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Geochemical transition shown by Cretaceous granitoids in southeastern China: Implications for continental crustal reworking and growth

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ABSTRACT

Zircon U–Pb ages and in-situ trace elements and Hf–O isotope compositions, together with whole rock geochemical and Sr–Nd–Hf isotopic data, are presented for Cretaceous granitoids in southeastern (SE) China in order to establish their origin and the evolution of the underlying lithosphere during the Late Mesozoic. Two stages of Cretaceous magmatism, with contrasting geochemical features, have been identified: an earlier adakite-like biotite granite as represented by the Shangying pluton and a later enclave-bearing monzogranite as represented by the Zaoshan pluton. The Shangying biotite granites have a zircon U–Pb age of 99 ± 1 Ma. They have relatively low Y and Yb contents, with high La/Yb and Sr/Y ratios, showing geochemical features of adakite. Their Sr–Nd–Hf isotope compositions are similar to those of Early Cretaceous mafic rocks in the same area, indicating that they were generated by partial melting of juvenile granulitic crust at a depth of about 40 km. The source was formed by underplating of enriched lithosphere mantle-derived magmas. In contrast, the Zaoshan calc-alkaline monzogranites, their enclaves and associated dolerite dykes from the Zaoshan pluton have an emplacement age of ~88 ± 1 Ma. The dolerites have high MgO contents, relatively low SiO_2 concentrations and low La/Yb ratios, and depleted Hf isotope compositions. All these geochemical features suggest that they were derived from a depleted spinel lherzolite mantle source. The enclaves have high SiO_2 contents, indicating that they were derived from a crustal source. They have variable zircon Hf and O isotope compositions, suggesting that two components, i.e., a high $\varepsilon_{Hf}(t)$ and a low $\delta^{18}O$ component and a low $\varepsilon_{Hf}(t)$ and high $\delta^{18}O$ component, were involved in their origin. The high zircon $\varepsilon_{Hf}(t)$ values and low $\delta^{18}O$ values are similar to those of the dolerites, indicating a common source. Thus, we suggest that the enclaves were generated by partial melting of newly underplated depleted mantle-derived materials. The monzogranites have distinctly different zircon Hf and O isotope compositions from the enclaves, indicating that the parental magmas were mainly derived from ancient crust that interacted with underplated depleted mantle-derived magmas. The monzogranites have relatively high HREE contents, suggesting a garnet-free source (<32 km), distinct from the Early Cretaceous adakite-like granites that were generated from a garnet-bearing source. Combined with previously published data, it is evident that Early Cretaceous adakite-like magmatic rocks (107–99 Ma) and associated mafic rocks (100–107 Ma) were widespread in SE China, indicating a crustal thickening event that was possibly induced by underplating of mantle-derived magma. Subsequently, between 99 and 87 Ma, crustal extension and lithospheric thinning induced the later widespread I-type granites with similar geochemical features to the Zaoshan pluton. A-type granites and syenites of this age are also present in SE China. The transition in geochemical and isotopic data, from enriched to depleted Hf isotope compositions as seen in the monzogranites, their enclaves and intrusive dolerites, suggest that depleted mantle-derived materials were involved in the generation of the monzogranites, further indicating continental crustal reworking and later crustal growth in SE China during the early Late Cretaceous.

1. Introduction

Granitic magmatism represents a major contribution to crustal growth and reworking and, consequently, is one of the most important mechanisms of geochemical differentiation of the Earth's crust since the Archean (Castro et al., 1999; Kemp and Hawkesworth, 2003; Kemp et al., 2007; Petford et al., 2000; Rudnick, 1995; Sawyer, 1998; Taylor and McLennan, 1995). One of the notable geologic features of eastern China is the massive amount of Mesozoic igneous rocks that are distributed from southeast to northeast China and belong to the major Phanerozoic circum-Pacific orogenic belts (Charvet et al., 1994; Guo et al., 2011; Jiang and Li, 2014; Li and Li, 2007; Li et al., 2010a,b,c; Q. Wang et al., 2012; Wu et al., 2002, 2005, 2012; Y.J. Wang et al., 2012; Zhou and Li, 2000; Zhou et al., 2006). Petrogenetic studies of the Mesozoic granitoids in northeast China and the North China Craton reveal that

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granitic magmatism was related to lithospheric thinning and transition from a thick, old, cold and refractory lithospheric keel to a thin, young, hot newly-underplated crust derived from fertile mantle (Wu et al., 2005; Xu et al., 2004; Yang et al., 2003, 2004, 2007a,b, 2008, 2010a). In southeastern (SE) China, detailed investigations of basalts and their xenoliths reveal that the subcontinental lithosphere mantle (SCLM) was thinned and the nature of the lithospheric mantle changed from enriched to depleted during the Mesozoic time (Liu et al., 2011, 2012; Zheng et al., 2004). Recent petrogenetic studies of Mesozoic magmatic rocks have produced a wealth of information about the geochemical evolution of the lithospheric mantle beneath SE China, which is linked to mantle–crust interactions and can help us to understand geological processes beneath the continental crust (He and Xu, 2012; Li, 2000; Liu et al., 2011, 2012; Q. Wang et al., 2012; Yu et al., 2003; Zheng et al., 2004; Zhou et al., 2006). However, the relationship between granitic magmatism and Mesozoic tectonic events is still unclear. The genesis of magmatism is a key factor for understanding lithospheric evolution and continental crustal reworking and/or growth and is the subject of this study.

Cretaceous intrusive rocks in the coastal area of SE China are dominated by calc-alkaline granites with minor A-type granites, syenites and gabbros (Chen and Jahn, 1998; Chen et al., 2001, 2004; Jahn, 1974; Li and Li, 2007; Martin et al., 1994; Xu et al., 1999; Zhou et al., 2006). Recent studies have identified a late Early Cretaceous belt comprising adakite-like rocks in the coastal area of SE China, associated with gabbros and diorites both temporally and spatially (Chen et al., 2005; Q. Wang et al., 2012; Xiong et al., 2003). These rocks are thought to be related to crustal thickening (Q. Wang et al., 2012). Following thickening of the crust, widespread syenites and A-type granites are considered to be related to crustal extension (Chen et al., 2013; Martin et al., 1994; Qiu et al., 2004). This change may correspond to considerable thinning of the continental crust and lithospheric mantle, which most likely occurred in the Late Mesozoic (Chen et al., 2001, 2004; Q. Wang et al., 2012).

To test these models, we present new zircon SIMS and LA-ICP-MS U–Pb ages and zircon Hf–O isotopic data, together with whole rock geochemical and Sr–Nd–Hf isotopic analyses of an adakite-like granitic pluton, as well as for a more typical calc-alkaline granitic pluton from SE China. Our results reveal the origins of these granitoids and clarify the relationship between granitic magmatism and the interaction of continental crust with lithospheric mantle during the Mesozoic time in SE China.

2. Geological background

Eastern China is composed of the Central Asian Orogenic Belt and the North China Craton in the north, the Dabie–Sulu orogenic belt in the central part and the South China Block in the south. Since the Mesozoic, it has become an important part of the circum-Pacific tectono-magmatic zone. Mesozoic volcanic rocks, calc-alkaline granites, adakites or adakite-like rocks and A-type granites are widely distributed in eastern China and other circum-Pacific areas (Collins and Richards, 2008; Girardi et al., 2012; Q. Wang et al., 2012; Wu et al., 2002, 2005, 2012; Yang et al., 2004, 2007a).

The South China Block is composed of the Yangtze Craton in the northwest and the Cathaysia Block in the southeast (Fig. 1a), which are separated by the Jiang-Shao (Jiangshan-Shaoxing) fault zone (Charvet et al., 1996; Chen and Jahn, 1998; Li and McCulloch, 1996). The Cathaysia Block can be further divided into interior (western Cathaysia) and coastal parts (eastern Cathaysia) along the Zhenghe-Dapu Fault (Fig. 1b), which may have different crustal evolution histories (Chen and Jahn, 1998; Xu et al., 2007). There are abundant Early Paleozoic granites and metamorphosed Early Paleozoic–Neoproterozoic sedimentary rocks of different metamorphic grades present in the interior of western Cathaysia, but few Precambrian rocks occur in the coastal part of eastern Cathaysia (Yu et al., 2010). Abundant Mesozoic granites are exposed in the Cathaysia Block (Fig. 1b) and these granites are conventionally considered to represent products of two periods of tectono-magmatic events: the Indosinian and the Yanshanian (Li and Li, 2007; Zhou et al., 2006). The Indosinian (240–205 Ma) granites and the Early Yanshanian (180–145 Ma) granites are concentrated in western Cathaysia, whereas the Late Yanshanian (145–90 Ma) granites are distributed across the coastal region of eastern Cathaysia (Zhou et al., 2006). Previous investigations indicated that, in the coastal area, Cretaceous igneous rocks range from monzogranites to alkaline feldspar granites, associated with local A-type granites and basalt–rhyolite bimodal volcanic rocks. Numerous K–Ar, Ar–Ar, Rb–Sr and Sm–Nd isotopic ages and a few TIMS and LA-ICP-MS zircon U–Pb ages indicate that the granites, basalt–rhyolite bimodal volcanic rocks and deformed granites in the coastal region formed between 146 and 77 Ma (Chen et al., 2001, 2004, 2008, 2013; Gilder et al., 1996; Guo et al., 2011; He and Xu, 2012; Jahn et al., 1976; Q. Wang et al., 2012; Tong and Tobisch, 1996; Y.J. Wang et al., 2012; Zhou and Wu, 1994; Zhou et al., 2006). Petrographic and geochemical studies suggest that mantle-derived magmas have played a significant role in the petrogenesis of these rocks (Chen and Jahn, 1998; Chen et al., 2013; Holden et al., 1987; Jahn, 1974; Martin et al., 1994; Q. Wang et al., 2012; Xu et al., 1999; Zhou et al., 2006).

3. Petrography

This study is focused on two representative plutons, the Zaoshan pluton and the Shangying pluton, both located in the coastal SE China (Fig. 1c & d). The Shangying pluton mainly consists of biotite granite (Fig. 2a & b), whereas the Zaoshan pluton consists of monzogranite, with felsic enclaves, and is intruded by dolerite dykes (Fig. 2c–f). The biotite granite is orange to red-brown and coarse-grained and mainly consists of K-feldspar (~25 vol.%), plagioclase (~35 vol.%), quartz (~25 vol.%), and biotite (~5 vol.%), with minor apatite, zircon, titanite and Fe–Ti oxides. The monzogranite of the Zaoshan pluton mainly consists of subhedral K-feldspar (~40 vol.%), plagioclase (~25 vol.%), anhedral quartz (~30 vol.%) and biotite (~3 vol.%). Accessory minerals include apatite, zircon, titanite and Fe–Ti oxides. Granophyric texture (quartz intergrown with K-feldspar) is present and there is no evidence of deformation of the monzogranite.

The dolerites and felsic enclaves occur within the Zaoshan monzogranites. The felsic enclave exhibits a fine granular texture and consists of quartz, plagioclase and K-feldspar. They have sharp contacts with the host monzogranite (Fig. 2d), suggesting that interaction (magma mixing or mingling) between the mafic magma and host felsic magma was minimal at this level of exposure. Contemporaneous dolerites occur as sheets of up to several meters in length and intrude the monzogranites (Fig. 2e& f). The dolerite mainly consists of pyroxene, plagioclase, biotite, K-feldspar and magnetite.

4. Analytical methods

4.1. Major and trace elements

Samples from the Shangying and Zaoshan plutons were analyzed at the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS), Beijing, China. Major and trace elements were determined by XRF and ICP-MS (Agilent 7500a), respectively. Analyses of rock standards indicate precision and accuracy better than 5% for major elements and 10% for trace and rare earth elements.

4.2. Whole rock Sr, Nd and Hf isotopes

Whole-rock Sr–Nd–Hf isotopic data were obtained using the Neptune-plus multi-collector mass spectrometer (MC-ICPMS) at the IGGCAS (Yang et al., 2010b, 2011a,b). Chemical separation was undertaken by conventional ion-exchange techniques. The detailed