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Late Cretaceous K-rich magmatism in central Tibet: Evidence for early elevation of the Tibetan plateau?

Yalin Li [a,*], Juan He [a], Chengshan Wang [a], M. Santosh [b,c], Jingen Dai [a], Yuxiu Zhang [a], Yushuai Wei [a], Jiangang Wang [d]

[a] State Key Laboratory of Geological Processes and Mineral Resources, Research Center for Tibetan Plateau Geology, China University of Geosciences, Beijing, 100083, China
[b] Division of Interdisciplinary Science, Faculty of Science, Kochi University, Akebono-cho, Kochi 780-8520, Japan
[c] Journal Center, China University of Geosciences Beijing, 29 Xueyuan Road, Beijing 100083, China
[d] School of Earth Sciences, Nanjing University, Nanjing, 210093, China

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ABSTRACT

Major and trace element, Sr–Nd–Pb and zircon U–Pb and Hf isotope data are presented for the newly discovered Abushan volcanic rocks in the southern Qiangtang Terrane, central Tibet. These results offer new insights into the evolution of the Tibetan plateau during Cretaceous. The Abushan volcanic rocks are composed mainly of andesites and trachy-andesites. Zircon U–Pb dating constrains the timing of emplacement as Late Cretaceous (79.9 ± 2.7–75.9 ± 0.49 Ma). Major element geochemistry shows that the Abushan volcanic rocks belong to high-K calc-alkaline series. All the andesites and trachy-andesites are enriched in large ion lithophile elements (LILE) and light rare earth elements (LREE), and depleted in high field strength elements (HFSE) and heavy rare earth elements (HREE). The geochemical features and ages of the Abushan volcanic rocks relate them with post-collisional setting. Furthermore, the volcanic rocks display negative $\varepsilon_{Nd}(t)$ (−3.1 to −2.5), relatively constant $^{87}Sr/^{86}Sr$ ratios (0.70614–0.70735) and negative $\varepsilon_{Hf}(t)$ values (−5.8 to −2.1). The Sr–Nd–Pb and Hf isotope signature suggests that the andesites and trachy-andesites were derived from the anatexis of mafic lower crust by intrusion or underplating of mantle-derived basaltic magma. The petrogenesis of Abushan andesites provides robust evidence for the crustal thickening, delamination and early uplifting of central Tibet during Late Cretaceous.

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1. Introduction

The Qiangtang Terrane, located between the Jinshajiang suture zone to the north and the Bangong–Nujiang suture zone to the south, is a key unit for understanding the tectonic evolution of central Tibet as well for the development of the Tibetan plateau (Fig. 1A, Dewey et al., 1988; Guilmette et al., 2012; Kapp et al., 2005; Li et al., 2012; Pierce and Deng, 1988; Wang et al., 2002, 2008; Yin and Harrison, 2000; Zhu et al., 2012). The closure of the Bangong–Nujiang Ocean and the collision between Lhasa and Qiangtang are recognized as the principal events in central Tibet during Cretaceous (Guynn et al., 2006; Kapp et al., 2005; Murphy et al., 1997; Otofuji et al., 2007; Schneider et al., 2003; Volkmer et al., 2007). In the past decade, much attention was focused on geological, structural and petrogenetic investigations in relation to the Mesozoic evolution of central Tibet.

However, there has been no consensus on the Mesozoic tectonics and the contribution of Lhasa–Qiangtang collision to the plateau growth. Among the several questions raised are the timing and mechanism of closure of the Bangong–Nujiang Ocean (Dewey et al., 1988; Girardeau et al., 1984; Kapp et al., 2005; Liu et al., 2010; Murphy et al., 1997; Pierce and Deng, 1988; Tang and Wang, 1984; Zhang et al., 2012; Zhu et al., 2009), and the question whether the Cretaceous contractional deformation in central Tibet was controlled by flat subduction (Zhang et al., 2004, 2007) or the Lhasa–Qiangtang continental collision (Kapp et al., 2005; Murphy et al., 1997; Volkmer et al., 2007; Yin and Harrison, 2000). The question whether central Tibet is characterized by a significantly thickened crust and at 3–4 km elevation prior to the Indo-Asian collision also remains unresolved (Kapp et al., 2003, 2005; Murphy et al., 1997; Volkmer et al., 2007; Zhang et al., 2002). As magmatism is known to play an important role in the crustal thickening and uplift of Tibet (Chung et al., 2005; Mo et al., 2007, 2008; Wang et al., 2005; Xia et al., 2010), the Cretaceous volcanism in Qiangtang Terrane provides an important window to the dynamics and evolution of this region.

In this paper, we report zircon LA-ICPMS age data from the newly discovered Abushan volcanic rocks from Guogencuo in the southern part of the Qiangtang terrane. We also present whole rock geochemistry, Sr–Nd–Pb isotopes and zircon Hf isotopic data with the aim of gaining a better understanding on the petrogenesis of the Late Cretaceous magmas in the Qiangtang Terrane. Our results provide

* Corresponding author. Tel.: +86 10 82321586; fax: +86 10 82321612.
E-mail address: liyalin@cugb.edu.cn (Y. Li).

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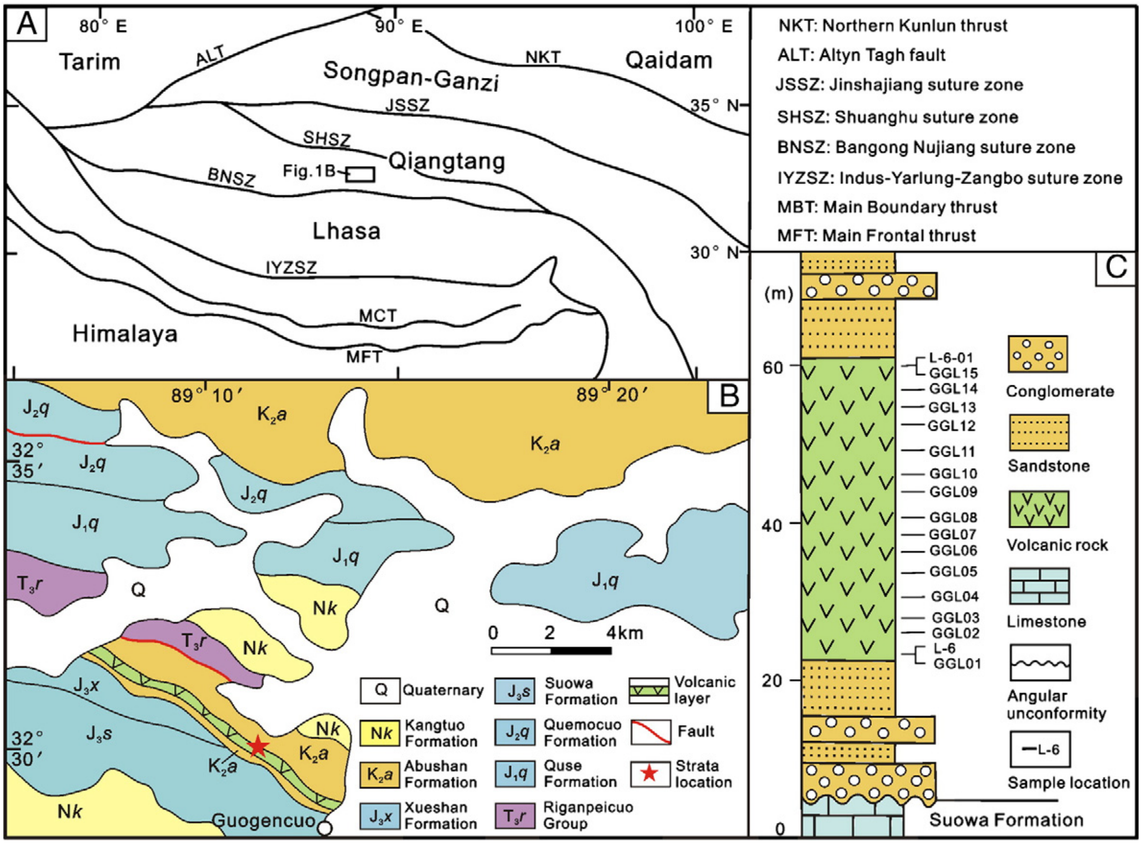

Fig. 1. (A) Tectonic outline of the Tibetan Plateau. (B) Geological map of the Guogencuo area. (C) Stratigraphic column with sampling locations of the Abushan volcanic succession.

valuable constraints on the geodynamic processes involved in the Lhasa–Qiangtang collision and the uplifting of the central Tibet during Cretaceous.

2. Geologic setting

The Tibetan Plateau is composed of four major terranes (from south to north): the Himalaya, Lhasa, Qiangtang and the Songpan-Ganzi (Fig. 1A). These blocks are separated by the Indus–Yarlung–Zangbo, Bangong–Nujiang and Jinshajiang suture zones, respectively (Aitchison et al., 2011; Hebert et al., 2012; Yin and Harrison, 2000; Zhang et al., 2013).

The Qiangtang Terrane is located in central Tibet and has a width of 500–600 km (Fig. 1A). The Triassic Shuanghu suture divides the Qiangtang Terrane into northern and southern sub-terranes (Liu et al., 2011; Zhang and Tang, 2009), which is marked by the assemblage of eclogites, metasediments, schists, gneisses and marble (Kapp et al., 2003; Liu et al., 2011; Yin and Harrison, 2000; Zhang and Tang, 2009). The northern and southern Qiangtang are dominated by Upper Triassic–Upper Jurassic marine deposits with a thickness of more than 5000 m. These marine deposits are unconformably overlain by the weakly deformed Cretaceous Abushan Formation (Kapp et al., 2005; Wang and Yi, 2001).

With regard to space–time relationship, two principal volcanic suites have been identified in the Qiangtang Terrane since Mesozoic: (1) Triassic volcanic rocks (234–219 Ma), which are mainly distributed in the northern Qiangtang Terrane, considered to have formed in a continental rift setting (Fu et al., 2010) or caused by post-orogenic collapse of the central Qiangtang (Zhang et al., 2011); and (2) Eocene–Oligocene volcanic rocks (50–26 Ma) characterized by high to very high alkali contents (Chung et al., 1998; Ding et al., 2003; Lai and Qin, 2012; Roger et al., 2000; Wang et al., 2008; Williams et al., 2004; Xia et al., 2010). Although these rocks have been widely considered to be the products of post-collisional volcanism, opinions have been diverse with regard to their petrogenesis and geodynamic setting. The models proposed include: (1) "back-arc" lithospheric extension (Chung et al., 1998); (2) northward underthrusting of the Indian continental lithosphere (Guo et al., 2006); (3) northward underthrusting of the Lhasa continental lithosphere (Chi et al., 2005; Lai et al., 2007); and (4) northward "continental underthrusting" of the Lhasa Terrane and the southward "continental underthrusting" of the Songpan-Ganzi Terrane (Ding et al., 2003; Roger et al., 2000). Nevertheless, there has been no report on Cretaceous igneous rocks in the Qiangtang Terrane, except for the Amdo trachyte, considered to have formed through post-orogenic volcanism triggered by the Lhasa–Qiangtang collision (Bai et al., 2009).

In contrast with the Qiangtang Terrane, the Mesozoic–Cenozoic igneous rocks are widespread throughout the Lhasa Terrane (Harris et al., 1990; Leier et al., 2007; Mo et al., 2007; Zhang et al., 2004; Zhu et al., 2006, 2009). These rocks define five distinct magmatic episodes during 190–175, 120–110, 100–80, 65–45, and 25–10 Ma, with two magmatic flare-ups at ca. 110 and 50 Ma (Zhu et al., 2006, 2009). The Cretaceous volcanic rocks are widely distributed in the northern part of the Lhasa Terrane (Kang et al., 2009; Liu et al., 2010; Ma and Yue, 2010; Zhu et al., 2009), which show distinct arc-related signatures (Zhu et al., 2009). Cenozoic igneous rocks in the Lhasa Terrane, including the syncollisional Linzizong volcanic rocks (65–40 Ma) and post-collisional Miocene adakitic rocks, were interpreted as melts of the Tethyan ocean crust (Mo et al., 2008) and partial melts of the thickened lower crust (Chung et al., 2003).

The Bangong–Nujiang suture zone is mainly composed of Jurassic–Cretaceous flysch, mélange and ophiolitic fragments, and represents the remnants of the Bangong–Nujiang Ocean (Baxter et al., 2009;

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