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Article

Much late onset of Quaternary glaciations on the Tibetan Plateau: determining the age of the Shishapangma Glaciation using cosmogenic ^{26}Al and ^{10}Be dating

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ABSTRACT

The onset of Quaternary glaciations is a critical event in the climate and tectonic history of the Tibetan Plateau. The Shishapangma Glaciation, defined based on the till deposit from the northern slopes of Mt. Shishapangma, has been identified as the oldest glaciation on the Tibetan Plateau. However, the timing of this glaciation has not been constrained. We measured ^{10}Be and ^{26}Al concentrations of a set of boulders on top of this till and simulated their complex exposure-burial histories. The simulated results indicate that the formation age of this till is likely around 835.2 ± 241.0 ka, representing the minimum timing of glacial onset on the Tibetan Plateau. The Shishapangma Glaciation is apparently much younger than the glacial onset in many other areas of the world, such as Europe and North America, and was likely driven by the coupled effect between tectonic uplift and climate cooling during the early–middle Pleistocene transition.

1. Introduction

The onset of Quaternary glaciations is an important climate event and provides key information to the coupled climate and tectonic history of the Tibetan Plateau. The Shishapangma Glaciation was identified as the earliest glaciation on the Tibetan Plateau during the Scientific Expedition of Mt. Shishapangma area in 1964 [1,2]. The till of this glaciation is deeply weathered and located on top of small hills (ranging from 5700 to 6100 m above sea level (a.s.l.)) on the northern slopes of Mt. Shishapangma (Fig. 1) [3,4]. Similar deposit is rare across the plateau; thus, this glaciation has been hypothesized to just represent local and limited glacial activities around a few high peaks along the Himalayas [5]. Although the geomorphic and sedimentary characteristics of the till indicate that it was formed by a much older glacial event, up to now, no numeric age has been obtained for this glaciation.

The development of cosmogenic nuclide (CN) dating provides a potential to constrain this undated Shishapangma Glaciation. CN surface exposure dating has been widely used in determining glacial chronologies on the Tibetan Plateau and its surrounding mountains since the recent decades [6]. However, it is still challenging to date old glacial deposits due to surface degradation and potential burial events by sediment, snow, and ice covers. Measuring multiple nuclides, such as ^{10}Be and ^{26}Al, provides an opportunity to evaluate complex exposure-burial history for a surface, and has been used to estimate the total exposure-burial duration of the bedrock surface under repeatedly covered and cold-based ice sheets [e.g. 7–11]. In the work reported here, we applied a similar approach to determine the age of the Shishapangma Glaciation by simulating the total exposure-burial duration of the boulder surface based on measured ^{26}Al and ^{10}Be concentrations. Although it is possible that even older glacial deposits are not found or dated, as the oldest glaciation identified so far, determining the age of the Shishapangma Glaciation helps constrain the minimum timing of glacial onset and provides important insight into the timing and mechanism of Quaternary glaciations on the Tibetan Plateau.

2. Study area

Mt. Shishapangma (28°21′07″N, 85°46′55″E), with an elevation of 8012 m a.s.l., is located in the middle section of the Himalayas, about 120 km northwest to Mt. Everest (Mt. Qomolangma) (Fig. 1). Quaternary glacial remains are widely distributed in the Mt. Everest-Shishapangma area, making this area an ideal location for reconstructing Quaternary glaciations. In the 1960 s, Chinese Academy of Sciences organized the Mt. Shishapangma area scientific expedition[3] and the Mt. Qomolangma (Everest) area

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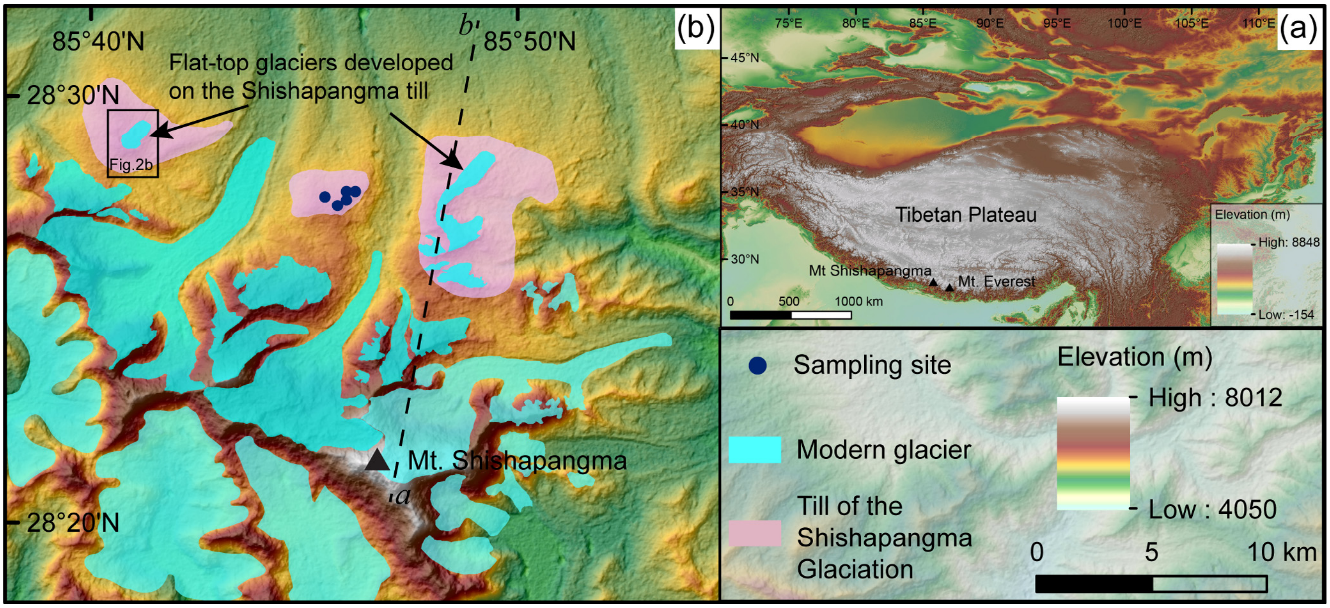

Fig. 1. Location of the study area – Mt. Shishapangma (a), and shaded relief map of the northern slopes of Mt. Shishapangma showing modern glaciers, the till of the Shishapangma Glaciation and sampling sites (b). The shaded relief map was generated from a digital elevation model (DEM) of the 30-m resolution ASTER GDEM2 (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model V2, http://asterweb.jpl.nasa.gov/gdem.asp, developed jointly by the U.S. National Aeronautics and Space Administration and the Japanese Ministry of Economy, Trade, and Industry). Modern glaciers were delineated from Google Earth images. The till of the Shishapangma Glaciation was delineated based on field investigation and Google Earth images. Rectangle shows the location of Fig. 2b. Dashed line *ab* shows the location of the topographic-geological profile of Fig. 3.

scientific expedition (1966–1968) [1,4]. Four main Quaternary glaciations were identified based on their stratigraphic and geomorphic sequences during these two expeditions, including the Shishapangma Glaciation (Early Pleistocene), the Nieniexiongla Glaciation (mid-Pleistocene), the Qomolangma Glaciation I or Jilongsi Glaciation (late Pleistocene, Penultimate Glaciation), and the Qomolangma Glaciation II or Rongbusi Glaciation (late Pleistocene, Last Glaciation). Small glacial expansions were also identified corresponding to the Neoglacial and the Little Ice Age [1,3,4].

With the development of absolute dating techniques, including Electron Spin Resonance (ESR), Optically Stimulated Luminescence (OSL), ^{14}C, and CN exposure dating, many of these glacial deposits and events have been dated, substantially improved the understanding of Quaternary glaciations in the Mt. Everest-Shishapangma areas. Many studies focused on the glacial events around Mt. Everest. On the southern slopes of Mount Everest, Richards et al. [12] identified three glacial events as the Last Glacial Maximum (LGM, 25–18 ka), Lateglacial (~10 ka) and Neoglacial (2–1 ka) using OSL dating; Finkel et al. [13] recognized at least 5 glacial events during the early Last Glaciation (86 ± 6 ka), Marine Isotope Stage (MIS) 3 (35 ± 3 ka), LGM (23 ± 3 ka), early Holocene (9.2 ± 0.2 ka) and Neoglacial (3.6 ± 0.3 ka and ~1 ka) using ^{10}Be exposure dating. On the northern slopes of Mt. Everest, Mann et al. [14] constrained glacial advances in the early Holocene (9520 ± 60 a BP) and Neoglacial (1920 ± 60 a BP) using ^{14}C dating; Owen et al. [15] identified 6 sets of moraines and assigned them to six main glacial advances as >330 ka, >40 ka, 27–24 ka, 17–14 ka, 8–2 ka and ~1.6 ka based on ^{10}Be exposure and OSL dating. Owen et al. [15] also pointed out that the asymmetric glacial patterns between the northern and southern slopes of Mt. Everest were mainly caused by different precipitation patterns: South Asian Monsoon brings more precipitation to the southern slopes, and glaciers on the northern slopes "are more sensitive to climate change possibly due to precipitation starvation". In contrast, only a few glacial chronological studies have been conducted around Mt. Shishapangma. Schaefer et al. [16] investigated the Fuqu Valley on the southeast slopes of Mt. Shishapangma using ^{10}Be and ^{21}Ne exposure dating, and identified glacial advances before or during MIS3, during the LGM (24–16 ka) and during the Lateglacial (12–11 ka); Liu et al. [17] determined two glacial advances of 42.1–22.3 ka and 18.6–14.8 ka on the northwest slopes of Mt. Shishapangma using ^{10}Be exposure dating. However, most previous studies in the Mt. Everest-Shishapangma areas constrained the glacial events during and since the Last Glaciation except for one older glacial stage of >330 ka reconstructed by Owen et al. [15]. No absolute dating work has been conducted to constrain the formation age of the Shishapangma Glaciation, the proposed oldest glacial event on the Tibetan Plateau based on the relative stratigraphic and geomorphic sequences.

The till of the Shishapangma Glaciation is located from 5700 to 6100 m a.s.l. on the northern slopes of Mt. Shishapangma (Figs. 1 and 2a). Small flat-top glaciers cover some of the till hills (Figs. 1 and 2b), indicating that the till might be buried repeatedly by ice during cold periods. The ice cover during the cold period was likely cold-based with limited erosion, so the till could have survived for multiple glacial stages. Therefore, the boulders on top of the till might have experienced complex exposure-burial history in response to multiple glacial advances and retreats in the past.

In this study, we investigated the Shishapangma till located on the west side of the Yebokangjiale Glacier (Fig. 1), where the Shishapangma Glaciation was originally proposed during the scientific expedition in Mt. Shishapangma [3]. This till consists of two small and gentle hills ranging from 5700 m to 6100 m a.s.l. with a local relief of 200–400 m. It is composed of deeply weathered boulders of granite, granitic gneiss, hornblende schist, and a few quartz sandstone and shale. These boulders are mostly 10–20 cm in diameter, with a few reaching 1–2 m (Fig. 2c). The till is poorly sorted and in angular or sub-angular shape with sorted patterned grounds developed on the surface (Fig. 2d). These two till-hills are currently not covered by ice (Figs. 1 and 2). The topographic-geological profile (Fig. 3) suggests that most boulders on this till, especially the granite and gneiss boulders, were