Geological and geomorphological processes impacting nature management in the coastal zone of Pacific Russia

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Abstract. The coastal zone of Pacific Russia (administrative areas of the Far East with access to the ocean) is characterized by many dangerous natural processes. However, due to the low population density of the region, their impact on nature management often goes unnoticed. This sometimes gives a false impression of their lack of strength compared to similar processes in other more populated areas of the world. However, if the population density in the coastal zone of Pacific Russia corresponds to the indicators of Japan or Indonesia, the consequences of their occurrence in most cases would be catastrophic. An inventory of hazardous natural processes in the region was carried out. The intensity of their manifestations in other parts of the world was compared and a division of these processes according to the degree of their danger to the region was made. In the category of the most significant processes, the force of manifestation of which corresponds to the maximum possible values observed on Earth, or is approaching them includes earthquakes, tsunamis, volcanic eruptions, avalanches and cryogenic processes. The second group includes mudflows, aufeises, river erosion, abrasion, landslides, screes, landslides, subsidence and suffosion. The third group (the probability and intensity of which within the coastal zone of Pacific Russia are minimal) includes gully erosion, sheet erosion, rock streams, heaving, shrinkage, karst and aeolian processes. If we compare with other Russian regions, some processes (volcanic eruptions and tsunamis) are distributed exclusively within the coastal zone of Pacific Russia, others (earthquakes, aufeises, abrasion, rock streams, cryogenic processes) have a generally higher intensity, the importance of the third (karst, subsidence, etc.) is obviously lower than in other Russian regions.

Keywords: seismic processes, cryogenic processes, avalanches, integrated management of coastal zone.

1. Introduction

From the point of view of a set of dangerous geological and geomorphologic processes and the essence of their impact on nature management Pacific Russia has significant differences from other Russian regions. These differences are due to its location in the transition zone of the two greatest structures of the Earth (the Eurasian continent and the Pacific ocean).

Describing various geological and geomorphologic processes typical for the coastal zone of Pacific Russia, it should be taken into account that due to the weak degree of development of the region and its low population, their impact on human activity is often practically not manifested. This sometimes creates a false perception of their lack of strength in comparison with similar processes in other, much more populated areas of the world. However, if we mentally transfer these natural processes to other more developed regions, or, on the contrary, hypothetically increase the population of the coastal zone of Pacific Russia, to the level of Japan or Indonesia, it would become clear that the consequences of these processes are truly catastrophic.
Most natural processes are characterized by different physical quantities, allowing to assess the intensity of their manifestations. This can be the amount of energy in the source of origin, the volume of moving masses, the speed of movement, etc. For example, earthquakes are characterized by scales of magnitude (Richter scale) and amplitudes (for example, Merkalli scale). The strength of volcanic eruptions is characterized by the Volcanic Explosion Index. Imamura-Iida intensity scale is used for tsunami assessment. Different scales exist for avalanches, mudflows, rockfalls, scree, landslides, aufeises, etc.

The nature of the manifestation of dangerous geological and geomorphologic processes of the coastal zone of Pacific Russia can be divided into three groups:

The first group includes the most significant processes, the intensity of which corresponds to the maximum possible values observed on Earth or approaching them.

The second group represents processes and phenomena that, although not so clear on a large scale, but, nevertheless, can significantly complicate the use of natural resources.

The third group includes processes, the probability of manifestation and intensity of which is minimal, but are potentially able in some cases to create problems for human activity.

2. Processes of the first group

These may include processes such as earthquakes, tsunamis, volcanic eruptions, avalanches and cryogenic processes such as frost heaving, thermokarst, cryogenic cracking, thermoerosion, thermoabrasion and solifluction.

2.1. Earthquakes

The highest seismicity is typical for the South-Eastern part of the Kamchatka Peninsula and the Kuril Islands. Here there were the strongest earthquakes with a magnitude of up to 8.0 and a seismic effect of up to 10 points. Their hypocenters were usually located at depths up to 80 km, more often they occurred in a relatively narrow strip between the oceanic trench of the Kamchatka and the Kuril Islands. Similar earthquakes occurred here in the 1737, 1780, 1792, 1841, 1918, 1923, 1952, 1963, 1969, 1994 and 1997. The 1994 Shikotan earthquake had a magnitude of 8.0 and an amplitude of 9-10 points. The Kronotsky earthquake, which occurred near the Eastern coast of Kamchatka in 1997, had similar parameters (7.9 and 9-10 points). Both of them caused significant material damage.

The seismicity of Sakhalin Island was somewhat lower, however, it was here that the most destructive Neftegorsk earthquake in the history of Russia occurred on May 28, 1995. Its magnitude was 7.5 on the Richter scale. As a result among 22 panel-five-storey buildings 17 houses were completely destroyed, 2 more buildings burned down. Out of 3,176 inhabitants of the settlement, 2,247 people were under the ruins, from whom 1,992 people were lost [33. The seismic effects of this earthquake have been heavily strengthened by the liquefaction of soils [27].

2.2. Tsunamis

First of all, the coasts of the Kamchatka territory and the Kuril Islands are exposed to tsunamis, which are caused by earthquakes under the bottom of the Pacific ocean, the Okhotsk, and the Bering seas. The most dangerous tsunamiogenic earthquakes are confined to the Kuril-Kamchatka zone, stretching along the North-Western outskirts of the Pacific ocean [35]. On the Okhotsk coast of Kamchatka, a tsunami was noted three times, at the Bering Sea coast – two times. In the North of Kamchatka, the average recurrence of strong tsunamis is every 150 – 200 years while in the South-East of Kamchatka, it’s 30 – 60 years [34].

The strongest was the tsunami of October 6, 1737 with the magnitude of the earthquake as 8.5 and the height of the wave setup as 30 m [38]. A comparable effect of tsunami waves was caused by an earthquake on November 4, 1952 [10]. At the height of waves of 14-20 m, there was an almost complete destruction of Severo-Kurilsk, in it no more than 5% of houses remained.

2.3. Volcanic eruptions

Within the coastal zone of Pacific Russia, volcanism is typical for the Kamchatka territory and the Sakhalin (Kuril Islands) region. In this region, there are 12% of all active volcanoes in the world [18].
On the Kamchatka Peninsula are the most active volcanoes on the Earth. Every year there are eruptions of 3-5 volcanoes [39]. Among the most dangerous of the Kamchatka volcanoes are Kluchevskoy, Bezymianny, Shiveluch, Karymsky and Avachinsky.Sopka volcano. The most dangerous Kuril volcanoes are Mendeleev volcanoes on Kunashir Island, Alaid ( Atlasova Island), Severgina (Kharimkotan island), Sarycheva (Matua Island) and Snow (Chirpoy Island) [5].

Volcanoes in Kamchatka and the Kuril Islands pose a serious threat to air transport. Near them lie a lot of air routes, which transport daily more than 20 thousand passengers. For example, during the eruption of a Klyuchevskoy volcano in October 1994, the ash plume crossed at an altitude of 9.5 - 11.5 km all major air routes connecting North America with Asia [7, 16]. The largest eruptions of the twentieth century are the eruptions of Bezymyannyi volcano in 1956 and Shiveluch volcano in 1964.

Lahars, formed in 2001 during the eruption of Shiveluch volcano, moved to a distance of 30 km and caused damage to the Klyuchi – Ust-Kamchatsk highway [5]. Lahars caused by snow melting under the action of hot pyroclastic flow material during the eruption of the Molodoy Shiveluch on May 9, 2004, blurred the dam and roadbed in the area of the Bekesh River at a distance of 30 km from the volcano [16].

2.4. Avalanches

Within the coastal zone of Pacific Russia, avalanche-prone areas are widespread. The average volume of avalanche in most regions is about 10 thousand to 100 thousand m³ [15]. To the greatest extent, their influence is characteristic of the Sakhalin region, where more than 183 thousand people live in the avalanche zone [37]. There are 57 settlements, 180 km of railways and about 200 km of roads [45]. Maximum avalanche hazard is characteristic of the mountainous territory of southern Sakhalin especially Mitsulsky and Kamyshevsky ridges.

During the entire period of observation of avalanches in the Sakhalin region from 1928 to 2015, 143 cases of people falling into them were registered. A total of 760 people fell into avalanches with 359 of them died. The largest was the avalanche catastrophes in Sakhalin region which occurred in the village of Srednyaya Medvezhka (Alexandrovsky district) on February 9, 1945. An avalanche with a volume of 170 m³ destroyed nine buildings; it gulfed 236 people, of whom 149 people, died [22].

December 25, 1959, on the Island of Paramushir, in the city of Severo-Kurilsk from the slope of the Aerodromnaya sopka came a large avalanche that destroyed several houses and 36 people died. Avalanches cause frequent interruptions in the movement of trains on the Yuzhno-Sakhalinsk railway.

In the former Koryak autonomous district, the maximum density of avalanche sites are in the area of Vetveisky range (more than 5 foci per 1 km of the valley floor). In other areas, it does not exceed 2-3 foci [5]. On the territory of the former Kamchatka region, avalanche-prone sites have area 274 thousand km² [40]. Here a network of avalanche sites is denser. On average, it is about five, sometimes reaching 10-12 foci per 1 km of the valley bottom [5].

At whole of the Kamchatka Peninsula are dominated avalanches of the medium volume of 30 to 250 thousand m³. In the river basins of the Ozernaya Kamchatka, Kashkan, Avacha, Paratunka, Vilucha and Zhirova, the largest avalanches reach 1 million m³ [40]. The duration of the avalanche period in the high-altitude zone of 1000-1500 m reaches 250 days and in the high-altitude zone of 500-1000 m, about 150 days. The average annual number of avalanche days is 20 – 30, maximum 45 and minimum about 10 days.

The main indicators characterizing the danger of an avalanche are the volume of snow carried, the speed of movement and the amount of pressure on a fixed barrier. The maximum volume of avalanches on the globe is 5-6 million m³ [29], the speed of movement reaches 125 m/s [32] while the record pressure value recorded in Japan is 300 t/m² [43].

In Kamchatka, the largest avalanches descend from the slopes of volcanoes namely Vilyuchinsky, Kozelsky, Koryaksky, Aug and volcanoes of the Klyuchevskaya group. They have a path length from 3 to 6.5 km, an avalanche snow deposition zone from 1.0 to 2.5 km², a height difference of 1000-2500 m and volumes up to 1.5-3.0 million m³. For example, an avalanche, coming down from the Kozelsky volcano on January 28, 1997, had a volume of 3.0 million m³, and the path length of 6.5 km. The
maximum speed of 50 m/s was recorded on avalanche descended from Vilyuchinsky volcano on January 22, 1998 with record force of low-pressure of an avalanche on construction (the unfinished avalanche cutter) of 50 t/m² [40].

In Kamchatka Krai, avalanche danger threatens 20 thousand people [7]. In 1947-1948 the facts of destruction by avalanches of fishing bases (artels) in the mouth of the River Zhivovaya are registered where more than 50 people were lost. On April 10, 2010 in the area of pass Dukuk (Srediny range), te result of an avalanche with a volume of approximately 300 m³ killed 10 people [40].

2.5. Cryogenic processes
The danger of cryogenic processes is currently increasing due to global warming, which is almost ten times more pronounced in the Arctic on the average than on the planet. The annual growth of phenomena associated with climate change on the territory of the Russian Federation is about 6% [11].

In the coastal zone of Pacific Russia, the geocryological danger in the conditions of climate change is most characteristic of the coast of Chukotka. Some areas of high risk are on the eastern coast of the Kamchatka territory, the northern coast of the Primorsky, the southern coast of the Khabarovsk territory and the North-Western coast of the Sakhalin region [3].

Cryogenic processes create serious problems in the construction and operation of engineering structures. Among the most dangerous processes include frost heave, thermokarst, cryogenic cracking, thermoerosion, thermoabrasion and solifluction [23].

3. Processes of the second group
Here, processes include: mudflows, aufeises, river erosion, abrasion, rockfalls and screes, landslides, subsidence processes, suffosion.

3.1. Mudflows
The greatest impact they have in the Sakhalin region. In total, the territories of 30 settlements of Sakhalin, including 7 cities, are exposed to mudflows, the most dangerous of which are Nevelsk, Kholmsk and Makarov [36].

The Sakhalin Island is allocated 14 mudflow areas. The most dangerous of them are concentrated in the South-Coastal mountain range and Okhotomorsky region [21]. There, cases of catastrophic manifestations of mudflows are not too rare. For example, on August 5-7, 1981 there was a mass descent of mudflows (282 flows) in the southern part of Sakhalin Island. They disabled all roads, railways and communication lines. In Nevelsk, Kholmsk and Uglegorsk have damaged houses. Twelve years later, on 12-14 August 1993, the situation was repeated on the east coast of the Island. On the site from the Vostochny village to the city of Makarov descended about 70 mud flows that interrupted road and railway for a few days [22].

Mudflows for the Kamchatka territory are quite typical. In the north, the average occurrence of large mudflows is 5 years [14]. To the south, the frequency is reduced. For example, in the area of Avacha sopka large mudflows are observed once in 11 years where small mudflows are observed once in 3-4 years [5].

Among the largest mudflows in Kamchatka are those that occurred in the Dolina of geysers between June 3, 2007, and January 4, 2014. The mudflow, which came down on June 3, 2007, moved at a speed of 35-40 km/h [44]. The volume of mud masses displaced on 4 January 2014 amounted to approximately 0.75 million m³ [30]. Thus, mudflows of Kamchatka though, are not outstanding, however, are quite large.

3.2. Aufeises
They have the maximum development in the North-East of the territory. So, the North of Chukotka annually generates a large number of giant aufeises fed by the underflow of water through and not through taliks. In total there are 262 aufeises with a total area of about 669.4 km². The water storage in
the aufeises during their maximum development is 1.44 km$^3$. Together, they occupy 942.3 km of the river network [2].

In the Kamchatka-Koryak aufeis region, located within the Kamchatka territory, there are 342 aufeises with a total area of 244 km$^2$, similar indicators for the Penzhinsk-Anadyr aufeis region, located at the junction of the Kamchatka territory and the Chukotka autonomous district, are 74 aufeises, totalling 100 km$^2$ [1].

Aufeises in the Kamchatka territory is formed on almost all rivers. The maximum spread of aufeis formation is observed in the upper part of the Penzhina river basin [24]. The largest aufeises (more than 1 million m$^3$) are typical for Pekulney range and the most elevated part of the Koryak upland [5].

3.3. River erosion
Among the most dangerous manifestations of river erosion is the erosion of the banks with an average speed of more than 10 m/year. Such values are typical only for large rivers. Within the coastal zone of Pacific Russia, this indicator is observed in the lower reaches of the Amur. High rates of erosion are also observed in the lower reaches of the rivers Yana, Omoloy, Indigirka, Kolyma and Amguema, passing through the plains.

In the areas of the possible threat of changes of river channels are settlements like Andryushino and Argakhthak on the river Alazeya, Chersky and Pokhodsk on the river Kolyma, Okhotsk on the river Okhota, Nikolaevsk-on-Amur, Krasneno and Markovo on the Anadyr River, Kozyrevsk on the Kamchatka River [9]. As a whole, the risk of coastal erosion in large rivers is much higher, but in small and medium-sized rivers, river erosion can also cause significant damage. For example, on the rivers of Kamchatka in the period from 2004 to 2008, 5 settlements experienced negative manifestations of the development of channel deformations.

So, in the village of Severnye Koryaki due to river erosion, there was a washout of the streets of the village and the collapse of a number of buildings into the river [42]. In some cases, they cause damage to roads and bridges (Sarainaya River in a basin of River Bolshaya, 2005; River Andrianovka in the basin of the River Kamchatka, 2007) [13].

3.4. Abrasion
In the coastal zone of Pacific, Russia abrasion is developed quite widely, but its extreme manifestations are generally not characteristic. On Sakhalin Island, a significant part of the coast is composed of loose or slightly compacted sediments. In General, more than 70% of the Sakhalin Island shore is abraded with varying degrees of intensity. The rate of coast retreat here is 2-5 m/year which can reach 22 m/year [8].

Sometimes abrasion leads to significant economic loss. Thus, in January 2010, the storm, which lasted four days, on 105 km of the Yuzhno-Sakhalinsk – Okha highway in three places, destroyed the breakwater wall and damaged the canvas. The asphalt surface was deformed for about 150 m by the value of up to 1.5 m [41].

Abrasion in the Kamchatka territory is more typical for the Okhotsk sea coast. In some areas (Sobolevo and Ust-Bolsheretsk) the linear velocity of the shore processing exceeds 10 m/year [5]. To a greater or lesser extent are blurred marine sand bars, which are located on Oktyabrsky, Ozernaya, Korf, Ilpyrskoe, Ivashka and Pakhachi willages [25].

3.5. Rockfalls and screes
In the coastal zone of Pacific Russia, rockfalls are widespread, but their intensity is generally low. A major rockfall was registered on January 4, 2014, in the Kamchatka Krai in the upper Dolina of Geysers. Then the collapsed block of rocks had a size of 250 m in length, 100 m in width and capacity of about 70-80 m. The collapsed mass of rocks slid down to the river and blocked the Geizernaya River, forming a dam lake, about 200 m wide and about 400 m long [30].
There are examples when the rockfalls posed a threat to human life and caused economic loss. So, in the Khabarovsky Krai in 2007 on the railway line Pivan – Sovgavan, there was a crash of the freight train from the blow of a rocky fragment weighing more than 10 t which fell from a mountain slope [26].

Scree is common in many mountainous areas. So, in the territory of the Kamchatka Krai with the most widespread scree processes in the territory of the Talovsky, Sredinno-Kamchatsky, Penzhinsky ridges and Lapganay-Tunul mountain [25].

3.6. Landslides
To the maximum extent, landslides complicate economic activity in the Sakhalin Oblast. The loss caused by landslides to the economy of the region is expressed in damage and destruction of roads and railways, communication lines and power lines, the rubble of the territories of settlements with landslide deposits, the destruction of houses and economic facilities. There are also human victims [31]. Landslides were recorded in 37 settlements, including 8 cities. The damaged area of territories of separate settlements of Sakhalin by landslide processes can exceed 30% (Makarov, Nevelsk, Kholmsk, etc.) [36].

In the Kamchatka krai, one of the largest is a landslide that descended on June 3, 2007, in the valley of the Vodopadny stream, the tributary of the Geizernaya River. At the same time, a number of outbuildings, two helipads and a diesel power plant were destroyed. In addition, it influenced the excursion and tourist activities, stopping the functioning of some geysers [44]. Certain problems of landslides are created in Petropavlovsk-Kamchatsky [5].

3.7. Subsidence processes
For the most part, subsidence processes are developed in the Kamchatka Krai mainly in the valley of the Kamchatka River, where the settlements of Kozyrevsk, Lazo, Dolinovka and Milkovo are located. The intensity of the processes is estimated as moderately dangerous. A small array of subsidence soils is also situated near Petropavlovsk-Kamchatsky and Yelizovo [5].

Separate areas with the spread of subsidence processes are available in the coastal zone of the Primorsky and southern part of the Khabarovsky Krai. In Primorye, almost all the Khasan district, the Peninsula Muraveva-Amur and valley of Partizanskaya River. In the Khabarovsky Krai, they are concentrated in the vicinity of the Udil Lake, the lower reaches of the Amgun River, in the coastal strip of the Ulban Bay and the Gulf of Nikolay [4].

3.8. Suffosion
Active development of suffosion processes is noted in the area of the airport "Magadan-Sokol" [17]. In the Kamchatka Krai, the most dangerous are now built-up areas along the main and bypass route of Petropavlovsk-Kamchatsky – Yelizovo (Konstantinova and Delemen, 2013). It also poses a certain danger on the section of the Sobolevo – Petropavlovsk-Kamchatsky gas pipeline route [12]. The suffosion complicates the construction and operation of engineering structures in Khabarovsky. There was a deformation of a number of buildings and there was a failure on the roadway of P.L. Morozova [6].

4. Processes of the third group
This can include rock streams, gully erosion, sheet erosion, heaving and shrinkage, karst and aeolian processes. These processes do not pose a serious threat.

5. Conclusion
It should be noted that the relationship between the spread of processes and the degree of their impact on nature management is not always direct. For example, from the regions of Pacific Russia to the greatest extent, natural processes impact economic activity in the Sakhalin Oblast. At the same time, from the point of view of the spread of geological and geomorphologic processes and the intensity of their manifestation, this region does not occupy a leading position.

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