PERMAFROST ROCKS AND GROUND WATERS OF THE ARCTIC AND PACIFIC COASTS, NORTHEASTERN RUSSIA

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ABSTRACT

The comparative analysis of conditions of distribution and composition of underground waters, and the thickness and intermittence of rocks, frozen of many years in the costal seas for the Arctic and Pacific Oceans was made. It was shown that the main feature of the Arctic coast of Eurasia is the spatial homogenety of frozen and hydrogeologic environments. On the Pacific coasts there are latitudinal geocryologic and hydrogeologic zonings; frozen and hydrogeologic environments are different. It was concluded that in the eastern sector of the Arctic there are no evidences of a modern rise in temperature. On the Pacific coast the processes of progressive rise in temperature are taking place that results in frozen and hydrogeologic peculiarities.

INTRODUCTION

Northeastern Russia's shores meet the slopes of the Arctic and Pacific Oceans with different hydrological regimes that affect the cryologic and hydrogeologic environments of the coasts in different ways. We have made a comparative analysis of the environments to determine their characteristic properties.

STUDIED DATA AND RESULTS

Geologic structure, as well as geologic history of the coasts are highly different, but we considered only fold-mountain areas and lowlands. Fold-mountain areas are low mountains, high plateaus, and ridges at an elevation up to 1000 m. Sea coasts are bold or cliffed, with a poorly developed beach zone. From the geological point of view, the fold-mountain areas are intrusive volcanogenic fields, folded structures composed of magmatic, metamorphic, and sedimentary, mainly terrigenous, lithified rocks of Pre-Cambrian - to - Cenozoic age. From the hydrogeological point of view, fold-mountain structures with fissure and fissure-veined water may be referred to hydrogeological massifs.

The low relief of the coast appears in the form of flat or gently sloping plains (lowlands, depressions) at elevations up to 50 meters. Typically, the coasts are swamped and beach barriers are well distinguished. Mouths and valleys of the largest rivers of the region (Kolyma, Amguema, Anadyr, Taui and others) are confined to these areas.

From the geological point of view, lowlands are superficial parts of sedimentary basins, inundated mostly by sea waters. A sedimentary cover is composed of lousse, slightly or moderately lithified terrigenous rocks of the Upper Mesozoic and Cenozoic age.

Hydrologically, these are structures with layered interstitial and fissure water. They may be considered as artesian basins.

In the fold-mountain areas of the Arctic coasts permafrost rocks (PR) are continuous. Taliks occur only in places where thermal water discharges eastward into the Koluychinskaya Inlet. Permafrost thickness in the water line ranges between 210-234 m (Valcumey massif) and is observed under the sea bottom. Permafrost thickness increases with the elevation of the terrain. The PR temperature at the base of the bed of the annual heat exchange varies in wide ranges. The minimum measured temperature in the area of the Valcumey massif was -10.2°C, often only -5°C. Ground ice of 1-2 cm thick fills rock fissures. Our observations in the Valkumey mine have not corroborated the existence of the regional underpermafrost cryogenic jointing.

In the lowlands of the Arctic coasts PR is continuous. Even such rivers as Chaun, Pegtymel, Ryveyem and others with a catchment area more than 1000 km^2 have no through taliks in their mouths. The thickness of

thickness decreases into the direction of the fold-mountain which may be explained by activization of the water exchange in the same direction. The minimum temperature measured on the sea coast was -9°C (the lower Ryveyem). Ground ice has different modes of occurrence. Layerd veins of ground ice of 1.5-2 m thick and more have been observed.

Traditionally, we divide ground waters into suprapermafrost, intrapermafrost, and subpermafrost. In the fold-mountain areas suprapermafrost waters are mainly waters of the active layer (AL). Talik waters occur only in creek valleys at the places of thermal water egress (Eastern Chukotka). Al waters form in June, and freeze completely in November. Talik water deposits reach maximum thickness (up to 3.5 m) by the beginning of September in the creek beds. Waters are hydrocarbonate-chloride, sodium by composition with a salt percentage no more than 0.03-0.04 g/l.

Hydrogeological massifs contain no intrapermafrost waters. As usual, the salt percentage of subpermafrost, fissure-veined waters is more than 1 g/l, and, in some places, brines with a salt concentration of 98 g/l are found (Valkumey mine). They are sodium-chloride or sodium- calcium by composition. With the desalinization of water, the proportion of hydrocarbonate-ion increases. Fresh water has been found in the form of a lens.

Its salt percentage is 0.9 g/l. Now the lenses is entirely drained off. All waters are pressure waters, their level marks are close to the modern sea level. Subpermafrost (fissure-veined) waters observed in the Valkumey mine while working at the horizon of "-100 m" and deeper are separated from the sea by permafrost layer, which hinders the connection between the sea and subpermafrost water.

But, as the result of mining, open fractures formed and the waters from the Chaun Inlet began penetrating into the mine workings. In flowing water over a 24-hour period measures up to 2400 m^3, that is 30 times as much as the inflow under undisturbed conditions.

In the lowlands of the Arctic coast (artesian basins) hydrological environments are more diverse. Superpermafrost waters of the active layer are found in all genetic varieties of the Quaternary deposits, including sea spits and bars.

In general, the waters are fresh with a salt percentage up to 0.2 g/l, chloride, chloride-hydrocarbonate, and sodium in composition. On the sea spits and bars, the salt percentage increases to 18 g/l. The thickness of water-bearing deposits is no more that 1.5 m.

In the mouths and lower reaches of large rivers and under the lakes, suprapermafrost taliks of 300-350 m wide form, the thickness of such deposits reaches 40 m. At the end of summer the water of the underflow deposits is fresh, the salt percentage - 0.1-0.3 g/l.

Waters are hydrocarbonate or chloride-hydrocarbonate, sodium or calcium-sodium. In winter, after the freezing of water streams and failure of the surface runoff, sea waters penetrate into taliks, increasing their salinity. In April - May 1985, Krukovsky Yu.B. observed water salinization of suprapermafrost talik in the riverbed of Chun (Palyavaam) at 10 km upstream from the mouth. Salt percentage increases up to 16-24 g/l.

The analogous seasonal changes in underflow water composition have been observed also in other rivers: Retkuchen, Yanranai, and Ryveem. Probably, the winter salinity of ground waters preserves suprapermafrost taliks. The water composition of underlacustrine taliks corresponds to the water composition of lakes. Intrapermafrost waters of high salt percentage and subzero temperature have been found in lowlands everywhere. They have a chloride-spdium composition, or less frequently, a calcium-sodium composition. The waters occur at depths of a few meters up to 90 m. Water containing rocks, sands, and gravels are often silted.

A water-resisting horizon and bottom are composed of frozen loams and claus. Sometimes, cryopegs fill hollows in a rock roof. Intrapermafrost water-bearing vessels may be connected with the sea, or have the form of closed lenses. Ground water levels are always above the horizon top, but water density, may be at the modern sea level or lower. The most concentrated cryopegs (130 g/l) on the coast of the Ryveyem lowland have been described by Arkhangelov A.A. They have been found at the depth of 90 m, the reduced level is 43.5 m lower than the modern sea level.

The indicated maximum concentration of cryopegs corresponds to the modern temperature of PR in BAHT or to higher temperature values. Subpermafrost waters of artesian basins have been discovered both below the bottom of sedimentary cover in the zones of tectonic faults of the basement and in Neogene sedimentary deposits. These are pressure waters with low water yield; the specific yield of wells is 0.01-0.03 l/s, the salt percentage is 5 g/l or more, and the water is hydrocarbonate-chloride sodium by composition. Moving away from the sea coast, in the zones of basement tectonic faults, fresh water is possible.

Fresh water have been found in the valley of the river Ryveyem in the fault zone 4-5 km from the sea. They occurred at depth of 290-335 m in cleaved sedimentary rocks of the lower carboniferous age. Waters flowed naturally from wells with yields of 0.5 l/s, specific yields ranged from 0.1-0.15 to 0.49 l/s. Salt percentage ranged between 0.6-1.1 g/l in the hydrocarbonate-chloride and chloride-hydrocarbonate sodium waters. Characteristically, outside the river valley, fractured zones contained subsaline waters.

Information on ground waters and permafrost rocks of the Arctic coasts and higher latitudes (Taimyr Peninsula, North America) obtained from the literature indicates similar cryologic and hydrogeologic environments that change very little with latitude and longitude. It may be explained by low tectonic activity in the area (except the coast of the eastern Chukotka massif) by the location above the polar circle where similar severe climatic environments exist.

At all latitudes we have the climate of the Arctic desert and Arctic tundra with annual average air temperature between -10 and -13°C, and only within the area under the influence of the Pacific is the air temperature -8.2°C (Uelen settlement) the annual precipitation less than 300 mm, and the frostless period 2 months or less.

Spacial homogeneity of principal cryologic and hydrogeologic parameters is a characteristic feature of Arctic coasts of eastern Asia and northern America. On the coasts of the Pacific Ocean (the Bering and the Okhotsk seas) permafrost varies from continuous to discontinuous (sporadic). Irrespective of distribution, the PR thickness fluctuates in wide ranges and depends on geologic and geomorphologic conditions, slope exposure, etc. Maximum permafrost thickness has been registered in the region of the Provideniya Bay and is equal to 150 m at an elevation of 30 m and a distance of 0.8 km from the sea coast.

The permafrost thickness decreases in the direction of the sea and probably is absent below the sea bottom. We may suppose that permafrost thickness will be greatest northward. In the coast of the Ola estuary of the Okhotsk Sea, the Lower Cretaceous effusive rocks are frozen as deep as 108 m. The temperature at the base of the bed of the annual heat exchange is -2.1°C. We have no data on the temperature of permafrost rocks in hydrogeological massifs for other sites of the Pacific coast. It may be assumed to be not below -7°C (that is not below the annual average air temperature in eastern Chukotka). So long as permafrost thickness is comparable or less than the depth of exogenous jointing distribution, the existence of the layer of subpermafrost jointing below the base of permafrost thickness may be assumed.

In lowlands of the Anadyr Gulf coast, the permafrost distribution from the north to the south is practically the same. From the Mechigmen Inlet up to the Navarin Cape, permafrost is slightly discontinuous with through taliks only under the river beds with the catchment area of several thousands of km^2 (Anadyr, Velikaya, Nakepeilaykh). It probably is connected with widely-distributed deposits in the sedimentary cover with low filtration qualities. Southwards, the through taliks form under the smaller streams, including under the creeks with a catchment area of tens of km^2 (coast of the Ugolnaya Bay). On the coast of the Okhotsk Sea (approximately at 60-59°N). There are areas with sporadic permafrost (Okhotsk, Magadan, Takhtoyamsk). Here, there are also perennially frozen slightly permeable deposits. With their wide square distribution permafrost becomes discontinuous. Permafrost thickness is also connected with water permeability of the sedimentary cover up to 100-150 m depth. When slightly lithified, deposits of poor filtration quality prevail in the section, permafrost thickness reaches 140-170 m at a distance of a several hundred meters from the sea coast, but crops out in the direction of the sea. It is supposed that there is no permafrost under the sea bottom.

According to the measurements in wells, permafrost temperature does not fall below -4.5°C on the coast of the Anadyr Bay, and not below -2°C on the coast of the Okhotsk and Bering Seas south from the mouth of the Khatyrka River.

The cryogenic structure of permafrost rocks varies with the prevailing layer and netted texture. Accumulations of stratum ice of several meters thick have been described, on the coast of the Okhotsk Sea (Skorodumov I.N., Meshkov A.P., 1990), sufficiently south of a representative isotherm - 3°C.

Hydrogeological environments of the Pacific coast differ from the Arctic coast. In the fold-mountain territories various types of ground waters occur. They have different modes of occurrence and chemical composition. Already on the coast of the Bering Strait, channel taliks in the lower reaches of the streams that have a catchment area of several hundreds sq. km. Such taliks also form in fans, and often they are used for water supply. Water-bearing deposits there are 20-30 m thick, interspersed with through taliks. The specific yield of wells is up to 1 l/s or more. Salt percentage is about 0.1 g/l. Waters are hydrocarbonate sodium by composition. Intrapermafrost waters have not been found in the hydrogeological massifs.

Subpermafrost waters are confined to the base of the layer of exogenous fractures rocks and to the zones of tectonic faults. There are pressure waters often hyperpiestic; the fault zones contain much more water in comparison with exogenous jointly rocks. So, on the coast of the Ugolnaya Bay, the specific yield of wells, stripped subpermafrost jointly layers, ranges from hundreds to thousands of l/s, and the specific yield of wells, stripped the fault zones, is up to 5.5 l/s.

Waters of regionally jointly rocks are subsaline (up to 5.4 g/l), chloride-hydrocarbonate and carbonate sodium. In local fractures zones the waters are fresh. They have been found in granodiorites on the coast of Provideniya Bay (Anadyr Gulf) at a depth of 150 m. Salt percentage is 0.3-0.5 g/l, the water is hydrocarbonate sodium, and the specific yield of wells from 0.4 to 0.8 l/s.

Fresh, fissure-veined waters are known also on the Okhotsk Sea coast (mouth of the Dukcha Rivers, Ola Estuary, etc.). According to geophysical data, the depth of fresh ground water occurrence reaches 400 m. According to indirect data, they probably supply submarine sources.

Artesian basins of the Pacific coast are characterized by the occurrence in the sedimentary cover of intrapermafrost waters of subzero temperature (cryopegs) north of the latitude 63°, which coincides with the geoisotherm of PR - 3°C; southward they have not been found. Suprapermafrost (and ground) water-bearing horizons, in contrast to the Arctic coast, contain much water (5-10 times as much) and are thicker (2-3 times as thick). Duration of the existence of the active layer increases up to 6-7 months. Underlacustrine and river channel taliks are distributed everywhere. Salt percentage of ground waters changes only in the underflow taliks, east of the coast of Chukotka, and winter salinization takes place only within the first hundreds meters from the river mouth. At the same time, many investigators have noted the influence of sea tides and storm surges in the level and chemical composition of ground waters. The influence of there factors grows from the northern to the southern latitudes, and in the valley of the rivers Khatyrka, Tanui, and others reaches 5-6 km, that is connected with the gradient and elevation of the river beds. South of the latitude 63°N on off-shore bars, barrier beaches, lenses of fresh water can be found, caused by the thawing condition of deposits of the coast relief forms.

Intraperafrost cryopegs on the coast of the Anadyr Gulf have been found both in isolated lenses and in basins connected with the sea. Perspectively, ground water datum levels vary from levels less than to the equal of modern sea level.

Cryopegs with the greatest salt percentage have been found on the eastern coast of the Cross Bay (Konergino settlement). Their salt percentage is 88.5 g/l, and water composition is chloride sodium or calcium-sodium. The depth of cryopegs tapping is 45 m. Water-containing rocks are gravels of the Quaternary or Neogene age. The confining bed is usually composed of clay, the base of which is clay and lithified rocks.

Cryopegs in lenses have the highest salt percentage. Their datum level is always 5-10 m below the modern sea level. Their modern temperature is -2.1°C, though the salt percentage of 88 g/l is equivalent to -5-6°C.

As a rule, subpermafrost stratal waters of artesian basins near the coast line are brackish and saline (salt percentage ranges from 3-4 up to 28 g/l). Chloride sodium and sodium-calcium (salt percentage - up to 95 g/l) waters have been found in subpermafrost troughs in the Anadyr region. The modern temperature of waters is about 0°C, and for their formation through the freezing of sea water freezing temperature equal to -6°C is needed. That is lower than the modern PR temperature. The waters of sporadic permafrost regions are brackish (up to 10 g/l), but they desalinate as far as moving away from the sea for several hundreds meters.

The separation line of fresh and salt waters is between the 200 and 300 m depth. These are pressure waters, but their levels are commonly close to the day surface level. A direct correlation of water salinization and water-permeability of rocks has been noted. Chloride sodium water of 57.2 g/l salt percentage, found at the depth of 250 m in the melt Neogene deposits on the coast of the Ola estuary, the Okhotsk Sea, is of scientific interest. These are pressure waters, their level is higher than the sea level (Arzhanovskaya V.I., 1990). In the modern conditions, such water may be formed by sea water freezing under the temperature -3.5°C.

In general, the diversity of cryologic and hydrogeologic environments on the Pacific coast evidences the active processes determining PR and ground waters regimes. Geocryologic and hydrogeologic latitudinal zonality, which corresponds to the climatic zone and to latitudinal changes of hydrothermal environments in the Pacific Ocean, is well pronounced. By these characteristics the Pacific coasts differ from the Arctic coasts.

CONCLUSIONS

On the basis of hydrogeochemical properties of ground waters, correspondence (or non-correspondence) od ground water salinization to the modern temperature, PR stratum structure and other characteristics, it may de argued that in the eastern sector of Arctic there are no signs of progressive warming. Cryologic and hydrogeologic environments are stable. On the Pacific coast, the climate is getting progressively warmer, as proved by a comparison of climatic characteristics based on the data of long-term meteorologic observation stations.

The revealed properties of the Arctic and Pacific coast may be used for planning economic and industrial activities, including the accumulation of liquid and gas materials in the bowels of the Earth.

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