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ГЕОЭЛЕКТРИЧЕСКАЯ ХАРАКТЕРИСТИКА ПОБЕРЕЖЬЯ ОСТРОВА САМОЙЛОВСКИЙ (ДЕЛЬТА РЕКИ ЛЕНА)

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На побережье острова Самойловский проведены геофизические исследования методами электротомографии и георадиолокации. Результаты сопоставлены с геологическим описанием обнажений. Показано, что на геоэлектрическом разрезе по результатам 2-D инверсии выделяется контакт разновозрастных отложений. Оценено строение подруслового талика в прибрежной зоне, локализованы ледовые жилы различной ширины. Полученные результаты полезны для геокриологических исследований в данном районе, поскольку изученные объекты типичны для дельты р. Лены.

Многолетнемерзлые породы, электротомография, георадиолокация

GEOELECTRICAL CHARACTERISTICS OF SAMOYLOV ISLAND COASTLINE (LENA RIVER DELTA)

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Permafrost structure of Samoylov island coastline was determined with geological and geophysical methods. Geoelectrical model based on electrical resistivity tomography and ground penetrating radar data was compared with geological observations. Structure of contact between different types of frozen deposits was determined, influence of river water on permafrost (talik borders were determined) was estimated, ice wedges of different thickness were localized. Results of the study could be useful in permafrost research in the region because studied objects are typical in Lena delta.

Permafrost, electrical resistivity tomography, ground penetrating radar

INTRODUCTION

Samoylov Island in Lena river delta is a key area of permafrost research – a number of studies are conducted here during last 20 years by Russian-German expedition «Lena Delta» [Boike et al., 2013]. Samoylov Island consists of 3 geomorphologic surfaces: 1) 1st terrace (max elevation – 8.5 m a.r.l.); 2) high floodplain (max elevation – 7.5 m a.r.l.); 3) low floodplain (max elevation – 6.5 m a.r.l.). These surfaces vary in sedimentary units, ground ice type, landform morphology properties and they are typical for the essential part of Lena delta [Bolshiyanov et al., 2015]. All these three types of deposits are well exposed in outcrop on the southern coast of the island. Beyond that this coast is under the intensive influence of thermal and mechanical erosion originated by the river water and ice. This work is dedicated to geological and geophysical studies of the most representative part of island deposits – the contact between the terrace (which includes ice wedges) and the floodplains in the nearby of water. Geophysical methods are widely applied in permafrost research [Hauck et al., 2008]. Development of geophysical techniques in this field are analyzed in the paper [Kneisel et al., 2008]. It is shown that such problems like sectional layering, estimation of ice and unfrozen water content, status monitoring of permafrost can be effectively solved with electrical resistivity tomography. Internal structure of permafrost and spatial extension of layers can be determined rather with ground penetrating radar. We have used both these methods to characterize permafrost structure of Samoylov island coastline. Following questions are raised within this study:

1. Is the geoelectrical structure of the contact between floodplains and first terrace corresponds the geological data?

2. How deep is the area of water influence on permafrost?

3. Could ice wedges be localized with ERT of GPR in present conditions?

In order to answer these questions geological description of the outcrop on the coast was done and two profiles were implemented with ERT (AB' and CD) and GPR (AB) (Fig.1).

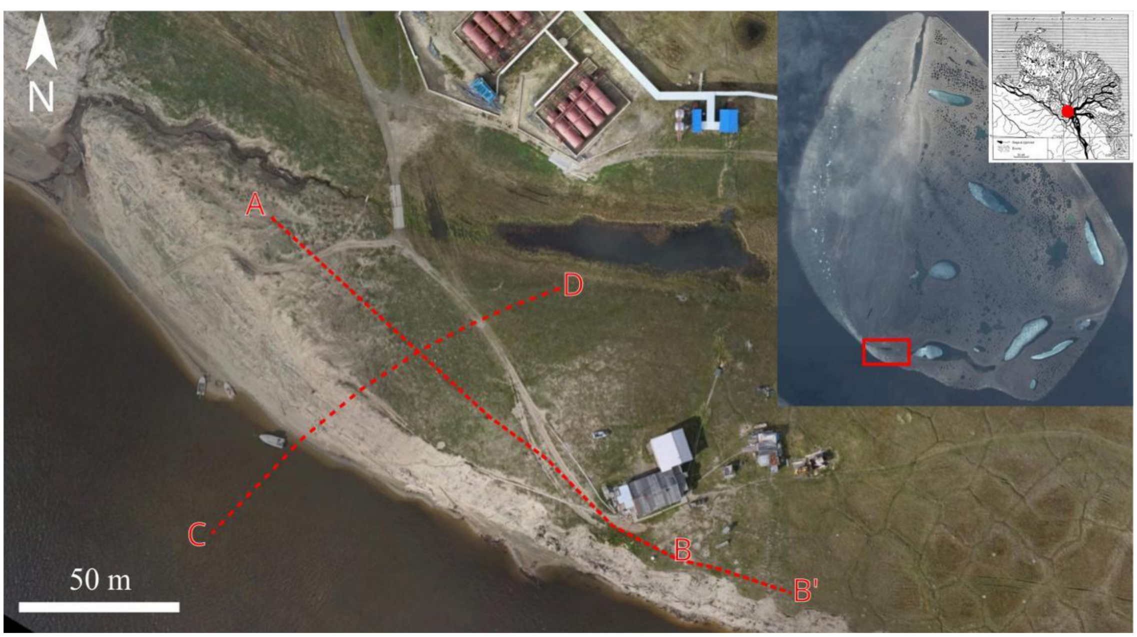

Fig. 1. Map of the study area: ERT (AB, AB' and CD) and GPR (AB) profiles are marked with red dotted line

METHODS

A revealing of geological bodies based on field deposit descriptions and observations from the outcrop, which is exposed by river erosion.

Electrical resistivity tomography (ERT): SibER-48 equipment with 48 electrodes.

2-dimensional inversion of the obtained data was done with RES2DINV Software.

The longer profile (AB and AB' in the Figure 1) was done with 1 m (AB) and 2.5 m (AB') step between the electrodes. Another profile which crosses the coast (CD in the Fig. 1) was done with 5 m step between the electrodes. All ERT surveys were conducted with Schlumberger and dipole-dipole arrays and then the data was processed both independently and jointly.

Ground penetrating radar OKO-2 with 150 MHz antenna was used on the AB profile. Distance between counts was 2 cm (counting wheel – motion sensor "DP–32" was used for this goal).

RESULTS AND DISCUSSIONS. GEOLOGY

Sediments of the 1st terrace and low floodplain can be seen in an outcrop situated in the south coast of the Samoylov Island (coordinates 72.36835º N; 126.47307º E). The section in this outcrop is our main object of investigation. The outcrop extends for 60 m in the west to east direction and is 11 m high for the 1st terrace and 8 m high for the floodplain.

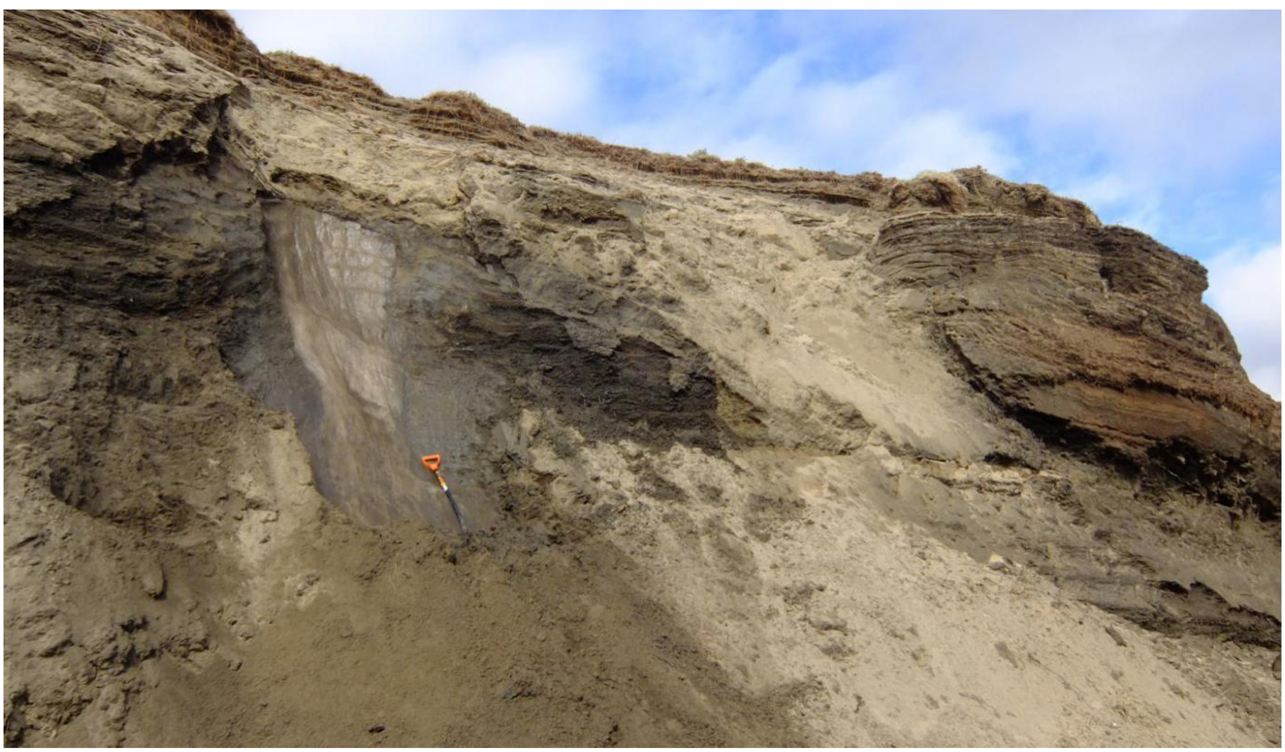

Fig. 2. Outcrop on the coast of Samoylov island: 1st terrace is covered by sandy floodplain deposits; ice wedge penetrates the 1st terrace deposits and thin sandy layer (in the middle part of the section)

The sequence includes 3 sediment units. Unit 1 belongs to the 1st terrace and Units 2.1 and 2.2 represent the floodplain sediments. Notable that Unit 2.2 overlaps both the floodplain sediments (Unit 2.1) and the terrace sediments (Unit 1). The relationship of sediments is shown in Fig. 2 and their structure is described below (bottom to top).

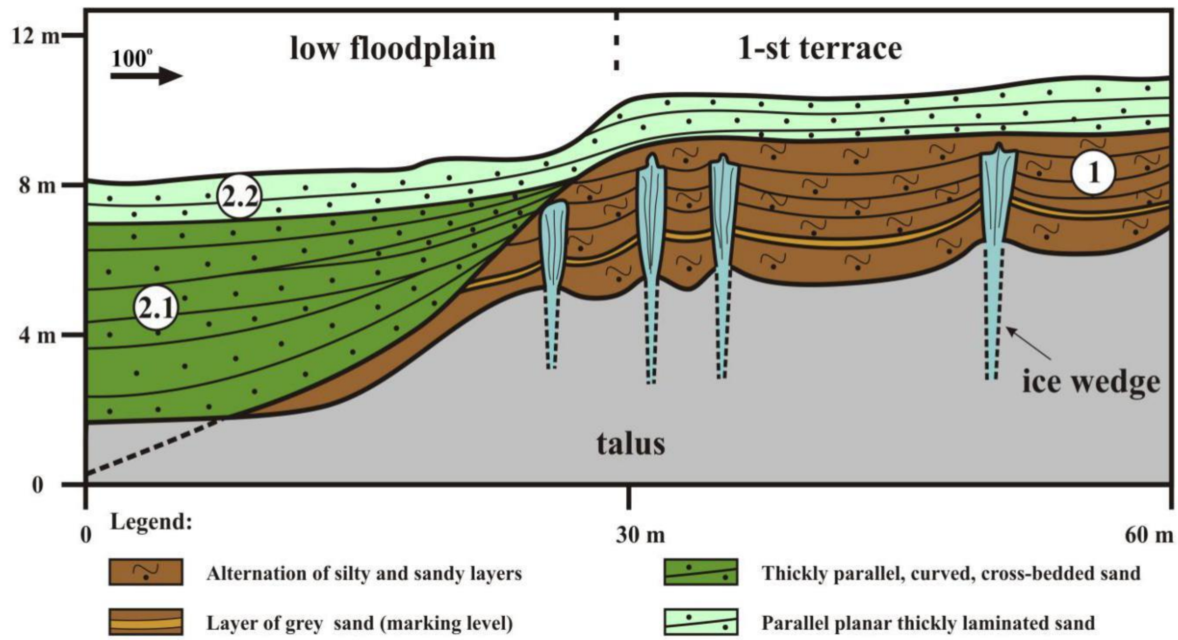

Fig. 3. Geological scheme of Samoylov Island coastline structure

Unit 1. Alternation of thin, 1–3 cm, parallel planar and wavy brownish-gray silty and sandy layers and dark-brown peat layers. A coarsely laminated 20 cm thick layer of grey medium-size sand with rare plant remnants occurs in the lower part of the unit. We can consider it as a marking level as it was found in many other 1st terrace coast outcrops of the Samoylov Island. Several syngeneic ice wedges complicate this unit. There are 4 ice wedges which have following dimensions: width 0.8–1.6 m, height above talus 4.5 m. These ice wedges are expressed at the island relief as polygonal network patterns. Furthermore, in unit 1 lenses of segregated ice 1–2 cm thick and pore ice occur.

Unit 2.1. Medium size sand: thickly parallel, curved, cross-bedded, of light gray color with intercalations of gray sandy silt. Thin 1 cm beds of dark gray sandy silt with plant remnants mark boundaries between layers. A very thin cross-lamination of 2-nd and 3-rd order with wavemarks is observed in layers. A unit bottom contact is erosional and cuts out the underlying Unit 1. Ice wedges and segregated ice are absent in this unit. Unit 2.1 consists of typical lateral accretion fluvial deposits.

Unit 2.2. Parallel planar thickly laminated light gray medium size sand with intercalations of grey sandy silt. A bottom transition with Unit 1 is very clear, but a bottom transition with Unit 2.1 is unclear. In general, Unit 2.2 reaches its maximum thickness (about 1.5 m) in the investigated outcrop and wedges-out further to the east. Additionally, cracks were observed above each ice wedge of Unit 1. Since these deposits overlap both the floodplain sediments (Unit 2.1) and the terrace sediments (Unit 1), as well as comprise parallel thickly laminated sands and silts, we infer that deposits formed during floods by vertical accretion.

GEOPHYSICS

ERT along AB' profile (Fig.1) yields following section (Fig. 4).

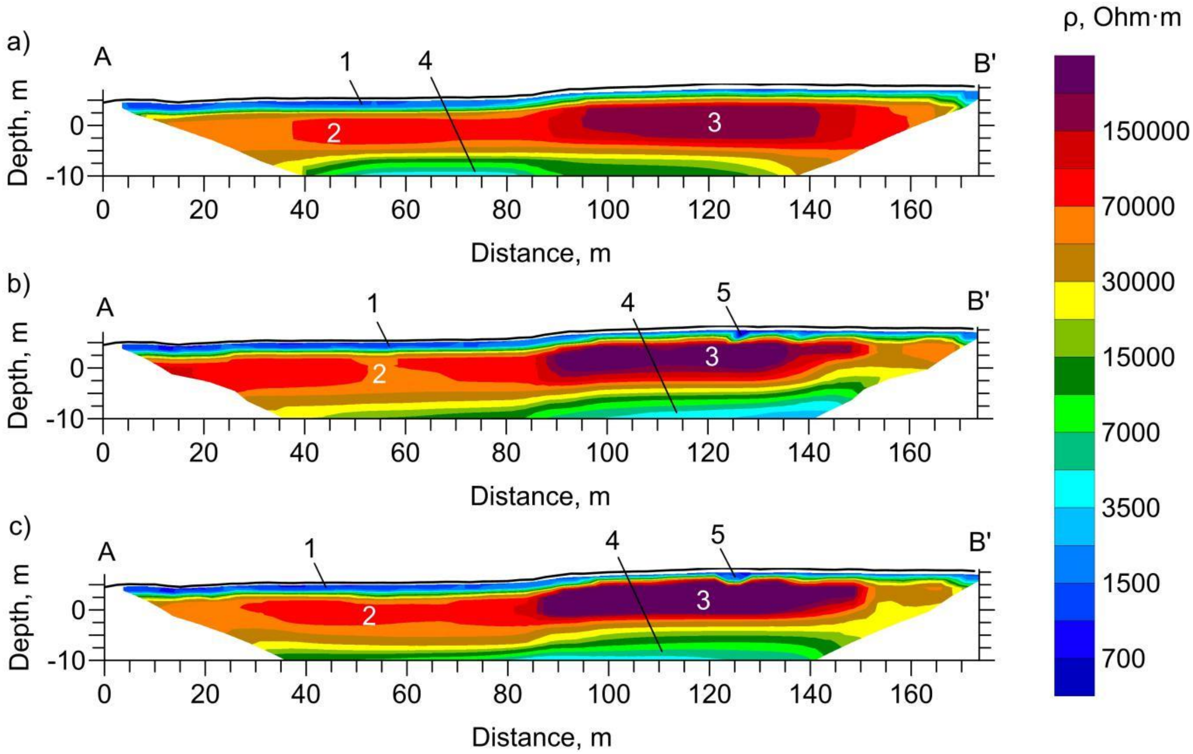

Fig. 4. Profile AB' – 2.5 m between the electrodes: results of inversion for Schlumberger (a) and dipole-dipole (b) arrays and joint inversion (c): 1 – active layer; 2 – frozen sand; 3 – organic-mineral deposits; 4 – anomaly of low resistivity (influence of the river); 5 – anomaly of low resistivity above ice wedges

Data obtained with Schlumberger array (Fig. 4a) yields generalized pattern of the geoelectrical structure. Upper layer of low-resistivity with the depth of up to 2 m corresponds the active layer. Organic-mineral deposits in the upper part of the section (90–170 m) has very high resistivity (more than 100 kOhm·m) due to high ice content and low unfrozen water content in permafrost [Boike et al., 2013]. Relatively low resistivity in the left part (20–100 kOhm·m) could be explained by higher unfrozen water content and less ice content in sand. Starting from the depth of 10 m decrease of resistivity is observed. It is presumably reasoned by the water influence – coast is at 20 m off the profile.

Section obtained with dipole-dipole array is more varied (Fig. 4b). Local low-resistivity anomalies are observed within the active layer. These anomalies relate to high humidity in active layer above ice wedges (for example – 127 m on the profile).

Section obtained with joint inversion (Fig. 4c) shows both local anomalies in active layer and different resistivity of left (sandy floodplain deposits) and right (organic-mineral 1st terrace deposits) parts of the section. Influence of water is observable as the false low-resistivity layer in the lower part of the section.

Ice wedges were not localized with this survey – probably because of the distance between the electrodes is bigger than the thickness of ice wedges. Therefore, more detailed ERT was done along the same profile (Fig. 5).

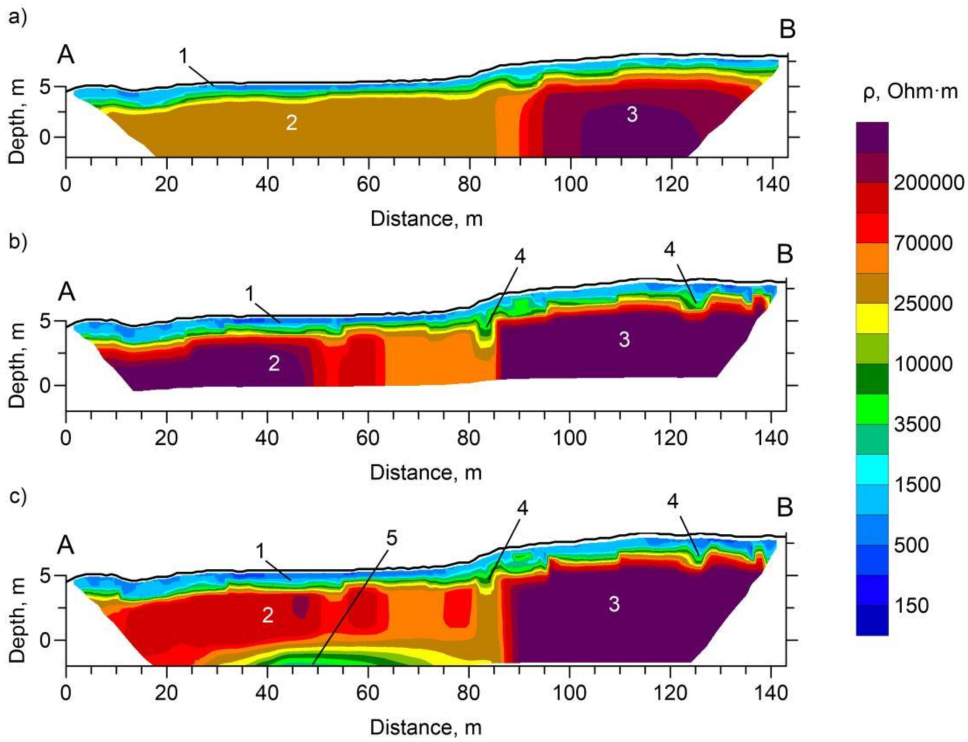

Fig. 5. Profile AB – 1 m between the electrodes: results of inversion for Schlumberger (a) and dipole-dipole (b) arrays and joint inversion (c): 1 – active layer; 2 – frozen sand; 3 – organic-mineral deposits; 4 – anomaly of low resistivity above ice wedges; 5 – anomaly of low resistivity (influence of the river)

The same pattern could be seen from Schlumberger array data (Fig. 5a) as it was in the long profile (above mentioned): left and right parts of the profile correspond to the flood plain and the first terrace. Active layer thickness is determined quite well – it is not more than 1.5 m along the whole study profile. Dipole-dipole array (Fig. 5b) yields irregular boundary of the active layer which could be linked to nonuniform thawing above ice wedges and between their locations. The dividing area in the central part is shown more detailed – it is presented by a steep contact, which could be explained by the difference in lithological and ice content. Within the right part the permafrost looks consolidated because the deposits were not penetrated by the current. Therefore, we cannot determine their structure reliably. Ice wedges which are seen in the outcrop in the right part are not visible in the ERT section on the high-resistivity background. Joint inversion section (Fig. 5c) shows low-resistivity area in the lower part of the section – probably the water influence from the side. Local anomalies in the left part could relate to high ice content – probably related to a young ice wedges forming in the flood plain deposits.

In order to estimate an area of water influence on the coast and underwater part of the island CD profile transverse to AB (Fig. 1) was conducted (Fig. 6).

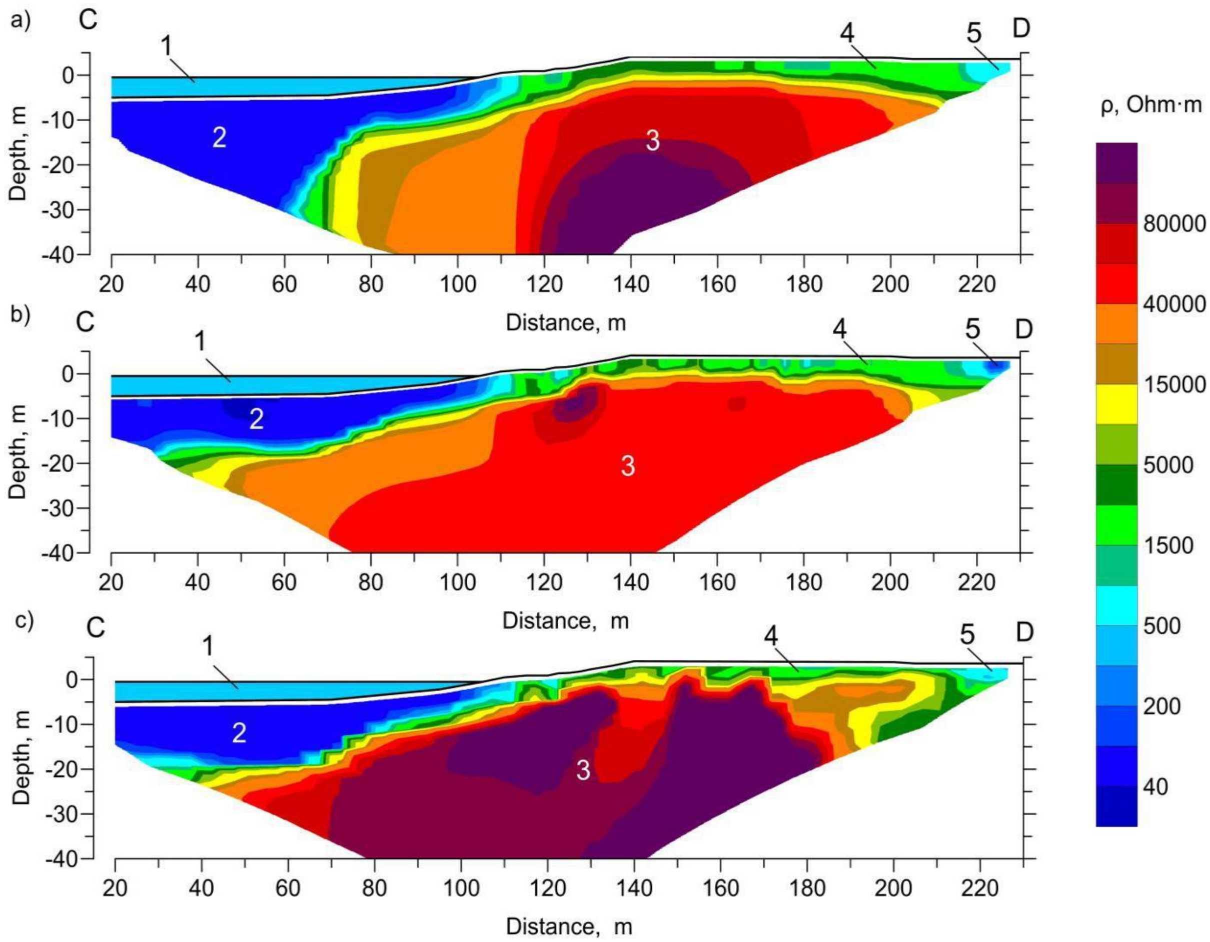

Fig. 6. Profile CD – 2.5 m between the electrodes: results of inversion for Schlumberger (a) and dipole-dipole (b) arrays and joint inversion (c): 1 – water; 2 – thawed rock (talik); 3 – permafrost; 4 – active layer; 5 – talik under the channel of a temporary watercourse

Geoelectrical section from Schlumberger array (Fig. 6a) shows main features of the coast structure: the active layer and underwater talik. Data from dipole-dipole array (Fig. 6b) has more details: the border between thawed and frozen deposits is quite distinct, local vertical high-resistivity anomalies within the active layer probably presumably relate to ice wedges. Right part of the profile (220–230 m) comes to a small lake (Fig. 1) which originates the low-resistivity anomaly in this area due to its temperature influence on surrounding permafrost. Joint inversion (Fig. 6c) shows the same picture but quite differs from dipole-dipole data in resistivity because of their high values (more than 50 kOhm·m) and respectively high uncertainty. Talik smoothly descends and reaches about 10 m at 50 meters from the coastline. Steep talik slope is typical in the case of permafrost under flowing water [Romanovskiy, 1972; Fotiev, 1978]. Presumably, the talik slope here is forming gradually simultaneously with coast erosion therefore it had no time to become steep.

GPR section along AB' profile is provided in the Fig. 7. GPR results yielded quite representative data.

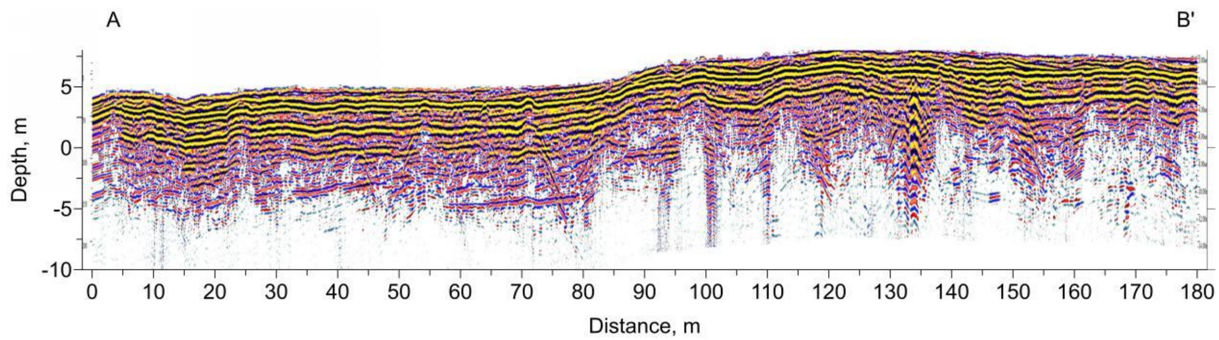

Fig. 7. Ground penetrating radar data along the AB' profile (Fig. 1)

The depth was calculated from the time section accepting the average electrical permittivity value of 6. Ice wedges reveal quite distinctively in the radargram as a diffraction on their upper boundaries (this question was considered in details by [Bricheva, 2014]) and simultaneously damping of the signal in the interior of the thick ice wedges in the right part. Thin ice wedges in the left part yield only the diffraction suggesting that their width in the upper part does not exceeds the size of the first Fresnel zone. It is in agreement with the genesis of these parts – the younger left (with still forming thin ice wedges there) and older right one (with more thick ice wedges).

In the Fig. 8 the fragment of the radargram in the interval of 60 to 120 m is shown. On the depth about 1.5 m a high amplitude reflection boundary is seen. It relates to the active layer bottom (1 on the Fig. 8). Partly ringing interfering wave is observable in the upper part of the section. Beyond that the quite thin sand layer which is seen in the outcrop (Fig. 2) is also detected as a reflected wave (3 in the Fig. 8).

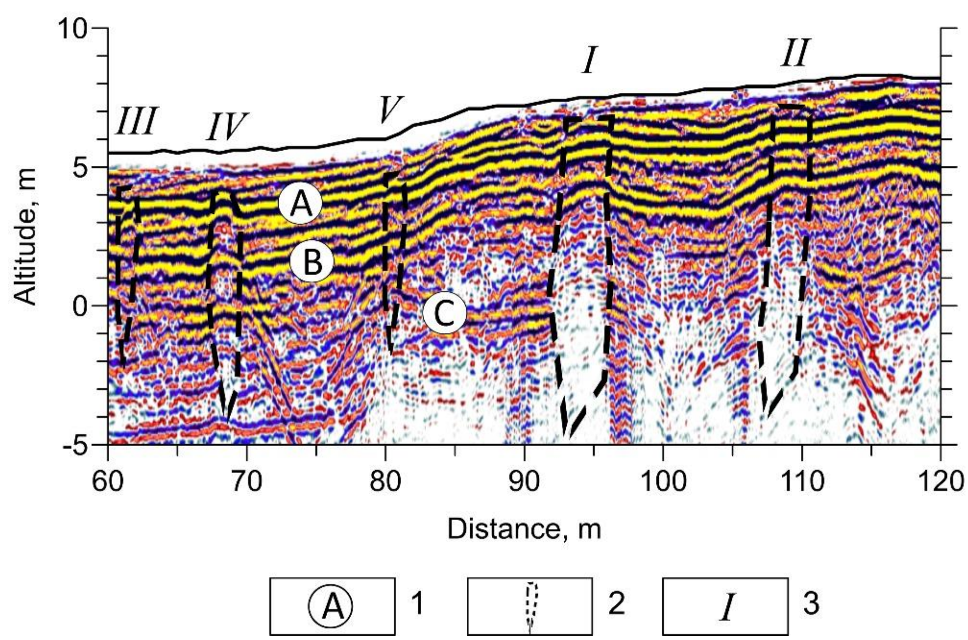

Fig. 8. A fragment of the radargram: 1 – waves: A – reflection wave originated by the active layer bottom, B – partly ringing interfering wave, C – reflection wave originated by the sand layer; 2 – ice wedges; 3 – numbers of the ice wedges; photo of the ice wedge II is provided in Fig. 2

ERT and GPR data are provided together in Fig. 9. Resistivity is relatively low within the left part of the profile (0–90 m) which corresponds to young sandy sediments. Diffraction hyperbolas caused by small ice wedges are observed there. Ice wedges are bigger in the right part (90–140 m) where sediments are older. Thus these organic-mineral sediments could be characterized by high ice content and contain thick ice wedges.

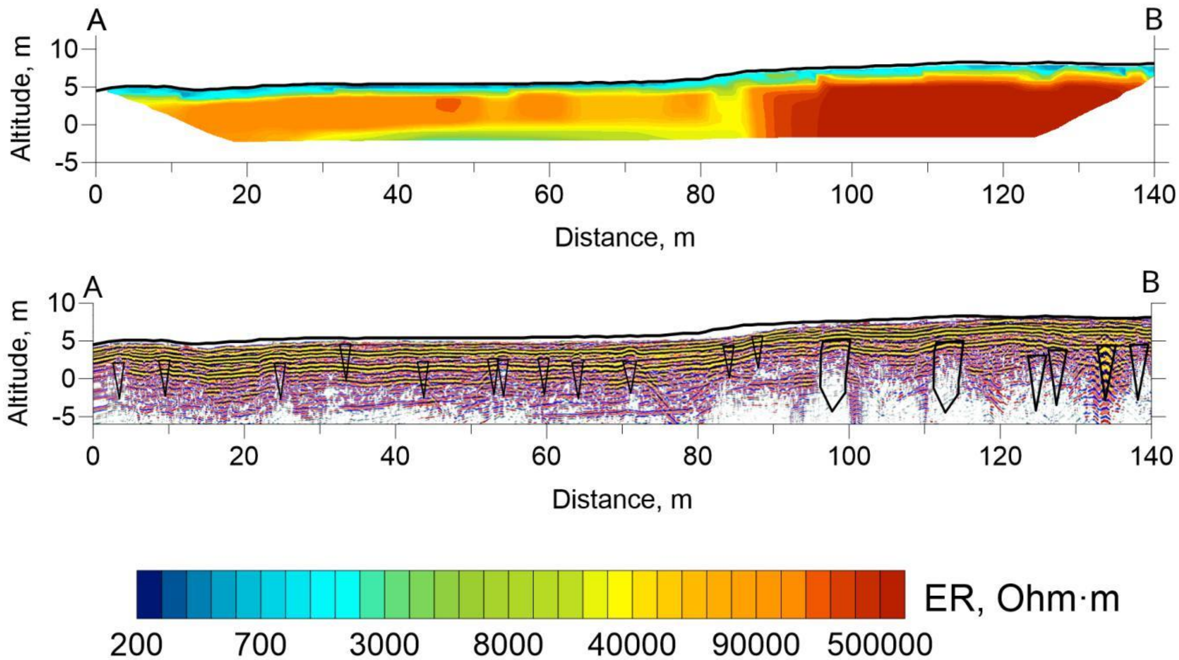

Fig. 9. Profile AB – comparison of ERT and GPR data: ice wedges are marked with black polygons

CONCLUSION

Geological and joint geophysical studies presented by electrical resistivity tomography and ground penetrating radar were done in permafrost of Samoylov island coastline. Both methods seem useful in provided conditions. In spite of quite complex structure of the object – contact between two different parts of frozen sediments, water influence, talik and ice wedges, geoelectrical structure was obtained and is in a good agreement with geological data. Nevertheless, some features and details, which are hidden from geological study, were registered with geophysics (ice wedges, form of talik).

Considering the questions which were raised in the introduction:

1. Is the geoelectrical structure of the contact between floodplains and first terrace corresponds the geological data?

Both ERT and GPR data generally corresponds to geological data. Main elements of geological structure (Fig. 3) are determined with geophysical survey. Contact of the floodplain and the first terrace is quite steep in electrical resistivity section contrary to geological scheme.

2. How deep is the area of water influence on permafrost?

Sligthly sloping talik was registered with ERT survey (Fig. 6). It smoothly descends and reaches about 10 m at 50 meters from the coastline. It could be explained by simultaneous talik propagating and coast erosion therefore it had no time to become steep.

3. Could ice wedges be localized with ERT of GPR in present conditions?

Ice wedges cause no representative anomalies in electrical resistivity section obtained with ERT, but they can be confidently registered with GPR due to diffraction on their upper boundaries and damping of the signal in the interior of thick ice wedges.

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