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Zircon U–Pb dating and *in-situ* Hf isotopic analysis of Permian peraluminous granite in the Lhasa terrane, southern Tibet: Implications for Permian collisional orogeny and paleogeography

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A B S T R A C T

The Lhasa terrane has long been interpreted as a simple tectonic block rifted from Gondwana during the late Paleozoic and then drifted northward before finally amalgamating with the Qiangtang terrane during the Early Cretaceous. In this paper we document Permian peraluminous granites near Pikang in the southern margin of the central Lhasa terrane, close to the recently documented Songdo eclogite of Permian age. Zircon SHRIMP and LA-ICPMS U–Pb dating for a Pikang granite sample gives an identical crystallization age of about 263 Ma and a wide age range of inherited zircons (283–2141 Ma). *In situ* Hf isotopic analyses for 20 zircons of 263 Ma yielded $\varepsilon_{\mathrm{Hf}(t)}$ values of −4.5 to +1.9. The Pikang granites have high A/CNK values (≥1.08) and high normative corundum (1.3–2.0%), indicative of peraluminous S-type granite. They are characterized by moderately negative Eu anomalies (Eu/Eu* = 0.48–0.61), and strongly negative Ba, Nb, Sr, P and Ti anomalies. The granites have high $\varepsilon_{\mathrm{Nd}(t)}$ values (−6.4 to −6.0) and low initial $^{87}Sr/^{86}Sr$ ratios (0.7082–0.7096) relative to melts derived from mature continental crust. These rocks are interpreted to have been generated by mixing between mantle melts and their induced melting of mature crustal materials. We interpret the Pikang peraluminous granite magmatism, the regional angular unconformity between the Middle and the Upper Permian and the eclogite of the same metamorphic age (~262 Ma) from the same geotectonic location to represent different products of a common event in time and space. We tentatively term this common event as syncollisional orogeny, i.e., "the Permian Gangdese Orogeny". We further hypothesize that the orogeny may be genetically associated with the collision between the Lhasa terrane and the northern margin of Australia, following the closure of the Paleo-Tethyan Ocean south of the Lhasa terrane.

1. Introduction

The Lhasa terrane located on the southern Tibetan Plateau (Fig. 1a) is widely considered not only as an archetype of a Cenozoic orogen as a result of India–Asia continental collision, but also as an Andean-type active continental margin that developed during the northward subduction of the Neo-Tethyan ocean lithosphere along the Indus–Yarlung Zangbo suture zone (IYZSZ) before the onset of India–Asia collision (Maluski et al., 1982; Xu et al., 1985; Coulon et al., 1986; XBGMR, 1991; Copeland et al., 1995; Yin and Harrison, 2000; Chung et al., 2005; Chu et al., 2006; Wen et al., 2008a; Zhu et al., 2008a,b, 2009). Numerous studies over the past decades on the Cenozoic geology have led to our current understanding of the India–Asia collision-related tectonic processes and the formation of the Himalayas and Tibetan Plateau (e.g., England and Searle, 1986; Yin et al., 1994; Murphy et al., 1997; Kapp et al., 2005, 2007; He et al., 2007; Wang et al., 2008). Although there has been a growing attention to the pre-Cenozoic history of the Lhasa terrane that led to the recognition of Late Triassic, Early Jurassic, and Cretaceous Gangdese orogenic events (Chu et al., 2006; Guynn et al., 2006; Liu et al., 2006a; Zhang et al., 2007; Zhu et al., 2008a, 2009), our knowledge on the nature and pre-Cenozoic history of the Lhasa terrane remains rather limited. For example, the tectonic history and paleogeography of the Lhasa terrane during the Permian remain unanswered and conflicting views exist (Leier et al., 2007; Zhu et al., 2008b, submitted for publication-b). Conventionally, the Lhasa terrane has been interpreted as a single tectonic block that developed in a rifting/back-arc extensional setting related to the separation of the Qiangtang terrane from Gondwana during the late Paleozoic (Dewey et al., 1988; Pearce and Mei, 1988; Leeder et al., 1988; Yin and Harrison, 2000; Metcalfe, 2002; Booth et al., 2004; Kapp et al., 2005, 2007; Leier et al., 2007), whereas recent studies

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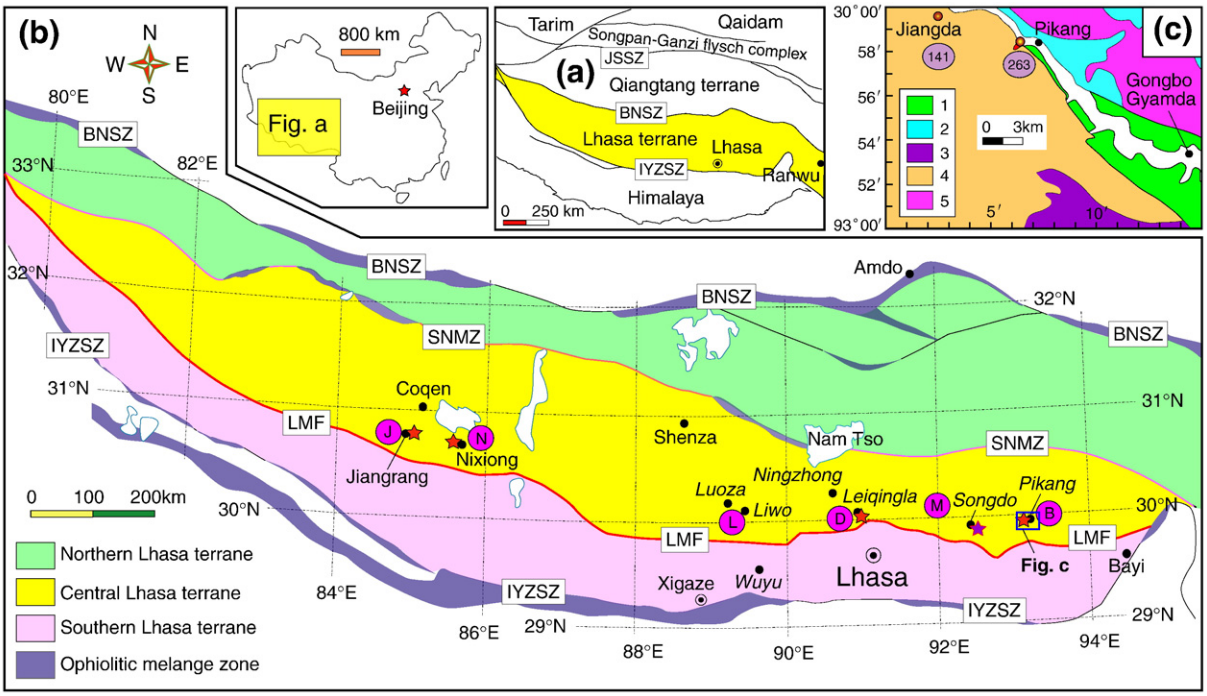

Fig. 1. (a) Tectonic outline of the Tibetan Plateau showing of the study area (Zhu et al., 2008a). (b) Tectonic framework of the Lhasa terrane showing the major tectonic subdivisions (Zhu et al., submitted for publication-b), the localities of Permian igneous rocks (red stars) and angular unconformity between the Middle and the Upper Permian (pink circles with letter, also shown in Fig. 7). JSSZ = Jinsha suture zone; BNSZ = Bangong–Nujiang suture zone; SNMZ = Shiquanhe–Nam Tso Mélange Zone; LMF = Luobadui–Milashan Fault; IYZSZ = Indus–Yarlung Zangbo Suture Zone. B = Bahe; M = Menba; D = Leiqingla; L = Liwo; N = Nixiong; J = Jiangrang. (c) Simplified geological map of the NW Gongbo Gyamda County (Yin et al., 2003) showing the location of the Pikang granites investigated in this study. 1 = Pre-Ordovician metasedimentary rocks; 2 = Upper Carboniferous–Lower Permian metasedimentary rocks; 3 = Lower Jurassic Yeba Formation; 4 = Early Cretaceous granitoids; 5 = Late Cretaceous granitoids. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

argue that the Lhasa terrane represents a volcanic arc system during the Permian (Pan et al., 2006; Zhu et al., submitted for publication-b).

The above contrasting views have resulted in variable paleogeographic reconstructions of the Lhasa terrane during the late Paleozoic, including (1) the Lhasa terrane was positioned adjacent to Greater India until the Late Permian (Golonka and Ford, 2000; Metcalfe, 2002; Scotese, 2004) or even the Late Triassic (Golonka, 2007), (2) the Lhasa terrane was located within the Paleo-Tethyan Ocean during the Late Permian (Enkin et al., 1992; Ziegler et al., 1997; Scotese et al., 1999; Stampfli and Borel, 2002), and (3) the Lhasa terrane may have been a separate intra-Tethyan oceanic block during the Early to Middle Permian (Zhu et al., submitted for publication-b). The most likely reason for these contrasting views is the limited data that have been accumulated from the Lhasa terrane in different stages. For example, the first two scenarios cannot explain the presence of paleontologically age-constrained Permian arc volcanic rocks (Zhu et al., submitted for publication-b) and the Songdo eclogite (Yang et al., 2009) recently recognized in the Lhasa terrane. The third hypothesis has incorporated these new observations. However, it remains unclear how the Early to Middle Permian subduction system of the Lhasa terrane might have evolved to Late Permian and how the location of the Lhasa terrane may have changed with time.

In this paper we report U–Pb age and Hf isotope data from zircons and whole-rock major and trace element, and Sr–Nd isotope data on granitoid samples from Pikang village in northwestern Gongbo Gyamda County of the Lhasa terrane (Fig. 1b). These data reveal the presence of strongly peraluminous granitoids (i.e., molecular Al_2O_3/($CaO+Na_2O+K_2O$) or A/CNK ≥ 1.1) of Permian age, which, in combination with the known arc-type volcanism, high-pressure metamorphism and other geologic observations, provide solid lines of evidence for the existence of a Permian Gangdese orogeny in the Lhasa terrane and place new constraints on the paleogeography of the Lhasa terrane throughout the Permian.

2. Geological background and samples

Geologically, the autonomous Tibet (the southern portion of the Greater Tibetan Plateau) comprises, from north to south, the following four blocks or terranes: the Songpan–Ganzi flysch complex, Qiangtang terrane, Lhasa terrane, and the Himalaya. These blocks are separated by the Jinsha (JSSZ), Bangong–Nujiang (BNSZ), and IYZSZ suture zones, representing Paleo-, Meso-, and Neo-Tethyan oceanic relicts, respectively (Fig. 1a) (Yin and Harrison, 2000).

The Lhasa terrane, which is bounded to the north by the BNSZ and to the south by the IYZSZ (Fig. 1a), can be divided into northern, central, and southern subterranes, separated by the Shiquan River–Nam Tso Mélange Zone (SNMZ) and Luobadui–Milashan Fault (LMF), respectively (Fig. 1b). The northern Lhasa terrane is inferred to be underlain by Cambrian crystalline basement, which has been reported only from the Amdo area (Amdo orthogneiss; Fig. 1b) (Xu et al., 1985; Dewey et al., 1988; Guynn et al., 2006). The main rock units exposed in this terrane are Jurassic–Cretaceous sedimentary and igneous rocks (Leeder et al., 1988; Yin et al., 1988; Pan and Ding, 2004; Zhang et al., 2004; Leier et al., 2007; Zhu et al., 2008a). The central Lhasa terrane consists predominantly of a Carboniferous–Permian metasedimentary sequence and a Late Jurassic–Early Cretaceous volcano-sedimentary sequence, with minor Ordovician, Silurian, and Triassic limestones (Leeder et al., 1988; Yin et al., 1988; Pan and Ding, 2004; Kapp et al., 2005; Ji et al., 2007; Leier et al., 2007; Zhu et al., 2008a) and rare Precambrian strata (Hu et al., 2005). The southern Lhasa terrane is dominated by the Cretaceous to early Tertiary Gangdese batholiths and Linzizong volcanic succession with minor Triassic–Cretaceous volcano-sedimentary rocks (Leeder et al., 1988; Pearce and Mei, 1988; Pan and Ding, 2004; He et al., 2007; Leier et al., 2007; Mo et al., 2007; Wen et al., 2008a; Zhu et al., 2008a). The Permian volcanic rocks are exposed discretely along the southern margin of the central Lhasa terrane from western Coqen County to central Leiqingla area (Fig. 1b) and