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Effects of a thaw slump on active layer in permafrost regions with the comparison of effects of thermokarst lakes on the Qinghai–Tibet Plateau, China

Yibo Wang[a,*], Zhe Sun[b], Yan Sun[a]

[a] College of Earth and Environment Sciences, Lanzhou University, Lanzhou, Gansu 73000, China
[b] Cryosphere Research Station on the Qinghai–Tibet Plateau, State Key Laboratory of Cryospheric Sciences, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China

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ABSTRACT

In this study, we monitored a thaw slump in the permafrost region of the Qinghai–Tibet Plateau in China, including its thaw settlement and solifluction creep characteristics, and analyzed the change in soil properties and hydrothermal process in the active layer. In addition, the change of the thaw slump active layer was compared with the change of the active layer in lakeshore areas, which were affected by thermokarst lakes, to study the relationship between thaw slump and thermokarst lake. Results showed that thaw slump solifluction creep displacement mainly occurred at the top 50 cm surface soil layer. Under the influence of the thaw slump, the active layer soil bulk density increases gradually along the slope; fine soil particles and soil organic carbon first deposit at the top 30–40 cm of the active layer at gentle slope area, and then are significantly leached at the slope bottom. Since the effect of thaw slump weakens the buffering effects of the active layer on heat transfer, the active layer gradually deepened along the slope and the ablation of the underlying ice–rich permafrost increased, which resulted in the increase of the thaw settlement. Concurrently, a large amount of thaw water from the thawed permafrost was released to the active layer, resulting in overland flow at the front part of the gentle slope area and ponding depression at the slope bottom. The active layer changes of the thaw slump and those of thermokarst lake shore were very similar. These results suggest that active layer soil properties were changed by thaw slump, leading to the increase in underlying permafrost ablation, causing large amounts of thaw water accumulating at poorly drained sites, to form sparse small–sized thermokarst lakes. For some large thermokarst lakes adjacent to a small thaw slump, lake coastal erosion caused the thaw slump, and further evolution of the thaw slump resulted in the changes of lakeshore active layer.

1. Introduction

Thaw slumps, which are widely distributed in ice–rich permafrost area (Zhou et al., 2000), are caused by melting of the exposed ground ice at slope areas, which greatly affects local hydrology, terrain stability, soils chemical compositions, and ecosystems (Kokelj et al., 2009; Niu et al., 2012; Malone et al., 2013a, 2013b, 2013c; G. Gao et al., 2014; Z. Y. Gao et al., 2014; Wang et al., 2015). Thaw slumps have two distinct characteristics: a vertical headwall and a flat slope floor (Burn and Friele, 1989; De Krom, 1990). Through field investigation, Malone et al. (2013a, 2013b, 2013c) pointed out that the thaw slumps could degrade more than 10 m deep permafrosts, and affect more than 100 km^2 of watershed–scale stream geochemistry. Kokelj et al. (2009) and Niu et al. (2012) reported that thaw slumps could lead to significant increase of the mean ground temperature and decrease of permafrost table.

The relationship between thaw slumps and thermokarst lakes has attracted the attention of the geocryology researchers for decades. Based on field observations, Burn (1992) summarized the formation process of thermokarst lakes in northern Canada as, ground subsidence and tilting of trees caused by permafrost degradation, followed by submergence of vegetation and formation of lakeshore thaw slump. Toniolo et al. (2009) monitored a thermokarst process for two years in a discontinuous permafrost region of Alaska, and found that the thaw slump had a significant impact on the thermokarst lake formation and development. Kokelj et al. (2009) found that the average depths of thermokarst lakes, which were affected by thaw slumps, were about four times greater than the same lakes with undisturbed shorelines.

* Corresponding author.
E-mail address: wangyib@lzu.edu.cn (Y. Wang).

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Lantuit et al. (2012) suggested that an intricate relationship existed between the formation of thaw slumps at an earlier period and the evolution of thermokarst lake shore.

The permafrost of the Qinghai–Tibet Plateau is very vulnerable and sensitive to anthropogenic disturbance and climate change (Yang et al., 2013). In recent years, due to the effects of global warming and engineering constructions, the active layer thickness continued to increase with ablating underground ice in permafrost regions of the Qinghai-–Tibet Plateau (Karlsson et al., 2012; Cheng and Jin, 2013). It resulted in increasingly frequent appearance of thaw slumps (Zhang and Wu, 2012; Niu et al., 2014). Since 1990's, dozens of big thaw slump developed only in the Fenghuoshan region of the Qinghai-Tibet Plateau (Wang, 1990), which had adverse effects on linear engineering and local ecosystems in cold regions (Wang et al., 2011; Yin et al., 2014). Previous researches on the Qinghai–Tibet Plateau thaw slumps mainly concentrated on erosion degree, geological disasters, and the effects on permafrost. However, studies on the effect of thaw slump on active layer are limited. Besides, many thaw slumps are adjacent to thermokarst lakes, but the relationship between them is still unclear.

In this research, we monitored data of a thaw slump from 2013 to 2015, in permafrost regions of the Qinghai–Tibet Plateau, China, to analyze the change in the active layer under the effect of the thaw slump. Thereafter, these results were compared to the changes in some lakeshore active layers affected by thermokarst lakes, to investigate the relationship between thaw slumps and thermokarst lakes.

2. Material and methods

2.1. Study area

The location (34°59′38″N; 92°58′59″E) of the studied thaw slump is in the northern half of Beiluhe basin with an elevation of 4601 m (Fig. 1). The slump, which faces northeast, is curved with an average slope angle 10°. Vegetation projective coverage of the unstable slope is less than 10% in a terrain of folded surfaces and imbricate structures by using the coverage frame method.

Fig. 2 shows the basic meteorological information of the study area.

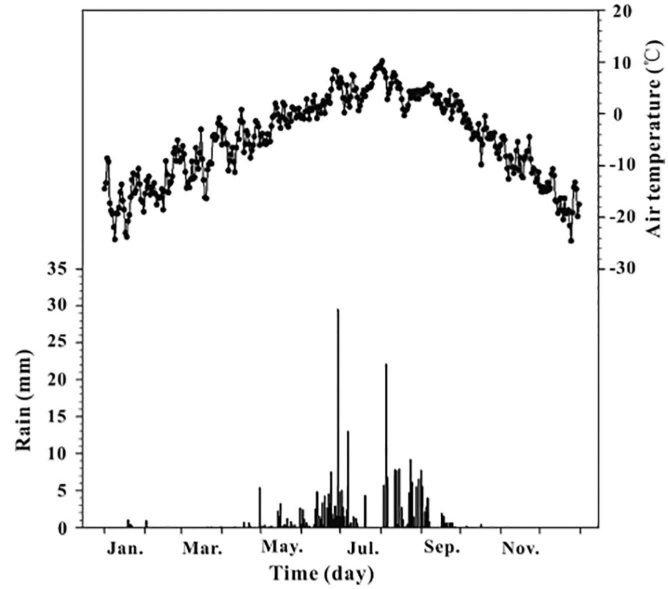

Fig. 2. Meteorological information of the study area.jpg.

The regional climate is a typical plateau continental climate, which has short warm seasons and long cold seasons. The mean annual air temperature is −6.24 °C, and mean annual temperature difference is 26.2 °C. Mean annual rainfall is 290.9 mm, with a mean evaporation of 1316.9 mm. The period, when the soil freezes, is from September to April of the next year.

2.2. Field monitoring

According to the slope angle and the topographic features, the studied slope was divided into three parts: headwall, gentle slope area, and slope bottom (Fig. 3). The headwall, with the largest slope angle between 12° and 18°, shows a ladder like slump and contains obvious transverse cracks (Fig. 3A). The gentle slope area with a slope angle

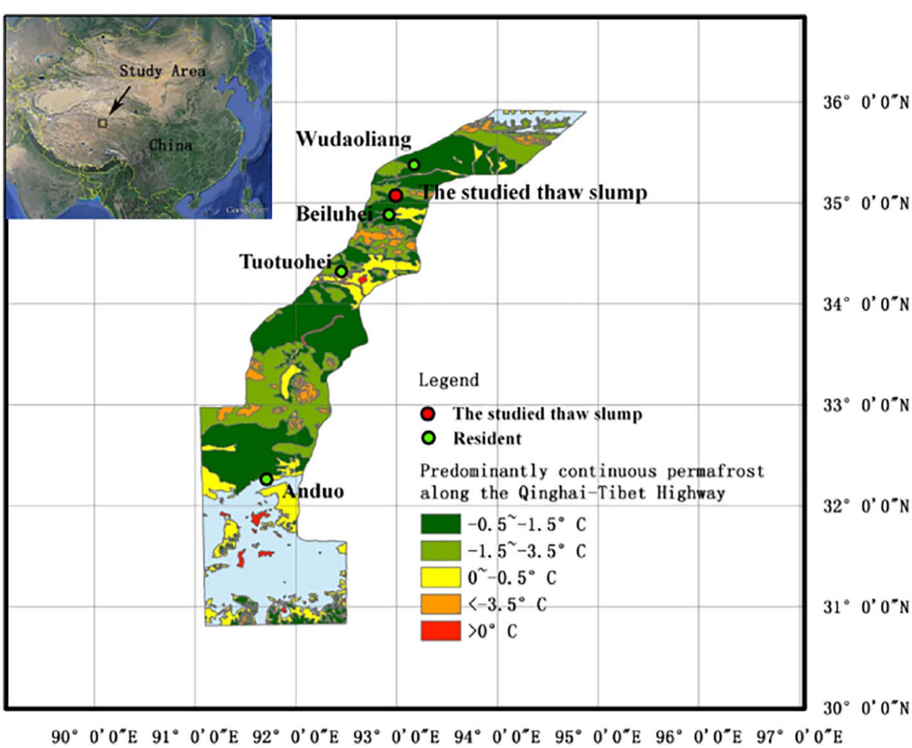

Fig. 1. Location of the study area.