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Thermal structure, rock exhumation, and glacial erosion of the Namche Barwa Peak, constraints from thermochronological data

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ABSTRACT

In this paper, we report thermochronological data from the southwest slope of Namche Barwa Peak, the core region of the eastern Himalayan syntaxis. The data include apatite fission track (AFT) ages of ten bedrock samples ranging from 0.5 ± 0.1 to 3.5 ± 0.5 Myr and biotite $^{40}Ar/^{39}Ar$ ages from 2.53 ± 0.14 to 5.57 ± 0.19 Myr, corresponding to elevations from 5370 to 3060 m. These ages are characterized by inverted age-elevation relationships (AERs), and the AERs of the AFT ages and the biotite $^{40}Ar/^{39}Ar$ ages are approximately parallel. Numerical modeling suggests that a possible change in the surface topography or faulting in this region could not have led to the observed inverted AERs. These observed ages demonstrate that a field of nonuniform exhumation rates existed in the relatively shallow crust (above the 110 °C isotherm) of the Namche Barwa Peak region. The exhumation rates increase significantly from 0.3 km/Myr to 5 km/Myr with increasing proximity to the peak. However, the exhumation rates in the relatively deep crust (below the 110 °C isotherm) of the same area are uniform at approximately 1.7 km/Myr. This distinctive exhumation field and the strong spatial correlation between the intense glacial erosion and high rock exhumation rate of Namche Barwa Peak suggest that glacial erosion most likely drives the rapid exhumation of Namche Barwa Peak.

1. Introduction

Over the last three decades, the interplay between surface processes and tectonics has received increasing attention (e.g., Molnar and England, 1990; Raymo and Ruddiman, 1992; Beaumont et al., 2001; Zeitler et al., 2001; Zhang et al., 2001). A number of analogue experiments and numerical models have demonstrated that surface processes directly influence crustal tectonic evolution (e.g., Koons, 1990; Avouac and Burov, 1996; Batt and Braun, 1999; Willett et al., 1993; Persson and Sokoutis, 2002). However, definitive field evidences to support this hypothesis are rare. Many researchers have reported spatial correlations between intense surface erosion and rapid rock exhumation in different mountain ranges (e.g., Tomkin, 2007; Enkelmann et al., 2009; Headley et al., 2013). However, whether the spatial variation in rock exhumation can be explained by other mechanisms must be determined before considering rock exhumation a tectonic response to surface erosion (Whipple, 2009).

The eastern Himalayan syntaxis is located at the eastern termination of the Himalayan orogenic belt (Fig. 1a). This area is part of a highly active compressional orogen and is characterized by high precipitation and numerous glaciers; the highest annual rainfall is more than 2500 mm (Yu et al., 2011). Therefore, the eastern Himalayan syntaxis is an ideal location to investigate the evolution of the Himalayan orogenic belt and the interaction between surface processes and tectonics (see the summary by Zeitler et al. (2001)). Many models have been proposed to analyze the geodynamic evolution of the eastern Himalayan syntaxis. Some of these models, such as the “compressional crustal folding” model (Burg et al., 1998) and the “tectonic aneurysm” model (Zeitler et al., 2001), regard surface processes as first-order factors that control geodynamic evolution. Other models, such as the two end-member “antiform of a duplex structure and indentation of folded crust” model (Ding et al., 2001), the “northeastward indentation” model (Zhang et al., 2004), and the “subduction followed by exhumation” model (Xu et al., 2012), consider tectonic activity the leading factor. In all of these models, thermochronological data can provide crucial evidence. The majority of published thermochronology data are from the valleys of the Yarlung Tsangpo River and its

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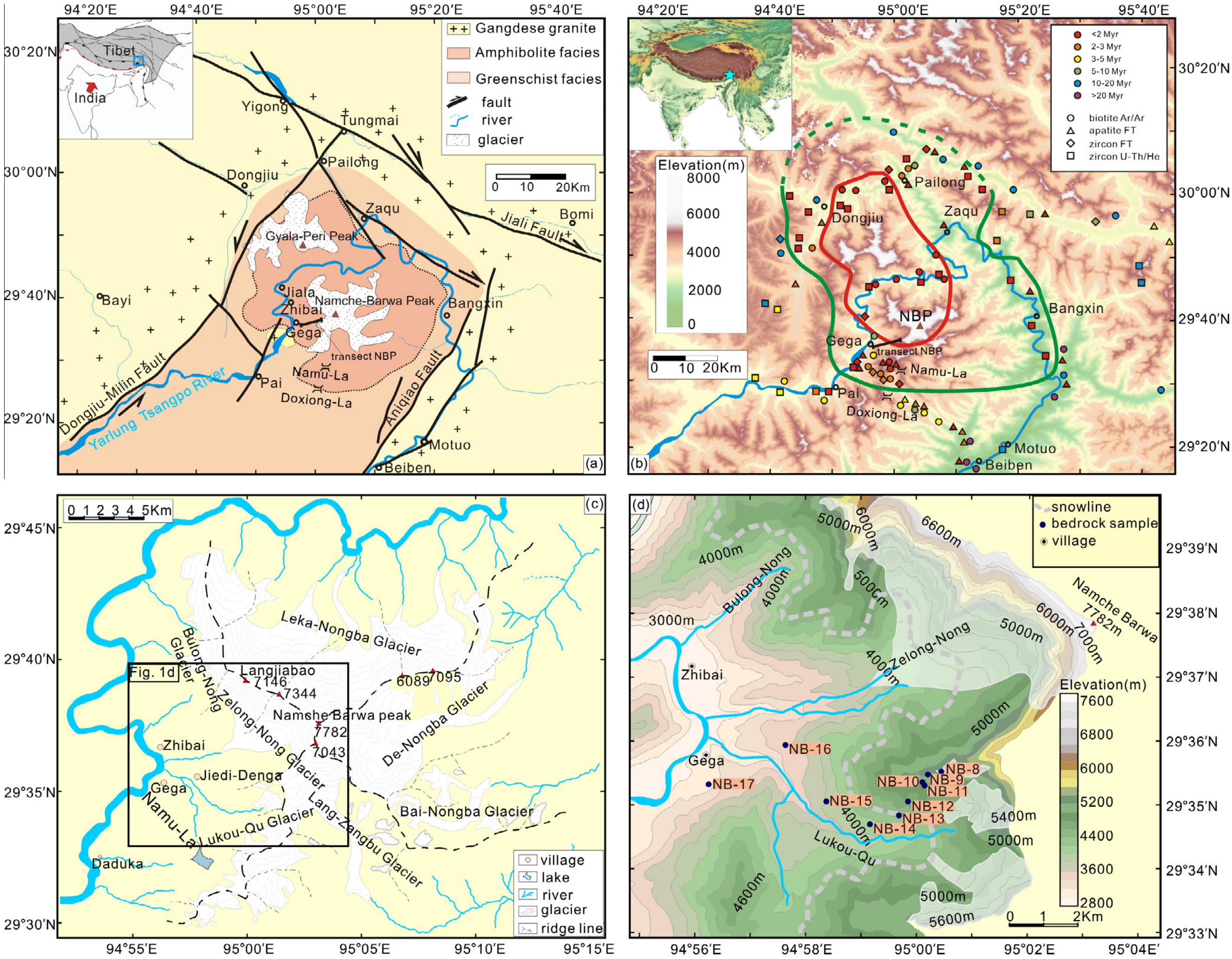

Fig. 1. (a) Geological sketch of the eastern Himalayan syntaxis showing the main geological units and structures. The location of the study area in the southeastern Tibetan Plateau is shown in the inset. (b) Shaded relief map of the eastern Himalayan syntaxis derived from Aster Global DEM V2 (http://gdex.cr.usgs.gov/gdex/) with published bedrock thermochronological ages. The legends for the ages are modified from Enkelmann et al., 2011. The zircon U-Th/He ages are from Stewart et al., 2008; the zircon fission track (FT) ages are from Burg et al., 1998 and Seward and Burg, 2008; the biotite $^{40}Ar/^{39}Ar$ ages are from Stewart et al., 2008; Zhang et al., 2004; Gong et al., 2008; Yu et al., 2011; and the apatite fission track (FT) ages are from Lei et al., 2008 and Yu et al., 2011. The green and red lines outline the areas with previously published young (<2 Myr) zircon U-Th/He and biotite $^{40}Ar/^{39}Ar$ ages, respectively (after Stewart et al., 2008). NBP: Namche Barwa Peak. (c) Distribution of glaciers on Namche Barwa Peak. The box shows the location of the area in d. (d) Topographic map of the western slope of Namche Barwa Peak. The locations of the outcrop sample collections are indicated.

tributaries. No age has been reported in the Namche Barwa Peak (NBP) region located in the core area of the eastern Himalayan syntaxis (Fig. 1b). Therefore, the exhumation history of the NBP region is unclear.

Thermochronology ages are mainly determined by geothermal fields, which are affected by rock exhumation rates and the variation in geomorphic surfaces (Braun, 2002, Braun et al., 2006). To interpret thermochronology ages accurately, these factors should be quantitatively analyzed. Furthermore, the closure temperature also influences thermochronological ages. The various thermochronological dating methods have unique closure temperatures (Harrison et al., 1985), and temperature correspond to depth in the crust. Therefore, the combination of thermochronological data with different closure temperatures can reveal the cooling histories of rocks from different crustal depths (e.g., Yu et al., 2011).

To study the cooling histories at different crustal depths of the NBP and to clarify the relationship between surface erosion and rock exhumation in the region, we dated ten bedrock samples from the southwest slope of the peak using apatite fission track (AFT) and biotite $^{40}Ar/^{39}Ar$ analyses. The closure temperatures of these two systems are approximately 110 °C (Green et al., 1986; Carlson, 1990; Carlson et al., 1999) and 330 °C (Harrison et al., 1985; McDougall and Harrison, 1999), respectively. We used a thermal-kinematic model code, “PECUBE” (Braun, 2003), to analyze quantitatively all factors that most likely control the age distribution of our samples. Based on the observed ages and modeling results, we describe the exhumation process of NBP and its probable triggering factor.

2. Background

2.1. Geologic setting

The eastern Himalayan syntaxis and nearby are mainly composed of two rock types: core metamorphic rocks and the Gangdese granites (Fig. 1a). The core metamorphic rocks primarily consist of meta-sedimentary greenschist-facies schists and amphibolite- to granulite-facies gneisses, including garnet biotite schist, biotite epidote schist, sillimanite garnet biotite gneiss, biotite