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Reworking of juvenile crust: Element and isotope evidence from Neoproterozoic granodiorite in South China

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Abstract

A combined study of geochronology and geochemistry was carried out for Neoproterozoic granodiorites at the southeastern margin of the Yangtze Block in South China. The results demonstrate that sedimentary rocks derived from juvenile crust were melted to form strongly peraluminous granite in an arc-continent collision zone, resulting in continental growth. LA-ICPMS zircon U-Pb dating yields two groups of age at 824 ± 6 and 882 ± 16 Ma, respectively. From CL images, the young zircons are new grains or rims of homogeneous structure with magmatic zoning, whereas most of the old ages occur in cores or as single xenocrysts. The granodiorites show high A/CNK ratios of 1.38–1.89 and strong negative Nb and Ta anomalies as well as high $\delta^{18}O$ values of 11.9–14.0‰ for quartz and 8.1–10.2‰ for zircon, pointing to a supracrustal origin characteristic of S-type granites. On the other hand, they have positive $\varepsilon_{Hf}(t)$ values of 3.4 ± 1.6 to 5.4 ± 2.6 for zircon, neutral $\varepsilon_{Nd}(t)$ values of -2.06 to 0.02 and low to medium initial $^{87}Sr/^{86}Sr$ ratios of 0.7033–0.7087 for whole-rock, indicating a magmatic source with significant components of juvenile crust similar to I-type granites. Relatively refractory minerals like zircon, garnet and quartz retain their magmatic O isotope ratios, whereas the other minerals, such as K-feldspar, plagioclase and biotite that show O isotopic disequilibria when paired with quartz, suffered different degrees of post-magmatic alteration at subsolidus temperatures. On the basis of element and isotope geochemistry, we interpret the 882 ± 16 Ma zircons as being inherited from arc-derived igneous rocks, and the 824 ± 6 Ma zircons as having crystallized from an anatectic crustally-derived magma. Arc-continent collision is inferred to have taken place at ca. 900 ± 20 Ma during assembly of the supercontinent Rodinia. Subsequent to weathering of juvenile crust in the back-arc basin, low-maturity sedimentary rocks were deposited from about 880 to 830 Ma between the Yangtze and Cathaysia Blocks. Extensional collapse of the collisional orogen at about 830–820 Ma is suggested as a geodynamic mechanism for burial and melting of the sediments of juvenile crust to produce the S-type granodiorites. As a result, the granodiorites are characterized by the features of both S- and I-type granites, and thus testify to the short-term recycling of juvenile crust with significant contributions to continental growth. The syn- and post-collisional magmatism may be a basic mechanism to result in compositional evolution from arc crust to continental crust.

Keywords: Peraluminous granite; Geochronology; Geochemistry; Petrogenesis; Arc-continent collision; Continental growth; Extensional collapse

1. Introduction

Granite is the most important component of continental crust, recording information about its formation

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and evolution in the processes of plate convergence and mantle upwelling. This issue has become particularly pertinent for Neoproterozoic igneous rocks in South China because their origin is closely associated with assembly and breakup of the supercontinent Rodinia. Recent studies of geochronology and geochemistry on these rocks hypothesize that granitoid rocks crystallized at ca. 830–740 Ma in the periphery of the Yangtze Block may petrogenetically be related to the Rodinia breakup that could be triggered by a mantle superplume event (Li et al., 1999, 2003a, 2003b). In view of trace element compositions, however, this genetic hypothesis has been challenged and an alternative scenario of island-arc origin has been proposed for some of Neoproterozoic igneous rocks (Zhou et al., 2002a, 2002b, 2004; Wang et al., 2004a, 2004b). Basic questions remain as to how to identify the contribution of energy and material from a mantle plume (or superplume) in granite petrogenesis and how to distinguish igneous rocks of island-arc origin from those derived from crustal melting in collision orogens. If no coeval mantle-derived material was added to granitoid magmas, extensional collapse of orogens may be a viable mechanism for generation of post-collisional granitoids (Dewey, 1988).

Neoproterozoic granodiorites at the southeastern margin of the Yangtze Block, particularly those geographically located in the southern part of Anhui province (South Anhui hereafter), have been one of the important targets for this controversy. Previous petrological and geochemical investigations show that they have high ratios of molecular $Al_2O_3/(CaO + Na_2O + K_2O)$, or A/CNK ratios, of 1.1–1.5 with the occurrence of cordierite (Li et al., 2003a), pointing to a sedimentary source that experienced chemical weathering. On the other hand, neutral $\varepsilon_{Nd}(t)$ values of −1.7 to −0.2 and low initial $^{87}Sr/^{86}Sr$ ratios of 0.70392 ± 0.00033 were obtained (Zhou and Wang, 1988; Li et al., 2003a), indicating a magmatic source with significant components of juvenile crust. These contrasting features provide us with a good opportunity to study the recycling of juvenile crust and its contribution to continental growth, with a potential resolution to the genetic controversy concerning the Neoproterozoic granitoids in South China. This paper presents a combined study of zircon U–Pb dating and Lu–Hf isotopes, whole-rock elements and Sr–Nd isotopes, and mineral O isotopes for the Neoproterozoic granodiorites in South Anhui.

Zircon is a refractory mineral that forms a highly robust phase in many geological environments and thus is readily amenable to methods of radiometric dating and geochemical tracing (Hanchar and Hoskin, 2003). Igneous zircons commonly have complex internal structures and may record the multistage evolution of their host rocks. Thus a combined study of in situ U–Pb dating and cathodoluminescence (CL) imaging can be used to decipher their protolith age and history. Furthermore, application of Hf isotopes in zircon has been well developed recently to trace igneous rock origin and the evolution of crust and mantle over time (e.g., Amelin et al., 1999, 2000; Griffin et al., 2000, 2002; Andersen et al., 2002; Samson et al., 2003; Zheng et al., 2006). The Sm–Nd isotope method is also a means of acquiring the average age of crustal residence (e.g., Jacobsen, 1988; DePaolo et al., 1991), and can be used to distinguish between juvenile young and recycled ancient crusts. On the other hand, the O isotope geochemistry of crust-derived magmas can reflect the long term mixing of mantle-derived melts with the crust, with a particular advantage for identification of surface water (Hoefs, 2004). Magmatic zircon has been demonstrated to be capable of preserving its igneous $\delta^{18}O$ value through subsolidus hydrothermal alteration and granulite-facies metamorphism (Valley, 2003; Zheng et al., 2004), so that the zircon O isotope method can be used to trace the geochemical nature of its magmatic source. This study has taken full advantage of these different approaches for the purpose of solving the problems concerning the origin of granites. The results indicate that orogenic belts formed by arc-continent collisions contain invaluable records of the continental growth and evolution.

2. Geological setting and samples

The South China Craton consists of the Yangtze and Cathaysia Blocks lying to the northwest and southeast, respectively, of the Jiangshan-Shaoxing fault that is bounded by the Jiangnan Fold Belt (inset in Fig. 1). Subduction of ocanic crust during the Late Mesoproterozoic to Early Neoproterozoic is commonly assumed for convergence between the two blocks, with arc-continent and/or continent–continent collisions postulated between them (e.g., Charvet et al., 1996; Zhao and Cawood, 1999; Li et al., 2002a; Li and Li, 2003). The Neoproterozoic granodiorites in South Anhui are located in the eastern part of the Jiangnan Fold Belt between the Yangtze and Cathaysia Blocks (Fig. 1). They have a total outcrop area of ca. 200 km^2, and include three intrusives: the Xucun (133 km^2), Xiuning (32 km^2) and Shexian (32 km^2) plutons. They intrude the Shangxi Group, a sequence of low-grade metasediments of late Mesoproterozoic to early Neoproterozoic age, but are unconformably overlain by middle Neoproterozoic sediments of the Xiuning Formation (Wang and Li, 2003). All three plutons consist of biotite-rich, cordierite-bearing gran-