

Lhasa terrane in southern Tibet came from Australia

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ABSTRACT

The U-Pb age and Hf isotope data on detrital zircons from Paleozoic metasedimentary rocks in the Lhasa terrane (Tibet) define a distinctive age population of ca. 1170 Ma with $\epsilon_{\text{Hf}}(t)$ values identical to the coeval detrital zircons from Western Australia, but those from the western Qiangtang and Tethyan Himalaya terranes define an age population of ca. 950 Ma with a similar $\epsilon_{\text{Hf}}(t)$ range. The ca. 1170 Ma detrital zircons in the Lhasa terrane were most likely derived from the Albany-Fraser belt in southwest Australia, whereas the ca. 950 Ma detrital zircons from both the western Qiangtang and Tethyan Himalaya terranes might have been sourced from the High Himalaya to the south. Such detrital zircon connections enable us to propose that the Lhasa terrane is exotic to the Tibetan Plateau system, and should no longer be considered as part of the Qiangtang–Greater India–Tethyan Himalaya continental margin system in the Paleozoic reconstruction of the Indian plate, as current models show; rather, it should be placed at the northwestern margin of Australia. These results provide new constraints on the paleogeographic reconstruction and tectonic evolution of southern Tibet, and indicate that the Lhasa terrane evolved as part of the late Precambrian–early Paleozoic evolution as part of Australia in a different paleogeographical setting than that of the Qiangtang–Greater India–Tethyan Himalaya system.

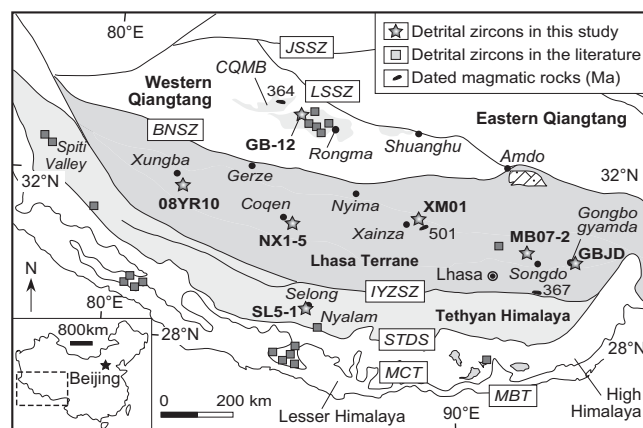
INTRODUCTION

The origin and evolution of the Tibetan Plateau have been widely accepted to have resulted from several collisional events between Gondwana-derived terranes (e.g., Qiangtang, Lhasa) or continents (e.g., India) and Eurasia since the early Paleozoic (e.g., Allègre et al., 1984; Yin and Harrison, 2000; Zhu et al., 2009). The Lhasa and the Tethyan Himalayan terranes, immediately north and south of the Indus–Yarlung Zangbo suture (Fig. 1), respectively, have thus received much attention as they best record the entire history of continental breakup, rift-drift, subduction, collision, and collision-related tectonism, magmatism, and metamorphism. However, the origin of the Lhasa terrane remains enigmatic. The dominant view is that the Lhasa terrane was rifted away from Indian Gondwana before it collided with the Qiangtang terrane to the north in the Mesozoic (cf. Allègre et al., 1984; Yin and Harrison, 2000; Metcalfe, 2009), although Audley-Charles (1983, 1984) proposed that the Lhasa terrane might have rifted from northern Australia in the Middle to Late Jurassic. However, this inferred Australian connection of the Lhasa terrane has not been widely considered by the scientific community because of the lack of supporting data in the previous models.

Using paleontology and stratigraphy to reconstruct paleogeography has a long history of success (cf. Metcalfe, 2009), but a new approach that combines in situ U-Pb dating

and Hf isotope analysis on detrital zircons from sedimentary rocks (and their metamorphosed equivalents) has proven to be a powerful tool for tracing their provenance and for paleogeographic reconstruction of continents in Earth history (cf. Veevers et al., 2005). In this paper we use a combined method of detrital zircon chronology, geochemistry, and provenance discrimination for Paleozoic metasedimentary rocks in the Lhasa, Qiangtang, and Tethyan Himalayan terranes to show that the Lhasa terrane most likely originated from Australian Gondwana, as proposed by Audley-Charles (1983, 1984), rather than Indian Gondwana. This result also offers a new understanding of the tectonic evolution of the Tethyan ocean systems in a global context.

Figure 1. Tectonic framework of Tibetan Plateau and Himalayas, showing sample locations of detrital zircons of this study and previous work (data sources in Table DR2; see footnote 1). Suture zones (SZ): JSSZ—Jinsha; LSSZ—Longmu Tso–Shuanghu; BNSZ—Bangong–Nujiang; IYZSZ—Indus–Yarlung Zangbo. STDS—Southern Tibetan detachment system; MCT—Main Central thrust; MBT—Main Boundary thrust; CQMB—Central Qiangtang Metamorphic Belt. Numbers indicate emplacement ages (Ma) of dated magmatic rocks (Ji et al., 2009; Dong et al., 2010; Pullen et al., 2011).



REGIONAL GEOLOGY AND DETRITAL ZIRCON ANALYSES

The Lhasa terrane is one of the three large east-west–trending tectonic belts in the Tibetan Plateau. It is located between the Qiangtang and Tethyan Himalayan terranes, bounded by the Bangong–Nujiang suture zone to the north and the Indus–Yarlung Zangbo suture zone to the south, respectively (Fig. 1). The sedimentary cover in the Lhasa terrane is nearly continuous from the Cambrian (Ji et al., 2009) to the late Mesozoic, although the Upper Permian is locally absent (Zhu et al., 2009). The crystalline basement of the western Qiangtang terrane is covered primarily by Paleozoic metasedimentary rocks, in contrast to the eastern Qiangtang terrane, where Mesozoic sedimentary cover is predominant (Pan et al., 2004). The Tethyan Himalaya in the northern Indian plate consists primarily of Paleozoic and Mesozoic sedimentary sequences (Pan et al., 2004). The Lhasa and western Qiangtang terranes are generally considered to have originated from the Himalayan (or Indian) Gondwana (cf. Metcalfe, 2009), whereas the eastern Qiangtang terrane is thought to have derived from the Yangtze craton (or pan-Cathaysian) continental margin (cf. Pan et al., 2004).

We have undertaken laser ablation–inductively coupled plasma–mass spectrometry U-Pb age and Hf isotope analyses of 446 detrital zircons recovered from Permian–Carboniferous metasedimentary rocks in the Lhasa terrane (samples 08YR10, NX1–5, XM01, MB07–2,

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and GBJD from 82°E to 93°E; Fig. 1). We also analyzed detrital zircons obtained from a Lower Permian sandstone sample (SL5–1; 98 grains) in the Tethyan Himalaya and from an Ordovician quartzite sample (GB–12; 81 grains) in the western Qiangtang terrane (Fig. 1) for comparison with the Lhasa samples. Sample descriptions and zircon details, analytical techniques, concordia plots, and zircon U–Pb age and Hf isotopic data of individual analyses are provided in Tables DR1–DR3 and Figures DR1–DR3 in the GSA Data Repository¹. The zircon isotope data reported in this study and in the previous work are synthesized in Figs. 2 and 3. Detrital zircons of varying size and shape were selected randomly, leaving out grains with obvious cracks or inclusions. Thus the number of zircons in each population is statistically representative.

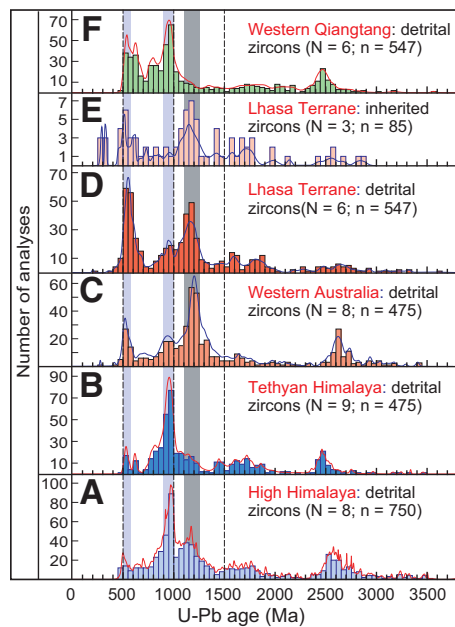


Figure 2. A–F: Summary of detrital zircon age distributions of metasedimentary rocks of this study and previous work. Important age peaks are shown in gray bands. N = number of samples, n = total number of analyses. The $^{207}\text{Pb}/^{206}\text{Pb}$ ages were used for those older than 1000 Ma, and $^{206}\text{Pb}/^{238}\text{U}$ ages were used for younger zircons. Results described in this study exclude analyses with >10% discordance. Data details are given in Table DR2 and Figure DR3 (see footnote 1).

¹GSA Data Repository item 2011221, Table DR1 (sample descriptions and zircon details); Table DR2 (zircon U–Pb age data of individual analyses); Table DR3 (Hf isotopic data of individual analyses); Figure DR1 (representative cathodoluminescence images of zircons); Figure DR2 (analytical techniques, concordia plots); and Figure DR3 (detrital zircon age distributions), is available online at www.geosociety.org/pubs/ft2011.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

DETRITAL ZIRCON AGE DISTRIBUTION AND HF ISOTOPES ACROSS TIBET

Ages of detrital zircons from the Ordovician quartzite sample (GB–12) in the central Qiangtang metamorphic belt of the western Qiangtang terrane range from 492 to 3564 Ma, with two peaks ca. 524 and ca. 942 Ma (Fig. DR2). This age distribution is similar to detrital zircon ages of metasedimentary rocks from the belt (Pullen et al., 2008; Dong et al., 2011) (Fig. DR3). The ca. 942 Ma age population yields varying $\epsilon_{\text{Hf}}(t)$ values (–28.2 to +7.5) with diverse crustal model ages (3.6–1.3 Ga) (Fig. 3A; Table DR3).

The Lower Permian sandstone sample (SL5–1) from the Selong area in the Tethyan Himalaya (Fig. 1) contains zircons ranging in age from 498 to 2754 Ma, with two major age peaks ca. 535 and ca. 949 Ma (Fig. DR2). These ages also correspond well to the age distributions of detrital zircons from a Neoproterozoic quartzite and Cambrian–Permian sandstones from Spiti Valley and Nyalam (DeCelles et al., 2000; Myrow et al., 2010), and from northern Bhutan (McQuarrie et al., 2008) in the Tethyan Himalaya (Fig. DR3). The zircons in the ca. 949 Ma peak have a wide range of $\epsilon_{\text{Hf}}(t)$ values (–26.2 to +12.6) with varying crustal model ages (3.5–1.0 Ga) (Fig. 3A; Table DR3).

Age distributions of detrital zircons in five samples (08YR10, NX1–5, XM01, MB07–2, and GBJD) from the Lhasa terrane are similar,

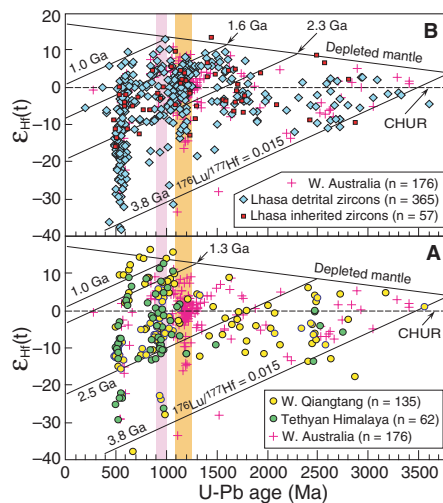


Figure 3. Plots of $\epsilon_{\text{Hf}}(t)$ (parts per 10⁴ deviation of initial Hf isotope ratios between zircon samples and the chondritic reservoir at the time of zircon crystallization) vs. U–Pb ages of the detrital and inherited zircons from the western Qiangtang and Tethyan Himalaya (A) and Lhasa Terrane (B). The detrital zircon data from Western Australia are shown for comparison. CHUR—chondritic uniform reservoir, n = total number of analyses. The declining parallel lines are Hf crustal model ages (T_{DM}^{C}) ages, and depleted-mantle (DM) lines are provided in Table DR3 (see footnote 1).

spanning a wide range from 363 to 3602 Ma, with two main peaks ca. 540 and ca. 1170 Ma (Fig. DR2). A similar age distribution is also conspicuous in inherited zircons from the Mesozoic peraluminous granites in the Lhasa terrane (Zhu et al., 2009, 2011) (Fig. 2E). The zircons in the ca. 1170 Ma age peak display a relatively narrow range of $\epsilon_{\text{Hf}}(t)$ values (–13.7 to +8.5) with a narrow range of crustal model ages (2.8–1.5 Ga) (Fig. 3B).

DISCUSSION

Provenance of the Distinctive Detrital Zircon Populations in Southern Tibet

The similarity in age distributions (Figs. 2B and 2F) recorded in detrital zircons from both the western Qiangtang (Pullen et al., 2008; Dong et al., 2011) and Tethyan Himalaya terranes (DeCelles et al., 2000; McQuarrie et al., 2008; Myrow et al., 2010) suggests that zircons from these two terranes likely have a common provenance. The Hf isotope data and crustal model ages on zircons of ca. 950 Ma age group confirm the interpretation that detrital zircons from the western Qiangtang and Tethyan Himalaya terranes had a common provenance, with an identical range of $\epsilon_{\text{Hf}}(t)$ values shared by zircons from both places (Fig. 3A). Furthermore, the two main age peaks of ca. 950 and 530 Ma defined by detrital zircons of Paleozoic metasedimentary rocks from the western Qiangtang (GB–12) and Tethyan Himalaya (SL5–1) terranes match those defined by zircons from the Neoproterozoic metasedimentary rocks in the High Himalaya (Gehrels et al., 2003, 2006a, 2006b) (Fig. 2A). These results suggest that the detrital zircons from both the western Qiangtang and the Tethyan Himalaya terranes may actually have been sourced from the High Himalaya during the Paleozoic.

An important observation is that the distinctive ca. 1170 Ma age population characteristic of zircons in the Lhasa terrane is absent in samples from both the western Qiangtang (Pullen et al., 2008; Dong et al., 2011) (Fig. 2F) and the Tethyan Himalaya terranes (cf. McQuarrie et al., 2008; Myrow et al., 2010) (Fig. 2B). Likewise, the distinctive ca. 950 Ma age peak common in detrital zircons from both the western Qiangtang (Fig. 2F) and Tethyan Himalaya (Fig. 2B) is rather weak (Fig. 2D) or essentially absent (Fig. 2E) in zircons from the Lhasa terrane. All these observations strongly suggest that the Proterozoic detrital zircons from the Lhasa terrane were derived from a source different from the common provenance of Proterozoic zircons in both the western Qiangtang and Tethyan Himalaya terranes.

The abundant occurrence of ca. 1170 Ma zircons from the Permian–Carboniferous metasedimentary rocks, which are extensive in the Lhasa

terrane (Pan et al., 2004), requires the presence of widespread outcrops of coeval magmatic rocks in the source region. The High Himalaya, which contains 1000–1350 Ma detrital zircons in the Neoproterozoic metasedimentary rocks (Gehrels et al., 2003, 2006a, 2006b) (Fig. 2A), may be considered a possible source for the Lhasa zircons. However, there is no evidence for the widespread existence and exposure of ca. 1170 Ma magmatic rocks in the High Himalaya (Singh and Jain, 2003) as a potential source of sediments for the Lhasa terrane. By contrast, ca. 1170 Ma magmatic rocks were extensively exposed in the Albany-Fraser belt in southwest Australia (cf. Clark et al., 2000) that supplied sediments to the Collie and Perth Basins in the north during the Permian (Sircombe and Freeman, 1999; Cawood and Nemchin, 2000; Veevers et al., 2005). The distinctive 1170 Ma age population of detrital zircons from the Lhasa terrane matches well that of detrital zircons in the Permian sandstones from the Collie Basin north of the Albany-Fraser belt and from the Perth Basin in the northern Pinjarra orogen (Cawood and Nemchin, 2000; Veevers et al., 2005) (Fig. 2C). These correlations suggest to us that the Lhasa, Collie, and Perth detrital zircons likely came from the Albany-Fraser orogenic belt in southwest Australia. Similar zircon Hf isotopic compositions and crustal model ages (Fig. 3B) further corroborate that the most likely source of the 1170 Ma detrital zircons in the Lhasa terrane was the Albany-Fraser belt in southwest Australia.

Implications for Paleogeographic Reconstruction and Tectonic Evolution in Southern Tibet

Our new U-Pb age and Hf isotope data of detrital zircons and provenance interpretations require a different paleogeographic reconstruction of the crustal mosaic of southern Tibet and its tectonic evolution. The widely accepted current models all suggest that the western Qiangtang and Lhasa terranes are continental slivers sequentially rifted and drifted away from the same Indian Gondwana supercontinent to the south (Allègre et al., 1984; Yin and Harrison, 2000; Metcalfe, 2009). However, if the Lhasa terrane were indeed part of the Indian component of Gondwana, it should contain abundant ca. 950 Ma zircons, as do the western Qiangtang and Tethyan Himalaya terranes (Figs. 2B and 2F). This is not the case, and ca. 1170 Ma zircons are absent in both the western Qiangtang and Tethyan Himalaya terranes (Figs. 2B and 2F). All these findings indicate that during or prior to Permian–Carboniferous time, the Lhasa terrane was not geographically in the vicinity of western Qiangtang, Tethyan Himalaya, and India, but was instead adjacent to northwest Australia.

On the basis of several independent lines of geological evidence (e.g., presence of late Paleozoic glacial deposits, distribution of key land floras, tropical and subtropical marine faunas), Audley-Charles (1983, 1984) suggested that the Lhasa terrane might have rifted from northern Australia. Our new data and interpretations support this inferred Australian origin of the Lhasa terrane. The abundant 1170 Ma detrital zircons in the Lhasa terrane (Figs. 1 and 2D) correlate well with those from 1100–1300 Ma granitic intrusions in the Albany-Fraser belt in southwest Australia (Clark et al., 2000; Veevers et al., 2005). The assembly of eastern Gondwana that was initiated in the late Neoproterozoic formed the Yilgarn craton with a well-developed drainage system flowing to the northwest (Veevers et al., 2005). As a result, the Albany-Fraser orogenic belt south of the Yilgarn craton supplied abundant sediments to the northern margin of the Australian continent throughout the late Neoproterozoic and early Paleozoic. The Lhasa terrane was still part of the northern edge of Australia at that time (Fig. 4), receiving detrital material from the Albany-Fraser orogenic belt south of the Yilgarn craton.

This inferred paleogeography and the supporting new data rule against the view that the Lhasa terrane originated from Indian Gondwana. We envision that a passive continental margin was present along the northern edge of East Gondwana south of the proto-Tethyan Ocean during the Neoproterozoic–early Paleozoic (Cawood et al., 2007). River systems draining the Albany-Fraser orogenic belt south of the Yilgarn craton in southwest Australia supplied sediments to the Lhasa terrane to the north, whereas those draining the High Himalaya or the Indian continent transported sediments to the Tethyan Himalaya and Qiangtang terrane to the north (cf. Myrow et al., 2010) (Fig. 4). The

long-distance transport of sediments from these source regions to the passive continental margin explains the presence of rounded detrital zircons in samples from the Neoproterozoic–Paleozoic metasedimentary rocks (Fig. DR1). Subduction of the proto-Tethyan Ocean seafloor beneath East Gondwana was initiated by 510 Ma at the latest, as indicated by the presence of subduction-related Cambrian granites in the Tethyan and High Himalayas (Cawood et al., 2007) and coeval rhyolitic rocks (ca. 501 Ma) in the Lhasa terrane (Ji et al., 2009). Subduction of the paleo-Tethyan Ocean seafloor beneath East Gondwana may have resulted in the separation of the Lhasa terrane from northern Australia and of the eastern Qiangtang terrane from northern India through backarc spreading that likely initiated in the latest Devonian, as indicated by the presence of coeval granitoids (ca. 367 Ma) in the southern margin of the Lhasa terrane (Dong et al., 2010) and in the western Qiangtang terrane (ca. 364 Ma; Pullen et al., 2011) (Fig. 1). This rifting event ultimately led to the isolation of the Lhasa terrane from Australian Gondwana (Zhu et al., 2010) and of the eastern Qiangtang terrane from Indian Gondwana within the Tethyan realm prior to the Permian–Carboniferous. An active continental margin setting during the Permian–Carboniferous (Zhu et al., 2010) provided a tectonic driver for the redeposition of detrital material eroded from the preexisting cover of the Lhasa terrane, explaining the presence of arkose, indicating short distance transport in the Permian–Carboniferous metasandstones in the Lhasa terrane (Fig. DR1).

CONCLUSIONS AND FUTURE WORK

The age distributions of detrital zircons from both the western Qiangtang and Tethyan Himalaya terranes in Tibet are remarkably similar (with two strong peaks ca. 530 Ma and 950 Ma),

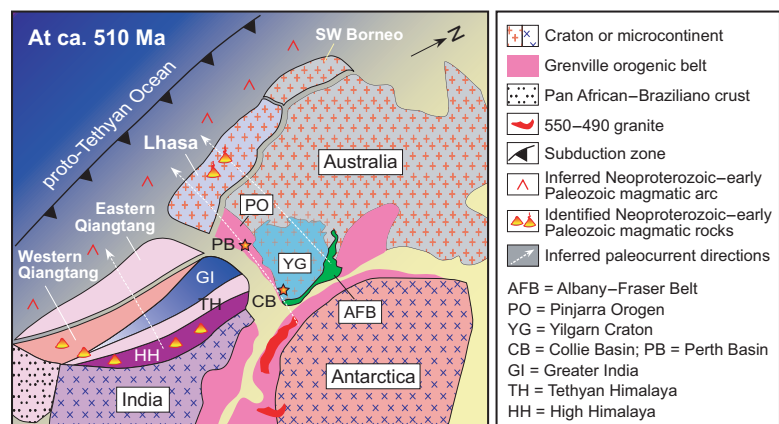


Figure 4. Reconstruction of eastern Gondwana ca. 510 Ma (modified from Audley-Charles, 1983, 1984; DeCelles et al., 2000) showing inferred paleocurrent directions in Western Australia (Veevers et al., 2005) and locations of early Paleozoic rhyolite in Lhasa terrane (Ji et al., 2009). Outlines of Tethyan Himalaya, Qiangtang, and Lhasa terranes, as well as southwestern Borneo (Metcalfe, 2009), are for reference only.

with a wide but identical range of $\epsilon_{\text{Hf}}(t)$ values of the ca. 950 Ma age population. This finding suggests that these two terranes shared a common provenance in the Paleozoic. The detrital zircons from the Lhasa terrane define, however, a distinctive age population of ca. 1170 Ma with a relatively narrow range of $\epsilon_{\text{Hf}}(t)$ values. This age and Hf isotope brackets correlate well with those of the detrital zircons from the Albany-Fraser belt in southwest Australia, suggesting that the ca. 1170 Ma detrital zircons in the Lhasa terrane most likely came from the Albany-Fraser belt. These results indicate that the Lhasa terrane is actually exotic to the widely accepted Tibetan Plateau system, and correlated paleogeographically with Australia during the late Precambrian–early Paleozoic.

Although this inferred paleogeography of the Lhasa terrane is based on scientifically and statistically reliable detrital zircon data, more work on the provenance of detrital zircons from Paleozoic sedimentary rocks in the northern margin of Australia is needed to further substantiate our results and their implications. It is clear, however, that the Lhasa terrane, one of the largest crustal blocks that make up the composite Tibetan Plateau, appears to have undergone late Precambrian–early Paleozoic evolution as part of Australia in a different paleogeographic setting than that of the Qiangtang–Greater India–Tethyan Himalaya system. This interpretation brings a refreshing new perspective to the Tibetan crustal evolution and shows that Tibet is more heterogeneous in its geological heritage than previously thought. Tracking the source of detrital zircons in other microcontinents in the broader Tethyan orogenic belt through systematic in situ U-Pb dating and Hf isotope analysis is expected to reveal equally exciting new results for the previously undisclosed paleogeographic origin and tectonic journeys of those continental blocks through time.

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