Gondwana Research xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

Cambrian ultrapotassic rhyolites from the Lhasa terrane, south Tibet: Evidence for Andean-type magmatism along the northern active margin of Gondwana

Huixia Ding [a], Zeming Zhang [a,*], Xin Dong [a], Rong Yan [a], Yanhao Lin [b], Hongying Jiang [c]

[a] State Key Laboratory of Continental Tectonic and Dynamics, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China
[b] Faculty of Earth Sciences, China University of Geosciences, Wuhan 430074, China
[c] School of Earth Science and Resources, China University of Geosciences, Beijing 100083, China

A R T I C L E I N F O

Article history:
Received 27 August 2013
Received in revised form 25 January 2014
Accepted 17 February 2014
Available online xxxx

Handling Editor: M. Santosh

Keywords:
Ultrapotassic rhyolite
Zircon geochronology
Andean-type orogeny
Lhasa terrane
South Tibet
Gondwana

A B S T R A C T

The petrogenesis and tectonic significance of early Paleozoic magmatic rocks in south Tibet is debated. In this paper, we report Cambrian ultrapotassic felsic volcanics from the Lhasa terrane. Petrographic and whole-rock geochemical studies indicate that these rocks are rhyolite and rhyolitic ignimbrite, and have varying SiO_2 (69.56–82.09 wt.%), Al_2O_3 (9.52–16.61 wt.%) and $Fe_2O_3^t$ (1.0–7.9 wt.%). The rocks are ultrapotassic (high K_2O 4.19–6.90 wt.%, and very low Na_2O 0.01–0.06 wt.%) and peraluminous (A/CNK = 1.41–2.22). They are enriched in Rb, Th, U, Pb, Zr and Y, and showed negative Ba, Sr, P, Nb, Ta and Ti anomalies, and slightly fractionated REE patterns with moderately negative Eu anomalies, typical of A-type granitoids. Zircons from six samples yielded crystallization ages of ca. 512 Ma. These zircons show $\varepsilon_{Hf}(t)$ values in the range of −4.7 to +1.3, and two-stage Hf model ages of 1734–1392 Ma. Combining with previous results, we propose that these ultrapotassic rhyolites were derived from the partial melting of middle Proterozoic crustal rocks in the lower crust under high-temperature and water-absent conditions in an extensional environment of active magmatic arc. Thus, this study provides new insights into early Paleozoic Andean-type orogeny along the northern margin of Gondwana supercontinent.

1. Introduction

The Himalayan–Tibetan orogen is the youngest and the most spectacular of all the continent–continent collisional belts on the Earth (e.g., Yin and Harrison, 2000). The Lhasa terrane, which is the main tectonic component of the orogen, experienced multistage magmatism, including Neoproterozoic magmatism associated with the opening of the Mozambique Ocean (Zhang et al., 2012a, 2014), Paleozoic magmatism related to the final assembly of Gondwana (Li et al., 2008a), the subduction of the proto-Tethyan lithosphere (Dong et al., 2009; W.H. Ji et al., 2009; Zhu et al., 2012; Hu et al., 2013), the opening and subduction of the Paleo-Tethyan Ocean (Dong et al., 2010; Dai et al., 2011; Zhu et al., 2013), the collision between the Lhasa terrane and the northern margin of Australia (Zhu et al., 2009a), the Mesozoic magmatism derived from the subduction of the Meso-Tethyan (Allègre et al., 1984; Zhu et al., 2009b, 2011) and the Neo-Tethyan lithosphere (Chu et al., 2006; Wen et al., 2008a,b; Chiu et al., 2009; W.Q. Ji et al., 2009; Zhu et al., 2009c; Zhang et al., 2010; Guo et al., 2012; W.W. Chen et al., 2012; Zhang and Santosh, 2012; Chen et al., 2014; Meng et al., 2014), and the Cenozoic magmatism associated with the subduction of the Neo-Tethyan lithosphere (Ding et al., 2003; Hou et al., 2006; He et al., 2007; Wen et al., 2008b; Guan et al., 2012) and the India–Asia collision (Chung et al., 2003; Mo et al., 2003; Chung et al., 2005; Mo et al., 2005; Hou et al., 2006; Mo et al., 2007, 2008; Chung et al., 2009; W.Q. Ji et al., 2009; Zhao et al., 2009; Xia et al., 2011; Zhu et al., 2011; J.L. Chen et al., 2012). These discoveries play an important role in evaluating and formulating the evolution and geodynamic models for the terrane.

Early Paleozoic magmatic rocks (~530–470 Ma) are ubiquitous along the northern margin of Gondwana (Fig. 1a), but their petrogenesis is still unclear and controversial. Investigations conducted so far have proposed mainly two scenarios: (1) Pan-African orogenesis in response to the final assembly of Gondwana (Murphy and Nance, 1991; Meert and Van Der Voo, 1997; Miller et al., 2001; Xu et al., 2005; Song et al., 2007; Qi et al., 2010; Xie et al., 2010; Liu et al., 2012; Yang et al., 2012) and (2) an Andean-type orogeny related to the subduction of proto-Tethyan oceanic lithosphere beneath the Gondwana continent (Li and Powell, 2001; Ramezani and Tucker, 2003; DeCelles et al., 2004; Gürsu and Göncüoglu, 2005; Cawood et al., 2007; Chen et al., 2007; Hassanzadeh et al., 2008; Horton et al., 2008; Zhang et al., 2008; Dong et al., 2009; W.H. Ji et al., 2009; Saki, 2010; Wang et al., 2011; B.D. Wang et al., 2012; Dong et al., 2012; Spencer et al., 2012; X.X. Wang et al., 2012; Zhang et al., 2012b,c; Zhu et al., 2012; Cai et al., 2013; Dong et al., 2013; Hu et al., 2013; Wang et al., 2013; Moghadama et al., 2014).

* Corresponding author at: Institute of Geology, Chinese Academy of Geological Sciences, No. 26 Baiwangzhuang Road, Beijing 100037, China. Tel.: +86 10 68999735; fax: +86 10 68994781.
E-mail address: zzm2111@sina.com (Z. Zhang).

http://dx.doi.org/10.1016/j.gr.2014.02.003
1342-937X/

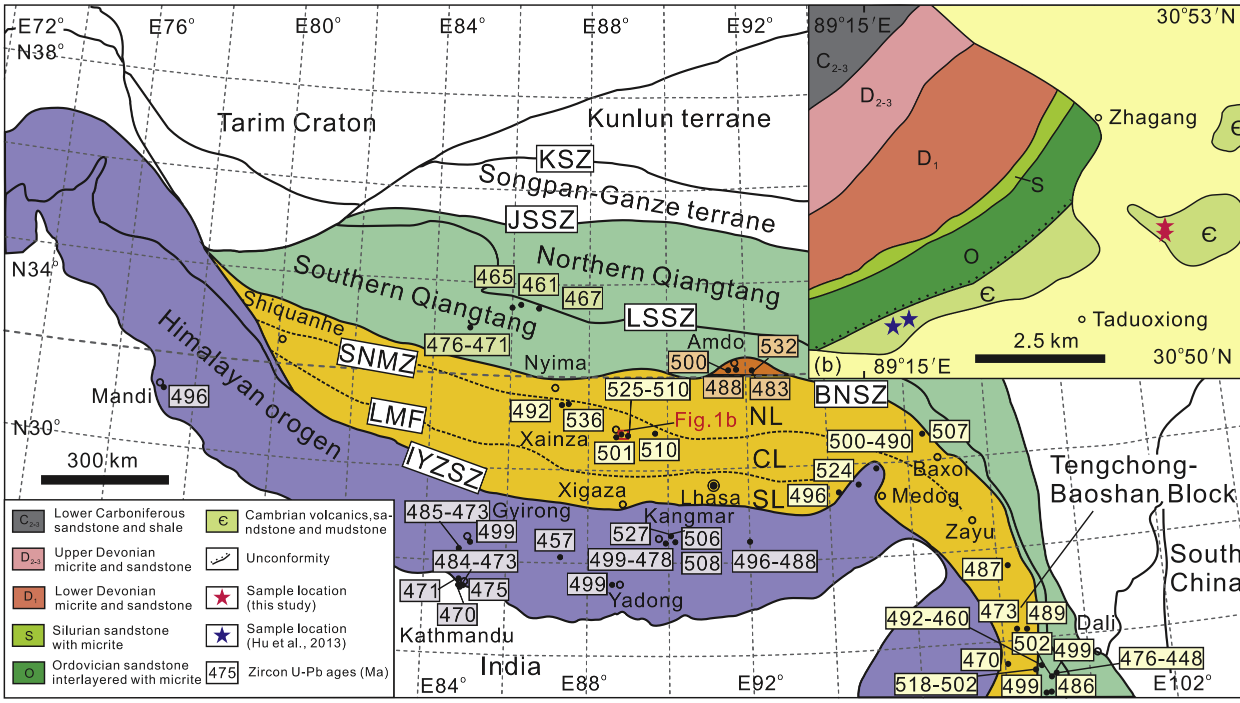

Fig. 1. (a) Simplified geological map of the Tibetan Plateau, showing the locations and related ages of early Paleozoic magmatic rocks in the southern Tibet. Data sources for the Southern Qiangtang terrane from the east to west: 476–471 Ma (Pullen et al., 2011), 465 Ma (Hu et al., 2010), 461 Ma (Wang et al., 2008; B.D. Wang et al., 2012), 467 Ma (Li et al., 2008b); Amdo from the east to west: 500 Ma (Zhang et al., 2012b), 488 Ma (Xie et al., 2010), 532 Ma and 483 Ma (Guynn et al., 2012); Lhasa terrane from the east to west: 492 Ma (Zhu et al., 2012), 536 Ma (Pan et al., 2012), 501 Ma (W.H. Ji et al., 2009), 525–510 Ma (Hu et al., 2013), 510 Ma (Gehrels et al., 2011), 496 Ma (Dong et al., 2009), 507 Ma (Li et al., 2008a); Himalayas from the east to west: 496 Ma (Miller et al., 2001); 499–473 Ma (X.X. Wang et al., 2012), 471 Ma (Johnson et al., 2001), 484–473 Ma (Gehrels et al., 2006), 470 Ma (Schärer and Allègre, 1983), 475 Ma (Cawood et al., 2007), 499 Ma (Wang et al., 2011), 457 Ma (Visonà et al., 2010), 499 Ma (C. Shi et al., 2010), 527 Ma and 506 Ma (Quigley et al., 2008), 524 Ma (Qi et al., 2010), 508 Ma (Lee et al., 2000), 500–490 Ma (Zhang et al., 2008); Tengchong–Baoshan Block from the north to south: 487 Ma (Song et al., 2007), 473 Ma (Liu et al., 2012), 489 Ma (Lin et al., 2012), 470 Ma (Chen et al., 2007); 492–460 Ma (Wang et al., 2013), 518–502 Ma (Cai et al., 2013), 476–448 Ma (Dong et al., 2013), 502 Ma and 499 Ma (Liu et al., 2009), 499 Ma (Yang et al., 2012), 486 Ma (Dong et al., 2012). JSSZ — Jinsha Suture Zone; LSSZ — Longmu Tso–Shuanghu Suture Zone; BNSZ — Bangong–Nujiang Suture Zone; SNMZ — Shiquan River–Nam Tso Mélange Zone; LMF — Luobadui–Milashan Fault; IYZSZ — Indus-Yarlung Zangbo Suture Zone; NL — Northern Lhasa subterrane; CL — Central Lhasa subterrane; SL — Southern Lhasa subterrane. (b) Geological map of the studied area showing the sampling locations of this study and Hu et al. (2013).

In this paper, we report a suit of Cambrian A-type ultrapotassic rhyolites from the Lhasa terrane, representing one of the microcontinents that originated from the northern margin of Gondwana (Allègre et al., 1984; Yin and Harrison, 2000; Metcalfe, 2006, 2009; Zhu et al., 2013; Zhang et al., 2014). Although not common, these rocks are similar to that of lavas reported from Rajasthan, India (Maheshwari, 1987; Sharma, 2005), the Yidun, Southeast Tibet (Qu et al., 2003) and the Sinai, Egypt (Samuel et al., 2007). The magmatism is correlated to extensional tectonic environments, such as continental rift (Sharma, 2005) and intraplate rift (Qu et al., 2003; Samuel et al., 2007). Here we present the petrology, zircon U–Pb geochronology and Hf isotopic data on the ultrapotassic rhyolites from the Lhasa terrane. The results provide insights into the early Paleozoic magmatism along the northern margin of Gondwana, and the Cambrian Andean-type orogeny of the Lhasa terrane.

2. Geological background and petrography

The Tibetan Plateau consists of the Songpan–Ganzi flysch complex, Northern Qiangtang, Southern Qiangtang, Lhasa terranes and the Himalayas from the north to south (Fig. 1a; Yin and Harrison, 2000; Tapponnier et al., 2001; Mo et al., 2006). These terranes are separated by the Jinsha, Longmu Tso–Shuanghu, Bangong–Nujiang, and Indus–Yarlung Zangbo suture zones. The Lhasa terrane, located in the southern part of Tibet, is a large crustal segment with a width of 100–300 km and a length of ca. 2000 km. The Lhasa terrane is divided into the northern, central, and southern subterranes, separated by the Shiquan River–Nam Tso Mélange zone and Luobadui–Milashan fault (Fig. 1a; Pan et al., 2004; Zhu et al., 2012).

The northern Lhasa subterrane consists of middle Triassic–Cretaceous sedimentary rocks, abundant early Cretaceous volcanic rocks and lower Cretaceous volcano-sedimentary sequence as well as Cretaceous granitoid batholiths (Pan et al., 2004; Zhu et al., 2011, 2012; Sui et al., 2013). The central Lhasa subterrane is composed of Precambrian basement (Lin et al., 2013; Xu et al., 2013), Cambro-Permian sediments and upper Jurassic–lower Cretaceous strata with abundant lavas (Liu et al., 2004; Pan et al., 2004; Zhu et al., 2012), and some Mesozoic and Cenozoic metamorphic rocks (Kapp et al., 2005; Dong et al., 2011a,b). The southern Lhasa subterrane is characterized by the growth of juvenile crust (Mo et al., 2008; W.Q. Ji et al., 2009; Zhu et al., 2011) with locally preserved Precambrian crystalline basement (Zhu et al., 2012). This subterrane consists mainly of the Cretaceous–Tertiary Gangdese batholith and the Paleogene Linzizong volcanic succession, with minor Triassic–Cretaceous volcano-sedimentary rocks (Pan et al., 2004; Zhu et al., 2012).

The present study area is located at the northern part of the central Lhasa subterrane (Fig. 1a), and consists of Cambrian–Carboniferous volcano-sedimentary successions (Fig. 1b). The Cambrian unit is unconformably overlain by Ordovician strata, and a continuous succession of the Ordovician–Carboniferous strata is preserved. Previous study has assigned the Cambrian strata to the Nyainqêntanglha Group, representing the Precambrian crystalline basement of the Lhasa terrane (Wang et al., 2003). However, our observation shows that this sequence consists mainly of sandstone, mudstone and limestone, with minor interlayered rhyolite and rhyolitic pyroclastic rocks. As described below, these rhyolitic rocks have a Cambrian crystallization age. Recent studies demonstrated that the Cambrian strata are common in south