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Application of electrical resistivity tomography in investigating depth of permafrost base and permafrost structure in Tibetan Plateau

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ABSTRACT

The changes in the thickness of permafrost and the distribution characteristics of ground ice are of great importance for engineering and environmental issue research in permafrost regions. This study was conducted in the permafrost observation field in Qumahe in the east of the Tibetan Plateau by using electrical resistivity tomography (ERT) for investigating the depth of permafrost base and the structure of permafrost. The results demonstrated that the ERT can detect the depth of permafrost base, identify the characteristics of ground ice and the variation of permafrost types in Qumahe. Also, the effects and accuracy of ERT were evaluated combining the information provided by borehole and ground temperature monitoring. The comprehensive analysis of the data shows that the distribution of permafrost and ground ice in this area is strongly influenced by geographical, topographical and other local factors. The depth of the permafrost base within the observation field differs by 30 m. Aspect, surface water and vegetation conditions have the most significant influence on the thickness of permafrost. A seasonal stream in the low-lying area of the observation field also brings strong influence to permafrost thermal disturbance and thickness. Meanwhile, different geomorphic unit and surface conditions significantly influence the development of ground ice. To be specific, the massive ground ice is mainly developed in the flat swamping wetland, especially the low-lying wetland. In terms of depth, the massive ground ice is mainly developed within 5 to 10 m below the permafrost table.

1. Introduction

The Tibetan Plateau is one of the most sensitive areas to the global climate change (Liu and Chen, 2000), and therefore, under the background of global warming, the changes of permafrost in the Tibetan Plateau produce significant influence on ecological environment and engineering construction (Cheng and Wu, 2007; Jin et al., 2008; Wu et al., 2005; Zhao et al., 2010). However, in predicting the future response of permafrost to the climate change, one of the main problems is the shortage of the three-dimensional information on subsurface composition, ice content and structure (Harris et al., 2009). Compared to drilling, temperature measurement and other survey methods, geophysical methods can be used for detecting continuous and large-scale permafrost with the advantages of fast and low cost (Kneisel et al., 2008). The premise of successfully applying geophysical method lies in the differences in the physical parameters of freezing and thawing soil, but from the moment when the water in soil begins freezing to the time when most pore water is frozen, the resistivity tends to increase exponentially (Pearson et al., 1983). Therefore, the electrical resistivity tomography (ERT) is believed to have a promising application prospect in detecting permafrost structure.

Among ground ice studies, the ERT has been widely applied to detect the ground ice in moraine layers, rock glaciers as well as in talus slopes (Hauck and Kneisel, 2006; Hauck et al., 2003; Marescot et al., 2003; Ross et al., 2007; Scapozza et al., 2011). Where there is ground ice of high ice content, the apparent resistivity achieved by ERT is generally higher than that in the surrounding non-freezing area or the area of low ice content by several orders of magnitude. With high resistivity gradient, the method can determine the distribution of ground ice. In detecting the thickness of permafrost, Lewkowicz et al. (2011) choose fields of different substrates, vegetation types and ground ice contents, and deduce the thickness of permafrost, which ranges from about several to 25 m in thickness by combining ground temperature measurements and ERT.

However, since the characteristics of permafrost geophysical model, the ERT also has some limitations. With the method of DOI (depth of investigation), Marescot et al. (2003) and Hilbich et al. (2009) compared the results of different reference models, and pointed out that with high resistivity gradient, the inversion results for high resistivity body became less reliable, which brought difficulty to the investigation of the permafrost base. Hauck et al., 2003 calculated the sensitivity of ERT in detecting rock glaciers, and showed that the lower boundary of high-resistivity body is of the lowest sensitivity, which indicated that the lower boundary of the high-resistivity body was not well restrained. Since the sensitivity of ERT decreased as the increase of depth and the

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low sensitive area is often confused by the inversion artifacts (Marescot et al., 2003; Rings and Hauck, 2009), the detection of the structure of deeper permafrost requires much more careful evaluation.

At present, some studies have discussed the factors that influence the effects of ERT from the perspective of numerical analysis. However, there are few actual measured data that record the accuracy of this method in detecting the depth of permafrost base as well as the distribution characteristics of ground ice. In this study, we analyzed the application of ERT in detecting the depth of permafrost base and the distribution characteristics of ground ice in the permafrost observation field in Qumahe in the east of the Tibetan Plateau, and further tested the effects and accuracy of the ERT by referring to drilling, ground temperature observation and ice content tests.

2. Study site

The research was conducted in the comprehensive observation field (N34° 54′, E94° 47′, 4470 m) in the Qumahe permafrost region, which is in the east of the Tibetan Plateau (Fig. 1), 15 km away in the west of Qumahe Village, Qumalai County, and is beside the Qumalai–Budongquan Road (Qu–Bu Road). The topography in this area is dominated by hills, and this area is located in the discontinuous permafrost regions (Zhou, 2000). According to the results of permafrost observation along the Qu–Bu Road, permafrost is only found in the alpine region and takes on sparsely island distribution. The lower limit of the permafrost is about 4200 m, and due to the influence of local factors, the thickness of the permafrost varies greatly.

Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Science and Heidelberg University Environmental Physics Research Institute, Germany cooperated to build up an unattended meteorological station (Fig. 2b) in the observation field in 2006, and the station mainly collects routine meteorological data and monitors the hydrothermal dynamics of the active layer. According to the monitoring data, the mean annual air temperature (MAAT) was −4.8 °C in 2008, the annual rainfall in 2007 and 2008 was 260 mm and 410 mm respectively, while the depth of the permafrost table was 1.2 m (Yu et al., 2006).

3. Methods

In order to study the development of permafrost in the observation field, the ERT was applied at observation field on the basis of the previously established comprehensive meteorological station as well as the layout of the existing boreholes and ground temperature observe results.

3.1. Drilling and ground temperature monitoring

The experiment site is located in a valley which goes from northwest to southeast in Qumahe (Fig. 2a), with slope of the southeast slope being 1.1°, of the northwest slope being 2.7°, and the maximum altitude difference being about 100 m. The middle part of the valley's southwest slope is the dry alpine meadow area, with about 70% of vegetation coverage. The bottom of the southwest slope is wet swamping wetland, with water gathering at some spots and over 90% of vegetation coverage. A stream, with the maximum width of about 2.0 m, and a depth of 0.5 m, is located at the bottom of the valley (Fig. 2c). It runs water in summer, but dries up in winter. The northeast slope is similar to the southwest slope, with gentle slope foot being swamping wetland while the middle of the slope being dry alpine meadow area.

In order to find out the development of permafrost under different conditions such as vegetation, water and surface runoff, 5 boreholes were drilled in July, 2009 on the southwest slope along the direction perpendicular to the valley development on the Qumahe profile (Fig. 2). B1 borehole is in the alpine meadow, middle of the southwest slope. B2 borehole is in the swamping wetland, lower part of the southwest slope. B3 borehole is in the center of the small stream. B4 borehole is in the swamping wetland, lower part of the gentle northeast slope. The depth of the first three boreholes is 20.0 m, while that of the 4th borehole is 50.0 m. Meanwhile, lithological identification and ground ice observation were conducted on the field, and complete cores were selected to test ice content. B5 borehole is 200 m away from the measuring line. Since it is far from the measuring line, only its lithological information is referred to.

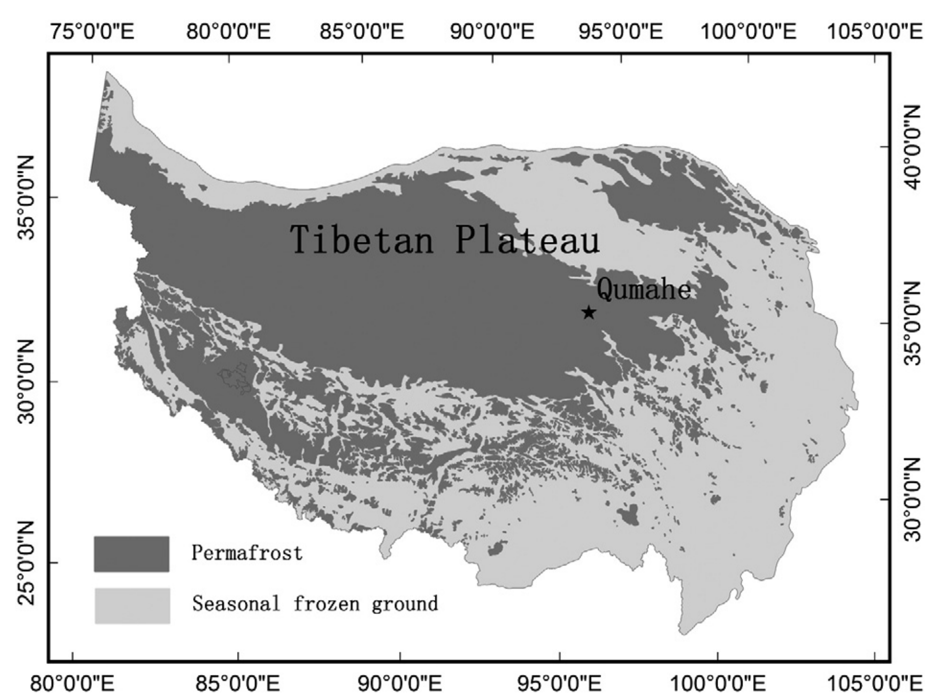

Fig. 1. The location of Qumahe in the Tibetan Plateau and distribution of permafrost.