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Late glacial ^{10}Be ages for glacial landforms in the upper region of the Taibai glaciation in the Qinling Mountain range, China

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ABSTRACT

Glacial landforms are well preserved on Taibai Mountain (3767 m), the main peak of the Qinling mountain range located south of the Loess Plateau and east of the Qinghai-Tibet Plateau. The timing and extent of Quaternary glaciation in the study area is important for reconstructing Quaternary environmental change however numerical ages for glaciation in this study area have not previously been well resolved. Using terrestrial in situ cosmogenic nuclides we dated four samples collected from two glacially eroded rock steps in the upper part of a valley near the main peak, in an area previously identified as having been occupied by ice during the Taibai glaciation. The ^{10}Be results are all late glacial in age: 18.6 ± 1.1 ka, 16.9 ± 1.0 ka, 16.9 ± 1.1 ka and 15.1 ± 1.0 ka. The spatial pattern of ages in the valley suggests fast retreat, with horizontal and vertical retreat rates estimated to be on the order of 0.4 and 0.09 m a^{-1}, respectively. A simple extrapolation of these retreat rates from the ages at the two sample sites suggests that the glacier retreat began during Last Glacial Maximum and that glaciers disappeared from the main peak by about 15 ka.

1. Introduction

In research focused on environmental change an important task is to reconstruct the climate characteristics of a specific time period, and in this field the study of Quaternary glaciations has become a key focus for global climate change research (Shi et al., 1989, 2011; Li et al., 1979; Yi et al., 2005; Zhang et al., 2013a,b; Zhao et al., 2011; Owen and Dortch, 2014). Through in-depth study, a systematic understanding is being developed of the occurrence, development, distribution and mechanisms of Quaternary glaciation throughout the world, including China (Cui et al., 2011). Based on large-scale patterns in the timing and scale of glacier advances, it has been suggested that there may be a coupling between major structural changes in central Asia and the timing and extent of glaciation (Shi et al., 2001; Shi, 2002; Zheng et al., 2002; Dortch et al., 2013). However, testing these ideas requires glacial histories constrained by numerical dating methods from different regions of central Asia. Because glacial deposits often lack organic matter, ^{14}C cannot be effectively used for dating, which limited our ability to date Quaternary glacial landforms until new dating techniques emerged (Zhou and Li, 2003). Great progress has been achieved in reconstructing the chronology of Chinese Quaternary glacial history using advanced dating techniques such as: surface exposure dating with in situ produced terrestrial cosmogenic radionuclides (TCN; Dielforder and Hetzel, 2014; Xu and Zhou, 2009; Wang et al., 2006; Zhou et al., 2007; Owen et al., 2005; Liu et al., 2011; Strasky et al., 2009; Siame et al., 2007; Tschudi et al., 2003; Hebenstreit et al., 2011); optically stimulated luminescence (OSL); thermo-luminescence (TL; Zhang et al., 2005; Cui et al., 2002); and electron spin resonance (ESR; Zhao et al., 2010a,b; Wang et al., 2013b). However, much of the numerical chronological data available has come from the Qinghai-Tibet Plateau and thus there is a strong need to add chronological data for the plateau edge and peripheral mountain regions that are key to testing hypotheses about links between patterns of structural change and patterns of glacial extent and timing.

The Qinling mountain range is in the transition between China's eastern plain and hilly areas and the western mountain areas, including the Qinghai-Tibet Plateau (Fig. 1), and is along the boundary between the subtropical monsoon climate and the temperate monsoon climate. It is also the dividing line between the

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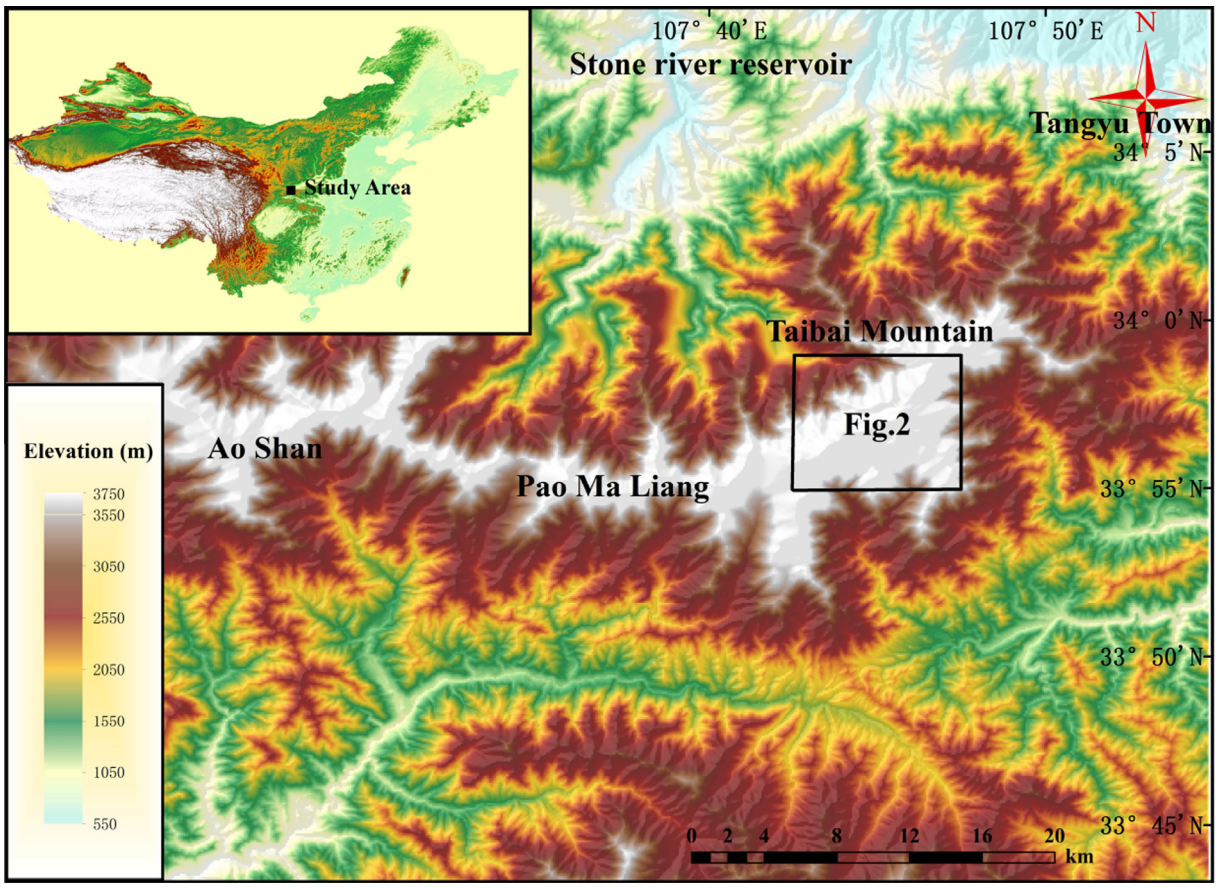

Fig. 1. Location of Taibai Mountain within China.

Yangtze River and Yellow River basins, and China's north and south regions, which means that it occupies an important geographical position in central Asia. The major peak of the Qinling mountain range is Taibai Mountain (3767 m) and previous work here has identified landforms and deposits that suggest the area was impacted by Quaternary glaciation (e.g., Tian, 1981, 1987; Tian and Huang, 1990; Wang, 1984; Qi et al., 1985; Ma and He, 1988; Xia, 1990; Rost, 1994, 2000). No numerical ages are available for the landforms, which limits the extent to which this key region can be used in assessing larger-scale patterns of glaciation related to possible structural driving forces. Here we report on work intended to provide chronological control for the last stages of Taibai glaciation, and to investigate whether patterns of ages in a valley could be used to infer glacial retreat rates.

2. Regional geographic-geological background

Mount Taibai is located at the junction between Mei County, Zhouzhi County and Taibai County, 150 km west of Xi'an, Shaanxi Province, at 107°19′–107°58′ E, 33°40′–34°10′ N. The peaks in the Qinling mountain range are higher to the north and lower to the south, and the range has a length of 61 km from west to east, and a width of 39 km from north to south. The range trends generally EW (Fig. 1), and the main peak on Mt. Taibai is Baxiantai (107°46′ E, 33°56.5′ N), which has an altitude of 3767 m. The study area is a fault-block mountain consisting of dominant granite batholith, as well as pre-Ordovician and Paleozoic metamorphic rocks (Qi et al., 1985). The lithology of the study area is mainly granite and granitic gneiss.

Mt. Taibai acts as a climate barrier. Taibai County (107°19.2′ E, 34°3.5′ N) on the western edge on the north slope of the mountain has an annual average temperature of 7.5 °C and an annual average rainfall of 752.6 mm whereas Mei County (107°45′ E, 34°16.5′ N) has an annual average temperature of 12.9 °C, and an annual average rainfall of 606 mm. The rainfall is concentrated in July through September (Tian, 1981). Plants show a significant vertical zonal distribution. On the south slope of the study area, a deciduous broad-leaved forest belt is located in the elevation range of 780–2300 m; a mixed broadleaf–conifer forest is found at 2300–2730 m; a cold-temperate coniferous forest is located at the 2730–3400 m level (including fir and Taibain sequoia) and subalpine meadows and moss dominate at 3400–3767 m (Tong et al., 1996; Liu et al., 2003). The modern tree line is located at approximately 3350 m on the northern slope, and at 3400 m on the southern slope (Qi et al., 1985).

3. Research methods and results

3.1. Basic principles of cosmogenic radionuclide dating

Several different numerical dating methods have been developed to constrain the timing of Quaternary glaciations (e.g., Zhang et al., 2005; Cui et al., 2002; Wang et al., 2013b; Zhao et al., 2010a,b; Yi et al., 2004). OSL and ESR methods are used for dating of glacial deposits, and the TCN method is used for both glacial deposits, such as exposure dating of erratic glacial boulders, and for dating glacial erosional landforms to determine either surface exposure time or erosion rates (e.g., Dielforder and Hetzel, 2014; Xu and Zhou, 2009; Li et al., 2005a; Fabel et al., 2004).