Journal of Asian Earth Sciences 156 (2018) 59–74

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Full length article

Petrogenesis of granitoids and associated xenoliths in the early Paleozoic Baoxu and Enping plutons, South China: Implications for the evolution of the Wuyi-Yunkai intracontinental orogen

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ARTICLE INFO

Keywords:
Xenolith
Ancient suture zone
Intracontinental orogeny
Continental growth
South China

ABSTRACT

The early Paleozoic Wuyi-Yunkai orogen was associated with extensive felsic magmatic activities and the orogenic core was mainly distributed in the Yunkai and Wugong domains located in the western Cathaysia block and in the Wuyi domain located in the central part of the Cathaysia block. In order to investigate the evolution of the Wuyi-Yunkai orogen, elemental and Sr-Nd isotopic analyses were performed for granites from the Baoxu pluton in the Yunkai domain and from the Enping pluton in the central part of the Cathaysia block. The Baoxu pluton consists of biotite granite with abundant xenoliths of gneissic granite, granodiorite and diorite, and the Enping pluton is mainly composed of massive granodiorite. Biotite granites (441 ± 5 Ma) and gneissic granite xenolith (443 ± 4 Ma) of the Baoxu pluton are all weakly peraluminous (A/CNK = 1.05–1.10). They show high Sr/Y and La/Yb ratios and have negative bulk-rock $\varepsilon_{Nd}(t)$ values (−7.0 to −4.4), which are similar to coeval gneissic S-type granites in the Yunkai domain and were probably derived from dehydration melting of a sedimentary source with garnet residue in the source. Granodiorites (429 ± 3 Ma) from Enping and granodiorite xenolith (442 ± 4 Ma) from Baoxu are metaluminous and have REE patterns with enriched light REE and flat middle to heavy REE, possibly generated by the dehydration melting of an igneous basement at middle to lower crustal level. Diorite xenolith from Baoxu is ultrapotassic (K_2O = 4.9 wt%), has high contents of MgO (7.0 wt%), Cr (379 ppm) and Ni (171 ppm) and shows pronounced negative Nb, Ta and Ti anomalies. This xenolith also has negative $\varepsilon_{Nd}(t)$ value (−3.6) and low Rb/Ba and high Ba/Sr ratios, and is thus interpreted to be derived from an enriched lithospheric mantle with the breakdown of phlogopite. Early Paleozoic I- and S-type granites in the Wuyi-Yunkai orogen mostly have negative $\varepsilon_{Nd}(t)$ values and do not have juvenile components, consistent with genesis by an intracontinental orogenic event. These early Paleozoic granites occur near the ancient suture zone between the Yangtze and Cathaysia blocks and have high La/Yb and Sr/Y ratios, likely due to the existence of residual garnet in the source, suggesting the thickened crust at ca. 440 Ma. The 450–440 Ma gneissic S-type granites near the suture zone are earlier than those in the central part of the Cathaysia block (~430 Ma). The crustal thickening along the ancient suture zone at 440 Ma propagated into the central part of the Cathaysia block as evidenced by the 430 Ma granites. Early Paleozoic I-type granites near the suture zone clearly show involvement of significant mantle-derived materials, in contrast to granites in the central part of the Cathaysia block. The ancient suture zone may have acted as channels for the emplacement of mafic magmas during the collapse of an intracontinental orogen.

1. Introduction

There are accretionary, collisional and intracontinental orogenic belts (e.g., Cawood et al., 2009). Both the accretionary and collisional orogenic belts formed along convergent margins and are the major sites of the continental growth because they were typically associated with extensive mafic and felsic magmatism (e.g. Jagoutz and Kelemen, 2015; Jahn et al., 2000; Mo et al., 2008). Mafic magmas represent juvenile materials transported from the mantle into the crust, whereas felsic magmas can be generated by crystal fractionation of basaltic magma (Greene et al., 2006; Jagoutz, 2010) or partial melting of pre-existing crust (Atherton and Petford, 1996). Cumulates/residues are denser than

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https://doi.org/10.1016/j.jseaes.2018.01.012
Received 4 August 2017; Received in revised form 24 December 2017; Accepted 14 January 2018

underlying upper mantle and would eventually sink back into the upper mantle, driving the continental crust to evolve towards andesitic composition (Arndt and Goldstein, 1989; Jagoutz, 2010; Jagoutz and Kelemen, 2015; Kay and Kay, 1993; Rudnick and Gao, 2003; Taylor and McLennan, 1985). On the other hand, the intracontinental orogeny away from the plate margins can result in crustal shortening, thickening and exhumation, which is fundamentally driven by the far-field activity of plate-boundary force and mainly localized in the weakened zone (Raimondo et al., 2014; and references therein). This process is illustrated by the uplifting of the Cenozoic Tianshan and Altai Belt in Central Asia (Avouac et al., 1993; Yin et al., 1998), the Neoproterozoic Peterman and the early Paleozoic Alice Springs orogens in central Australia (Raimondo et al., 2014 and references therein), and the Cenozoic Sprigg's orogen in south Australia (Coblentz et al., 1995; Dyksterhuis and Müller, 2008). These intracontinental orogenic belts generally developed low- to middle-grade metamorphism and are lack of large-scale magmatism. Consequently, the intracontinental orogeny may contribute little to the growth and evolution of the continental crust.

The early Paleozoic Wuyi-Yunkai orogeny (Li et al., 2010a; Huang et al., 2013) represents the first extensive tectonothermal event in South China Block (SCB) since break-up of the Neoproterozoic Rodinia supercontinent (e.g., Li et al., 1999, 2006). This orogeny affected a broad area bounded by the Anhua-Luocheng fault in the west and the Zhenghe-Dapu fault in the east (Fig. 1b), including the eastern Yangtze block and most part of the Cathaysia block. The Cathaysia block was uplifted during the orogeny with a widespread unconformity between the Devonian and pre-Silurian strata, together with significant crustal shortening and thickening (e.g. Li et al., 2010a; Wang et al., 2011). However, the nature of the Wuyi-Yunkai orogen has been hotly debated for decades (Guo et al., 1989; Hsü, 1994; Hsü et al., 1990; Huang et al., 2013; Li et al., 2010a; Ren, 1991; Shu et al., 2014; Shui, 1987; Wang et al., 2011, 2013a; Yu et al., 2016). Several lines of evidence suggest that the Wuyi-Yunkai orogen is an intracontinental orogenic belt that was driven by far-field force, including the absence of early Paleozoic ophiolite and subduction related volcanic rocks, lack of syntectonic high-pressure metamorphic rocks and dominant neritic-bathyal sedimentary setting in the early Paleozoic (Li et al., 2010a; Shu et al., 2014; Wang et al., 2011). However, the Wuyi-Yunkai orogeny was also associated with extensive felsic magmatism and high-grade metamorphism in some areas (Fig. 1b; Chen et al., 2012; Chen and Zhuang, 1994; Huang et al., 2013; Li et al., 2010b; Wang et al., 2007a, 2011, 2013a; Yu et al., 2016; Zhang et al., 2012; Zhong et al., 2013), indicating this orogenic belt is quite distinct from other typical intracontinental orogens. Therefore, some studies proposed a collisional orogeny model for this orogenic belt (Guo et al., 1989; Zhang et al., 2015). Early Paleozoic granites in the Wuyi-Yunkai orogen developed mainly from ca. 460 Ma to 400 Ma and include gneissic S-type granites and massive S- and I-type granites. Clarifying the petrogenesis of these granites can give us important insights into the evolution of the Wuyi-Yunkai orogen. Furthermore, the Wuyi-Yunkai orogen may also provide an opportunity for better understanding of magmatic activities during an intracontinental orogeny and its role in the continental evolution, both of which are still poorly constrained.

In this paper, we present zircon U-Pb dating results, mineral compositions, whole-rock major and trace elemental and Sr-Nd isotopic data of samples from the Baoxu pluton in the Yunkai domain located in the western Cathaysia block, and from the Enping pluton in the central part of the Cathaysia block. These samples exhibit great diversity in elemental and isotopic compositions, implying their multiple origins. These results are integrated with the previously published data of early Paleozoic felsic and mafic rocks in the SCB, in order to: (1) investigate their magma sources and petrogenetic processes; (2) illustrate the evolution of the Wuyi-Yunkai orogeny and associated magmatic activities; and (3) offer new perspectives on the intracontinental orogeny in terms of its contribution to the growth and evolution of the continental crust.

2. Geological background and sample descriptions

The SCB consists of the Yangtze block in the northwest and the Cathaysia block in the southeast (Fig. 1a), which were amalgamated during the early Neoproterozoic (e.g., Li et al., 2006, 2008a, 2009a; Wang et al., 2007b). The present northeastern boundary between the two blocks is commonly accepted to be the northeasterly striking Jiangshan-Shaoxing Fault (Fig. 1b) evidenced by Neoproterozoic ophiolites (Chen et al., 1991; Yao et al., 2014), arc-type granites (Li et al., 2008b) and HP/LT blueschists (Li et al., 2009a). The southwestern extension of this boundary is uncertain because of the poor exposure and younger tectonic modifications (Li et al., 2010a; Wang et al., 2013a), which may extend from the Shaoxing-Jiangshan-Pingxiang fault zone to the Hengyang and Longsheng areas (Shu et al., 2015). However, both geochemical and geophysical evidence support the Chenzhou-Linwu Fault as the southwestern boundary between the two blocks (Fig. 1b; Wang et al., 2003; Yu et al., 2016; Zhang and Wang, 2007; Zhang et al., 2013). The Yangtze block contains a Precambrian basement composed predominantly of Paleoproterozoic and a small amount of Archean rocks known as the Kongling Complex (e.g., Gao et al., 2011; Qiu et al., 2000). The Archean-Paleoproterozoic crystalline basement was surrounded by the late Mesoproterozoic to early Neoproterozoic strata, which are locally unconformably overlain by weakly metamorphosed Neoproterozoic strata (i.e., the Banxi Group) and unmetamorphosed upper-Neoproterozoic to Paleozoic succession (Zhao and Cawood, 2012 and references therein). Precambrian basement of the Cathaysia block outcrops mainly in the northeastern Wuyi domain and is composed of Paleoproterozoic granites, meta-sedimentary and volcanic rocks (Fig. 1b; Yu et al, 2009, 2010).

The Yunkai domain in the western Cathaysia block (Fig. 1b) is bounded by the Wuchuan-Sihui fault zone in the east and the Cenxi-Bobai fault zone in the west and covers an area about 2500 km^2 (Fig. 2; Wan et al., 2010; Wang et al., 2007a). The domain was suggested to consist of metamorphosed Proterozoic basement that was once divided into Palaeoproterozoic to Mesoproterozoic "Gaozhou complex" and Mesoproterozoic to early Neoproterozoic "Yunkai group" based on conventional zircon bulk dissolution and evaporation ages and metamorphic grade (Qin et al., 2006; Qiu et al., 1996; Zhong et al., 1996; Zhou et al., 1994, 1996). The "Gaozhou complex" consists of migmatites and supracrustal paragneiss, schist, quartzite and marble, which were metamorphosed at amphibolite facies and locally granulite facies (Chen and Huang, 1994; Chen et al., 2012; Wan et al., 2010; D. Wang et al., 2013). The low-grade metamorphic "Yunkai group" always surrounds the domains of high-grade metamorphic "Gaozhou complex" and consists mainly of schist, slate and phyllite with minor paragneiss, amphibolite and marble. However, recent geochronology data suggest that the so called "basement" should form during the Neoproterozoic and Paleozoic (Wan et al., 2010; Wang et al., 2007a). The Gaozhou complex and Yunkai group are unconformably overlain by the Devonian and younger sedimentary sequences, with the absence of Silurian sedimentary strata (Fig. 2). The granitic plutons outcropped in the Yunkai domain are composed of dominant gneissic granites formed at ca. 452–415 Ma, and subordinate massive granitoids that mostly emplaced during the Permian-Cretaceous (Fig. 2; Wang et al., 2007a). The gabbroic plutons at north of the Xinyi city have the crystallization age of 423 ± 8 Ma (Fig. 2; Wang et al., 2013b).

The Taishan batholith in the central part of the Cathaysia block (Fig. 1a) intruded into the Cambrian and Ordovician strata and was overlain by lower-middle Ordovician conglomerate and sandstone (Fig. 2; GDBGMR, 1988; Li et al., 1993; Huang et al., 2013). The rocks are massive and include biotite granodiorite, hornblende-bearing granite and biotite granite with crystallization age of about 436 ± 3 Ma (Huang et al., 2013).