



Zircon U–Pb dating and the petrological and geochemical constraints on Lincang granite in Western Yunnan, China: Implications for the closure of the Paleo-Tethys Ocean

Guochen Dong^{a,*}, Xuanxue Mo^{a,b}, Zhidan Zhao^{a,b}, Dicheng Zhu^{a,b}, Robbin C. Goodman^a, Huilei Kong^a, Shuo Wang^a

^a China University of Geosciences, Beijing 100083, China

^b State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Beijing 100083, China

ARTICLE INFO

Article history:

Received 11 November 2011

Received in revised form 25 September 2012

Accepted 4 October 2012

Available online 27 October 2012

Keywords:

Lincang granite

Zircon U–Pb dating

Petrological and geochemical features

Paleo-Tethys

China

ABSTRACT

Lincang granite is a batholith located in the Sanjiang region and is an important research subject for understanding subduction and collision during the Paleo-Tethyan period. It is widely exposed in the Lincang Terrane and extends south into Burma. Based on various petrological and geochemical investigations performed from south to north across the Lincang granite, a new set of data, which includes zircon chronological and Hf isotopic data, is presented to discuss the origin of the Lincang granite and its tectonic significance. The Lincang granite is a peraluminous, high-K calc-alkaline body with sub-parallel REE patterns and a strong negative Eu anomaly. This anomaly is characteristic of a post-collision peraluminous S-type granitic batholith. The 200–230 Ma formation age of the Lincang granite was determined using LA-ICP-MS zircon U–Pb dating. Thus, it has been confirmed that the granite formed during the late Triassic period, and the formation process lasted for approximately 30 Ma. Geochemical and isotopic compositions indicate that the primary magma of Lincang granite most likely originated from a crustal source, and possibly underwent an assimilation–fractionation crystallization (AFC) process during its emplacement. The Lincang granite formed during the continental collision between the Baoshan–Gengma Terrane and the Lanping–Simao Terrane after the northeast subduction of the Paleo-Tethyan Oceanic Plate. Therefore, the late Triassic Lincang granite is important evidence for the closure of the Paleo-Tethyan Ocean.

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1. Introduction

In Southeast Asia, there are two major continental masses, the Indochina Terrane and the Baoshan–Sibumasu Terrane, which collided with each other after the prolonged subduction of the Devonian–Triassic Paleo-Tethys Ocean (Sone and Metcalfe, 2008). The Nujiang–Lancangjiang–Jishajiang area, which is also known as the Sanjiang area, is an area in Eastern Tibet, Western Sichuan and Western Yunnan, and it is key to understanding the tectonic development of the Paleo-Tethys (Houseman and England, 1993; Leloup et al., 1995; Wang and Burchfiel, 1997; Chonglakmani et al., 2001; Heppe et al., 2007; Cai and Zhang, 2009; Fan et al., 2010). Lincang granite exists as a batholith in the Sanjiang area and is one of the key geological records for understanding subduction and collision during the Paleo-Tethyan period. However, its origin and tectonic setting is still hotly controversial (Metcalfe, 1995; Zhong et al.,

1998; Zhu et al., 1999; Chonglakmani et al., 2001; Hennig et al., 2009; Kong et al., 2012). A wide range of interpretations have been proposed within the last several decades (Huang et al., 1984; Helmcke, 1985; Liu et al., 1989a; Li, 1996; Zhu et al., 1999; Peng et al., 2006; Sone and Metcalfe, 2008; Liu et al., 2008b; Hennig et al., 2009; Kong et al., 2012). Lincang granite is generally interpreted to have a magmatic arc origin (Li, 1988; Chen, 1989; Sone and Metcalfe, 2008) or an allochthon (Yang, 1995, 1996). The tectonic unit in which Lincang granite is located has been given different names, including the Lincang Arc Terrane (Li, 1988, 1996), the Lincang Massif (YBGMR, 1990), the continental margin (Yu et al., 2003) and the syn- or post-collisional environment product (Liu et al., 1989a,b; Zhu et al., 1999; Hennig et al., 2009; Fan et al., 2009, 2010; Kong et al., 2012).

This study, which is based on detailed petrological and geochemical investigations performed across the Lincang granitic intrusion from the south to the north combined with existing data, presents a set of new data, including zircon U–Pb chronological and Hf isotopic data, for the granite and discusses its origin and tectonic significance.

* Corresponding author. Tel.: +86 10 8232 1610.

E-mail addresses: donggc@cugb.edu.cn, guochdong@263.net (G. Dong).

2. The geological setting of Lincang granite

Two sub-parallel suture zones have long been recognized along the belt of convergence between the Baoshan–Gengma Terrane (northern part of the Baoshan–Sibumasu terrane) and the Laping–Simao block (northern extension of the Indochina terrane) that extends in an approximately south to north direction. The western Changning–Menglian–Inthanon suture represents an extensive accretionary complex of the Paleo-Tethys, and the eastern Jinghong suture, which extends to the south of the Nan and Sra Kaeo sutures, represents a closed back-arc basin (Sone and Metcalfe, 2008). A former island arc existed, extending from Western Yunnan south to Thailand, between the two parallel sutures (Fig. 1b).

The Lincang granite is a late Paleozoic to Triassic composite batholith (Liu et al., 1989a; Li, 1996; Yu et al., 2003) that occurs as a “Z” shape in Sanjiang, Western Yunnan, and covers an area of 7400 km². In the north–south direction, it is 350 km in length, and from east to west, it is 10–48 km in width (Fig. 1a). It is defined as the southern extension of the Leiwuqi–Wandashan granitic belt in the Zhuka–Yanjing area of the Northern Lincang River, (YBGMR, 1990; Liu et al., 1993) and it extends into the Sukhothai Terrane in Northern Thailand and Peninsular Malaysia (Barr et al., 2000; Hennig et al., 2009), forming a giant magmatic belt along the Lincang River in the Sanjiang area (Fig. 1b). It is also one of the largest granite intrusions including both Sn and Ge mineralization in Western Yunnan (Li, 1996; YBGMR, 1990).

Lincang granite intruded into Proterozoic metamorphic rocks (Lincang Group) to the west and was defined by a major compressive fault zone to the east. It also intruded east to the mid- to late Triassic basaltic and rhyolitic rocks (Xiaodingxi Fm.) and has local intrusive contact with Paleozoic metamorphic rocks and a Mid- to Late Triassic volcano in the sedimentary series (Manghuaihe Fm.) to the northeast (Li, 1996; Yang et al., 1994; Hennig et al., 2009; Wang et al., 2012). The Lincang granite was overlain with nonconformities by the terrestrial red-beds of Mid Jurassic volcano-sedimentary rocks far to the east. There are also various inclusions of Proterozoic metamorphic rocks (Damenglong Group) within the granite in the west. Due to poor outcrop conditions, the nature of the contact has been disputed. It has been believed to be associated with a postulated Triassic subduction along the Lincang River Fault (Zhang et al., 1993) and has been inferred to be allochthonous (Yang, 1995, 1996). There are small granodiorite intrusions (zircon U–Pb age 282–284 Ma) in the Jinghong area, and the Baimaxueshan granodioritic intrusion (zircon U–Pb age 239 Ma) is approximately 250 km north of the Lincang granite. Both are characteristic of an arc setting and are similar to arc-like andesites (Hennig et al., 2009). Several small intrusions developed favoring Mesozoic Yanshanian orogeny nearby, which were locally intruded into the granite. This was interpreted as a post-orogenic stage product with an isotopic age of 130 Ma (Li, 1996; Yu et al., 2003; Liu et al., 2008b).

The composition of Lincang granite predominately consists of biotite monzogranite with a few granodiorite located in the central area of the Lincang granite (Li, 1996; Zhu et al., 1999; Yu et al., 2003; Fan et al., 2009). Although the granite was considered to be split into three parts in the N–S direction by two faults (Li, 1996), it is predominantly monzogranite in nature (Yu et al., 2003; Peng et al., 2006; Liu et al., 2008a,b; Kong et al., 2012). With regard to its lithological attributes, the granite mainly consists of an assemblage of fine- to medium-grained potash-feldspar biotite monzogranites (Fig. 2a). The main-phase rock, biotite monzogranite, is composed of 25–35% K-feldspar, 20–30% plagioclase, 30–35% quartz, and 10–15% biotite (Fig. 2b and c). The K-feldspar is mainly composed of microcline and orthoclase, which are 1–3 mm long planar grains that are weakly sericitized with a

perthitic ex-solution. The plagioclase are 0.5–3 mm semi-idiomorphic grains exhibiting oscillatory zoning with variable chloritization and epidotization. The quartz exhibits a clean anhedral shape with a local undulatory extinction. The biotite is brown color and is locally chloritized. The accessory minerals consist of apatite, zircon and a few opaque minerals, such as magnetite.

There are some local micro-mafic enclaves (MME) and meta-sedimentary xenoliths, particularly in the middle part of the granite intrusion. The MME are fist-sized or smaller, are unzoned and primarily appear as indistinct inclusion shadows within the changing parallel alignment of the biotite (Fig. 2d), indicating a possible magma-mixing paragenesis between the MME and its host rocks. The meta-sedimentary xenoliths spread out through the west part of the intrusions. Local crenulation cleavage can be observed in the remnants, which also developed in the country rock.

Ten granite samples were collected for the petrological, chemical and zircon Hf isotopic analyses and for the U–Pb geochronology measurements in both the southern and northern sections of the granitic intrusion (Fig. 1a).

3. Analytical techniques and results

3.1. The analytical techniques for major and trace elements

Field investigations were completed across three profiles from the north, middle and south of the granitic intrusion using chemical analyses of rock samples to gain an understanding the lithological variations (Fig. 1, Table 1). The major elements were measured using XRF at the State Key Laboratory of Geological Processes and Mineral Resources (GPMR), China University of Geosciences, Beijing, China. The analytical uncertainty was generally less than 5%. Trace elements were analyzed with an Agilent 7500a ICP-MS at the State Key Laboratory of Geological Processes and Mineral Resources (GPMR), China University of Geosciences, Wuhan, China. The detailed sample digestion procedure for the ICP-MS analysis, the analytical precision and the accuracy were the same as those described in Liu et al. (2008a).

3.2. Major element results

The rocks are composed of SiO₂ (66.07–70.91%, average 68.20%), Al₂O₃ (13.2–14.66%, average 14.20%) and alkalis with an Na₂O + K₂O content of 4.36–7.08%. Chemically, all of the samples fall within the monzogranite area on the QAP diagram (Fig. 3a), which is in general agreement with the results of previous studies (Heppe et al., 2007; Liu et al., 2008b; Hennig et al., 2009; Kong et al., 2012). The K₂O/Na₂O ratios vary between 1.41 and 2.21 and are all greater than 1. Therefore, the samples are generally high-K calc-alkaline granite (Fig. 3b). Similarly, the molecular A/CNK ratios of the samples, excluding sample LC1054, which had a ratio of 0.97, are 1.01–1.82 (average 1.16). This suggests that the Lincang granite is peraluminous with both S- and I-type characteristics. The differentiation index (DI), which is the total percentage of the mineral content composed of Q + Or + Ab, varied between 75.15 and 85.18 (average 79.25), indicating that the magma was differentiated. The contents of MgO, Al₂O₃, CaO and P₂O₅ exhibited decreasing trends within the Harker diagrams as SiO₂ increased (Fig. 4). This observation also suggests possible magma differentiation during the intrusive process.

3.3. Rare earth elements and trace elements

The total rare earth elements (ΣREE) of the samples varied from 174 ppm to 264 ppm (average 230 ppm). The chondrite-normalized REE patterns are mostly sub-parallel, with an intensive

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