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Timing and dynamics of glaciation in the Ikh Turgen Mountains, Altai region, High Asia

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ABSTRACT

Spanning the northern sector of High Asia, the Altai region contains a rich landform record of glaciation. We report the extent, chronologies, and dynamics of two paleoglaciers on opposite flanks of the Ikh Turgen mountains (In Russian: Chikhacheva Range), straddling the border between Russia and Mongolia, using a combination of remote sensing-based glacial geomorphological mapping, ^{10}Be surface exposure dating, and geomorphometric analysis. On the eastern side (Mongolia), the Turgen-Asgat paleoglacier, with its potential for developing a large accumulation area (~257 km^2), expanded 40 km down valley, and mean ages from a latero-frontal moraine indicate deglaciation during marine oxygen isotope stage (MIS) 3 (45.1 ± 1.8 ka, n = 4) and MIS 2 (22.8 ± 3.3 ka, n = 5). These minimum age constraints are consistent with other ^{10}Be glacial chronologies and paleoclimate records from the region, which indicates glacier culmination during cold and wet conditions coinciding with MIS 3 (piedmont-style glaciation; inferred for a few sites across the region) and glacier culmination during cold and dry conditions coinciding with MIS 2 (mainly valley-style glaciation; inferred from several sites across the region). On the western side (Russia), the Boguty paleoglacier had a smaller accumulation area (~222 km^2), and advanced 30 km down valley across a low gradient forefield. Surface exposure ages from two moraine complexes on this side of the mountains exhibit wide scatter (~14–53 ka, n = 8), making paleoclimate inferences and comparison to other proxies difficult. Ice surface profile reconstructions imply that the two paleoglaciers likely shared an ice divide.

1. Introduction

The Altai Mountains are located in the northern sector of High Asia (Fig. 1); a rugged and land-locked region consisting of a series of NW–SE trending mountain ranges, with maximum elevations of up to ~4500 m a.s.l. High Asia is located at the convergence of several atmospheric circulation systems. In the Altai Mountains, during summers, the Mid-Latitude Westerlies (MLW) deliver humid air masses from the Atlantic Ocean. During winters, the Siberian High-pressure system (SH) brings cold and dry air masses from the Arctic, deflecting the Mid-Latitude Westerlies further to the south (Cheng et al., 2012, Fig. 1 inset map). Migration of these air circulation systems causes large annual and seasonal differences in precipitation partitioning and temperature (Gillespie and Molnar, 1995; Rupper and Roe, 2008). Other large

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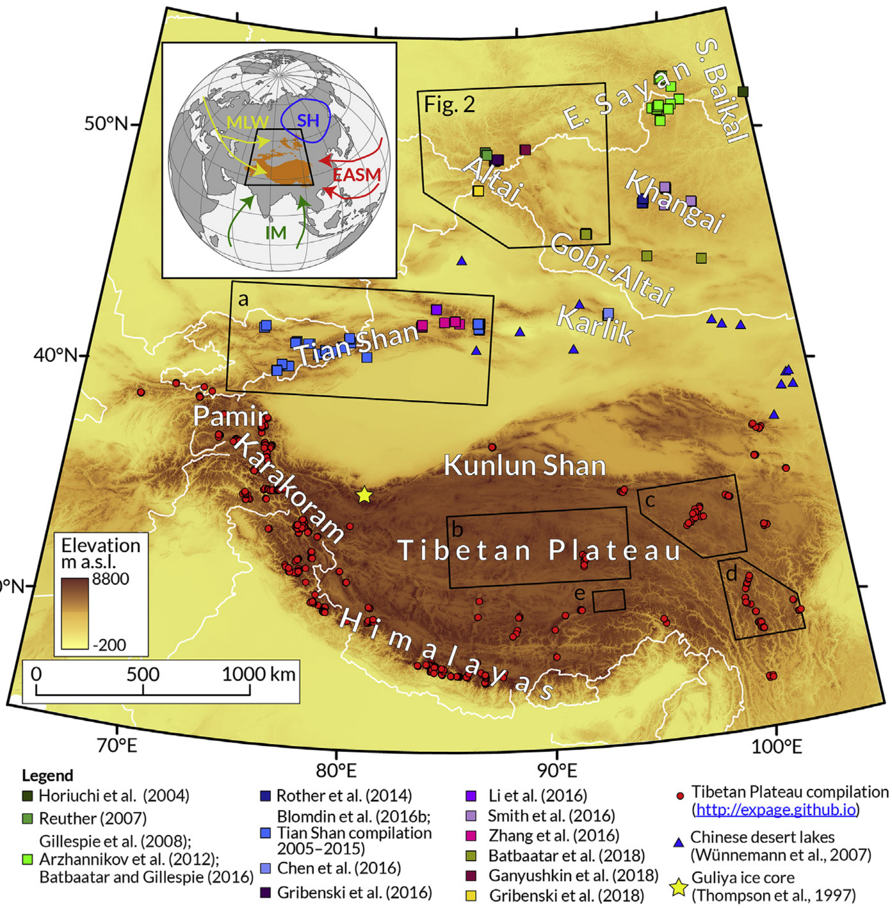

Fig. 1. Physiography of High Asia. Locations of previously mapped regions indicated with black boxes (cf. Fig. 2 for the Altai and western Sayan mountains; Blomdin et al., 2016a); a) the Tian Shan (Stroeven et al., 2013), b) the central Tibetan Plateau (Morén et al., 2011), c) Bayan Har Shan (Heyman et al., 2008), d) Shaluli Shan (Fu et al., 2012), and e) the Maidika region (Lindholm and Heyman, 2015). Also indicated are the locations of all published ^{10}Be surface exposure age samples (n = 2699) from glacial settings across High Asia (extracted from: http://expage.github.io), the location of the Guliya ice core (Thompson et al., 1997) and Chinese desert lake core records (Wünnemann et al., 2007). References are provided for studies mentioned in the text and illustrated in Figs. 9 and 10. Inset map shows the location of High Asia, with topography higher than 2000 m a.s.l. shaded orange and locations of major atmospheric circulation systems, SH = Siberian High-pressure system, MLW = Mid-Latitude Westerlies, IM = Indian Monsoon and EASM = East Asian Summer Monsoon (Cheng et al., 2012). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

atmospheric circulation systems prevailing across High Asia are the Indian and East Asian summer monsoons (IM & EASM), but these have little or no effect on the Altai Mountains today (Winkler and Wang, 1993, Fig. 1 inset map). In addition to the interaction between the Siberian High and the Mid-Latitude Westerlies, the pronounced topography of the Altai Mountains also produces steep precipitation gradients from west to east (Tronov, 1949; Dolgushin and Osipova, 1989; Klinge et al., 2003; Lehmkuhl et al., 2004), depleting the westerly sourced moisture and causing rain shadow effects on the eastern flanks of Altai Mountains.

Glaciers located at the confluence of major circulation systems are particularly sensitive to their climate variability (Rupper and Roe, 2008; Rupper et al., 2009). Hence, the topographic and climatic settings of the Altai Mountains impact the evolution and distribution of glaciers, both present-day and Pleistocene glaciers (Lehmkuhl et al., 2016). In general, present-day glaciers occur at lower altitudes in the wetter northwestern regions of the Altai rather than in the drier eastern regions (Lehmkuhl et al., 2004; 2011; 2016; Nuimura et al., 2015). The spatial pattern of present-day glacier area change varies significantly across the different sectors of the Altai Mountains; glaciers in the Chuya and Kurai basins (Fig. 2), in the Russian Altai, exhibited glacier area change of −9–27% between the years 1952 and 2008 (Narozhniy and Zemtsov, 2011), while glacier area changes in the Mongolian Altai varied between +10 to −36% for the years 1990 and 2010 (Kamp and Pan, 2015). This spatial variation in modern glacier area change likely both reflect regional climate change (generally warming trend) and differences in glacier morphologies (Kamp and Pan, 2015).

Understanding the timing and dynamics of past glaciation in the Altai Mountains provides insight into how glaciers across a mountain system respond to regional climate change. Reconstructed paleoglacier extents can be used as paleoclimate proxies; glacier expansion and retreat of a glacier is a function of variations in air temperature and precipitation (e.g. Oerlemans et al., 1998). Topographic factors may also control the extent and dynamics of glaciation. Large, high-elevation catchments, for example, are more likely to sustain large glaciers compared to small low-elevation catchments. Catchment morphology, valley width, length, slope and aspect, also influence glacier dynamics (Barr and Lovell, 2014). While topographic factors affect the style of glaciation, chronologies reconstructed from glacial deposits across a large area may provide location-specific nodes of local climate information (Kirkbride and Winkler, 2012). If glaciers spanning a large region behave similarly (i.e. synchronous expanding or retreat), the glaciers are likely responding to regional-scale climate variations as opposed to local non-climatic factors (Rupper and Roe, 2008).

Proposed glacial reconstructions for the Altai region, range from limited alpine style-glaciation with centres of glaciation consisting of ice caps and ice fields (Lehmkuhl et al., 2004; Lehmkuhl and Owen, 2005; Blomdin et al., 2016a) to a large ice sheet covering the Altai Mountains (Grosswald et al., 1994; Grosswald and Rudoy, 1996; Rudoy, 2002). Although most studies support limited alpine style-glaciation, additional mapping, dating, and modelling studies will provide quantitative constraints on the timing and dynamics of glaciation. The extent of past glaciation in the Altai Mountains can be evaluated using extensive marginal moraine deposits, located beyond the main mountain fronts (Blomdin et al., 2016a). These glacial deposits indicate a style of Pleistocene glaciation comprised of valley glaciers, as well as ice caps and ice fields, in which large outlet glaciers extended well beyond the mountain fronts onto the lowlands or intermontane basins (Lehmkuhl et al., 2004; 2016; Blomdin et al., 2016a). The dynamics and style of Pleistocene glacier cover has been extensively characterized (cf. Grosswald et al., 1994; Grosswald and Rudoy, 1996; Lehmkuhl, 1998; 2012; Lehmkuhl et al., 2004; 2011; 2016; Blomdin et al., 2016a). Fewer