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Internal structure of rock glaciers in Altai (The case of talus rock glacier in Dzhelo River Valley)

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In 2019, a comprehensive study of the internal structure of the talus rock glacier in the Dzhelo River valley was carried out (North-Chuya Range). The identification of the internal structure was performed using electrical resistivity tomography and GPR sounding. In order to compare the internal structure of the rock glacier with its surface morphology, we carried out aerial photography and constructed a digital terrain model. The study revealed that the depth of the rock-ice core varies from 2.5-3 m to 10 m, and the thickness ranges from 7 m to 30 m. The consolidation cores of the rock-ice material are confined to inter-ridge depressions in the rock glacier body. The potential volume of a rock-ice core is 800 thousand m^3, which is 53% of the rock glacier total volume, the ice volume in the rock-ice core can be as much as 400 thousand m^3.

Key words: Altai; Talus rock glacier; Electrical resistivity tomography; GPR sounding

Introduction

The reduction of fresh water resources as a result of the glaciation degradation is an urgent problem for the intracontinental regions of Asia. According to our estimates, over the past fifty years, large Altai glaciers annually lose up to 100 thousand m3 of ice. Moreover, this value tends to increase from year to year. Such rates of glacier degradation will naturally lead to the reduction in their runoff in the future. These processes cannot but cause certain concerns. This will lead to a cascade changes in the landscapes and economic activities of the population from highlands to adjacent downstream territories. On the other hand, there are hidden sources, which fresh water reserves are difficult to estimate. These are permafrost and glacial-permafrost rock formations (Dyakova, 2014), more commonly known as rock glaciers. Rock glaciers are clusters of ice-bound rock material in the mountains, reminiscent of glaciers in shape and capable of its own movement under gravity. They may contain fresh water and are also able to accumulate ice even during the periods of glaciation degradation. In the summer of 2019, comprehensive geophysical studies of the active slope (talus) rock glacier internal structure were carried out in the Dzhelo River valley (Central Altai, North-Chuya Range) in order to estimate the ice nucleus thickness of the rock glacier and the potential volume of the ice contained in it.

Research Methodology

The morphology of the rock glacier surface and the adjacent area was taken from a digital terrain model obtained from aerial photographs by DJI Phantom 4 quadcopter (Ostanin, 2019) (Figure 1). The study of the rock glacier internal structure was carried out by the following methods:

- The method of electrical resistivity tomography with the use of the multi-electrode electroprospecting station "Skala-48". In order to obtain electrical resistivity tomography data, we used three-electrode direct and counter units with a 5-meter step along the profile. The maximum penetration depth reached 50 m.
- The method of GPR sounding by applying the Phyton-3 monostatic deep-laid georadar, with the use of an antenna unit (frequency of 50 MHz). The maximum penetration depth reached 40 m, the resolving power is 2 m.

The method of ground penetrating demonstrates good results in solving geocryological tasks due to the contrast in the values of dielectric inductivity of fresh ice and water (e=3.3 and e=81 respectively). Thus, the GPR method helps to solve the main tasks of thE study – the allocation of the permafrost table and the sole of the rock glacier stone-ice core in the valley of the Dzhelo River. The georadar data was processed with the GeoScan32 software. The processing graph included subtracting the average, bandpass filtering at 0.0013 GHz, cutting to 182 depth samples and setting the terrain.

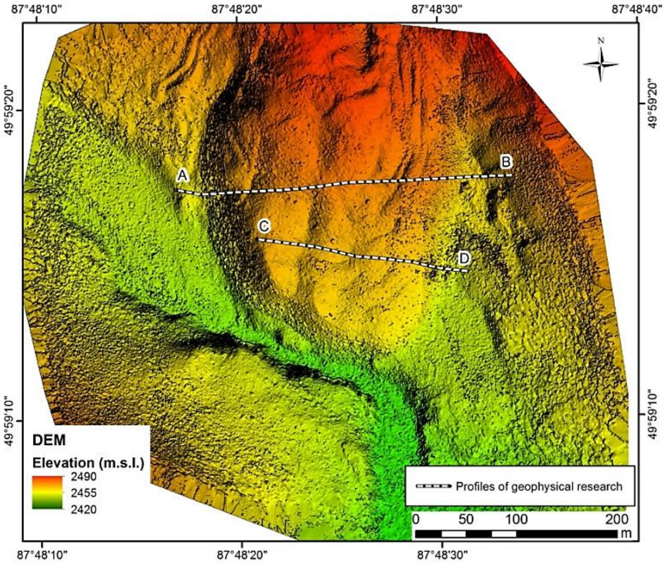

Figure 1. Digital terrain model of the rock glacier and the adjacent territory. Section lines of the electrical resistivity tomography and GPR sounding.

Results

Figure 2 shows the results of the rock glacier study in the valley of the Dzhelo River, the profiles of the GPR sounding and electrical resistivity tomography methods are laid perpendicular to the motion vector of glacial-permafrost rock formations.

The AB resistivity section (Figure 2b) has the length of 355 m and extends in the central part of the rock glacier across its structure. In the upper part of the resistivity section AB, a high-resistance bed of rock-ice material ranging from 15 to 22 m in thickness and characterized by the specific electrical resistance (hereinafter – SER) of about 6-40 koh mm can be distinguished. In addition, in the near-surface part of the profile (from 60 to 75 m), anomalies with SER of 0.5-1 koh mm are observed, which can be interpreted as thawing niches. In the lower part of the section, there are several conductive anomalies with SER less than 0.2 koh mm located immediately under the thawing niches. These anomalies are presumably meltwater discharge areas.

When analyzing a radargram along the AB profile (Figure 2), the permafrost table of the rock-ice material was allocated at a depth of about 2.5-3 m, while according to the electrical resistivity tomography data, the permafrost table of the rock-ice material cannot be clearly distinguished in the near-surface part of the section. The bottom boundary of the rock glacier stone-ice material is not traced; several separate reflecting horizons are observed. From 185 m to 215 m of the profile and from 80 m to 110 m of the profile, one can observe reflecting horizons that coincide with the bottom boundary of the rock-ice material in glacial-permafrost rock formations, identified by means of the electrical resistivity tomography data. Moreover, the radargram distinguishes several reflecting boundaries in the near-surface part of the section that coincide with the anomalies of increased resistances in the layer of rock-ice material.

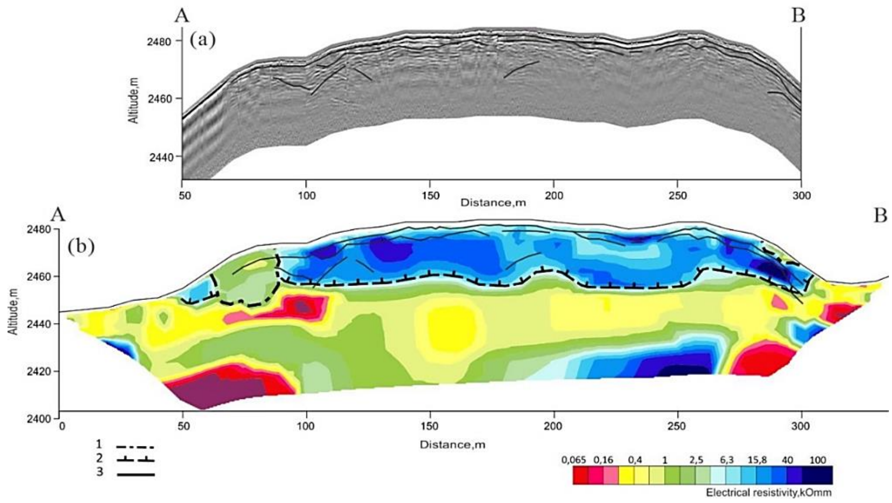

Figure 2. Results of the rock glacier study in the Dzhelo River valley: (a) radargram along the AB profile; (b) resistivity section along the AB profile. Here and in Figure 3: 1 - thawing niches; 2 - permafrost table of rock-ice material; 3 - sole of rock-ice material

The CD resistivity section (Figure 3d) is located hypsometrically below the AB section (closer to the frontal ledge of the rock glacier) and has a shorter length (235 m).

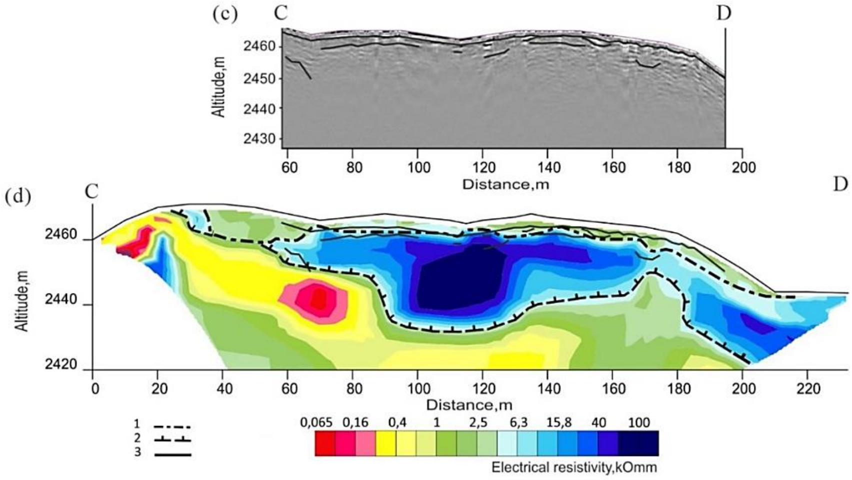

Figure 3. Results of the rock glacier study in the Dzhelo River valley: (c) radargram along the CD section; (d) resistivity section along the AB profile.

In the upper part of the CD section, one can observe a bed of rock-ice material ranging from 7 m to 30 m in thickness, its specific electrical resistance exceeding 6.3 koh mm and reaching 100 koh mm in the central part of the ice core. A low-resistance active layer is distinguished in the near-surface part from 60 m up to the end of the profile. Moreover, from 35 m to 65 m of the profile, one can identify a thawing niche with a meltwater discharge area below. The radargram along the CD profile (Figure 3c) discriminates the permafrost table of rock-ice material in the upper part of the section, at the depth of 3-5 m. The identified boundary practically coincides with the permafrost table of the rock-ice material, distinguished according to the electrical resistivity tomography data. The sole of rock-ice material in the section along the CD profile is not allocated according to the data from GPR.

Conclusion

Thus, we analyzed the distribution of rock-ice material in the body of a rock glacier in the Dzhelo River valley. The resistivity sections reveal the thickness of the rock-ice material (7 m to 30 m), allocate thawing niches and meltwater discharge areas. The analysis of the rock glacier surface morphology showed that contrary to the assumption that the high-resistance cores of ice material consolidation are confined to ridges complicating the formation surface, the consolidation cores appeared to be confined to inter-ridge depressions. According to the results presented in this paper, as well as previously published materials (Goreyavcheva, 2019), the potential volume of a rock-ice core is 800 thousand m^3, which is 53% of the rock glacier total volume. Taking into account the work of A.G. Tarakanov (Tarakanov, 1989), the ice volume in the rock-ice core can be as much as 400 thousand m^3.

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