Geospatial conditions of landslide formation on the territory of Sakhalin Island

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Abstract. The paper considers the conditions for the formation of landslide-prone areas of Sakhalin Island, the intensity of development and the main characteristics of landslides of various types common on the territory of Sakhalin Island. Sakhalin Island, determined by the geospatial location of the territory. It is due to the geospatial location of the territory as a result of the tectonic and geological history of its development that the present relief, in addition to extensive sedimentation basins, is represented by steeply sloping erosion-denudation and abrasion forms of macro and mesorelief with high potential energy, overlain by thick layered significantly dislocated and structurally disturbed terrigenous strata represented by relatively weak rocks, the accumulation of which occurred as a result of cyclic sedimentation. The tectonic and accompanying seismic activity, as well as the geologic history of the terrane formation, have led to the formation of complex engineering, geological, and hydrogeological conditions of the territory. Furthermore, the marginal position of the region determines its monsoon climate with high cyclonic activity, leading to a general high moisture content of the territory and activation of exogenous processes. Thus, due to the geospatial position of Sakhalin in the transition zone, a whole complex of natural factors of landslide formation was formed in the territory, including global factors (tectonic, climatic) and their subordinate determinants, as well as secondary (trigger) factors (geomorphologic, geological, hydrogeological, seismic), contributing to the widespread development of modern active landslides of different scales, characteristics, as well as types of landslide process and mechanism of mountain displacement.

1 Introduction and problem statement

Sakhalin is subject to active development of hazardous exogenous processes of nival, fluvial, coastal, gravitational and water-gravity character, which largely determine the present-day mesorelief of the territory. In many respects the wide development of dangerous exogenous processes is determined by the geospatial location of the island in the transition zone "ocean-matter", which is characterized by active heat and mass transfer in the atmosphere and hydrosphere, tectonic activity and volcanism, features of cyclic

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sedimentation and terrane formation, which determines the natural conditions of occurrence and development of dangerous exogenous processes.

Among geodynamic processes, landslides are one of the most widespread on the territory of Sakhalin Island, 70% of the island's territory is exposed to them. Among the settlements 107 are located in the landslide-prone zone, which is 81% of the total number of settlements [1]. For some coastal settlements, e.g., Kholmsk, Makarov, Korsakov with high frequency and intensity of landslide formation, the area affected reaches 30% (Fig. 1).

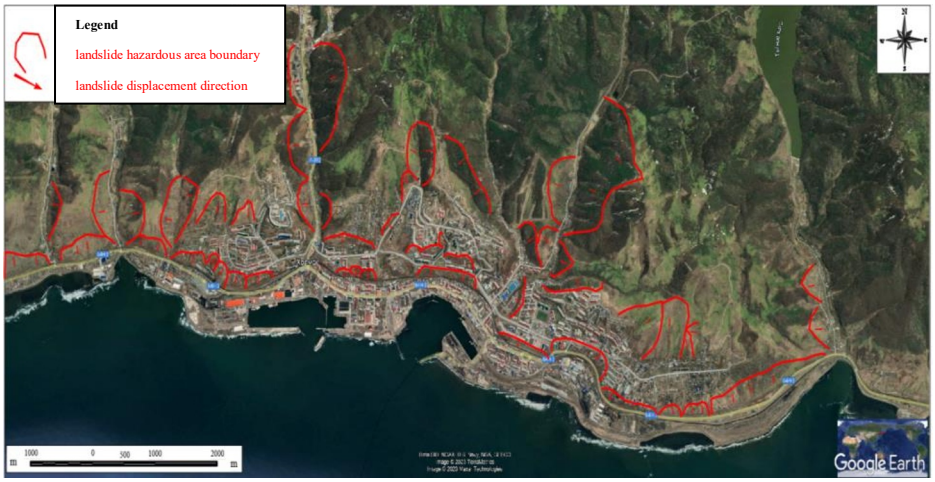

Fig.1. Scheme of natural landslide massifs in Kholmsk

The widespread occurrence of landslides on the territory of Sakhalin Island. Sakhalin Island, their significant threat and potential damage to transportation routes, residential facilities, national economy and population, as well as the significant role of landslides in the formation of the modern mesorelief of the territory and contribution to heat and mass transfer of geodynamic processes are of great scientific and practical interest.

For a comprehensive approach to the study of the natural conditions of landslide-prone areas on Sakhalin Island. It is necessary to assess the intensity of development and the main characteristics of landslides of various types prevalent in the territory, to consider the conditions of their formation, including those determined by the geospatial position of the territory.

The purpose of this work is to determine the geospatial conditions of formation of different types of modern landslides on Sakhalin Island.

2 Materials and Methods

In different years, the works of S.M. Alexandrov (60-70s of the XX century), G.V. Polunin (70-80s of the XX century), and A.I. Sheko (90s of the XX century) were devoted to the systematic study of landslides and natural conditions of their formation on the territory of Sakhalin [2-4].These materials allowed to form the main body of theoretical data on landslide formation processes on the territory of Sakhalin and became the starting point for most of the further more in-depth specialized studies of dangerous exogenous processes on the island. Since 2002, some systematic studies of landslides in the most landslide-prone areas of the Sakhalin region within the framework of scientific and technical works have been carried out on the basis of the established Sakhalin branch of the Far Eastern Geological Institute under the guidance of N.A.Kazakov and Y.V. Gensiorovsky.

Since 2007, the author of the paper has conducted extensive field work on the territory of Sakhalin Island. Since 2007, the author of the article has conducted extensive field studies of dangerous exogenous processes, including landslides and genetically related exogenous processes of water-gravity character: slope mudflows of landslide initiation, landslide flows, moistened scree, etc. on the territory of Sakhalin Island. The works were carried out within the framework of scientific activities, scientific and technical support of engineering surveys in terms of hazardous exogenous processes, pre-project solutions and territorial planning. Study of mechanisms and conditions of landslide formation was carried out during field studies and on the basis of analysis of archival data on landslides and periods of their mass formation for the period 1875 - 2023. In the course of works observations of landslides and other slope exogenous processes were carried out, a large array of engineering-geological and meteorological data, morphometric and morphological characteristics of landslide massifs, including potential ones, were processed, which allowed solving the main research tasks, the results of which are published in this paper.

3 General description of landslide processes on the territory of Sakhalin Island

A landslide process or a landslide proper is understood as a displacement of rock masses, usually loose and water-saturated, under the influence of gravity to a lower hypsometric level while maintaining contact with a fixed base. Thus, landslides are referred to exogenous processes of water-gravity character.The sizes and volumes of landslides vary greatly from individual blocks of several m^3 to masses of hundreds of millions of m3.

There are many domestic and foreign classifications of landslides: by A. P. Pavlov (1932), F. P. Saverensky (1934), I. V. Popov (1946), N. N. Maslov (1955), T.S. Zolotorev (1964), V.L. Lomtadze (1977), D. Varnes (1978), J. Hutchinson (1988), D. Cruden (1996) and others. These methods classify landslides by one or complexly by several different features: age and stage of landslide process development, direction of landslide process development, volume, velocity, depth of rock entrapment, structure of the landslide, mechanism and cause of stability failure, etc. In addition, there are a number of regional classifications of landslides based on regional climatic, engineering-geological and hydrogeological conditions. Currently, the most complete comprehensive classification of landslides is enshrined in the current technical standard SP 420.1325800.2018 "Engineering surveys for construction in the area of landslide development" (used in this paper), developed by a scientific team of authors based on the analysis of existing methods of landslide classification [5].

On the territory of Sakhalin almost all types of landslides are represented by the scale of the phenomenon (volume and depth of rock entrapment) and type of landslide process from very small superficial landslides and insectional (shearing) shear landslides with the volume not more than 10 m^3 with the depth of rock entrapment less than 1 m, to very deep (more than 20 m) large consecutive (sliding) shear landslides with the volume of several 100 thousand m^3 to 1 million m^3 (single cases) (Table 1). It should be noted that no modern extremely large and grandiose in volume landslides have been recorded on Sakhalin Island. Landslides of this scale are confined to ancient halted or completed predominantly seismogenic landslides.

Shear (slip) landslides. These are the most widespread on Sakhalin Island and occur on rocks of virtually all geologic formations. The surface of landslides is bumpy, stepped and often complicated by bulge shafts and blowout cracks. Modern and active forms are characterized by well-defined landslide scarps and failure walls. The bodies of ancient landslides are weakly expressed in the relief, strongly reworked by complex denudation processes.

The insectivorous (shearing) sub-type of slip landslides is most developed in split-grained clayey, loamy and sandy loam soils that form the accumulative and basement marine terraces that extend almost along the entire coast of Sakhalin Island. Sakhalin Island. Landslides are predominantly circular in plan and less frequently frontal. The slip surface is concave and is caused by the physical and mechanical properties of the rocks. The depth of rock entrapment usually does not exceed the depth of the active layer of seasonal freezing-thawing and is 1 - 2 m, in some areas of undercut slopes, including as a result of anthropogenic impact or abrasion, can reach 5 m. Volumes range from several m^3 to several 100 m^3. In some extended sections of the coastline can reach several tens of thousands of m^3 with the length of the line of detachment tens of meters. They are also found on slopes of river terraces and valleys, less frequently on mountain slopes in deluvial strata of rubbly soils with loamy filler. In mountainous areas, the average volumes and depth of rock entrapment of insecticidal landslides are slightly higher.

Consequent (sliding) type of landslides is developed in sedimentary weakly lithified rocks. It is widespread in mountainous areas, on coasts (basement terraces, escarpments) and slopes of mountain river valleys. The line of detachment of landslides is always conditioned by the line of strike of rocks and can be located at an angle to the slope edge. Landslides are confined to inclined slip surfaces, which may be represented by rocks with a different degree of lithification and petrographic composition than the rocks of the landslide massif. Due to the geologic history of the region, in addition to cases where lithified "bedrock" underlain by split-grained dealluvial sediments represents a wetted water-retaining slip surface, there are often interspersed packs of lithified and split-grained rocks on slopes, where deeper slip surfaces may be represented by split-grained sandy loam or loamy soils with lower physical and mechanical characteristics. Often the stability of a potential landslide massif is disturbed when the angle of slope embedment exceeds the angle of rock dip. This mechanism of landslide activation is particularly common on the coast, where abrasion scarps of relatively resistant lithified rocks are often complicated by slumps, screes, and consequent landslides. The depth of rock entrapment of consecutive landslides varies widely and ranges from a few meters to several tens of meters. Average volumes are 10 thousand - 100 thousand m3, large landslides on the coast and in mountainous areas with volumes up to 1 million m^3 with a long line of detachment up to 0.5 - 0.7 km are encountered. The largest modern landslide processes on Sakhalin are represented by this type of landslide. Often consecutive landslides form a whole series of landslides, regressively developing up the slope until the potential landslide massif reaches equilibrium by unloading. All subtypes of shear landslides in the active phase of the landslide process are predominantly characterized by moderate to fast landslide mass movement velocity up to several m/minute.

Extrusion landslides. This type of landslide is developed in clayey, predominantly plastic soils capable of exhibiting rheological properties, i.e., slow deformation over time under load. On the territory of Sakhalin, this type of landslide occurs sporadically exclusively on natural and man-made slopes: on the banks of rivers, lakes, seas and reservoirs, in the sides of ravines and quarries, in road excavations and in other man-made structures. The mechanism of landslide process development is a relatively slow extrusion of soil from under the bottom of the slope scarp and its displacement together with the sediments previously formed on the slope. Landslide process development occurs due to the slope base treatment (abrasion, channel deformations, mechanized undercutting, etc.) as a result of which weaker plastic soils underlying the base are deprived of support and begin to deform under the action of the load from the stronger soils located above. It is also possible to develop technogenic landslides of extrusion during dumping of high embankments of dumps and earth bed on weak clay soils of dealluvial deposits on slope areas, as a result of which their deformation and extrusion towards the free surface of the

slope takes place. The rock engagement depth of extrusion landslides depends on the geologic structure and morphometric characteristics of the slope. In general, squeeze landslides are classified as deep and very deep landslides because they require significant thickness of the overlying soil layers to create sufficient pressure on the underlying weak clayey soils. All squeeze landslides are characterized by their significant length relative to the slope edge, it can reach from several tens to several hundreds of meters and is one of the conditions for their development, since other types of landslides develop on relatively short sections of undercut landslide slopes with lengths of several meters. These types of landslides are usually large in size and frontal in plan. Taking into account the deformable soil layers located above, the volumes of landslides are significant and amount to tens and hundreds of thousands of m3. Squeeze landslides are predominantly slow landslides, their speed is several meters per year. However, at the final stage and slope collapse the speed can reach several meters per hour.

Viscoplastic landslides. After shear (slip) landslides on Sakhalin Island, these are second in terms of frequency of formation and scale of development. They occur in split-grained loamy, less frequently sandy loam soils with a high degree of plasticity and fluidity. Widespread both on the coast, developing on slopes of accumulative and basement marine terraces, and in mountainous areas on dealluvial slopes, where they have significant volumes.

Shallow splays have a depth of rock entrapment typically 1 - 2 m, and are confined to the depth of the seasonal freeze-thaw layer. Volumes range from several m3 to several thousand m3. The mechanism of formation is different. In summer and autumn period overmoistened condition of soils as a result of precipitation leads to formation of landslides. In spring, the formation of landslides occurs as a result of solifluction - slow runoff of thawed soils along the frozen underlying roof.

Landslide-flows can be from several meters deep to several tens of meters deep. Volumes range from several hundred m3 to hundreds of thousands of m3. Flows landslides are formed as a result of prolonged overwatering of the soil of a potential landslide massif. The flow plane is usually predetermined by the bed of the bedrock slope or by the thickness of the loose clastic zone of the modern weathering crust.

Viscoplastic landslides in the active phase of the landslide process have a wide range of velocities. Splashes and slumps are characterized by rapid movement velocities that reach several meters per minute: the landslide massif is unloaded within a few minutes. Stream landslides can move with extremely low velocities of up to several centimeters and even millimeters per year, in connection with which some large stream landslides in mountainous areas and on the coast are in the active phase of the landslide process for tens of years. Extremely fast velocities of movement up to several meters per second are also noted among the landslide flows, as a result of which, when moving down the slope, there is destruction and liquefaction of the landslide body, and subsequent formation of slope mudflow. It should be noted that this mechanism is the most frequent in the occurrence of slope mudflows on the coast.

Hydrodynamic failure landslides and sudden liquefaction landslides. These landslides have a similar mechanism of landslide mass movement, which is characterized by almost complete destruction of the original structure of the landslide body in the process of its movement to a lower hypsometric level, but the causes of disturbance of the potential landslide mass stability for these two types of landslides are different. These types of landslides are widespread on coasts in water-saturated sandy, clayey and dusty soils in the areas of accumulative and basement marine terraces, as well as river terraces composed of alluvial deposits. Less frequently they occur in deluvial sediments in mountainous areas in sections of foothill pediplains and plumes in places where groundwater emerges from fracture zones to the day surface. In plan, landslides have a circular shape. Landslides are

characterized by fast velocities of the landslide process development from several m/min to several m/s, in connection with which at relatively high relief energy and long transit zone at these types of landslides is often characterized by the transformation of the landslide body into a landslide-flow or connected slope mudflow. Disturbance of potential landslide massif stability during the development of sudden liquefaction landslides is associated with the progressive decrease of physical and mechanical characteristics of partitioned-grained and watered soils, a significant part of which is in partially suspended or decompacted state. Soils in the watered state are capable of transmitting a significant physical impulse, including from man-made or seismogenic dynamic impacts, which leads to an increase in pore pressure, liquefaction of the landslide massif and loss of its stability.

Sudden liquefaction landslides on Sakhalin are predominantly represented by seismogenic liquefaction landslides; man-made sudden liquefaction landslides have not been reliably documented in the entire observation history. It should be noted that seismogenic sudden liquefaction landslides have small volumes, usually from 100 m^3 to several thousand m^3, with an average depth of rock entrapment from several meters to 5-10 m. During earthquakes, their number and scale relative to other geodynamic processes (seismogenic mudflows, flow landslides, consecutive landslides) are very small, and therefore detailed studies of seismogenic sudden liquefaction landslides have not been conducted on Sakhalin.

Hydrodynamic failure landslides on Sakhalin are more widely represented than sudden liquefaction landslides, but their volumes are much smaller, ranging from several m^3 to several thousand m^3, with rock entrapment depths up to several meters. Among these types of landslides, hydrodynamic landslides are predominantly developed on the territory of Sakhalin, while suffosion and karst processes are poorly developed on the territory of Sakhalin. The mechanism of development of hydrodynamic upslope landslides is associated with long-term overwatering of soils, growth of pore pressure of groundwater at unchanged pressure and subsequent decompaction of the landslide massif. It should be noted that high groundwater level and the presence of filtration flow at the base of the slope usually leads to the development of shear (sliding) landslides. Hydrodynamic outburst landslides have local distribution and are mainly confined to places of active development of vertical weathering crusts, the position of which is determined by the presence of runoff troughs or other erosive forms of micro and mesorelief, as well as modern structural disturbances of rock strata occurrence.

Rock avalanches. Practically do not occur on the territory of the region, as geological conditions are unfavorable for their development. The majority of rocky and semi-rocky soils even within the largest mountain structures are represented by rocks of weak (mudstones, siltstones) and medium (sandstones, shales) degree of lithification, which are not resistant to weathering. In case of relatively fast weathering, it forms thick deposits of dispersed soils, in which other types of landslides develop. Individual rock avalanches ("rockavalanche" according to foreign classification) of small volumes up to 10 thousand m3, mainly of seismogenic origin, can be formed from eluvial-deluvial deposits of intrusions represented by strongly lithified volcanogenic, less often metamorphosed rocks. However, due to the regional peculiarities of the territory, the de-alluvial deposits of rock avalanches quickly become buried by other colluvial deposits within 2-3 years, which practically excludes the possibility of their interpretation on the ground, as well as with the help of space or aerial photographs.

Table 1. Landslide types on Sakhalin Island

Types (subtypes) of landslide processes (by mechanism of rock displacement) according to SPP 420.1325800.2018		Characteristics of rocks of the main deformable horizon	Pattern of manifestation	Max. volumes, m^3	Displacement rate and mode of motion	Depth of rock capture, m
Shear (sliding) landslides	Insectivorous (shearing)	Sparse-grained clayey, loamy and sandy loam soils	Displacement of rock blocks on a concave curvilinear surface with simultaneous tilting of the blocks	Dozens of thousands of m^3	Rapid displacement	Up to 5 meters
	Consequential (slipping)	Layers of split-grained soils in the thickness of stronger soils and weakening surfaces sloping towards the slope dip	Displacement of massif or rock blocks along weakening surfaces	> 1 mln. m^3	Rapid displacement	Dozens of meters
Extrusion landslides		Clayey, predominantly plastic soils	Soil extrusion from under the bottom of the slope scarp and its displacement together with previously formed landslide accumulations on the slope	Hundreds of thousands of m^3	Slow displacement	Up to 10 meters
Viscoplastic landslides	Landslide-flows	Sparse-grained loamy, less often sandy loamy soils with a high degree of plasticity and fluidity	Viscoplastic flow of a mass of soil	Hundreds of thousands of m^3	Rapid displacement	Dozens of meters
	Splovy (splashing)			100 - 3000 m^3		1 – 2 m
Hydrodynamic landslides destructions	Suffosion (not common)	Water saturated sandy and clayey dusty soils	Rupture of the landslide body or collapse of the suffosion niche with subsequent spreading of the displaced water-saturated mass	-	-	-
	Hydrodynamic dislocation			Several thousand m^3	Slow displacement	Up to 10 m
Sudden liquefaction landslides	Non-seismogenic liquefaction (undocumented)	Weakly compacted clay and sandy water-saturated soils subject to rapid decompaction under dynamic actions	Liquefaction under dynamic impact (anthropogenic shaking or seismic shocks) and rapid viscous flow of liquefied soil along the relief slope	-	-	-
	Seismogenic liquefaction			Several thousand m^3	Rapid displacement	Up to 5-10 meters
Rock avalanches		Strongly lithified volcanogenic, less often metamorphosed rocks	Rapid movement of very large and grandiose rock slides affecting large areas at the foot of the slope and opposing slopes to significant heights	Up to 10,000 m^3	Rapid displacement	A few meters

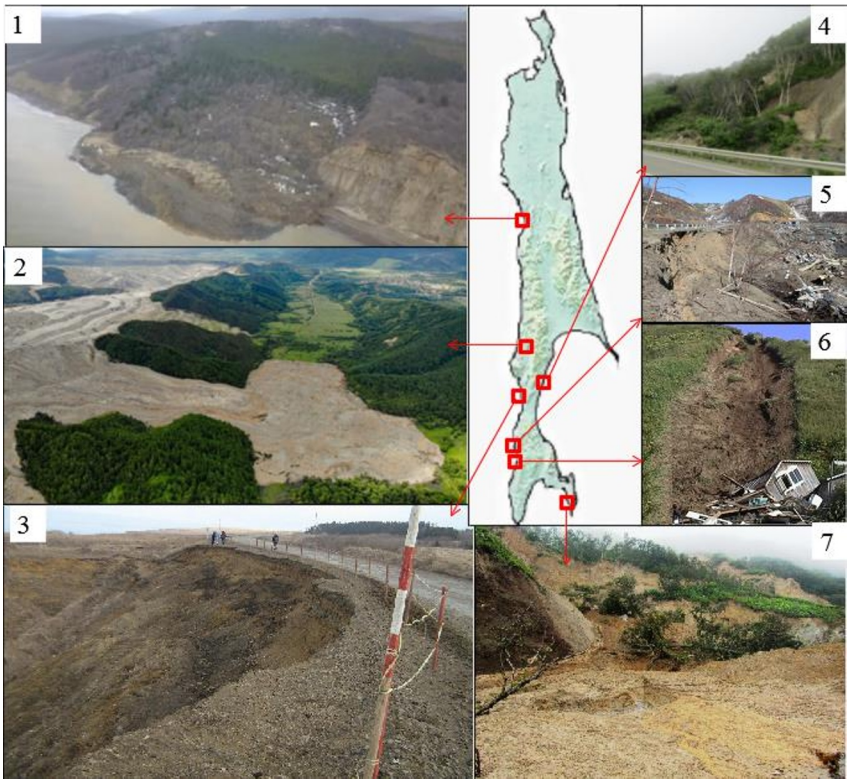

Fig.2. Types of landslides on Sakhalin Island. Sakhalin Island:1. Insequent landslide. Alexandrovsk-Sakhalinsk district. Photo instagram account @khalupdenis. 2. Flood landslide. Uglegorsk district. Photo ugiegorsk.news. 3. Consequential landslide. The highway Nevelsk - Tomari - Shakhtyorsky airport. Photo Okopny V.I. 4. Insequent landslide. Makarovsky district. Photo Rybalchenko S.V. 5. Consequential landslide Kholmskiy pass. Photo by Rybalchenko S.V. 6. Landslide-swimming. Nevelsky district. 7. Liquefaction landslide Tonino-Anivsky Peninsula.

4 Factors of landslide processes development on the territory of Sakhalin Island

The widespread occurrence of landslide processes on the territory of Sakhalin Island.The widespread occurrence of landslide processes on Sakhalin Island is caused by a specific set of natural factors that determine the possibility of development and the degree of activity of water-gravity exogenous processes, including landslides.

Among natural factors of landslide formation we can distinguish global factors (tectonic and climatic) caused by the geospatial position of the territory and their subordinate determinants, as well as secondary (trigger) factors (geomorphological, geological, hydrogeological, seismic), which are the direct cause of landslide formation.

Geospatially, the territory of Sakhalin Island belongs to the Pacific Ocean. The territory of Sakhalin Island belongs to the Pacific mobile belt, which is a transition zone from continent to ocean, within which convergent interaction of lithospheric plates (oceanic and continental) is actively taking place in the form of subduction, i.e. subduction of the oceanic crust under the continental crust, its sinking and melting in the mantle. Subduction zones of the Pacific mobile belt have a specific and regular manifestation of orogenesis, sedimentation, magmatism, metamorphism and tectonic deformations, which determine the

manifestation of structural, petrological and metallogenic zonality.

In addition to the lithosphere and asthenosphere in the "ocean-mainland" transition zone, active heat and mass transfer between the continent and the ocean takes place in the atmosphere and hydrosphere, which determines the climatic and hydrological characteristics of the territory, as well as affects the sedimentation regime.

Tectonic activity on the territory of Sakhalin has largely determined its present-day relief, geological structure and seismicity. The inversion associated with the change of the northeastern direction of regional compression of tectonic plates from continental to latitudinal about 1.8 Ma resulted in the formation of large mountain structures, the slopes and foothills of which were overlain by thick strata of easily erodible terrigenous rocks [6]. In these rocks there are many structural disturbances, which are expressed in their inclined bedding, the formation of folding and discontinuities, in connection with which in relatively small areas there are different lines of strike, azimuths and angles of dip of rocks, which forms complex engineering-geological and hydrogeological conditions of the territory, contributing to the active development of landslides.

Due to its geospatial location, Sakhalin has a monsoonal climate with high cyclonic activity. The territory of Sakhalin is located in close proximity to the trajectory of tropical cyclones. During the year about 100 cyclones pass over Sakhalin causing wind strengthening, cloudy weather with precipitation, and in late summer and early fall there are outbursts of deep tropical cyclones (typhoons) originating near the equator. The passage of typhoons is accompanied by gale force winds reaching speeds of more than 40 m/s and heavy rainfall, for a few days often falls more than a month's norm of precipitation [7]. Annual precipitation in valley bottoms and on the sea coast of Sakhalin Island varies from 400-500 mm in the north to 800-1200 mm in the south. In the warm period, 65-80% of the annual precipitation falls[8]. The monsoon climate and cyclonic activity on the island leads to significant overall moisture content of the territory, and in combination with complex engineering, geological and hydrological conditions, to active landslide formation.

Geomorphologic factor of landslide formation is expressed in high energy of macro- and mesorelief of the territory. The main orographic units of the area, which determine its macrorelief, are the submeridial mountain structures of the West and East Sakhalin Mountains, stretching along the western and eastern coasts, respectively.The orogenesis of these mountain systems is confined to the Meso-Cenozoic tectonomagmatic epoch of the Alpine folding, although within the epoch these alpids were formed in different phases of tectonogenesis and often inherited relics of the relief. However, although absolute elevations range from 100 - 1600 m on Sakhalin Island, its potential energy content is sufficient to form modern large landslides, as well as very large landslides in previous geologic epochs.

Despite the presence of large mountain structures, it should be noted that the greatest contribution to the development of landslide processes is made by the mesorelief of the territory due to the wide development of erosion-denudation processes, which leads to high frequency, depth of relief dissection and formation of numerous landslide-prone slopes. Among landslide-prone slopes of erosion-denudation and abrasion origin it is worth highlighting particularly active slopes of ancient accumulative and basement marine terraces. Due to the location of Sakhalin in the transition zone as a result of a significant drop in the level of the World Ocean during the Pleistocene glaciation epoch, ancient marine terraces are developed along most of the coast of Middle and South Sakhalin, which causes extremely high landslide incidence in the area. Their relative height reaches 180 m with the height of the scarp up to 40 m. It is to the slopes of ancient marine terraces that the most landslide-prone areas of Sakhalin are confined.

The geological factor of landslide formation is related to the wide distribution of split-grained and weakly lithified Quaternary and Tertiary sediments with low physical and

mechanical properties and poor resistance to weathering. More resistant strongly lithified volcanogenic and metamorphosed rocks are mostly sporadically distributed in the territory. The geological sections show a variegated composition of rocks and their layered structure, which are caused by the peculiarities of the cyclic mode of sedimentation of regressive and transgressive formations of marine and continental sediments, rhythmically traced over large areas. The vast majority of these sedimentary rocks were deposited or accumulated on the bottom of deep seas and oceans, with the oldest of these rocks deposited on the bottom of the deep ocean. In more recent times, deep oceanic sedimentation conditions at the Sakhalin site were gradually replaced by shallower marine, and then coastal-marine and even freshwater-continental conditions.

High seismic activity of the area often leads to massive activation of landslide processes, in some cases to the formation of seismogenic liquefaction landslides. The seismic impact is capable of breaking the stability of a potential landslide massif as a result of exceeding the total shear forces over the restraining ones, or as a result of complete almost instantaneous destruction of the landslide body. In addition to the direct impact on the superposition of forces in potential landslide massifs or the consistency state of landslide bodies, seismic events and their high intensity affect engineering-geological and hydrogeological conditions, forming multiple structural disturbances (faults, fractures, crushing zones), within which secondary weathering crusts, including linear vertical crusts, are subsequently formed under the active action of groundwater.

Hydrogeological factor of landslide formation affects the activation of landslide processes on the territory of the region, and, as a rule, serve as a trigger for landslide formation, and for some types of landslides (viscoplastic, hydrodynamic outburst landslides) and the cause, especially with pressurized groundwater.

Due to the peculiarities of climate, geological and tectonic structure, history of geological development, variability of physical and geographical conditions and lithological composition of rocks, the territory of Sakhalin is a complex basin of non-pressure and pressure waters of the first order, associated with basins of fracture and artesian waters. The fractured water basins are found predominantly in the mountainous landslide-prone areas of Southern and Middle Sakhalin. The thickness of the fractured weathering zone, to which the main groundwater resources are confined, does not exceed 100 meters. The water permeability of the rocks is low and does not exceed 50 m^2/day in the most fractured varieties found along the valleys of mountain rivers. In these areas, hydrogeologic conditions are often a secondary rather than a determining factor in landslide formation. Water-bearing horizons of artesian basins in Quaternary sands with gravels and pebbles, lenses and interlayers of sandy loam, loam and clay are widely developed along the valleys of plain rivers and the sea coast. The thickness of water-bearing rocks reaches 300 m, while the Pliocene waters can have a head up to 100 m high. The average water permeability of the rocks is about 300 m^2/day. It is in these areas that the development of hydrodynamic upslope landslides is possible.

5 Conclusion

Geospatially, the territory of Sakhalin is located in the transition zone of the "ocean-mainland" system, which is characterized by active heat and mass transfer in the atmosphere, hydrosphere, lithosphere and asthenosphere, which is accompanied by a high intensity of endogenous and exogenous processes, including exogenous processes of water-gravity character - landslides.

It is due to the geospatial position of the territory as a result of tectonic and geological history of its development that the modern relief, in addition to extensive sedimentation basins, is represented by steeply sloping erosion-denudation and abrasion forms of macro-

and mesorelief with high potential energy, overlain by thick layered significantly dislocated and structurally disturbed terrigenous strata, represented by relatively weak rocks, the accumulation of which occurred as a result of cyclic sedimentation, and the formation of terrigenous rocks. The tectonic and accompanying seismic activity, as well as the geologic history of the terrane formation have led to the formation of complex engineering, geological and hydrogeological conditions of the territory. Also, the marginal position of the region determines its monsoon climate with high cyclonic activity, which leads to overall high moisture content of the territory and activation of exogenous processes.

Thus, due to the geospatial position of Sakhalin in the transition zone, a whole complex of natural factors of landslide formation was formed in the territory, including global factors (tectonic, climatic) and their subordinate determinants, as well as secondary (trigger) factors (geomorphologic, geological, hydrogeological, seismic), contributing to the widespread development of modern active landslides of different scales, characteristics, as well as types of landslide process and mechanism of mountain displacement.

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