content in the interval of the annual thermal rotation layer.

Deposits of the Salekhard plain are represented by complex and multi-layered interlacing of clay and sandy rocks with inclusion of coarse-grained material (pebbles, gravel, boulders). By area, about 50% of loams demonstrate a moraine-like appearance, about 75% of the sediments are with high clay content. Loamy-clay soils, strongly icy to lightly icy, cryogenic texture is layered and not full-layered. Sandy sediments are lightly icy, of massive cryotexture. Down the section the ice content decreases. The sediment thickness varies from 30–50 to 100–130 m.

The section of the Kazantsevskaya plain is composed of fine and silty sands, sandy loams and loams. The deposits are characterized by the presence of organic substances. Sands and sandy loams are with massive cryotexturing. Loams are icy and low-icy, with porphyritic and incomplete cryotextures. The ice content decreases with depth below the land surface.

In the bottoms of the depressions and within the ancient lake basins, loams are covered with a layer of peat with a thickness of 0.2–1.0 to 2–3 m. The sediment thickness is 10–20 m, rarely more than meters. Deposits of the Zyryansk lake-alluvial plain are represented by sands of various sizes, sandy loams, loams and silts with a large amount of organic matter. The sediments are indistinctly layered, often rhythmically stratified. On the third terrace, extensive tracts of wetland mineral soils and peatlands are widespread.

Sandy loam and loam are strongly icy, icy and lightly icy, layered and with incomplete layer cryotexture. Sands are lightly icy, with massive cryotexture. Capacity usually does not exceed 10 m.

The section of lagoon-sea sediments is represented by fine and silty sands, sandy loams and loams, often ground. Sandy-loamy deposits are characterized by high ice content that does not decrease with depth. Soils in this case have a layered and mesh cryogenic textures. The nature of the cryogenic textures and the high ice content of the rocks throughout the section suggest that freezing of the upper horizons of these sediments occurred simultaneously with sedimentation. Sediment thickness is 5–12 m.

In the section of alluvial deposits, sands of various sizes, sandy loam, loam and clay, silted, with inclusions of gravel-pebble rocks are involved. In the valleys of small rivers and streams, sands with more silt prevail than in the valleys of large rivers, loams and dark clays are characteristic. Channel sediments (coastal and riverbed spit, coastal shoals) on all rivers are represented by sands of various sizes. Sands are lightly icy, massive cryo texture. Sandy loam, loam and clay icy and weakly icy, layered cryo-texture. The sediment thickness is up to 3–5 m and more (depending on the order of the river).

Bog sediments, represented mainly by medium and well decomposed peat with single pieces of wood, are characterized by ataxitic and porphyritic cryotextures, with ice occupying more than 50% of the frozen rock. According to the ice content of peat, it should be attributed to strong icy rocks. Sediment thickness is from 0.2–0.5 to 4–5 m.

The average annual temperature of the permafrost within the runway range varies over a wide range. The main factor shaping the heterogeneity of the temperature regime of soils is the spatial unevenness of snow cover thickness in this region, depending on the microrelief of the area and vegetation. The vegetation cover has a small effect on the temperature regime of soils, its role is manifested indirectly through the influence on the accumulation of snow cover: the presence or absence of vegetation leads to a change in the power of snow several times.

On watersheds, the average annual temperature of the permafrost varies in the range from minus 3°C to minus 7°C. The lowest PERMAFROST temperatures (from minus 5°C to minus 7°C) are characteristic of the watershed surfaces of the Salekhard sea plain, where the snow cover has an insignificant thickness (0.1–0.2 m) and is often lacking vegetation cover or with poorly developed vegetation. The average annual temperatures of PERMAFROSTs (from minus 3°C to minus 5°C) are characteristic of the watershed surfaces of the Kazan coastal-sea and Zyryan lake-alluvial plains, and for the lagoon-sea terrace.

The average annual temperature of the permafrost from minus 1.5°C to minus 3°C is typical of the floodplain of rivers, ancient erosion troughs of small streams and rivers. The highest average annual temperatures (from 0.5°C to minus 1.5°C) are in the beds of large rivers and lakes, in local areas of the floodplains, where shrub thickets are up to 2 m high and more, and the snow thickness reaches a significant value.

Relief and hydrography

The northern part of the Nenetsky Upland, which is characterized by a complex multi-tiered relief, enters the territory of the peninsula. About 70% of the area is occupied by elevated half-shallow and hilly-low-lying low-subsurface sea, coastal-sea and lacustrine-alluvial middle and upper-quaternary plains with absolute elevations from 45 to 90 m. with absolute marks of 10–40 m. The above-flood terraces of large rivers have the same marks.

In the relief of the region, two sea plains are clearly expressed [СП, 2004; Козлова, 2013], a lake-alluvial plain and a lagoon-sea terrace, in the river valleys only a flood plain is developed. The most ancient geomorphological element is the Salekhard sea plain (m, mg IIsh). The relief of the plain is slopingly hollow, with absolute marks of 45–70 m. The surface of the plain is intensely dissected by valleys of rivers, streams and temporary streams and a system of ravines and ravines, slightly underfoot and dimmed.

The coastal marine Kazan plain (m, pm IIIkz) is widespread in the study area. The absolute heights of the plain reach 50 m a.s.l. The ledge separating it from the Salekhard plain, is strongly flattened and often indistinguishable. The surface of the Kazantsevskaya plain is flat, divided to varying degrees by river valleys, temporary watercourses and ravines. Areas not affected by erosion, have a completely flat surface and the constancy of elevations. Watersheds are characterized by a wide development of bogging and flat-hooded peatlands. The surface is characterized by a relatively large surface.

The Zyryansk lake-alluvial plain (la IIIzr) occurs in small areas near the coast. The relief of the plain is flat, less often it is hollow-riddled, the surface is strongly swamped and involves numerous lakes. Thermokarst relief forms are widely developed on the land surface.

The young lagoon-sea terrace (lm IV) is present only in the north, along the coast of the Taz Peninsula. The floodplain (a IV) is distinctly subdivided into a high and a low ones. For the high floodplain, fans of wandering of the river bed, along the river banks and the abundance of old lakes are characteristic. The low floodplain to the near-bed part of the valley bottoms and gradually passes from the high floodplain to the near-bed sandbanks without vegetation and with well-defined traces of the riverbed activity, rippling currents and rugged relief. The orientation of the manes and shafts reflects the process of meandering of the water flow. The low floodplain is composed of silty-sandy soils and is flooded with water during the flood period. Biogenic deposits (b IV) with a thickness of 0.2–5.0 m are widespread at all geomorphological levels from the surface.

The greatest density of the water-flow network (up to 1.5–2.5 km/m^2) is recorded in the west and north of the peninsula; the depth of erosion cutting reaches 30–50 m. In the central part of the peninsula, the density and the depth of dissection are reduced to 0.3–1.0 km/m^2 and 10–25 m respectively. High bog area (35%) and area of lakes (20%–25%) are noticed here.

Most lakes are of thermokarst origin. In the central and southern parts of the peninsula, there are many residual thermokarst basins. In the upper reaches of the river Hadutte, in the basin of the river Enyaha and in the area of Lake Khantyato, linearly oriented ridges are widespread.

The heterogeneity of the permafrost-geological situation due to the diversity of natural conditions in the Pleistocene, as well as significant cryogenic and post-cryogenic sediment transformations in the modern period create difficult conditions for conducting gas production [СП, 1997].

The spread of permafrost on the shores is continuous. Frozen rocks are developed at all geomorphological levels, starting from the layd and low flood plains to the terraces. Permafrost occurs directly from the surface, below the seasonal thawing layer. Within the land areas, the permafrost power can be 200–350 m. It can decrease to 150–200 m at laydas. In the stream parts of the rivers flowing into the bays, the power of the permafrost can be reduced to 40–50 m.

The main factors of the natural environment that determine the formation of a layer of seasonal thawing are: lithological composition and properties of soils, vegetation cover, topography, surface drainage. The thickness of the seasonally low-lying layer varies from 0.3 to 2.5 m. The maximum thickness of the seasonally low-lying layer is 2.0–2.5 m, occurs on forested, flooded areas of floodplains, where the warming effect of surface and groundwater is manifested. The minimum depth of seasonal thawing is 0.3–0.6 m, observed on peatlands and peaty, often boggy areas with a powerful moss cover [Тумель, 2016].

Within the watershed surfaces with shrub-moss-lichen tundra, composed of rocks, the thickness of the seasonally depleted layer ranges from 0.5–0.8 to 1.0–1.2 m. The open areas of floodplains, intensively cooled in winter, they are characterized by approximately the same order of thickness of the seasonal layer as the watershed surfaces.

On hills and ridges composed of fine sand from the surface, the thickness of the layer of seasonal thawing can increase to 1.5–1.8 m. On fast-growing slopes and in the bottoms of small rivers, the seasonal thawing depth does not exceed 0.8 1.0 m due to a delay in the onset of thawing due to late snow cover.

Perennial permafrost mounds are common at all geomorphological levels, with the exception of heavily dissected areas adjacent to the coast of the Gulf of Ob. They are represented by three types. The first one includes peat hummocks, located in swampy depressions or within flat peatlands. The hummocks have an oval shape in plan, their height rarely exceeds 3–4 m. The maximum ice content is observed either in peat or in mineral soils at the contact with peat covering them. An ice ground core with a thickness of up to 2–3 m is usually formed here [Гребенец, 2007].

The hummocks of the second type (Bulgunyakhs) are located in Khasrei or extensive marshy depressions on interfluvial spaces [Геоморфологический..., 2002]. They are found mainly in the central and eastern parts of the region. The height of the mounds reaches 8–10 m, the diameter of the base varies from 30 to 100 m and more. Hillocks are composed, as a rule, of sands and sandy loams with loam interlayers. Peat with a thickness of up to 1 m often lies on the surface. The ice or ice-ground core is located at different depths and can have a thickness of up to 6–10 m, less often more.

Hummocks of the third type (fells, sopkas) have maximum sizes, they are found locally at the outcrops of Paleogene clays. Their height can reach 20–30 m (hills Parnet-Sed, Anoraha-Sed, and others). The bodies of the hillocks are composed of strongly broken fissured clays; no ice or ice-ground core is observed.

The forms of cryogenic heaving also include linearly oriented ridges up to 10–15 m high and up to 0.7–0.8 km long. Their cryogenic structure is identical to the structure of hillocks of the third type and can be jointly considered as paragenetic formations.

Seasonal swelling manifests itself widely at all geomorphological levels, in rocks of various composition, from clays to silty sands. This process is responsible for the formation of stain-medallions (in combination with frost cracking of rocks), small-hilly relief and seasonal heaving of heaving up to 1 m high.

Thermokarst forms occur widely but are unevenly distributed. They are concentrated mainly in the central, southern and eastern parts of the region. Small thermokarst forms are characteristic of flat watershed areas, gentle slopes of river valleys and streams. They are represented by interpoligonal ditches, hollows, depressions or small lakes. Larger thermokarst lakes are also confined to poorly drained surfaces. Their morphology depends on the composition and ice content of the enclosing sediments, as well as on the age of the lakes. The greatest number of lakes occurred during the melting of segregation ice. Their depth rarely exceeds 1.5–2 m [Трофимов, 1980].

The depression-hollow forms of thermokarst are identified within the linear-ridge relief and heaving bumps. Their depth can reach 6–10 m. Hasyrei (thermokarst depressions formed during the thawing of epigenetically frozen high ice sediments and stratal ice deposits) [Лейбман, 2001] are confined to the wings of positive new structures that are 1 km in diameter or more, often terraced. They are concentrated in the central and western parts of the region. Currently, active thermokarst under natural conditions has a very limited distribution and is low-intensity.

Frost cracking and the associated polygonal-vein structures are developed throughout the peninsula, both in mineral and peat soils, and rewired ice in mineral soils become more common towards the north of the latitudinal segment of the Hadutta river, to the south they are found only within the peatlands. The sizes of polygons are various, on average they are 12–20 m in diameter. The thickness of the ice veins is small, on average 3–4 m, in the north of the region up to 8 m. Syngenetic vein ices in mineral soils are found north of 70°C. w., to the south they are common only in peatlands. Epigenetic ice veins in peatlands are widespread, especially in the central and northern parts of the region. Pseudomorphs after re-vein ice are also typical of the area; initially ground polygonal vein structures are found on convex mineral sites. The thickness of the veins is 1.0–2.0 m. Within the Tazskaya region, the polygonal-vein relief is in all stages of development: from the growth stage to the destruction stage [Соломатин, 2017].

Erosion and thermo-erosion forms (ravines, beams, gullies) are developed mainly in the west and north of the region. The total area of plots with a developed ravine-gully network does not exceed 10%–15% of the area of the region. Currently, many ravines are growing.

Eolian processes are active mainly along the river banks and the sides of ravines in the western, central parts of the peninsula on non-sodded plots on sandy sediments. Among the eolian forms, on the watershed plains and terraces, the negative ones (hollows, pits, blowing ditches) predominate, whereas the positive ones (shafts, hills, shallow dunes) dominate on the floodplains.

Solifluction processes, locally active in the western and northern parts of the peninsula on loams and clays, lead to the formation of tongues and small terraces. Waterlogging is quite widespread in the southern and eastern parts of the peninsula.

Hydrometeorological conditions

The climate of this territory is very severe. Winter is long and cold. Summer is relatively short, late spring and early autumn frosts, short transitional seasons spring and autumn.

The cold Kara Sea, being a source of cold in summer and strong winds in winter, increases the severity of the climate. Its effect is manifested in a slight decrease in summer temperatures. During the cold season, with the predominance of anticyclonic weather with low cloudiness, there is a strong cooling of the continent.

The project zone belongs to the I area, the 1G subdistrict of climatic zoning for construction in accordance with CN&R (Construction Norms and Rules) 23-01-99 [СНиП, 1999].

The climatic characteristic is accepted according to the nearest SMS (State Migration Service) — Tazskoye (Halmer-Sedo) and Novy Port [Справочник..., 1968].

In general, this region is characterized by a sharply continental climate with a severe long winter and a short cool summer, with short transitional periods in the spring and autumn seasons. The frost-free period is very short. Sharp temperature fluctuations during the year and even days.

The average monthly air temperature of the coldest month (January) is minus 26.7°C, and the hottest month July is 13.4°C. The absolute minimum temperature falls on February (minus 60°C), whereas the absolute maximum on June-July (32°C). The duration of the frost-free period is 84 days, frost-resistant period counts 206 days. Date of the first freeze in the fall — September the 8th, the last in the spring — May the 15th. This area belongs to the zone of excessive moisture. The annual precipitation is, on average, 394 mm. The maximum precipitation is observed in July and August (62 mm), the minimum in June (46 mm). The rainfall for the year is 394 mm, of which 109 mm fall from November to March, and from April to October there falls 285 mm, during the warm period the precipitation falls more than the cold one. The average number of days with precipitation is 180. The date of occurrence of average daily temperatures above and below 0°C is May 31 and October 1, respectively [Козлова, 2013].

The average date of formation of a stable snow cover is the 10th of October, and its destruction is the 2nd of June. Average annual maximum snow depth of 30 cm at a density of 0.26 g/cm^3 in open space. The average annual number of days with blizzards is 83, with fog — 46.

Wind regime during the whole year is formed depending on circulation factors and local conditions. The local conditions significantly influence the wind direction at certain points: uneven terrain, the direction of the river valleys, various obstacles.

The prevailing wind directions during the year are southerly, southwesterly, northwesterly and northern winds. The average annual wind speed is 6.2 m/s, in January 6.9 m/s, in July 5.3 m/s. The average temperature per year is minus 9.3°C, the absolute minimum per year is minus 60°C, the absolute maximum per year is 32°C. The date of the first ground freezing is August the 23rd, the date of the last ground freezing is June the 22nd, the duration of the frost-free period is 61 days.

The study area is located within the northern part of the permafrost zone of Western Siberia and is characterized by continuous distribution of permafrost, both in area and vertically, by low temperatures of permafrost, by a large thickness of freezing of the geological section and its pronounced cryological layering.

Vegetation and landscapes

The study area is located in the natural zones of the tundra and forest-tundra. Open drained spaces are occupied by shrub-moss-lichen vegetation. Thickets of shrubs up to 1–2 m high are recorded at the lower parts of the slopes, the bottoms of khasrey and small streams. In the south of the peninsula in the river valleys along with bushes there are birch-larch woodlands.

INTERACTION OF ECONOMIC ACTIVITIES AND NATURAL CONDITIONS

Anthropogenic transformation of relief and activation of exogenous processes

The processes of transformation of the relief caused by changes in the temperature regime of permafrost are described in a number of works of similar territories [Евдокимов, 2006; Юрьев, 2009; Хомутов, 2016; Печкин, 2018].

The development of mineral deposits on the territory of the Taz Peninsula is accompanied by the construction of infrastructure for exploration and mining, transportation facilities (pipelines, roads, electric power lines) and industrial and residential facilities [Козлова, 2013]. All these types of anthropogenic impact create pressure on the environment and its transformation, especially in conditions of weak stability of geosystems [Кружалин, 1992].

In the study area, there is an increase in erosion processes. The following economic activities caused the formation of gully erosion:

- Digging of various holes, dredging, trenches, cutting of slopes;
- Poor quality earthworks — insufficient tamping, embedment of the soil, tracks from tracked vehicles;
- Construction of roads, creation of paths between and along the slopes.

"During the construction of industrial and residential facilities (field camps, industrial bases, gas distribution stations, railway stations and other infrastructure facilities), a site is prepared in advance: the vegetation cover is almost completely destroyed, planning is carried out (the relief is leveled). As a result, there is a change in surface and underground runoff, a change in the state of permafrost due to thawing and freezing, a change in the direction and intensity of the complex of cryogenic processes" [Козлова, 2013].

In addition to erosion, deflation is observed on the Taz Peninsula. Destruction of vegetation cover in the places of quarry digging in sandy sediments leads to the appearance of initial foci of deflation. A strong wind causes great damage to the gas industry: it destroys communication facilities, electric power lines, various buildings. In the cold period, wind intensification is accompanied by blizzards, snow corrosion and snow drifts that impede the work of transport [СНиП, 1985].

Landslides that occur during construction, operation of facilities and economic use of territories may correspond to any type of possible displacement mechanisms. Most often they have the nature of landslides of shear (slip) and viscoplastic, and in rare cases are landslides of extrusion, hydrodynamic destruction (suffusion, hydrodynamic expansion) and sudden liquefaction.

The occurrence of technogenic landslides is mainly associated with the construction of various temporary (construction) and permanent excavations (trenches, trenches, road excavations and half-grooves), unsuccessful topography planning and overload of unstable elements of slopes (especially landslide bodies in their head parts), as well as additional moisture ground mass on the slopes in violation of surface runoff and removal of vegetation [Большаник, 2017].

The maximum danger of cryogenic creep is retained on the concave slopes of all geomorphological levels. The danger of the formation of large landslides on flat slopes increases when moving from low geomorphological levels to high. The danger of the formation of small cryogenic sliding landslides on conventionally horizontal surfaces increases with an increase in the dissection of the ravine-gully network and valleys of small watercourses irrespective of the geomorphological level.

"Area violations occur during the construction of field camps, industrial bases, gas pumping stations, at the founding of well clusters, during the development of quarries and other structures. In this situation, the heat and moisture regime of the soil is disturbed, which entails a change in the depth of seasonal thawing — frost penetration and, consequently, the activation of waterlogging processes, heaving, uneven precipitation of the soil and the development of thermal erosion processes" [Козлова, 2013].

Gas wells, under conditions of continuous distribution of permafrost, spread their influence over large areas of various landforms.

A thawing area is formed around the well core, the ground subsides, and the lowering is filled with water, which stimulates the development of thermokarst processes (Fig. 1). With the secondary freezing of this area, heaving processes are already

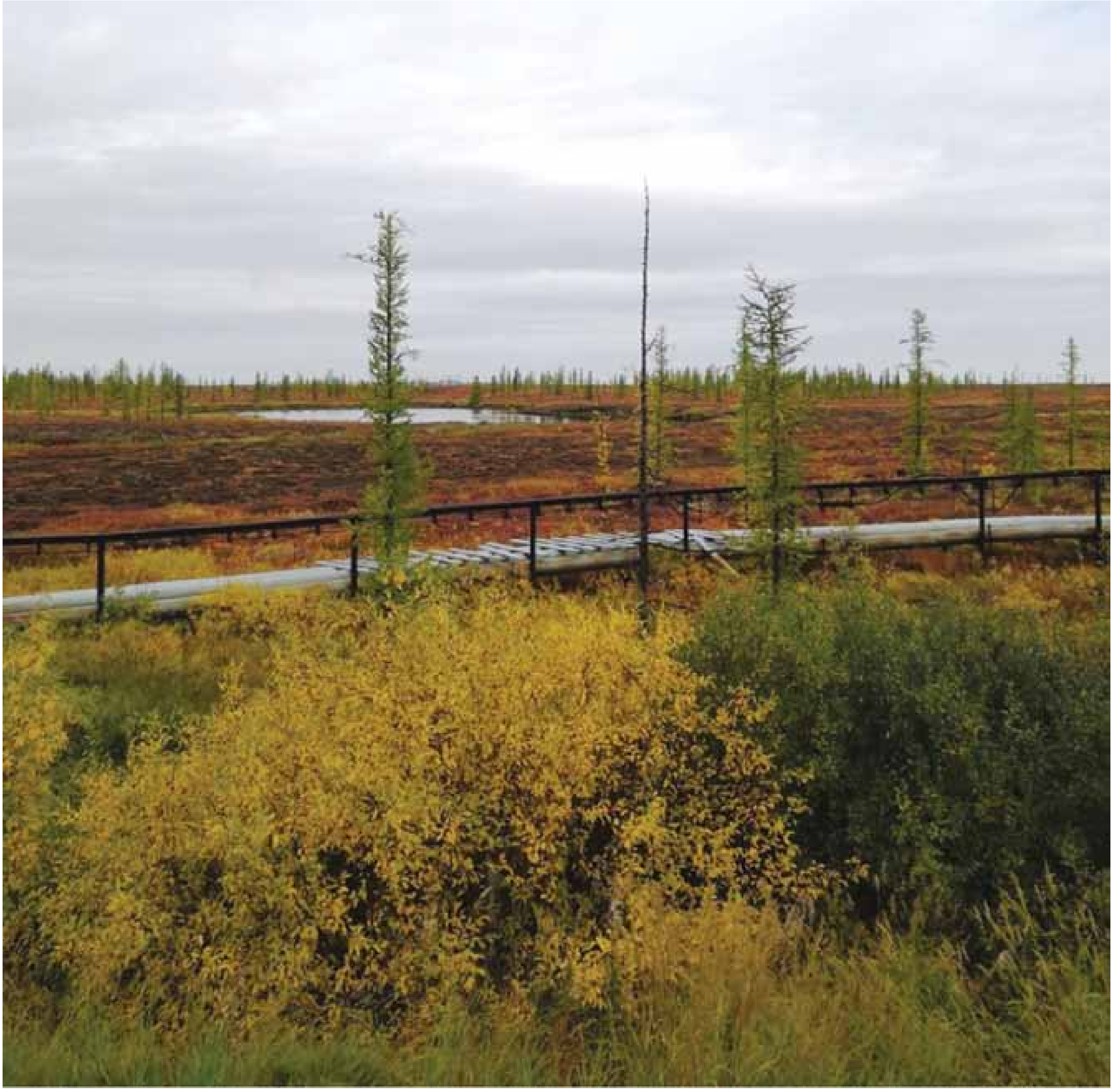

Fig. 1. Laying a gas pipe over the valley of a small watercourse. In the background is thermokarst lake

Рис. 1. Прокладка газовой трубы над долиной малого водотока. На заднем плане термокарстовое озеро

beginning to develop, leading to deformation of the wellbore. In the end, such a sharp change in the directivity and intensity of anthropogenic-cryogenic processes can lead to emergency situations.

The swelling of sediments during freezing and the reduction of soil volume during thawing are the main cause of the structures' deformation, since during the soil freezing process, moisture, mainly film-like, migrates to the areas of freezing. As a result of freezing of migratory moisture in the soil, lenses, interlayers and other forms of ice inclusions appear.

Physically, frost heaving is expressed in the uneven lifting of the freezing soil, and the stresses and strains that occur in the process of heaving have a significant impact on the foundations and ground structures of buildings.

The most usual types of anthropogenic relief changes are: ruts of motor vehicles, dumping and mounds of soil. The ruts of large vehicles on the terraces surface reach a depth of up to 0.5 m, which leads to water concentration in linear depressions, their waterlogging and siltation, or activation of linear erosion along them, destruction of moss-lichen cover. Various fortifications in the form of dumping and mounds of soil experience erosion of the slopes, the sliding of overwetted sand [Булдович, 2000]. This in turn causes a reduction in the area or the disappearance of lakes, the formation of shallow puddles and waterlogged bare plots at the site of buried water bodies and the flooding of anthropogenic structures.

Based on the described natural conditions, which have direct and indirect effects on the gas pipeline lines, two groups of defects are identified, caused by physiographic factors and processes: corrosion defects and repositioning of the axis of gas pipelines.

The change in the design position of the axis of the pipeline is associated with the following defects: the ascent of gas pipeline sections in the flooded soil with access to the surface of the water; gas pipeline bulges due to frost heaving; sagging and subsidence of the pipeline resulting from the thawing of permafrost soils.

Engineer-geocryological zoning

To substantiate the routes of gas pipelines, it is necessary to know the peculiarities of the permafrost geography. Work on the mapping of permafrost [Демедюк, 1983; Аристархова, 1996; Гаранкина, 2015; Грязнов, 2017], the spread of ecological and geographical regions were carried out in neighboring territories [Чехина, 2004; Гребенец, 2007; Васильчук, 2011; Большаник, 2017]. They were taken as the basis for the analysis of the soils of the Taz Peninsula.

In order to plan the development of the Taz Peninsula territory, geo-cryological zoning was carried out for mining operations, which contains information on the main characteristics of the permafrost necessary for making design decisions under difficult construction conditions:

- geomorphological level;
- type of sediment origin;
- lithological composition of soils, their ice content and cryogenic texture;
- spreading of permafrost;
- average annual temperature of permafrost;
- cryogenic processes and formations.

There are 4 geomorphological levels identified in the area (Fig. 2): sea plain, coastal-sea plain, lagoon-sea plain, erosion troughs of small streams and rivers.

According to the genesis and age of sediments within the territory under consideration, the following stratigraphic-genetic complexes are distinguished:

Mid-Quaternary marine, ice-marine sediments (m, gm IIsh);

- Upper Quaternary marine, coastal marine sediments (m, pm IIIkz);
- Upper Quaternary lacustrine-alluvial deposits (la IIIzr);
- modern lagoon-sea sediments (lm IV);
- modern alluvial deposits (a IV);
- modern swamp deposits (b IV).

Many geomorphological levels are characterized by common features of geocryological engineering conditions. First of all, this is a continuous distribution of mainly low-temperature, icy, in places heavily icy permafrost, their almost universal occurrence under a thin (up to 1.0–2.0 m) layer of seasonal thawing of rocks, wide development of re-vein and formation ice, development on surfaces thermokarst forms of relief and perennial tufts of heaving.

Deeply embedded valleys of watercourses (as deep as 30–50 m) are bordered by slopes of steepness 6° and more, on which thermal erosion, cryogenic landslides and spills, solifluction can develop. Occurrence of ice layers at the surface of the sediments forming the valleys walls. With their natural (undermining the coast) or artificial (cutting of the ground) outcropping on the ice, thermal erosion circuses and niches begin to form.

CONCLUSIONS

The Upper Neopleistocene-Holocene sediment formations in the study area are the most studied and, from the point of view of engineering geological conditions, are characterized by the greatest complexity. Their features are a reflection of the facies, climatic conditions of the Late Pleistocene and Holocene and their changes over time.

In the area of the peninsula lowlands dominate, which are represented by marine, coastal-sea, lake-alluvial plains, coastal-sea and lagoon-sea terraces.

The continuity of the permafrost is interrupted from the surface only under the river beds and lakes, as well as in depressions of the relief with dense thickets of bushes, where there is increased snow accumulation. A characteristic feature of the cryogenic structure of the Quaternary sediments is a high ice content.

As a result of the anthropogenic leveling of the relief, there is a change in the surface and subsurface runoff, a change in the state of the permafrost due to the thawing and freezing processes. An abrupt change in the direction and intensity of anthropogenic-cryogenic processes near wells can lead to emergency situations. The occurrence of technogenic landslides is mainly due to the construction of negative relief forms, unsuccessful land layouts and slopes overload, as well as additional wetting of the soil massif on the slopes in violation of surface runoff and vegetation cover removal.

Intensive thermokarst processes are active in the areas of economic development in the course of exploration of gas fields. Thermokarst processes are recorded in poorly drained, waterlogged areas.

The pipeline route is planned to be laid on a flat plain intersected by shallow watercourses. The territory of the projected route is characterized by

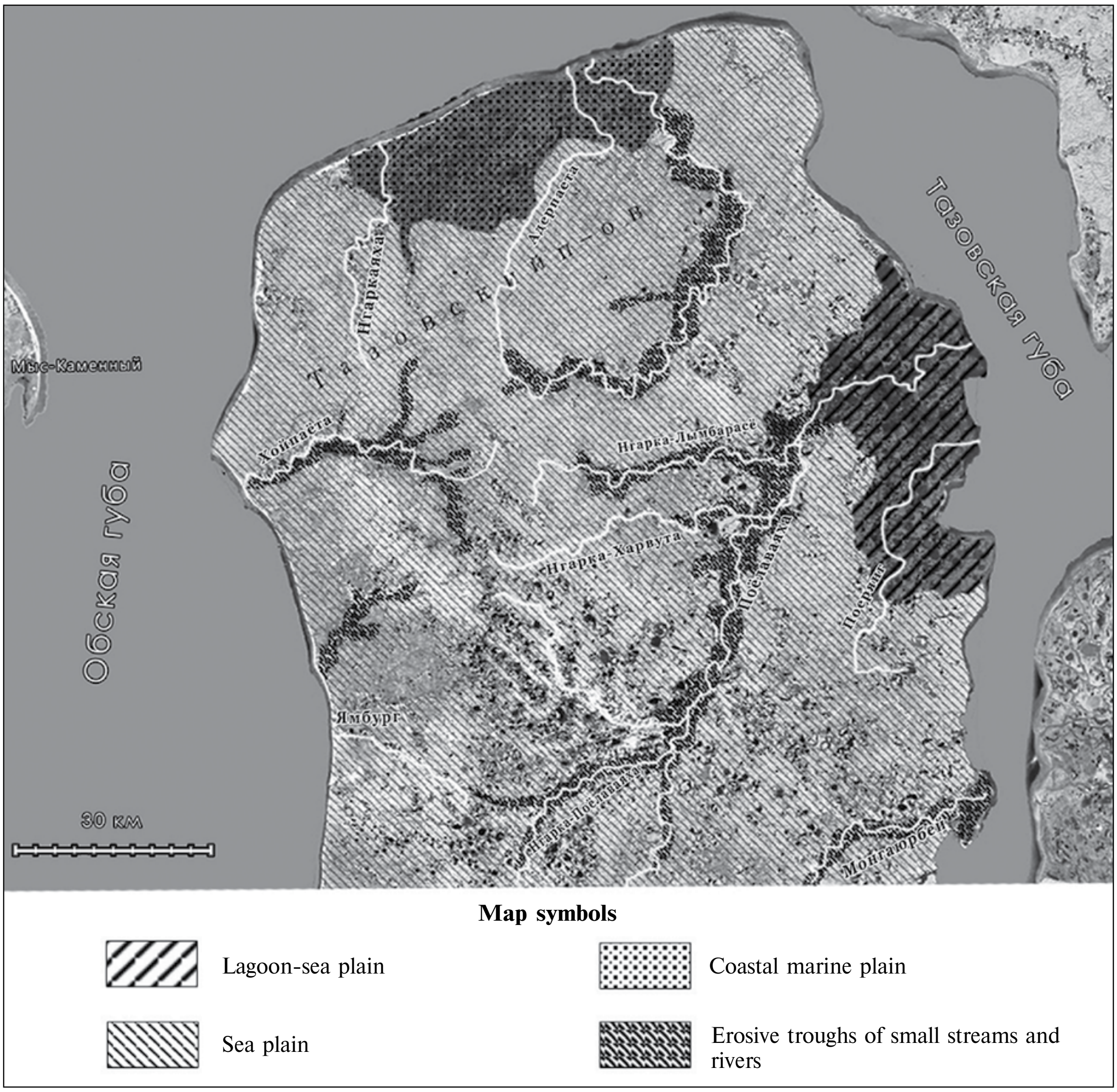

Fig. 2. Scheme of geomorphological levels of the territory of the Taz Peninsula
Рис. 2. Схема геоморфологических уровней территории Тазовского полуострова

a deep occurrence of bedrock, quaternary rocks are represented by sediments mainly of lake-alluvial genesis. The route of the projected gas pipeline is laid in the zone of continuous permafrost with an average annual temperature from minus 1.5°C to minus 3°C. The most severe geocryological conditions are characteristic of the lower parts of the slopes and the bottoms of the valleys of watercourses. The most unfavorable physiographic processes for the construction of a gas pipeline within the studied territory are the processes of permafrost nature, landslide processes and solifluction.

The nature of the manifestation of geoecological problems, due to the action of adverse geomorphological processes on the territory of the Taz Peninsula, is heterogeneous. The most common geomorphological processes in the territory of the Taz Peninsula triggered by the anthropogenic factor are cryogenic swelling of soils, thermokarst, landslide processes and erosion, and, less commonly, deflation.

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