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Petrogenesis of the early Paleozoic strongly peraluminous granites in the Western South China Block and its tectonic implications

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ABSTRACT

Strongly peraluminous (SP) granites have A/CNK (molecular $Al_2O_3/(CaO+Na_2O+K_2O)$) ratios >1.1, indicating a predominant origin from the partial melting of metasedimentary rocks. However, an increasing number of studies have documented that mantle-derived magmas can also be involved in the petrogenesis of some SP granites. This is the case in the Dulong batholith in the southeastern Yunnan province, southwestern South China Block, which is typically composed of SP granitic rocks with high A/CNK values (>1.1). Zircon U–Pb dating of four samples from this batholith yielded consistent crystallization ages of ca. 430 Ma, synchronous with the widespread late-orogenic magmatism (including S- and I-type granites and mafic igneous rocks) in the Wuyi–Yunkai orogen, South China Block (SCB). All the granites have fractionated REE patterns ($(La/Yb)_N = 1.28–12.3$) and conspicuous negative Eu anomalies ($Eu^*/Eu = 0.07–0.43$) with a similar depletion in HFSE (Nb, Zr, Hf), P, Ba and Sr, suggesting that these granitic magmas had a dominantly crustal source, likely the Neoproterozoic metasedimentary rocks (i.e., the Danzhou or Banxi groups) that are dominated by pelitic rocks with minor interlayered siltstones in the western Yangtze Block. However, their zircon Hf isotopic results also reveal an important input of the mantle-derived melts into their parental magma. Taken together, their geochemical and isotopic compositions reflect a derivation by magma mixing between the crust- and mantle-derived (~10% in volume) magmas. Their chemical variations resulted from the fractionation process during the emplacement from the magma chamber after magmatic mixing.

In conjunction with regional data within the SCB, it is most likely that the magmatism younger than 435 Ma was generated in a post-collisional extensional regime related to the partial delamination of an overthickened lithospheric mantle root without lower crust.

1. Introduction

Granites are among the predominant rocks in the continental crust and their generation reflects the principal mechanism by which continental material is transferred from the deep crust to near the surface of the Earth. Despite the relative simplicity in their rock-forming mineral components (including mainly quartz, feldspars and minor amount of mafic minerals), the origin of their parental magma and the mechanism to form the magma is still a key subject of study (e.g., Wu et al., 2007; Wang et al., 2013a; Tang et al., 2014). Notwithstanding strongly peraluminous (SP) granites (with A/CNK (molecular $Al_2O_3/(CaO + Na_2O + K_2O)$) ratios >1.1) that indicate a direct derivation by crustal melting (e.g., Chappell and White, 1992; Patiño Douce, 1995), an increasing number of studies have revealed that some complicate processes and different source materials may have been involved in their genesis (e.g., Gray, 1984; Collins, 1996; Healy et al., 2004). It is likely that mantle-derived magma makes a crucial contribution to the generation of some SP granitoids (e.g., Belousova et al., 2006; Phillips et al., 2011), including not only the heat input but also mafic material incorporation. For example, high CaO/Na_2O ratios (>0.3) along with high ($FeOt + MgO + TiO_2$) values (>4) in some SP granites can be ascribed to mixing of basaltic melts with pelite-derived melts, rather than simple anatexis of psammites (e.g., Sylvester, 1998). Also, studies on microgranitoid enclaves

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(e.g., Elburg, 1996; Mass et al., 1997; Waight et al., 2001) have revealed such a likely magma mixing origin for some SP granites. More importantly, isotopic signatures have evidenced that magma mixing (between crust- and mantle-derived magmas) play an important role in the genesis of some SP granites, such as the Lachlan granites in eastern (e.g., Collins, 1996; Healy et al., 2004; Belousova et al., 2006) and southeastern Australia (e.g., Gray, 1984).

The South China Block (SCB), which is one of the biggest granite provinces in the world, is characterized by exceptionally extensive occurrence of granitoid rocks with different emplacement ages and with a total exposure area up to 1,000,000 km^2 (e.g., Sun, 2006; Hua et al., 2013). It is well documented that numerous economically important metallic deposits (i.e., W, Sn, Nb, Ta and REE deposits) are closely associated with granites in the area (e.g., Hua et al., 2013 and references therein). Therein, the early Paleozoic granitoids that are dominated by SP granitic rocks (e.g., Wang et al., 2007, 2011; Li et al., 2010; Zhang et al., 2012b) with minor I-type granites (e.g., Huang et al., 2013; Zhao et al., 2013), are distinctly different from other granitic generations in the SCB, although the total exposure is relatively less than those of the Yanshanian granites (e.g., Sun, 2006; Hua et al., 2013). The existence of such a huge volume (up to 10,000 km^2) of early Paleozoic SP granitoids in the SCB has triggered extensive discussion about its origin and genesis, particularly in recent five years (e.g., Wang et al., 2007, 2011, 2012; Li et al., 2010; Zhang et al., 2012b). Nonetheless, the genesis and tectonic implications of these granites, particularly whether the mantle-derived magmas were involved in the SP granite formation, are still unclear due to the lack of contemporaneous mafic rocks, although some authors have invoked the addition of some basic materials to account for their geochemical signatures (e.g., Wang et al., 2011; Zhang et al., 2012b).

More recently, Yao et al. (2012) and Wang et al. (2013d) have recognized some early Paleozoic mafic igneous rocks in the Wuyi–Yunkai orogen. Consequently, it is necessary to reevaluate the contribution from mantle-derived magma to the resultant formation of SP granites in the area. In particular, for the early Paleozoic SP granites that crop out along the southwestern margin of the SCB, far away from the core of the Wuyi–Yunkai orogen, whether they share a common origin and tectonic setting with those in the core of the Wuyi–Yunkai orogen needs further investigation. Furthermore, the new identification of the early Paleozoic mafic igneous rocks in the SCB provides crucial clues to better constrain the transition timing of tectonic regime from syn-orogen to post-orogen stages and likely shed light on the mechanism of post-collisional magmatism.

In this paper, we present whole-rock geochemical and Sr–Nd isotopic compositions, and zircon U–Pb dating and Lu–Hf isotope results for the early Paleozoic granites in the southeastern Yunnan, Southwestern SCB. Based on our results along with regional data, our aims are to: (1) constrain their main emplacement time; (2) provide an insight into the origin of the early Paleozoic granites, and their rock-forming regime; (3) decode the geodynamic mechanism for their generation; and (4) discuss the space–time relationships between the early Paleozoic crustal anatexis and the tectonic evolution of the Wuyi–Yunkai orogeny.

2. Geological background

The SCB consists of the Yangtze Block, in the northwest, and the Cathaysia Block, in the southeast (Fig. 1 insert), which was amalgamated during Neoproterozoic time (e.g., Li et al., 2002, 2009; Zhao and Cawood, 1999, 2012). The tectonic zone is named as the Jinning or Sibao orogen (e.g., Li et al., 2007). The present boundary between the two blocks is the northeasterly trending Jiangshan–Shaoxing Fault (Fig. 1) (e.g., Chen and Jahn, 1998; Wang et al., 2008; Zhang et al., 2012b), but the southwesterly extension is uncertain due to poor exposure and intensive younger tectonic modification. The Yangtze basement consists predominantly of Proterozoic rocks, with minor outcrop of Archean rocks such as the Kongling complex that was dated up to ca. 3.2 Ga (e.g., Qiu et al., 2000). Neoproterozoic igneous rocks crop out widely around the Yangtze Block (e.g., Wang et al., 2006b). In the Cathaysia Block, the oldest basement rocks were the amphibolite dated at ~1.80 Ga (LA-MC-ICP-MS method) in the Wuyishan area, mainly in the northeastern portion (e.g., Li et al., 2011), although some older detrital zircons (>2.0 Ga) have also been revealed (e.g., Yu et al., 2008). In addition, minor Mesoproterozoic granitic rocks that were dated at ~1.43 Ga were also recognized in the Hainan Island, to the south (Li et al., 2002). Recently, some Neoproterozoic mafic rocks with similar ages to those around the Yangtze Block were also recognized within the Cathaysia Block (Zhang et al., 2012a).

The recognition of an angular unconformity between post-Silurian cover and strongly deformed pre-Devonian strata in the SCB indicates the occurrence of an orogenic event during early Paleozoic time. Ting (1929) initially defined the event as the Kwangsian movement, whereas other workers subsequently named it as the "Caledonian Orogeny" (e.g., Huang, 1978; Ren, 1991) or the Wuyi–Yunkai orogeny (e.g., Li et al., 2010; Zhang et al., 2012b). As for the nature of the orogeny, some researchers believed that the mountain-building event was the result of the finial closure of the Huanan/Paleotethys Ocean and subsequent collision of the Yangtze and Cathaysia Blocks (e.g., Guo et al., 1989; Hsü, 1994; Chen et al., 2006; Yan et al., 2006). However, the absence of the subduction-related rock associations (e.g., ophiolites, magmatic arc, subduction complexes and high-pressure metamorphic rocks) in the whole SCB convincingly precludes the existence of an ocean basin between the Yangtze and Cathaysia Blocks during early Paleozoic time, which led some researchers to propose an intracontinental orogenic event (e.g., Charvet et al., 1996, 2010; Faure et al., 2009; Li et al., 2010). More recently, on the basis of the fact that the 460–400 Ma event was mainly restricted to the Cathaysia Block, Zhao and Cawood (2012) further suggested that the early Paleozoic (460–430 Ma) orogeny in the Cathaysia Block was a continent–continent collisional event. This resulted in the region occupied by the present-day southeastern margin (Cathaysia) of South China to have amalgamated with an unknown continental block, which later was rifted away along the Zhenghe–Dapu Fault (e.g., Gao, 1991). They thus proposed that the Cathaysia Block represented a continent–continent collisional belt during early Paleozoic time (460–430 Ma), similar to the Appalachian–Caledonian belt in North America and Europe (e.g., Dewey, 1969).

The early Paleozoic granites making up over 30% of exposures and ranging from Ordovician to Late Devonian in age (ca. 400–462 Ma; Li et al., 2010; Wang et al., 2007, 2011; Chu et al., 2012a; Zhang et al., 2012b and references therein), are mainly exposed in the Wugong, Wuyi, Baiyun and Yunkai areas. Most of them are located in the core of the Wuyi–Yunkai orogen, with minor outcrops far away from the orogen (more than 500 km; Fig. 1), such as the Xuefeng and Dulong–Song Chay granitic batholiths (e.g., Roger et al., 2000; Wang et al., 2007, 2011; Li et al., 2010; Chu et al., 2012a). Overall, all the exposed early Paleozoic granitoids show a planar-shaped distribution pattern to the east of the Anhua–Luocheng Fault, the eastern SCB (e.g., Chu et al., 2012a; Zhang et al., 2012b). Most recently, minor early Paleozoic mafic igneous rocks, including high-Mg basalts (Yao et al., 2012) and diabases and gabbros (Wang et al., 2013d) have also been recognized in the Wuyi–Yunkai orogen (Fig. 1b). These igneous rocks have been interpreted as the products of the Wuyi–Yunkai orogeny or Kwangsian orogeny (e.g., Li et al., 2010; Wang et al., 2007, 2011, 2013c; Zhang et al., 2012b; Huang et al., 2013; Zhao et al., 2013). More detailed information on the geological characteristics and field relationship in the SCB has been summarized by Li et al.