Petrophysical approach of ERI data interpretation for various salinity deposits in permafrost areas

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Abstract

In this paper are presented the results of electrical resistivity imaging (ERI) survey performed in several areas of the Yamal Peninsula. The objective of the study was to use geophysical approach with petrophysical and statistical analysis to distinguish spatial distributions of various lithological units and characterize permafrost properties including soil salinity and ice content.

Keywords: petrophysical modelling, saline permafrost, near surface geophysics, unfrozen water content.

Introduction

In this study we investigated a near-surface cross section in the north-west part of the Yamal peninsula using ERI. According to the borehole data, each site was composed of 10-20 m of loams in the subsurface followed by 10-20 m of sands and loams in underlying area.

Here simultaneous ERI data statistical processing and petrophysical modelling were used to distinguish and map the deposits of various lithology and to characterize such properties as salinity and volumetric ice content in the permafrost.

Statistical analysis and petrophysical approach

Resistivity histograms (Fig. 1) show that there are different effective electrical resistivity intervals at different sites, while borehole data gives the same lithology (view details in discussion).

Petrophysical modeling was performed in PetroWin program (Matveev & Ryzhov, 2006) which allows to calculate electrical resistivity for each type of soil material, taking into account porosity, ice, clay and unfrozen water content, temperature, cation exchange capacity, porous brine salinity etc., since resistivity of frozen ground is known to depend on such parameters (Dafflon *et al.*, 2016).

Based on core analysis, previous surveys data and borehole logging we confined petrophysical properties within total ice content of 12-68%, unfrozen water content 2-20% for -4^{0}C temperature for frozen loams and ice content 24-49%, 1-7% unfrozen water content for -4^{0}C temperature and 41-49% porosity for frozen sands.

The model of unfrozen ground was limited in porosity (40-60% for loams and 35-50% for sands) and moisture content (40-60% for loams, 10-50% for sands). Also, for resistivity models pore water salinity varied from 0.1 to 40 g/l for all types of modeled soils.

Discussion

The main results of petrophysical modelling are assumed in Figure 2. According to histograms, as compared with petrophysical modelling, for site 1 resistivity values 10^3-10^4 Ohm·m correspond to relatively high ice content (~50%) in subsurface loams and sands at the bottom; comparatively low resistivity values 10^2-10^3 Ohm·m in the middle part of the cross-section are related to conductive heterogeneities in sands with increased unfrozen water content.

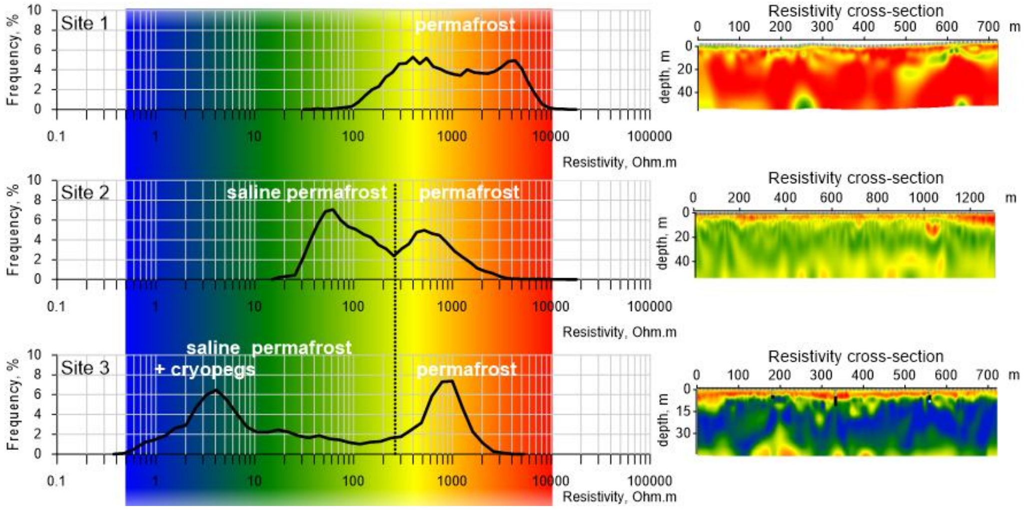

Figure 1. ERI histograms and cross-sections at different sites.

In the upper parts of the cross-sections on sites 2 and 3, resistivity values about 10^3 Ohm·m coincide with frozen loams with ice content ~30% and low total dissolved salts, which is confirmed by numerous studies (Badu, 2015). The middle part of site 2 cross-section is presented by 10-300 Ohm·m resistivity layer interpreted as frozen loams and sands with salinity and unfrozen water content increasing with depth.

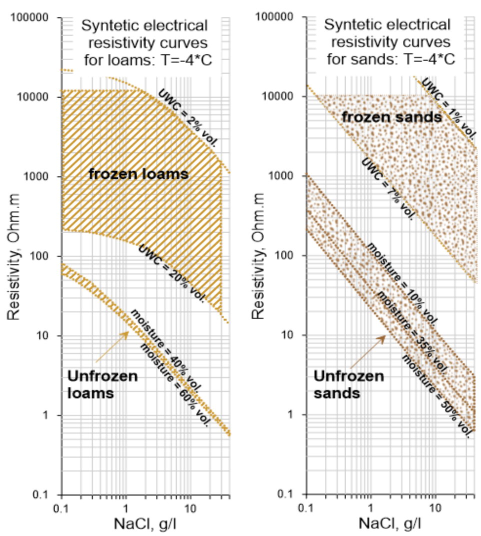

Figure 2. Calculated resistivity models for frozen and unfrozen material.

In the middle part of site 3 cross section a low resistivity area 0.4-100 Ohm·m corresponds to unfrozen permafrost caused by progressively elevated soil salinity in underlying deposits. Gradual increment of resistivity values (10^1-10^3 Ohm·m) is attributed to total ice content elevation.

Conclusions

Through the simultaneous ERI data statistical processing and advanced petrophysical modelling we distinguished and mapped deposits with various lithology and characterized such properties as salinity and ice content in selected permafrost areas.

This study improves understanding and quantifies relations between electrical resistivity in this permafrost and such parameters as porosity, ice, clay content, temperature, cation exchange capacity and unfrozen water properties that provide an essential input in electrical resistivity values.

References

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