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Extensive glacial advances during the Last Glacial Maximum near the eastern Himalayan syntaxis

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ABSTRACT

Climatically, the eastern Himalaya are mainly controlled by the Indian Summer Monsoon (ISM) and important region for understanding the relationship between ISM and glacial change. This region is therefore useful for studies of the relation between glacial changes and ISM. Using a geomorpho-stratigraphic method combined with GIS, we investigated and mapped the outmost lateral-frontal moraine of the most extensive glaciations that occurred in the Basongcuo (BSC) catchment, near the eastern Himalayan syntaxis. Using optically stimulated luminescence (OSL) and ^{10}Be surface exposure dating technique, we dated five boulders and 23 sediment samples. The resultant OSL and ^{10}Be ages show that the region's glaciers were at their most extensive positions between ~16 and 31 ka. Glacial coverage was 507.5 km^2, 9.9 times greater than it is today (51.5 km^2), with an equilibrium line altitude (ELA) depression of ~690 m. The rapidity with which the Last Glacial Maximum (LGM) glacial advance and retreat occurred suggests that temperature was the dominant control on glacial change.

1. Introduction

Vast quantities of glacial sediments, representing direct evidence for Quaternary climate change, are distributed in the high mountains of the Tibetan Plateau (TP) (Shi et al., 2006a). However, the timing of any glacial advance and its scale during the Last Glacial Maximum (LGM) is still under debate (*e.g.*, Zhang et al., 2006; Ali and Juyal, 2013; Amidon et al., 2013; Owen and Dortch, 2014). Phillips et al. (2000) reported that the most extensive glacial advance occurred during the period of enhanced moisture conditions correspondent to Marine Isotope Stage (MIS) 3, and further argued that glacial advance across the Himalaya was asynchronous with Northern Hemisphere ice sheet volumes. Subsequent research has demonstrated that glaciers advanced extensively during MIS 3 in the western Himalaya, while such advances were limited in scale during the LGM (*e.g.*, Owen et al., 2002, 2010; Finkel et al., 2003; Hedrick et al., 2011; Amidon et al., 2013), suggesting that glaciers situated in arid regions were more sensitive to changes in quantities of precipitation transported to those regions by the Indian Summer Monsoon (ISM) (*e.g.*, Owen and Dortch, 2014). However, glaciers advanced extensively during the LGM in the eastern Tibet (Schäfer et al., 2002; Zhou et al., 2007, 2010; Fu et al., 2013); and the lowering of the glacial snowline might also have been a response to North Atlantic cooling (Schäfer et al., 2002). Zech et al. (2009) deduced that glaciers situated in high precipitation areas were more sensitive to decreases in temperature. Amidon et al. (2013) reviewed the glacial chronology throughout the Himalayan-Tibetan orogen, and revealed that the timing of glacial advances was asynchronous across the Himalaya-Karakoram-TP. Further glacial chronological studies are therefore required for a more accurate identification of the climatic controls on climate change in this region.

The Himalayan region is controlled by two major weather systems: the ISM and the mid-latitude Westerlies (Benn and Owen, 1998; Yao et al., 2012, 2013). Climatically, the western and central Himalaya are predominantly influenced by the mid-latitude

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Westerlies, while the eastern Himalaya is largely controlled by the ISM. Most Quaternary glacial chronological studies have focused on the western and central Himalaya, and the eastern sector of southeastern Tibet (*e.g.*, Amidon et al., 2013; Owen and Dortch et al., 2014 and references therein). Although the Quaternary glacial sediments near the eastern Himalayan syntaxis have been widely investigated (Ward, 1936; Li et al., 1986; Zhang, 1988; Jiao and Iwata, 1993; Montgomery et al., 2004; Liu et al., 2006; Zhou et al., 2007, 2010; Zhu et al., 2013a; Chen et al., 2014), there have been only a few glacial chronological studies of Quaternary glaciations in this region (Zhou et al., 2007, 2010; Chen et al., 2014). The ^{10}Be and ^{14}C ages suggest that glacial advances occurred during MIS-6, MIS-2 and MIS-1 in the Boduizangbo River Valley (Zhou et al., 2010), and the OSL dating from the Daba and Charao valleys suggest that the most extensive glacial advances occurred during the LGM (Chen et al., 2014). We have previously reported on the optically stimulated luminescence (OSL) dating results for glacial sediments from the Basongcuo (BSC) catchment near the eastern Himalayan syntaxis (Hu et al., 2015). In this study, new ^{10}Be exposure ages were dated to supplement these OSL ages. In combination with geomorphologic investigations, we investigated the catchment's outermost latero-frontal moraine sequence in an attempt to reconstruct the LGM environment and reveal the relationship between glacier advance and climate change.

2. Setting

Southeastern Tibet is bounded by the Nyainqentanglha Mountains to the north, the Himalaya to the west and the Henduan Mountains to the east. The highest mountain in the region is Namche Barwa, with an altitude of 7756 m above sea level (asl). According to a meteorological record from Bomi (29.52°N, 95.46°E, 2736 m asl), mean annual precipitation (MAP) between 1961 and 2008 was 835 mm, with 74.9% of each year's precipitation falling between April and September (Zhu et al., 2013b). Moisture is derived principally from the ISM. There are over 4000 mountain glaciers, located around the "Great Bend" of the Yarlung Zangbo River (Fig. 1a) (Shi, 2006).

The BSC catchment was selected for glacial chronological and geomorpho-stratigraphic study. It is located on the southern slopes of the junction of the eastern Nyainqentanglha and Himalaya Mountains, ~110 km northwest of Namche Barwa (Fig. 1a and b). The BSC Valley, the main valley in the catchment, is presently occupied by Lake BSC (Fig. 1c). The valley has four U-shaped

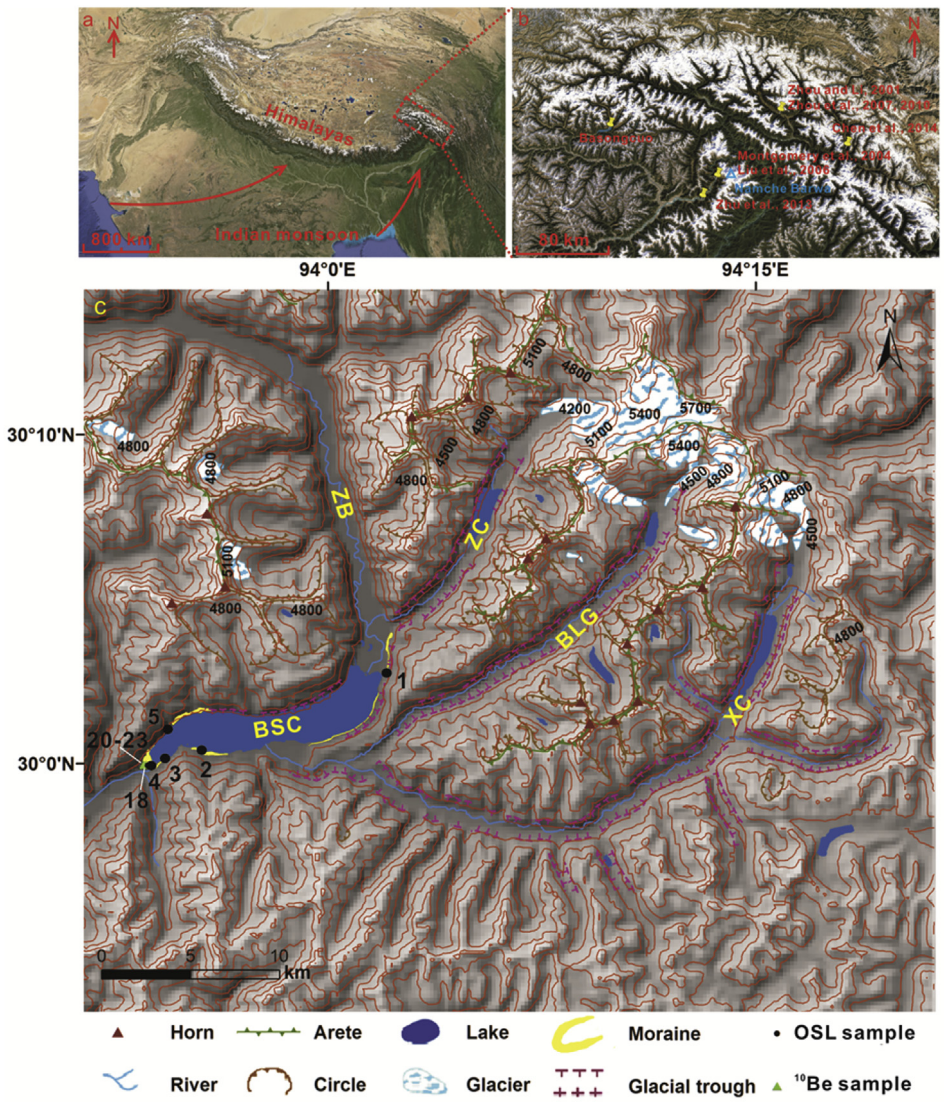

Fig. 1. (a) and (b). Google Earth images showing the location of the Basongcuo (BSC) catchment and previous studies in southeastern Tibet; (c) the DEM of the BSC catchment, showing glacial coverage, valley, moraines, and sampling sites. ZB, ZC, BLG, XC and BSC represent the Zaba, Zhongcuo, Bailangou, Xincuo tributary valleys and Lake BSC, respectively.

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