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The disappearance of glaciers in the Tien Shan Mountains in Central Asia at the end of Pleistocene

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ABSTRACT

Glaciers in Central Asia are among the largest ice masses in the Eurasian continent and have supplied vital water to local inhabitants for thousands of years. The glaciers in this region are generally believed to be remnants of the last deglaciation, however, glacier variability in the central Asian mountains since the Last Glacial Maximum (LGM) has not been well documented. Here, we report an 86.87 m-deep ice core record drilled on an ice cap in the Tien Shan Mountains of Central Asia. Radiocarbon dating of organic soil from the bottom of the ice-core borehole showed that the age of the soil was 12,656 – 12,434 cal years before present, coincident with the beginning of the Younger Dryas cold period (YD). This result indicates that the ice cap did not exist in the Bølling-Allerød period (BA), which was the warm period before the YD, and that the BA climate was significantly warmer than at present. It also indicates that the ice cap has never entirely disappeared in any warm periods throughout the Holocene. We estimated that during the BA its extent was 43% or less of the present glacier coverage in the mountains. Our results suggest that this region at the end of Pleistocene was considerably warmer than at present, and that most of the present glaciers in this region are not relics of the Last Glacial period, but are composed of ice formed during the YD and Holocene.

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1. Introduction

The Tien Shan Mountains are one of the major mountain systems in Central Asia. The range extends over 2000 km, from east Uzbekistan (69°E, 42°N) to northeast of the Taklamakan Desert in China (95°E, 43°N). The major Tien Shan peaks rise from over 4000–7000 m a.s.l. in height. Seasonal precipitation in Central Asia is triggered by the interactions between the atmospheric circulation from the Siberian high and the westerlies (Aizen et al., 1997). The Tien Shan Mountain ranges pose a barrier to western and northern air masses moving toward Central Asia, thus playing an important role in determining the local climate.

Glaciers presently exist in mountains mainly above 3500 m a.s.l. and most rivers originating from the Tien Shan glaciers flow down through the steppes and deserts surrounding the mountains to form the Aralo-Caspian, Balkhash, Issyk-Kul, and Tarims endortheic basins. Water from the mountains has sustained the local inhabitants of this arid area for thousands of years and has maintained the Silk Road, a famous ancient trade route between Asia and Europe (Stein, 1925; Yang, 2001; Yang et al., 2006a). Changes in glacier runoff in the Tien Shan Mountains have always been a major cause for the migration of human communities during their long history in the region. Nevertheless, the present Central Asia settlements and their millions of inhabitants still depend very much on water from the glaciers, and any decline in glacial area and volume poses a major concern to the countries of Central Asia (Barnett et al., 2005; Sorg et al., 2012).

Although the change of glacier extent in the Holocene and the late Pleistocene is a great concern in this region, the deglaciation

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process has not been documented well, particularly in the end of Pleistocene. There have been many geomorphological studies for the Pleistocene and the Holocene in this area (e.g. Koppes et al., 2008). For example, glacier chronological studies have revealed that glaciers in the Tien Shan largely extend in the Last Glacial Maximum in 19,000 years before the present (yr BP), gradually retreat after 11,000 yr BP, and that present glaciers are generally remnants of the last deglaciation (Grosswald et al., 1994). However, it has been suggested that the dating the glaciers on the basis of age of moraines in Tien Shan does not give clarity due to picking of samples from the pseudo-moraines, which were formed mainly during mass gravitational lithogenesis as a reaction to the disappearance of glaciers in the late Pleistocene and causes even greater confusion in dating (Melnikova, 1987; Shatravin, 1992, 1994a, 1994b, 2007, 2012; Romanovskiy, 2007). Furthermore, although geomorphic mapping of moraine sequences could reveal advances of glacier extent, it is unable to reconstruct minimal extent or disappearance of glaciers since the evidences are usually beneath the present ice coverage. The model of stadial glacier recession in late Pleistocene and Holocene has been adopted for Tien Shan by Shitnikov (1957) on the basis of the alpine classical model (Penck and Bruckner, 1909). According to this model, the modern glaciation in Tien Shan is a continuous extension of the Pleistocene decaying glaciation. Shitnikov believed that since the maximum glaciation in the late Pleistocene, the glacier recession has formed eight stadial moraines correlated with 1850 yr rhythms of climate variability, i.e. changes in atmospheric moisture flow over the continents (wet/dry periods). Until the 1980s many researchers followed this model defining stadial glacial moraines in Central Asia based on the description of alpine landform and random radiocarbon dating of allochthonous organic matter from the moraine surface soils (Sevastyanov, 1974; Pomortcev, 1980; Maksimov, 1980). Later, Maksimov et al. (1987) has concluded that this method was not correct because the descriptively defined moraines do not match the radiocarbon dating in many cases. A hypothesis about a “quasi-stationary” state of the Tien Shan glaciers in Holocene also scientifically not motivated, because the dendrochronological and lichenometric dating of the Tien Shan glacial stadials reflect only the late Holocene, i.e. not more than the last 1000 years (Solomina, 1999).

Ice core studies provide a means of reconstruction of continuous climate history. However, there have been only two ice cores in Central Asia that cover the entire Holocene and the Pleistocene deglaciation (Thompson et al., 1989, 1997b). Furthermore, their oxygen-isotope records, which are commonly used as air temperature proxies, have some difficulties of interpretation due to effect of melt and multiple moisture sources. The age of the basal section of ice cores can be indicative of ice-free conditions in the mountain when the climate was warmer and/or dryer than present. For example, onset of neoglaciation of 6000 years ago in western Mongolia has been identified by the age of basal ice (Herren et al., 2013). This approach could reveal minimal glacier extent in the past, which cannot be determined by geomorphological studies. Although ice cores have been recovered from some glaciers in the Tien Shan Mountains (e.g. Thompson et al., 1997a; Kreutz et al., 2001; Lee et al., 2003), they were generally shallow, covered only the last decades, and did not reach the bedrock.

The Grigoriev Ice Cap is located in the Teskey Ala-Too Range in Inner Tien Shan, an area running southward from Lake Issyk-Kul, the world's second largest mountain lake (Fig. 1). The ice cap is a simple ice cap covering a small mountain approximately 8 km^2 in area. Most of the glaciers in this region are ice caps or small valley glaciers. Thus, the shape of the Grigoriev Ice Cap is representative in this region in terms of size, location and topography and response of this glacier to climate change is probably typical in the region.

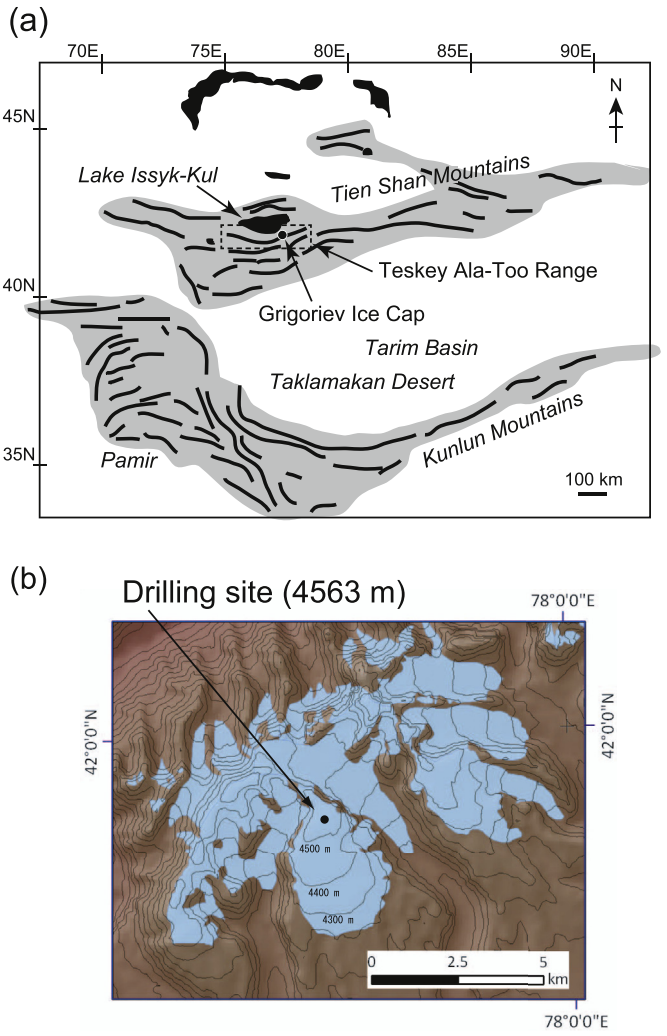

Fig. 1. Location (a) and map (b) of the Grigoriev Ice Cap in Kyrgyzstan, Central Asia, showing the drilling site. Light blue area indicates present glacial coverage based on a satellite image (ASTER) acquired on Aug. 14, 2004. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The top is a flat snow field at an elevation of 4563 m a.s.l. According to our 2-year instrumental records at the summit of the ice cap (2005–2007), the annual total precipitation is approximately 290 mm (Fujita et al., 2011). Water vapor is mainly supplied by the westerlies (Numaguti, 1999). Shallow ice cores have been recovered in 1990, but they were 16.5 and 20 m in length and covered only the last 50 years (Thompson et al., 1997a). We successfully drilled an ice core from the surface to the bottom at the same site on the ice cap in 2007. This study aims to document the variability of glaciers and climate in Central Asia using the ice core of the Grigoriev Ice Cap in Tien Shan Mountains. In particular, we discussed the climate and glacier extent when the ice cap did not exist based on the dating of bottom of the ice core.

2. Study site and methods

The ice core was drilled in September 2007 at the top of the Grigoriev Ice Cap (41°58′33″N, 77°54′48″E) in Kyrgyzstan (Fig. 1), with an electro-mechanical drill manufactured by Geo Tecs Co., Japan. The barrel size of the drill was 135 cm in length and 9.5 cm in inner diameter. The detailed specification of the drill was described in Takeuchi et al. (2004). The drill reached bottom of the ice cap at a

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