Quaternary Science Reviews 98 (2014) 7–23

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Timing and extent of Quaternary glaciations in the Tianger Range, eastern Tian Shan, China, investigated using ^{10}Be surface exposure dating

Yingkui Li [a,*], Gengnian Liu [b], Yixin Chen [b], Yanan Li [a], Jon Harbor [c,d], Arjen P. Stroeven [d], Marc Caffee [e], Mei Zhang [b], Chuanchuan Li [b], Zhijiu Cui [b]

[a] Department of Geography, University of Tennessee, Knoxville, TN 37996, USA
[b] College of Urban and Environmental Sciences, Peking University, Beijing 100871, China
[c] Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN 47907, USA
[d] Bolin Centre for Climate Research, Department of Physical Geography and Quaternary Geology, Stockholm University, S-106 91 Stockholm, Sweden
[e] Department of Physics, Purdue Rare Isotope Measurement Laboratory, Purdue University, West Lafayette, IN 47907, USA

A R T I C L E I N F O

Article history:
Received 3 December 2013
Received in revised form
13 May 2014
Accepted 15 May 2014
Available online 13 June 2014

Keywords:
Cosmogenic nuclides
Glacial chronology
Quaternary glaciations
Tian Shan
Central Asia

A B S T R A C T

Reconstructing glacial chronologies with consistent methods is critical for efforts to examine the timing and pattern of past climate change. Cosmogenic ^{10}Be surface exposure dating has been widely used to constrain the timing of glacial events on the Tibetan Plateau and in Central Asia. However, few such studies have been conducted in the Chinese Tian Shan and available ^{10}Be ages from this region have only provided evidence for glacial events during the global Last Glacial Maximum (gLGM) and Lateglacial. Here, we present 45 ^{10}Be surface exposure ages from glacial landforms in the Ala and Daxi valleys, two formerly glaciated valleys draining the Tianger Range, eastern Tian Shan. Combined with previously published ^{10}Be surface exposure ages from the Daxi Valley in the source area of the Urumqi River, the new ages record five major glacial events during Marine Oxygen Isotope Stages (MIS) 6 or older, 4, 3, 2, and 1 (during the Little Ice Age, LIA). Landforms from glacial events since MIS 2 are found on the northern slope of the Tianger Range (Daxi Valley), whereas evidence for the older glacial events is only preserved on its southern slope (Ala Valley). This disparity may be caused by different preservation- and micro-climatic conditions on the northern and southern slopes of this mountain range, due to differences in gradient and aspect. The LIA glacial advances are apparently the only Holocene glacial event recorded in this area. Earlier Holocene glacial events were probably so restricted in extent that they were destroyed by subsequent LIA advances.

1. Introduction

Mountain glaciers are sensitive to climate change, especially in regions located within the confluence of different climate systems (Ehlers and Gibbard, 2007; Thackray et al., 2008). Central Asia, in particular, is controlled by the interactions of the westerlies, the Siberian High, and potentially the Asian monsoon (Benn and Owen, 1998). Glaciers develop in its highlands, such as the Tian Shan, Altai, and Pamir, in response to temporal variations in the dominance of precipitation systems from the Atlantic Ocean, from closed drainage-basin sources such as the Aral, Black, and Caspian seas, and from the Arctic Ocean (Benn and Owen, 1998; Kreutz et al., 2001; Olivier et al., 2003; Aizen et al., 2004, 2005; Henderson et al., 2006). Each of these systems might produce a distinctive pattern of glaciation within a region. These glaciation patterns will likely be complicated and reconstructing the timing and extent of past glacial variations is a critical element in achieving a comprehensive understanding of the impacts of these interacting climate systems.

Although some paleo-glacial reconstructions in Central Asia have been conducted (e.g. Yi et al., 2002; Abramowski et al., 2006; Zhao et al., 2006, 2009, 2010; Seong et al., 2007; Koppes et al., 2008; Kong et al., 2009; Li et al., 2011; Röhringer et al., 2012; Zech, 2012; Stroeven et al., 2013; Zech et al., 2013), this area has not been extensively studied. Dating glacial landforms and deposits in arid environments like this is challenging because there is

* Corresponding author.
E-mail address: yli32@utk.edu (Y. Li).

http://dx.doi.org/10.1016/j.quascirev.2014.05.009
0277-3791/

usually a paucity of organic matter for radiocarbon dating in glacial deposits and landforms, and the timescale of radiocarbon dating (<50 ka) is insufficient to provide more than minimum-limiting ages for much older glacial events (Balco, 2011). Cosmogenic nuclide surface exposure dating (mostly ^{10}Be) has been and continues to be used to improve glacial chronologies in the Central Asian highlands (e.g. Abramowski et al., 2006; Seong et al., 2007; Koppes et al., 2008; Kong et al., 2009; Li et al., 2011; Röhringer et al., 2012; Zech, 2012; Zech et al., 2013). Except for a few sites from the eastern Tian Shan (Kong et al., 2009; Li et al., 2011), most ^{10}Be surface exposure dating studies of glacial landforms have been conducted in the western Tian Shan and in the Pamir (Abramowski et al., 2006; Seong et al., 2007; Koppes et al., 2008; Röhringer et al., 2012; Zech, 2012; Zech et al., 2013).

The source area of the Urumqi River in the Tianger Range of the eastern Tian Shan is one of the few sites where glacial landforms and deposits have been dated using ^{10}Be surface exposure dating (Kong et al., 2009; Li et al., 2011). It is also one of the most intensively studied field areas in the world for glacial geomorphology because of its spectacular landforms and the presence of a research station of the Chinese Academy of Sciences (Tianshan Glaciological Station) in the Daxi Valley since 1959. In addition to ^{10}Be surface exposure dating, other techniques used to date glacial landforms and deposits in this valley include radiocarbon (^{14}C), lichenometry, thermoluminescence, and electron spin resonance (ESR) (Wang, 1981; Zheng and Zhang, 1983; Chen, 1989; Li, 1995; Yi et al., 2002, 2004; Zhao et al., 2006). However, few studies have been conducted in adjacent valleys on the northern slope of the Tianger Range, and there is no glacial chronology established from the southern side of the mountain range.

Our primary focus was on establishing a glacial chronology in the Ala Valley, a major formerly-glaciated valley on the southern side of the Tianger Range using cosmogenic ^{10}Be surface exposure dating. We also collected samples from a suspected Little Ice Age (LIA) moraine in the Daxi Valley for exposure age determination. These measurements, together with published ^{10}Be exposure ages in this area, allow for a comparison of the timing and extent of Quaternary glaciations on both sides of the Tianger Range. We also compare the composite ^{10}Be-derived glacial chronology with published ESR ages from this area to evaluate the performance of ESR in dating glacial deposits.

2. Geomorphologic setting and previous work

The Tian Shan, known as the "Water Tower of Central Asia" (Sorg et al., 2012) because of an abundance of glaciers, is a WSW–ENE trending ~2500 km long arc of mountains extending from the western boundary of Kyrgyzstan, across most of the Xinjiang Uyghur Autonomous Region, China, almost to the Mongolian border (Fig. 1). It is one of the driest regions in the world. The orographic effect of this mountain range leads to a pronounced gradient in precipitation from northwest (annual precipitation of 1500–2000 mm) to southeast (~100 mm) (Sorg et al., 2012). The geomorphological imprint of Quaternary glaciations varies along the length of the Tian Shan and mirrors the distribution of the highest peaks (Stroeven et al., 2013). The climate of the Tian Shan is presently dominated by the westerlies and the Siberian High (Benn and Owen, 1998). The shifting dominance of these two circulation systems are expected to have played a key role in driving the timing and extent of Quaternary glaciations in this area.

The Tian Shan consists of several smaller mountain ranges including the Tianger Range in the eastern Tian Shan. The highest peak of the Tianger Range is Tianger Peak II (43.111°N, 86.798°E; Fig. 2) at ~4486 m above sea level (m a.s.l.). Modern glaciers around this peak occur mainly within the north-facing valleys and cirques, and are limited to cirque glaciers, hanging glaciers, and small valley glaciers. Abundant glacial landforms, erratics, and deposits are distributed along major valleys >10 km downstream from modern glaciers or from headwalls in ice-free valleys (Fig. 2).

The source area of the Urumqi River is located in the Daxi Valley on the northern slope of the Tianger Range (Fig. 2). This area is particularly well known in glacial geomorphology because of the presence of double (U-in-U) troughs in formerly glaciated valleys (Cui, 1981; Li et al., 2001a,b). Five groups of moraines have been identified in the Daxi Valley. Detailed description of these moraines and other related glacial landforms can be found in Zhao et al. (2006) and Li et al. (2011). Although glacial landforms and deposits within this valley have been dated using multiple techniques, there is still some controversy about their ages. This controversy arises primarily because of differences between ^{10}Be and ESR ages: ^{10}Be ages date only to the global Last Glacial Maximum (gLGM), whereas ESR ages from the same landforms are significantly older (ranging from 27 to 184 ka, Yi et al., 2002; Zhao et al., 2006).

The Ala Valley is a major south-facing, formerly-glaciated valley on the southern slope of the Tianger Range (Fig. 2). Most glaciers within this valley have disappeared and only a few small glaciers remain, perched within shaded north-facing cirques in valley heads. We investigated glacial landforms/deposits distributed from the valley head of the west branch of the Ala Valley (Arexigongjin (AR) Valley, around 3800 m a.s.l.) to the confluence between the Ala Valley and the Dundesala (DDSL) Valley around 2900 m a.s.l. (Fig. 2). Several groups of moraines remain well preserved in this >20 km long valley section.

There is a set of fresh-looking lateral-terminal moraines a few hundred meters away from the terminus of the modern glacier near

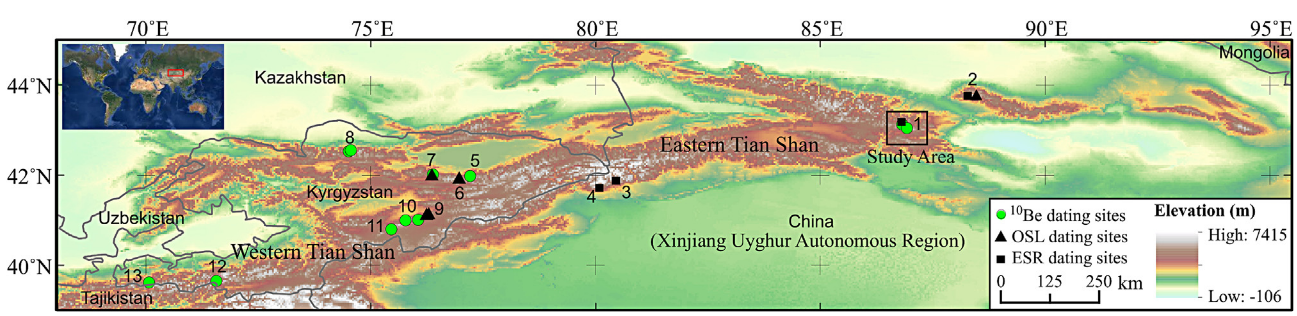

Fig. 1. Relief map of the Tian Shan illustrating available ^{10}Be, OSL, and ESR dating studies across the Tian Shan. (1) Daxi (Yi et al., 2002; Zhao et al., 2006; Kong et al., 2009; Li et al., 2011; this paper) and Ala (this paper) valleys, Tianger Range; (2) Heigou and Gubanbogeda valleys, Bogeda Range (Zhao et al., 2012); (3) Muzart Valley (Zhao et al., 2010); (4) Ateaoyinake Valley (Zhao et al., 2009); (5) Gulbel Pass, Terskey Ala Tau Range (Koppes et al., 2008); (6)Temir-Kanat area, Terskey Ala Tau Range (Narama et al., 2009); (7) Ala Bash Basin (Koppes et al., 2008) and Turasu Valley (Narama et al., 2007), Terskey Ala Tau Range; (8) Ala Archa and Chor Kyrchak valleys, Kyrgyz Front Range (Koppes et al., 2008); (9) Chong-Tör and Sary-Tal valleys, At Bashi Range (Narama et al., 2009); (10) Djo Bog Gulsh and Terekçu valleys, At Bashi Range (Koppes et al., 2008); (11) Kitschi-Kurumdu Valley, At Bashi Range (Zech, 2012); (12) Koksu Valley, Alay Range (Abramowski et al., 2006); and (13) Aksu Valley, Turkestan Range (Abramowski et al., 2006).