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Integrating TDR and GPR methods to study the structure of peatland

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ABSTRACT. In this study we compared time-domain reflectometry (TDR) data from boreholes and the results of ground-penetrating radar (GPR) along the cross-sections on a peat deposit. The studied mire located on the Zaonezhye Peninsula (Republic of Karelia, Russia); its structure included layers of peat and bedding lake sediments. To perform the measurements we used GPR with antenna unit 150 MHz and TDR system TDR200 with probe. The mire structure was characterized by a medium basin structure (7 m max depth) and sloping mire topographic. Comparison TDR and GPR data yielded similar dielectric constant values for peat layers. The average mistake in dielectric constant values between TDR and GPR observation was 5 units. The conditions for the formation of interfaces on GPR cross-sections were studied by analyzing dielectric constant change across the peat deposit. We found that the depth positions of the GPR interfaces were quite accurately (±20 cm) coincides with the intervals of the change of peat type. Our results indicate the difficulty of interpreting GPR cross-sections contained multi-reflectors for subsurface with sub-horizontal structure such as peat deposits or lakes bottom sediments.

Keywords: GPR, TDR, dielectric constant, peat type, decomposition

1. Introduction

Ground penetrating radar (GPR) is widely used to study mire massifs, providing information on their structure and helping identify discontinuities in the peat deposit. There are broad discussion about possibility of using GPR at to determination of peat thickness (e.g. Plado et al., 2011; Parsekian et al., 2012; Parry et al., 2014). However, setting GPR criteria for different types of peat is unsolved. Thus, one of the ways to determine the electrical physical parameters of peat is to combine GPR and time-domain reflectometry (TDR). These techniques can be integrated as they employ similar principles of measuring electromagnetic wave propagation velocity at similar frequencies and deriving the parameters of the medium. In TDR, point measurements are taken through probes in peat samples from boreholes or trial pits, while GPR observations are done from the topsurface of peat deposit. The aim of this study was to determine the electrical physical properties of structural elements of a peat deposit.

2. Materials and methods

The GPR method has been applied to study peatland over 40 years (Finkelstein et al., 1979). GPR reliably determines the depth at which the peat deposit is confined by its mineral bed, and can sometimes identify the intermediate layers made up of peat with different characteristics. Wherefore GPR was actively used at the studies of mire stratigraphy and hydrology (Slater and Reeve, 2002; Comas et al., 2004). A particular concern in such studies is the response of the electromagnetic pulses propagation to variations in peat density, moisture and organic matter content (Ryazantsev and Mironov, 2018). Peat deposit parameterization problems can be handled by test boreholes or integrating geophysical techniques (Walter et al., 2016).

TDR is a technique where the velocity of electromagnetic wave propagation in a medium is measured by inserting a special probe into it, and it is actively used to monitor water content in the ground (Jones et al., 2002). This is a tool widely used in the

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studies of peat and peat deposits (Oleszczuk et al., 2004), and can be very effective when combined with GPR. A comparison of the peat electrical parameters with its organic characteristics is provided new criteria for GPR cross-sections interpretation.

The object of this study is the mire situated in the northern part of Zaonezhye Peninsula, Republic of Karelia. The mire covers 3.5 hectares and occupies an elongate depression, oriented NW to SE, filled with peat and lake sediment.

We established a GPR line across the mire with 5 boreholes with peat samples taken each 25 cm. The dielectric constant and conductivity of peat samples were measured by TDR200 with CS635 probe (Campbell Scientific, USA). The botanical composition and rate of decay were described for each sample. GPR survey was done OKO-2 with 150 MHz antenna unit (Logis-Geotech, Russia).

3. Results

The resultant data shows dielectric constant variations across the deposit. The magnitudes decrease with depth – from 65–75 in peat to 30–40 in varved clay. The intensity of GPR interfaces emergence does not always match with the maximum difference in dielectric constant. There is a series of intensive interfaces between peat and gyttja, although the change in dielectric constant between them is in 5–10 units. In regions with high contrast, reflectors can not be illuminated. These are the facts indicate that peat parameters exert a combined effect on the GPR records. A comparison of the boreholes and GPR cross-sections (Fig.) showed that the boundaries between different types of peats were quite accurately determined (within expected error bounds, e.g. ±20 cm).

The GPR interfaces are matched with the profile of dielectric constant changes. The fact is that, a change of peat type is usually accompanied by a change in rate of peat decay. This effect is sharply appeared in the 2–4 meters depth, where a linear increase in rate of decay leads to an abrupt change in dielectric constant, as result a complex combination of reflectors was formed. The data about peat parameters has enabled an estimation of the reliability of indirect dielectric constant determinations inferred from the hyperbola of the diffracted wave generated by point objects. Fallen tree trunks generate multiple distinct hyperbolas at various depths inside a peat deposit, and dielectric constant can thus be compared. Our results demonstrate a fairly convergence of the direct TDR asses of peat dielectric constant and the indirect GPR asses by means of the hyperbolic fitting.

4. Discussion

The emergence of reflecting boundaries in the study of peat deposits is a complicated question. The variation of peat properties and environmental conditions does not permit for a common set of universal parameters to be made up. A promising approach is to

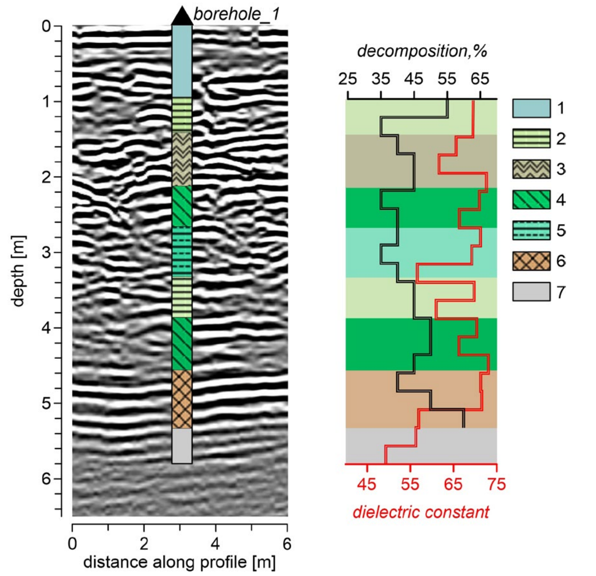

Fig. Comparison GPR and borehole data: 1 – water-saturated peat, 2 – buckbean-sedge peat, 3 – sphagnum peat, 4 – hypnum peat, 5 – sedge peat, 6 – organic gyttja, 7 – clay.

study the interrelated characteristics, i.e. density and degree of decomposition, on which water content is to some extent contingent. The peat decomposition generally results in an increase in electrical conductivity, whereas dielectric constant values remain the same. A question here is the causality of the observed GPR interfaces; whether it is peat density, decomposition or some other factor that produces the greatest effect on the electrical properties, and what GPR patterns do they have. More complex data need to be involved to solve this problem.

5. Conclusions

The reported studies prove the combined application of TDR and GPR is effective. A detailed survey of the peat deposit demonstrated a differential change of electrical physical properties along a gradient. The analysis of data from boreholes helped reveal the source of reflector emergence inside the deposit. Even minor variations in dielectric constant were found to be able to induce the emergence of reflecting boundaries. The patterns identified in the distribution of peat electrical physical properties enabled an interpretation of the GPR profiles, which would have otherwise been impossible.

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Conflict of interest

The authors declare no conflict of interest.

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