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Processes in GeoMedia—Volume IV

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Processes in GeoMedia—Volume IV

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Contents

Coastal Geology and Geomorphology of the Kasatka Bay (Iturup Island, South Kuril Islands, SE Russia)

M. A. Kuznetsov and D. E. Edemsky

Abstract Iturup is the largest and most explored island of the Kuril Archipelago. It is known for the activity of tectonic processes, active volcanoes and geothermal sources, and is rich in minerals. However, much less attention is paid to the study of the geological and geomorphological structure of the coast. As a result of our studies, we identified 3 morpholithogenetic types of coasts in Kasatka Bay, of which 49% are in the accumulative coasts with sand-pebbles beaches, and 51% are on the erosion and erosion-denudation coasts (bay flanks and Chertovka rock). Using the joint use of geomorphological and geophysical methods, the geological and geomorphological structure of marine terraces in the central part of the bay has been clarified. Geological and geomorphological sections of low sea terraces were obtained on the basis of GPR sounding using the common midpoint method. It has been established that a 5–15 m accumulative terrace level lies on top of an ancient bench, developed, most likely, in proluvial pre-Holocene deposits. The measurements showed that the pyroclastic cover with buried soils at terrace levels of 25–40 m and 45–60 m has a subhorizontal flat-layered structure from 3 to 5–6 m thick. with a thickness of 3 to 5–6 m. Studies of terrace 45–60 m structure above Chertovka rock showed the presence of ancient lahar deposits under pyroclastic cover with buried soils.

Keywords Kuril Islands · Coastal classification · GPR · Marine sediments · Marine terraces

1 Introduction

Iturup Island is located in the southern part of the Great Kuril Ridge. Its area is 3175 km^2, with a length of about 200 km, a width from 7 to 27 km. Iturup is part of the Pacific seismic belt, which is characterized by the intensity of volcanic and tectonic processes, a high level of seismicity and may be affected by tsunamis

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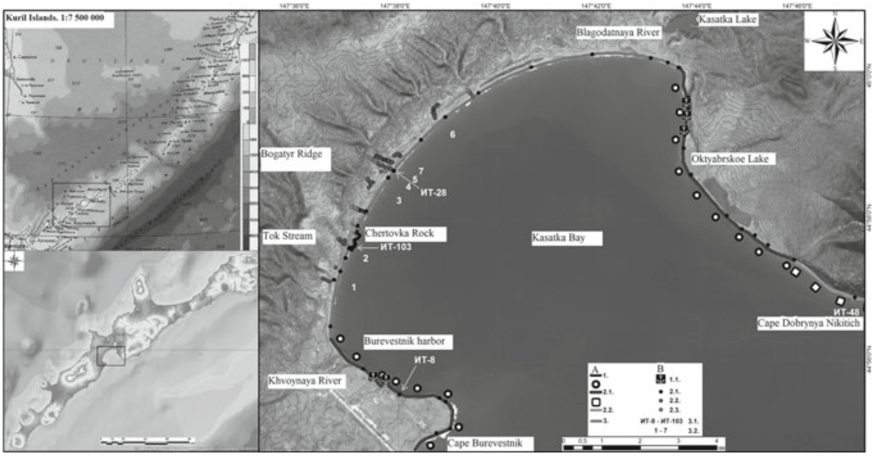

Fig. 1 Map of the study area and morpholithogenetic types of coasts of Kasatka Bay. **a**–types of coasts. Indices see Table 1. **b**—other symbols: 1.1—coastal technogenic landforms; 2.1—waypoints, 2.2—pickets of georadar profiling, 2.3—points of geomorphological profiling; 3.1—points with the most characteristic coastal structure, 3.2—numbers of georadar profiles

(Sergeyev 1976). There are 9 active volcanoes on the island (Atlas of the Kuril Islands 2009), the last phreatic eruption of Ivan Groznyy volcano occurred in 2013 (Zharkov and Kozlov 2013). Iturup is the most studied among all the islands of the Kuril archipelago. Main researcher's attention was paid to study its geological structure, minerals and relief (Geology of the USSR. T. XXXI 1964; State geological map of the Russian Federation 1980; Grabkov and Ishchenko 1982; Fedorchenko et al. 1989). However, a much smaller number of works is devoted to the study of the geological and geomorphological structure of the coast (Bulgakov 1994; Razjigaeva et al. 2004; Afanas'ev et al. 2018; Dunaev et al. 2019).

In 2019, during a expedition of the Russian Geographical Society "East Bastion—Kuril Ridge", field studies were conducted in Kasatka Bay, located on the Pacific side of Iturup Island (Fig. 1). The article considers the typification of the coast of the bay and clarifies the geological and geomorphological structure of marine terraces in the central part of the island.

This study has not only theoretical but also applied significance in connection with the planned expansion of the economic development of shore of central part of the Iturup island.

2 Materials and Research Methods

Route studies were planned based on a preliminary analysis of topographic, geological and geomorphological maps of different scales and open-source satellite imagery from DigitalGlobe [QuickBird, WorldView, GeoEye with meter spatial resolution in the GoogleEarth program (https://www.google.com/earth/)]. During the routes, geomorphological descriptions and coastal profiling were performed and morpholithogenetic types of coasts were identified. The leading relief-forming processes on the coasts and adjacent marine terraces are identified.

Study of the geological and geomorphological structure of marine terraces in the central part of Kasatka Bay was carried out by the method of pitting and deposition description, as well as using the geophysical method of georadiolocation—an effective method of engineering and geotechnical inspection of soils at depths from a few centimeters to tens of meters. The work on the research site was carried out by the Loza—V GPR and radar antenna systems with central frequencies of 300 and 50 MHz. To correctly interpret the obtained radar profiles and reconstruct the geological section from them in characteristic areas, sounding was carried out using the common midpoint (CMP), which allows one to determine the speed of electromagnetic waves in the medium and to convert the GPR section from the time scale to the depth scale without involving a priori information (Vladov and Starovoitov 2004; Edemskiy et al. 2010).

3 Research Results and Discussion

The marine relief of Iturup Island is divided into surface and underwater, which in turn are divided into modern and ancient. The surface marine relief is most fully represented in the southwestern and central parts of the island, including Kasatka Bay. Within the bay, we distinguished three morpholithogenetic types of coasts: erosion (stable) coast in volcanic rocks with steep cliff, erosion-denudation (stable) coast in volcanic rocks and lithified pyroclastics and accumulative coast with a wide sandy beach with rare pebbles. The identification of coast types is based on morphogenetic classification (Ionin et al. 1961). The distribution by their length is shown in Fig. 1 and Table 1.

1. **Erosion (stable) coast in volcanic rocks with steep cliff**, located in the area of the Chertovka Rock. They are confined to places where erosion-resistant effusives enter the water area. A section of this coast in the plan has the form of

Table 1 Length of morpholithogenetic types of coasts of Kasatka Bay

Type (subtype) of coast	Length (km)	%
1. Erosion (stable) coast in volcanic rocks with steep cliff	0.9	3
2. Erosion-denudation (stable) coast in volcanic rocks and lithified pyroclastics	12.6	48
2.1. With a boulder-block pavement	10.5	40
2.2. With rockfall cones	2.1	8
3. Accumulative coast with a wide sandy beach with rare pebbles	12.6	49
Total	26.1	100

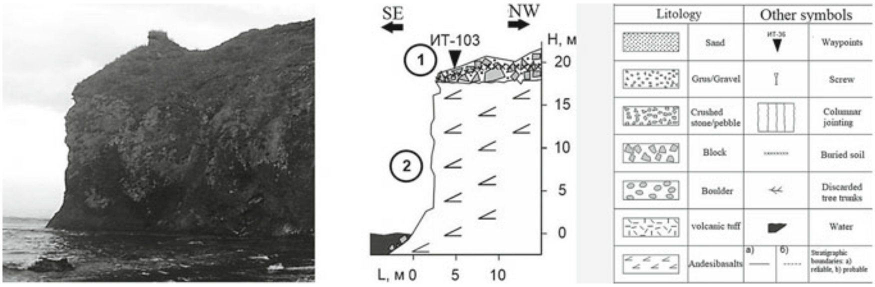

Fig. 2 Geological and geomorphological structure of erosion (stable) coast in volcanic rocks with steep cliff (point ИТ-103). Symbols for profiles 2–5

heavily indented capes of complex shapes. At point ИТ-103 (Fig. 1), the most characteristic structure of this type of coast is observed. In a steep abrasion ledge (Fig. 2) 18–20 m high, the following are discovered: (1)—unsorted, compacted gravel-block deposits with a dark brown sand aggregate and buried soils. The maximum thickness of the stratum is up to 3 m, the sole of the stratum is quite even and clear. Judging by the nature of the occurrence and the composition of the deposits, this is a mixture of pyroclastic and proluvial material. Massive gray andesitobasalts are revealed below (2), the apparent thickness of the formation is about 15 m. In some places, the overhang of the roof of effusive rocks over shallow bays is observed. According to State geological map of the Russian Federation (2002), the age of these volcanic rocks is Miocene-Pliocene.

At the base of the cliff, there is a bench with a visible underwater width of up to 10–15 m. It consists of boulder-block material lying on top of the highly fragmented surface of the erosion terrace. Between the headlands at the base of the cliff leaning pebble-gravel "pocket" beaches with a width of up to 20 m are observed. They have pebble drying, pebble festoons with gravel in the splash zone. In some places at the base of the cliff, shallow (up to 2–3 m), uneven (from 2–3 to 8–9 m) wave-breaking niches were formed.

2. **Erosion-denudation (stable) coast in volcanic rocks and lithified pyroclastics** are located on the flanks of the bay (Fig. 1), and they can be divided into 2 subtypes.

2.1. Erosion-denudation (stable) coast in volcanic rocks and lithified pyroclastics with a boulder-block pavement. Developed on the bay flanks and in the vicinity of Cape Burevestnik, point ИТ-8 (Fig. 1). In a steep (from 35–40° to 60°) erosion-denudation ledge 13–15 m high (Fig. 3), the upper 2–3 m are represented by dark brown hummed loams (1). Under them, 4–5 m (visible thickness) of sand with gravel and pebbles were revealed, while the number and average size of pebbles increases downward (2). According to State geological map of the Russian Federation (2002), these are deposits of marine genesis, late Pleistocene age. Marine sediments lie on the Miocene-Pliocene effusives of andesitobasaltic composition, which do not come

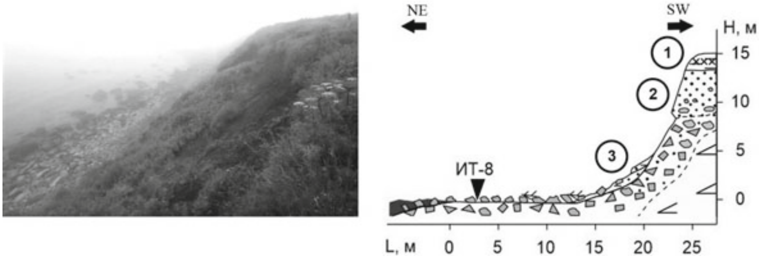

Fig. 3 Geological and geomorphological structure of erosion-denudation (stable) coast with a boulder-block pavement (point ИТ-8)

to the surface, but their fragments of boulder-block size form the bench and the lower part of the cliff (3).

The surface of the bench is a boulder block area up to 20 m wide, taking into account its visible underwater part, up to 40–50 m, block sizes up to 2–3 m. As a rule, in the river mouths (the Khvoynaya River) and streams, flowing into Kasatka Bay, there are remnants of eroded alluvial-marine terraces. In these places, the blind area is the widest, up to 100 m.

In the boulder-block blind area on the flanks of the bay are anthropogenic landforms, technogenic passages and berthing facilities of the port on Cape Burevestnik. One of such passages on the eastern flank of the bay (north of Oktyabrskoe Lake) was used during the landing of the expedition in 2019. It should be noted that most of the berthing facilities at Cape Burevestnik are located correctly, however, significant investments are needed for their stable and safe use.

2.2. Erosion-denudation (stable) coast in volcanic rocks and lithified pyroclastics with rockfall cones, located at Cape Dobrynya Nikitich in the southeast of the bay. This type of coast is formed at the foot of high (more than 150 m) and steep ledges composed of effusives and lithified pyroclastic. In the steep slopes (point ИТ-48, Fig. 1), intercalation of gray andesite-basalt composition effusives (1) (with a noticeable coarse separation) and red-brown tuffs (2) is revealed. According to State geological map of the Russian Federation (2002), the age of these rocks is Pliocene—Mid Quaternary (Fig. 4).

The foot of the ledge is a rockfall cone, composed of large block fragments. The main feature of such deposits is their unsorted nature. A feature of the coast is that its formation is not determined by the activity of wave processes. Deformation of the shore topography has gravitational and seismic causes.

3. **Accumulative coast with a wide sandy beach with rare pebbles.** This coast type is most pronounced in the center of the inner part of Kasatka Bay (Fig. 1), where we laid several geological, geomorphological, and georadar profiles, the main of which is located in the alignment of point ИТ-28 (Fig. 5).

In the relief, a full profile beach is represented by a coastal ridge up to 30 m wide, 0.5–1 m high, piled with different-grained sand with rare pebbles in the lower part, and exclusively sand in the upper part. The external appearance of the beach

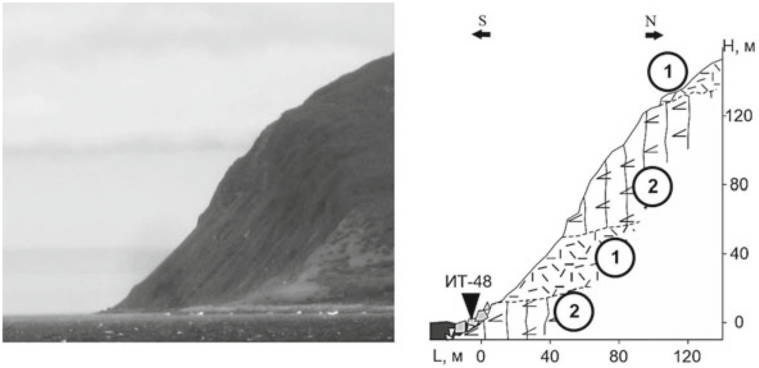

Fig. 4 Geological and geomorphological structure of erosion-denudation coast with rockfall cones (point ИТ-48)

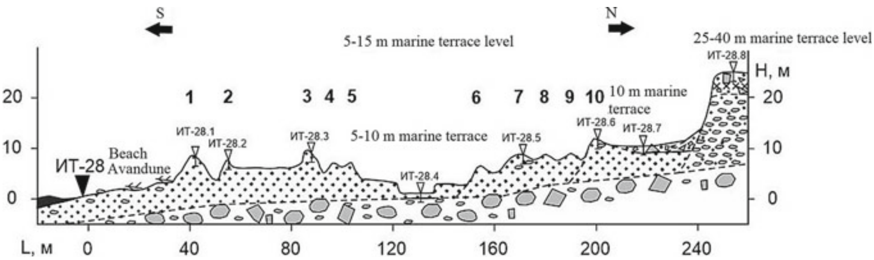

Fig. 5 Geological and geomorphological structure of accumulative coast and low sea terraces in the central part of Kasatka Bay, point ИТ-28. 1–10—serial numbers of coastal ridges

in the central part of Kasatka Bay is shown in Fig. 6. The surface of the beach

Fig. 6 Accumulative coast with a wide sandy beach with rare pebbles in Kasatka Bay, point ИТ-28

is technogenically disturbed. The avandune adjoins the beach (Fig. 5), up to 5 m wide, up to 0.5 m high. In the rear part it is partially sodded, sometimes it passes into a modern terrace of 2–3 m, most pronounced near the stream mouths. Further towards land on the profile line, a system of coastal ridges of a 5–15-m terrace level is developed.

On the coast of Iturup Island, different authors distinguish a different number of marine terraces from 200–300 m to 2–3 m: Chemekov Yu.F. allocates 9 terraces (Chemekov 1961); Grabkov V.K.]—7 terraces (Grabkov and Ishchenko 1982); Kulakov A.P.—6 terraces (Kulakov 1973); Razzhigaeva N.G. et al.—4 terraces for the central part of the island (Razjigaeva et al. 2003). The authors of this work observed marine terrace levels at Kasatka Bay at absolute heights of 100–120 m, 45–60 m, 25–40 m, 5–15 m, and 2–3 m.

A georadar survey of the coast of the central part of Kasatka Bay was carried out according to seven georadar profiles on a stretch of more than 5 km (Fig. 1). The lengths of the profiles ranged from 160 to 360 m; they were laid at terrace levels of 5–15 m, 25–40 m, and 45–60 m. Figure 7 shows the main geomorphological profile of ИТ-28, combined with the results of georadar survey. On this profile: beach with avandune—0–35 m; terrace level of 5–15 m with preserved coastal ramparts—35–240 m; terrace level of 25–40 m, partially covered with bamboo, shrubs and cedar dwarf—240–700 m.

A marine terrace level of 5–15 m is everywhere observed in Kasatka Bay, with a maximum width of up to 500 m (near Lake Blagodatnoe). It is composed mainly of sandy material. On the accumulative terrace of 5–10 m, coastal ridges stand out—up to 13 in the western part of the bay, and up to 3 in the eastern part. In the alignment of the ИТ-28 profile (Fig. 8), 10 ridges with a width of up to 30 m, a relative height of up to 3–4 m and up to 10 m in the eastern part of the bay (due to aeolian accumulation and technogenic interference) are observed. The length of the ramparts reaches 8.5 km, they are divided by numerous valleys of streams and the valley of the Blagodatnaya River.

In the east of the inner part of Kasatka Bay, in the areas of large lagoon lakes Blagodatnoe and Kasatka, at heights of 5–7 m, there are small sections of flat marshy

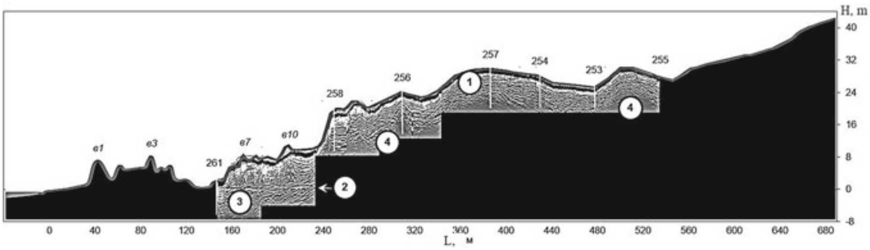

Fig. 7 Combined geomorphological and georadar profiles along the ИТ-28: 1—pyroclastic cover with buried soils; 2—groundwater level; 3—pebble-boulder deposits; 4—bedrock, basement of the marine terrace

Fig. 8 Coastal ridges in the alignment of profile ИТ-28 in the central part of Kasatka Bay

alluvial-lake and lagoon-sea plains composed of loam, sandy loam and clay. The age of the level is Holocene (Razjigaeva et al. 2002).

On the ИТ-28 profile (Fig. 5), eight pits are laid: five on the ridges, one in the hollow between ridges, one on the 10-m marine terrace adjacent to the ledge 25–40 m of the terrace level, and also one in the near-shore part of this level. The structure of the most characteristic ridges is shown in Fig. 9.

Description of the ИТ-28.3 and ИТ-28.5 pit deposits allows us to conclude the presence of genetically different layers: the upper 100–150 cm are represented by aeolian deposits (silty sand of different grains) with buried soil horizons (sand is moist, unwashed, humified), below are well-washed marine sands. This indicates the activity of the aeolian transfer of material from the beach.

The coastal ridges are located on a rather wide (up to 250 m) subhorizontal surface (Figs. 5 and 8), on which the cone of removal from gully valleys and the sea terrace rest, adjacent to a dying cliff about 25 m high. By pitting this subhorizontal surface in several places, including at the bottom of a wide hollow between the 5th and 6th ridges (point ИТ-28.4, Fig. 5), it was found that under sea sands with a thickness of up to 80 cm pebble-boulder sediments with a visible fragment size of up to 20 cm are revealed. Judging by the nature of the sediments composing this surface and the presence of a dead paleocliff, we can assume that this is a bench developed in proluvial pre-Holocene sediments that entered the coastal zone, presumably from the Bogatyr Ridge (Fig. 1). The coastal ridges are adjoined by a lined 10-m terrace with a width of about 30 m (Figs. 5, 7 and 9), partially covered by a pyroclastic cover or slope deposits, adjacent to a paleo-erosion ledge of 25–40 m of a marine terrace level.

Using the georadar survey, the structure of the upper coastal ramparts was clarified (*6–10*, Fig. 5), which confirmed the presence of a bench *(3)* on the radarogram (Fig. 7), which is recorded as unstructured multiple reflections in the form of hyperbolas from local objects. The presence of regular structures on the back of the ridges *(3)*

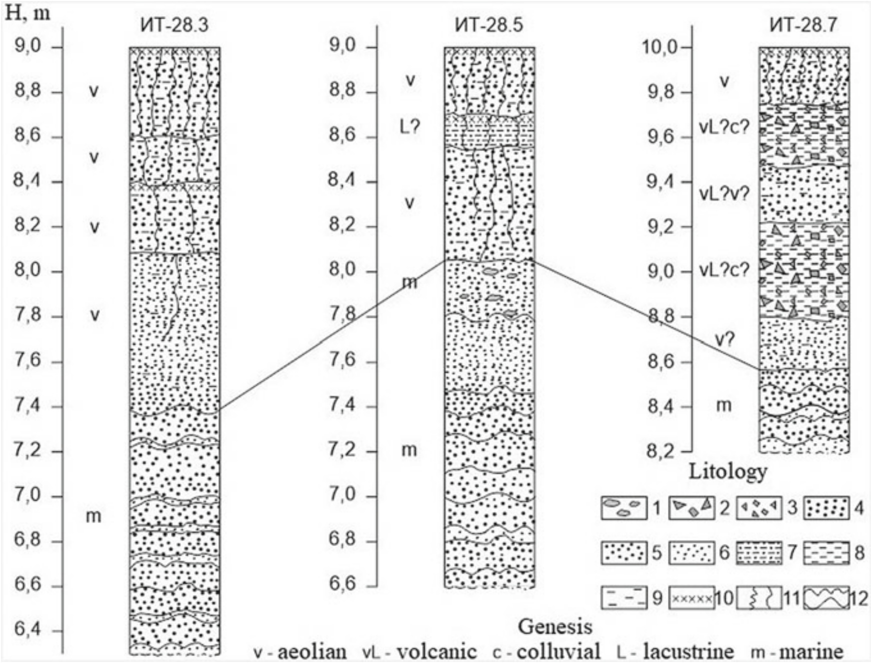

Fig. 9 The geological structure of coastal ridges and a 10-m marine terrace in the center part of Kasatka Bay (profile ИТ-28): 1—pebbles, 2—crushed stone, 3—grus, 4—coarse sand, 5—medium sand, 6—fine sand, 7—sandy loam, 8—loam, 9—silt, 10—soil (including buried), 11—roots of vegetation, 12—wavy layering

(Fig. 10a, b) confirms that the main tendency for the development of such shores is rare episodes of active, sometimes catastrophic, tsunamigenic erosion against the background of prolonged gradual accumulation of beach sediments, accompanied by aeolian processing of the ridges. On these profiles, according to the nature of the wave pattern, it is possible to distinguish the boundary of pebble-boulder deposits *(2)* and the intensity of the common-mode line *(1)* to trace the level of groundwater.

The terrace level of 25–40 m is hollow (3–5°) towards the coast and consists of 2 terraces: 25–30 m and 30–40 m. The rear seams and edge of the terraces are clearly defined, the total width of about 400 m (Fig. 7) Above the terraces are overlain by alternating layers of brown humus loam and a woody-gravelly stratum with a sand filler of the same color. Judging by the composition of the deposits and the nature of their occurrence, this is a pyroclastic cover with buried soils. The thickness of the loose cover of this terrace level, according to State geological map of the Russian Federation (2002), is 5–13 m. The terrace of 25–30 m is of marine origin, as can be judged by the pebbles opening in the valley of the Tok Stream at a depth of 4.5 m from the edge. The age of this terrace is defined as the Middle Pleistocene (Razjigaeva et al. 2003). The terrace is heavily technogenically disturbed, on its surface are located the Shumi-gorodok village and Burevestnik village. The terrace of 30–40 m in its

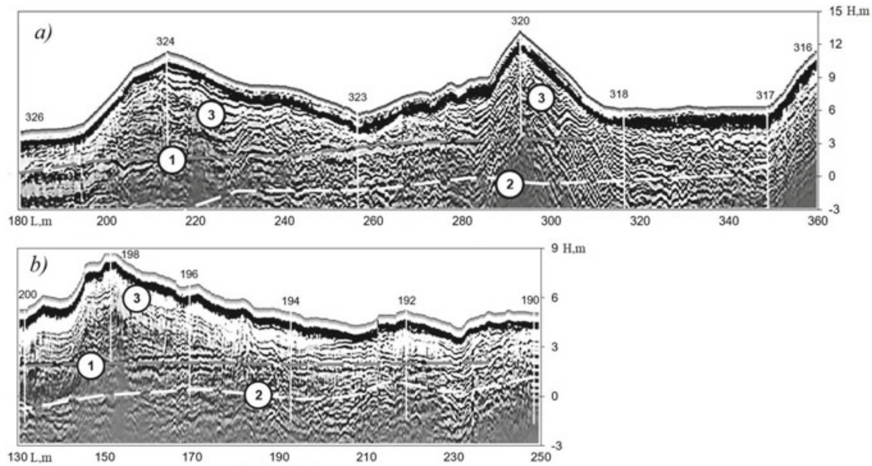

Fig. 10 Marine terrace level 5–15 m: **a**—GPR profile, central frequency 300 MHz, profile *(6)* (Fig. 1); **b**—GPR profile, center frequency 300 MHz, profile *(7)* (Fig. 1); 1—groundwater level; 2—pebble-boulder deposits; 3—sea sands homogeneous, layered

morphological appearance practically does not differ from the 25–30 m of the terrace; we can assume their similar structure. In the alignment of profile ИТ-28, the rear seam of the terrace 30–40 m is located on abs. 35 m high (in the southwest of the inner part it is located at an abs. height of 40 m).

In Fig. 11 shows the GPR profile of the terrace 25–30 m. The analysis of the wave pattern (Fig. 11a), the georadar profile *(5)* (Fig. 1), made it possible to distinguish two georadar complexes in its structure (Vladov and Starovoitov 2004), the interpretation of the georadar data is shown in Fig. 11b. The GPR complex *(1)* is presented in the form of extended subhorizontal in-phase axes and is a pyroclastic cover with buried soils, with alternating ashes and sands with a thickness of 3 m in the picket area *(244)* to 10–12 m in the picket area (370). The sole of the complex *(1)* is the roof of bedrock (terrace basement) *(2)*, the upper part of which *(3)* is heterogeneous, partially destroyed. Its increased fracturing is emphasized by characteristic radio images, which are marked on the profile by subvertical lines. Similar results were obtained on the terrace of 30–40 m, profile *(1)*, *(6)* (Fig. 1), except that the power of the PCP along its entire profile is almost unchanged and averages 4–5 m.

A **terrace of 45–60 m** is slightly inclined towards the coast (2–4°), width is up to 200 m. The rear seam is quite clear; the edge is smoothed. According to State geological map of the Russian Federation (2002), the thickness of the loose cover is 5–30 m. According to Grabkov and Ishchenko (1982), the age of the terrace from is estimated as mid-Quaternary. The terrace can be diagnosed by vegetation—a cedar dwarf tree is actively growing on it, while on a ledge below and above the terrace there is a forest of stone birch with bamboo.

Analysis of the wave pattern of the georadar profile of the terrace (Fig. 12a), profile *(2)* (Fig. 1), allowed us to distinguish three georadar complexes. The interpretation of

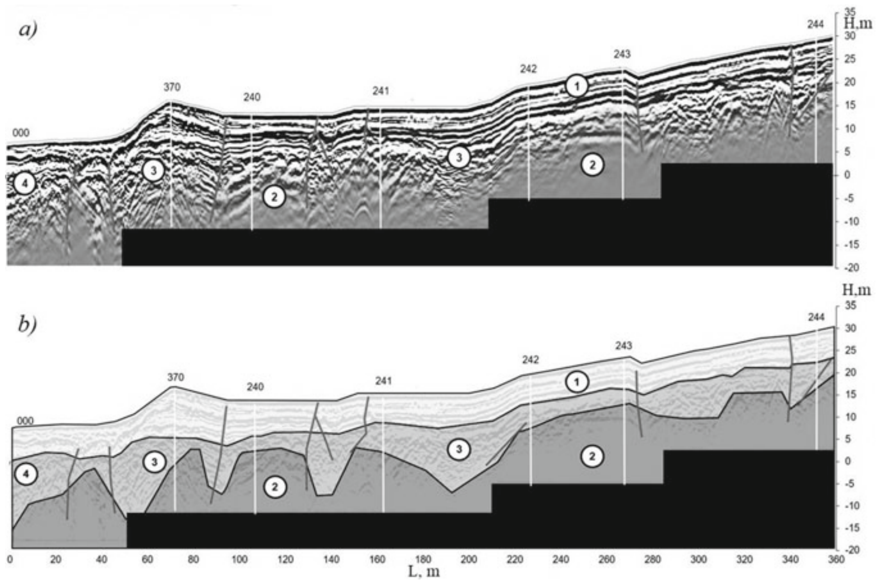

Fig. 11 Marine terrace 25–30 m, profile *(5)* (Fig. 1): **a**—GPR profile, central sounding frequency of 50 MHz; **b**—a profile with the allocation of georadar complexes; 1—pyroclastic cover with buried soils; 2—bedrock, basement of the marine terrace; 3—destroyed, highly fractured basement of marine terrace; 4—pebble-boulder deposits

georadar data is shown in Fig. 11b, the boundaries between the complexes are drawn along the line of changing the morphology of the in-phase axes corresponding to the boundaries of disagreement (Vladov and Starovoitov 2004). The georadar complex *(1)*, 2.5–4 m thick, whose pattern is presented in the form of extended subhorizontal in-phase axes, the intensity of which is stable along the profile, is a pyroclastic cover with buried soils. Starting from the bottom of this complex, the GPR section acquires a characteristic irregular wave pattern *(2)* with a thickness of 0–6 m, which indicates the presence of local unsorted gravel-block deposits. The sole of this georadar complex, the high-intensity phase axis *(3)*, is the roof of bedrock *(4)*, the basement of the terrace, covered with loams with a thickness of about 1 m.

A **terrace of 100–120 m** is represented in the area of Cape Burevestnik, as well as on the site of Chertovka rock—Lake Blagodatnoe. Its surface is flat, slightly inclined towards the coast, dissected by river and stream valleys from U-shaped to canyon-shaped profiles. On the sides of the valleys, effusive openings are revealed, over which a cover of loose deposits lies with a visible thickness of 20–30 m. It is composed of layered loams, tephra, sand and pebbles (State geological map of the Russian Federation 2002). The rear seam is indistinct, the edge of the terrace is flattened and most pronounced in places where it is bordered by a steep (30–40°) ledge up to 50 m high. In the coastal part of the terrace, we laid ИТ-28.9 pit, 1.5 m deep. The upper meter is represented by hummed loams of dark brown color, overlapping with sandy loam of brown color. 1–1.5 m are represented by highly compacted loam

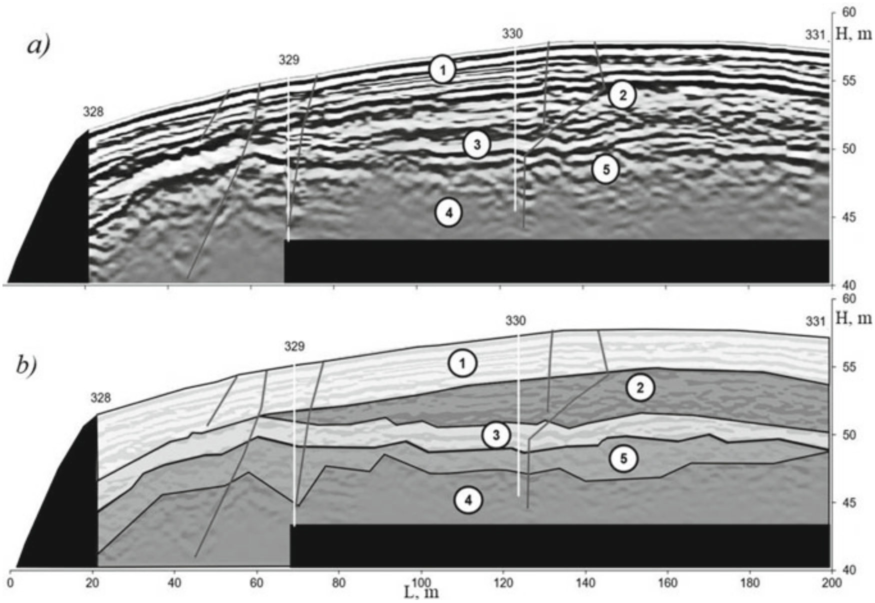

Fig. 12 Marine terrace 45–60 m, profile (2) (Fig. 1): **a**—GPR profile, center frequency 50 MHz; **b**—GPR profile with the allocation of GPR complexes; 1—pyroclastic cover with buried soils; 2—unsorted gravel-block deposits; 3—loam; 4—bedrock, basement of the marine terrace; 5—destroyed, highly fractured basement of marine terrace

with numerous fragments of wood-grained dimension. This is a pyroclastic case with buried soils. The age of the terrace is estimated as early Quaternary (Grabkov and Ishchenko 1982).

4 Conclusion

Three morpholithogenetic types of shores are distinguished in Kasatka Bay, of which 49% are in Accumulative coast with a wide sandy beach with rare pebbles (inner parts of the gulf), and 51% are in erosion (stable) and erosion-denudation (stable) coast (gulf flanks and Chertovka rock).

Using the joint use of geomorphological and geophysical methods, the geological and geomorphological structure of marine terraces in the central part of the bay has been clarified. Description of pit deposits in the coastal ridges allows us to conclude that the aeolian transport of material from the beach is active (the upper 100–150 cm are represented by aeolian sediments). It was established that a 5–15 m accumulative terrace level lies on top of an ancient bench, developed, most likely, in proluvial pre-Holocene sediments that entered the coastal zone, presumably from the Bogatyr ridge.

Marine terraces of 25–30 m and 30–40 m are almost identical in morphological appearance. The results of the analysis of georadar data obtained in the study of the erosion-accumulative terrace of 25–30 m made it possible to distinguish a pyroclastic cover with buried soils from 3–4 m thick (at the rear of the terrace) to 6–12 m (at the edge), and for the terrace 30– 40 m—up to 4–5 m. According to georadar sounding, an increase in the thickness of the cover in the region of the edge of the terrace occurs due to an increase in the number and thickness of individual interlayers. The sole of this complex is adjacent to the base of the fractured bedrock, their upper part is heterogeneous, partially destroyed.

A georadar survey of 45–60 m of the marine terrace revealed the presence of ancient, presumably, lahar deposits under a pyroclastic cover with buried soils. This complex on the GPR section has a characteristic irregular wave pattern and was observed by us only in the area of Chertovka rock. The maximum power of this complex on the profile is ~6 m.

The data obtained during the work on the geological and geomorphological structure of the coasts and marine terraces are necessary for the rational use of natural resources both in the coastal zone and on the shore and can be used for the economic development of this territory.

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