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Using ground-penetrating radar to detect permafrost degradation in the northern limit of permafrost on the Tibetan Plateau

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Abstract

We used 50-MHz ground-penetrating radar to detect the boundary of permafrost in Xidatan region, the northern limit of the marginal and sporadic permafrost area on the Tibetan Plateau, China. We interpreted the lower limit of permafrost from nine radar profiles to determine the boundary between the permafrost and non-permafrost region. We also sketched the locations of permafrost table along the nine profiles and acquired the lower alpine limit of permafrost in this area. Based on the lower alpine limit of permafrost determined in this field survey, a new permafrost distribution map was drawn with the help of GIS analyses. Comparing with the research work in 1975, permafrost in Xidatan is reduced 12% in area and the lower alpine limit has increased by 25 m. The situation of global warming, apparent climatic warming recorded at two stations near Xidatan, could be responsible for permafrost degradation in this area.

Keywords: Permafrost degradation; Ground-penetrating radar survey; Tibetan Plateau; Climatic warming

1. Introduction

Permafrost is a significant feature of the Tibetan Plateau (hereafter TP) and is attributed to its cold climate. The TP permafrost has an area of about 1.50×10^6 km^2 and developed during its rapid uplifting in the Quatenary. It has been degrading since the warming period in the Holocene occurred from 9.0 to 3.5 ka BP until the beginning of the last glaciation (Jin et al., 2000). The development and distribution of permafrost on the TP depends on climatic, topographic, geologic, hydrologic and surface cover conditions. Among them, climatic conditions undoubtedly play a predominant role in the distribution, thickness, temperature and stability (Nelson, 2003).

Permafrost is also considered to be a product of climatic changes as well as an indicator (Rein et al., 1995). There is evidence to indicate that the TP is one of the most responsive areas to global climate change (Liu and Chen, 2000), especially in the relatively lower altitudinal zones of marginal and sporadic permafrost

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near the northern and southern limits. The northern TP limit of permafrost is located in the Xidatan region (Fig. 1). Previous studies (Wang and French, 1994; Li and Cheng, 1996; Wang, 1997; Wu et al., 2000; Wang et al., 2003) indicate that permafrost degradation under climatic warming has occurred during recent years on the TP. On the basis of long-term ground temperature monitoring, Wang et al. (2000) indicated that an increase of 0.1–0.5 °C in the mean annual ground temperature has occurred since the 1970s and that the lower alpine limit of permafrost has risen 40–80 m on the TP. Wu and Liu (2004) concluded that seasonally frozen ground and sporadic permafrost on the TP has increased 0.3–0.5 °C, and that the northern boundary of permafrost on the TP receded 0.5–1.0 km south from the 1970s to the 1990s.

Our objectives were to delineate any further changes in the permafrost limit by using ground-penetrating radar reflection profiling. Ground-penetrating radar (GPR) is a geophysical technique that uses the continuous reflections of pulsed electromagnetic waves to image discontinuities in the shallow subsurface geological structures and stratigraphic units characterized by changes in electrical conductivity and dielectric permittivity (Davis and Annan, 1989; Daniels, 1996; Reynolds, 1997; Cagnoli and Russell, 2000; Arcone et al., 2002). GPR can be well suited to imaging the near-surface thermal structure and profiles of permafrost because of the strong dielectric permittivity contracts between frozen and unfrozen wet materials. The advantages of using GPR to detect the thickness and other characteristics of permafrost were proven through a series of case studies (Arcone et al., 1998a; Hinkel et al., 2001; Moorman et al., 2003). Xidatan region is characterized by discontinuous permafrost, therefore we chose 50 MHz as the midband radar frequency to improve permafrost penetration (Arcone et al., 1998b).

Based on our GPR survey and geographic information system (GIS) analyses, permafrost degradation during recent decades in Xidatan was revealed in this paper.

2. Study region and methods

Xidatan region (35°43′N, 94°11′E), 4480 m a.s.l. on average, covers an area of 220 km^2. It is located in

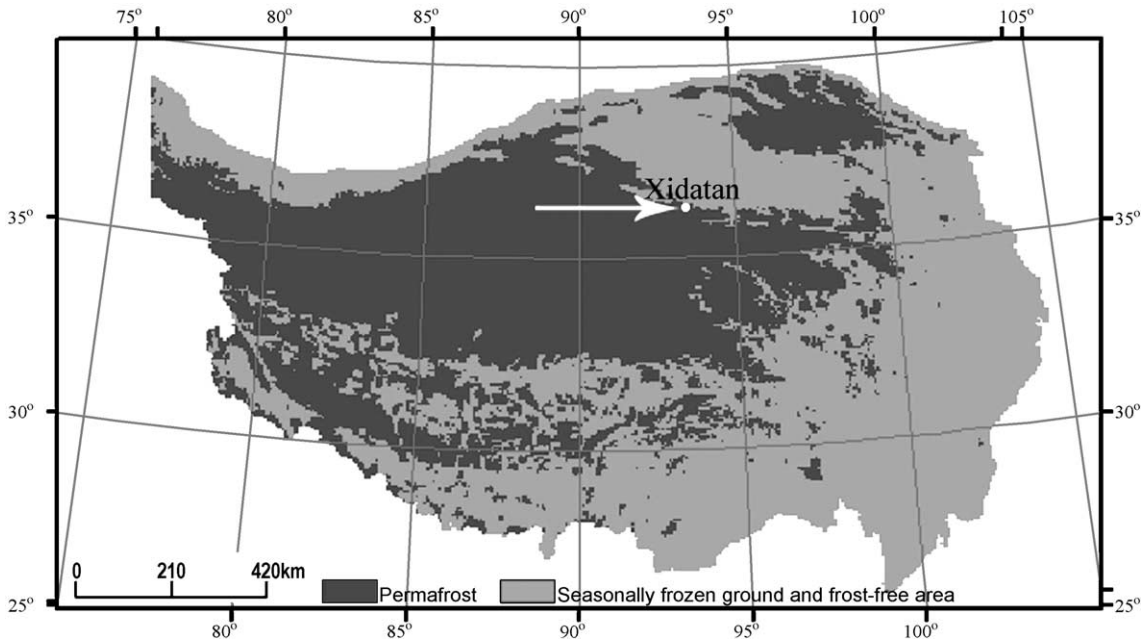

Fig. 1. The location of Xidatan over the TP and permafrost distribution on the TP.