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Early Paleozoic crustal anatexis in the intraplate Wuyi–Yunkai orogen, South China ☆

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ABSTRACT

Early Paleozoic amphibolite- to granulite-facies metamorphism, crustal anatexis and coeval magmatism are extensively developed in the Wuyi–Yunkai intraplate orogen in the South China block. However, the exact timing of granulite-facies partial melting and its link with orogenesis have not been well constrained. In this study, the charnockites, gneissic migmatites and Al-rich gneisses (Grt–Sil–Bt gneiss and Bt–Pl gneiss) from the Gaozhou Complex of the Yunkai uplift in the Cathaysia block were selected for the analysis of whole-rock major elements and zircon U–Pb dating, trace elements and Lu–Hf isotopes. The Gaozhou Complex experienced early Paleozoic regional high-temperature (up to 850 °C), low- to medium-pressure (4–7 kbar) metamorphism accompanied by crustal anatexis. The melts were produced through the dehydration of mica, such as biotite + quartz + plagioclase = orthopyroxene + K-feldspar + melt and biotite + quartz + plagioclase + sillimanite = garnet + K-feldspar + melt in the charnockites, and muscovite + quartz + plagioclase = sillimanite + K-feldspar + melt in the Grt–Sil–Bt gneisses. The charnockites, gneissic migmatites and gneisses are felsic with $SiO_2 > 64\%$ and peraluminous with A/CNK > 1.0, reflecting protoliths with affinities to sedimentary rocks. Zircons from these rocks partly show clear core–rim structure and yield concordant ages mainly around 440–425 Ma, with minor groups at 2.8–2.4 Ga, 1.5–1.25 Ga, 1.2–0.9 Ga, 850–540 Ma and 460–450 Ma. The 440–425 Ma grains are euhedral, oscillatorily-zoned and have steep slopes from the LREE to the HREE with a positive Ce anomaly and clear negative Eu anomaly, suggesting they (re-) crystallized in the melts. These early Paleozoic zircons have negative ε_{Hf} (t) (−34.1 to −1.5) and much older T_{CRUST} (3.6–1.5 Ga), demonstrating they were formed by re-melting of old crustal materials (>1.5 Ga). The zircons with ages of 2.8–2.4 Ga, 1.6–1.2 Ga and 1.2–0.9 Ga have relatively high ε_{Hf} (t) values (up to +10.2–+15.2). The 850–540 Ma zircons show variable ε_{Hf} (t) values of +9.0 to −24.0 with T_{DM} (depleted mantle Hf model ages) = 2.2–1.0 Ga and T_{CRUST} (crustal Hf model ages) = 3.1–1.1 Ga. Combined with the published data, we suggest that the Cathaysia block contains Archean materials as old as 3.6 Ga and has had a complex evolution, including the addition of juvenile materials at ca 2.7 Ga, 1.6–1.2 Ga and 1.2–0.9 Ga. Reworking of old crustal components dominated at ca 850–750 Ma, 750–540 Ma, 460–450 Ma and more intensively at ca 440–425 Ma. Synthesizing the obtained results, we argue that the Yunkai charnockites, gneissic migmatites and Bt–Pl gneisses were formed due to the early Paleozoic high-T crustal anatexis, which may have been triggered by crustal shortening and thickening during the intraplate Wuyi–Yunkai orogeny in the South China block.

1. Introduction

Crustal differentiation is mainly achieved through partial melting and segregation of felsic melt from more mafic residue (Brown and Rushmer, 2006; Hawkesworth and Kemp, 2006; Kemp et al., 2007). In continental collision belts, regional high-grade metamorphism accompanied by crustal anatexis has long been of interest to petrologists (e.g. Brown, 1994; Sawyer, 1998). Crustal anatexis, represented by the presence of granitic melts or formation of migmatites, is common and plays an important role in regulating the tectonic evolution of large-scale orogenic belts (Beaumont et al., 2001; Brown, 2007; Grujic et al., 2002; Hollister, 1993; Zeitler et al., 1993). To understand the thermal and mechanical significance of crustal melting in orogens, it is crucial to determine the timing of magmatic and metamorphic events associated with the tectonic evolution of orogenic crust (Whitney et al., 2003). However, it is difficult to constrain the exact geochronology of crustal anatexis, partly because of the high temperature and multiple

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episodes of metamorphism (Foster et al., 2001). In-situ U–Pb dating of zircon, combined with analysis of Hf isotopes, has been developed not only to trace rock origins and the evolution of crust and mantle (Amelin et al., 2000; Griffin et al., 2000, 2002), but also to reveal the processes involved in the generation of crustal partial melts (Flowerdew et al., 2006).

The early Paleozoic Wuyi–Yunkai orogen covers the southeastern half of the South China block (Fig. 1). It is considered to be one of the few examples of an intraplate orogen in the world (Z.X. Li, 1998; Li et al, 2010) and is a key to understanding the formation and evolution of East Asia, the process of intraplate orogenesis and global early Paleozoic geodynamics (Li et al, 2010). Granitoids and high grade metamorphic rocks occur widely in the Wuyi–Yunkai orogen (e.g. Wang et al., 2011; Y.J. Wang et al., 2013; Yu et al., 2009). The Gaozhou Complex in the Yunkai uplift (Fig. 1) is mainly composed of high-grade metamorphic rocks (Wan et al., 2010 and references therein). It underwent extensive high-T, low- to medium-P amphibolite- to granulites-facies metamorphism and crustal anatexis in early Paleozoic time (Chen et al., 2012). This provides an opportunity to probe the relationships between regional metamorphism, anatexis and intraplate orogeny. However, little evidence of crustal anatexis, in terms of petrographic features and melt-producing reactions, has been recognized in the Yunkai orogenic belt. Especially, the timing of crustal melting and the constraints on the intraplate orogenesis are still uncertain (Wang et al., 2007, 2011).

Following detailed petrographic observations, here we present the whole-rock chemistry, and the U–Pb ages, trace-element and Hf-isotope compositions of zircon from the charnockites, gneissic migmatites and Al-rich gneisses in the Gaozhou Complex of the Yunkai orogenic belt in the South China block. Our aims are: 1) to illustrate the nature and source of the protoliths of the Gaozhou Complex; 2) to recognize the possible melt-producing reactions and the exact timing of crustal anatexis in the Yunkai uplift and 3) to discuss the relationships between the early Paleozoic crustal anatexis and the intraplate Wuyi–Yunkai orogen.

2. Geologic setting and sampling

The South China block consists of the Yangtze block in the northwest and the Cathaysia block in the southeast (insert of Fig. 1): these two blocks were amalgamated roughly along the Jiang Shao Fault zone in early Neoproterozoic time (Charvet et al., 1996; Chen and Jahn, 1998; Zhao and Cawood, 1999). The Nanhua Rift (or the Nanhua rift basin) developed in the newly amalgamated South China block from 850 to 750 Ma (Charvet et al., 2010; Li et al., 2005; Wang and Li, 2003), evolved with a thick sedimentation in its middle part until the Ordovician. The early Paleozoic Wuyi–Yunkai orogeny closed the Nanhua Rift (Z.X. Li, 1998; Li et al., 2003; Wang et al., 2007). This orogen covers the southeastern half of the South China block, stretching for ~2000 km in a northeasterly direction (Fig. 1, Ren et al., 1999). Due to the lack of early Paleozoic ophiolitic rocks or arc magmatism (Charvet et al., 1996; Shu et al., 1991), the Wuyi–Yunkai orogen is generally regarded as an intraplate orogen (Charvet, 2013; Li et al., 2010; Wang et al., 2011). This is compatible with the

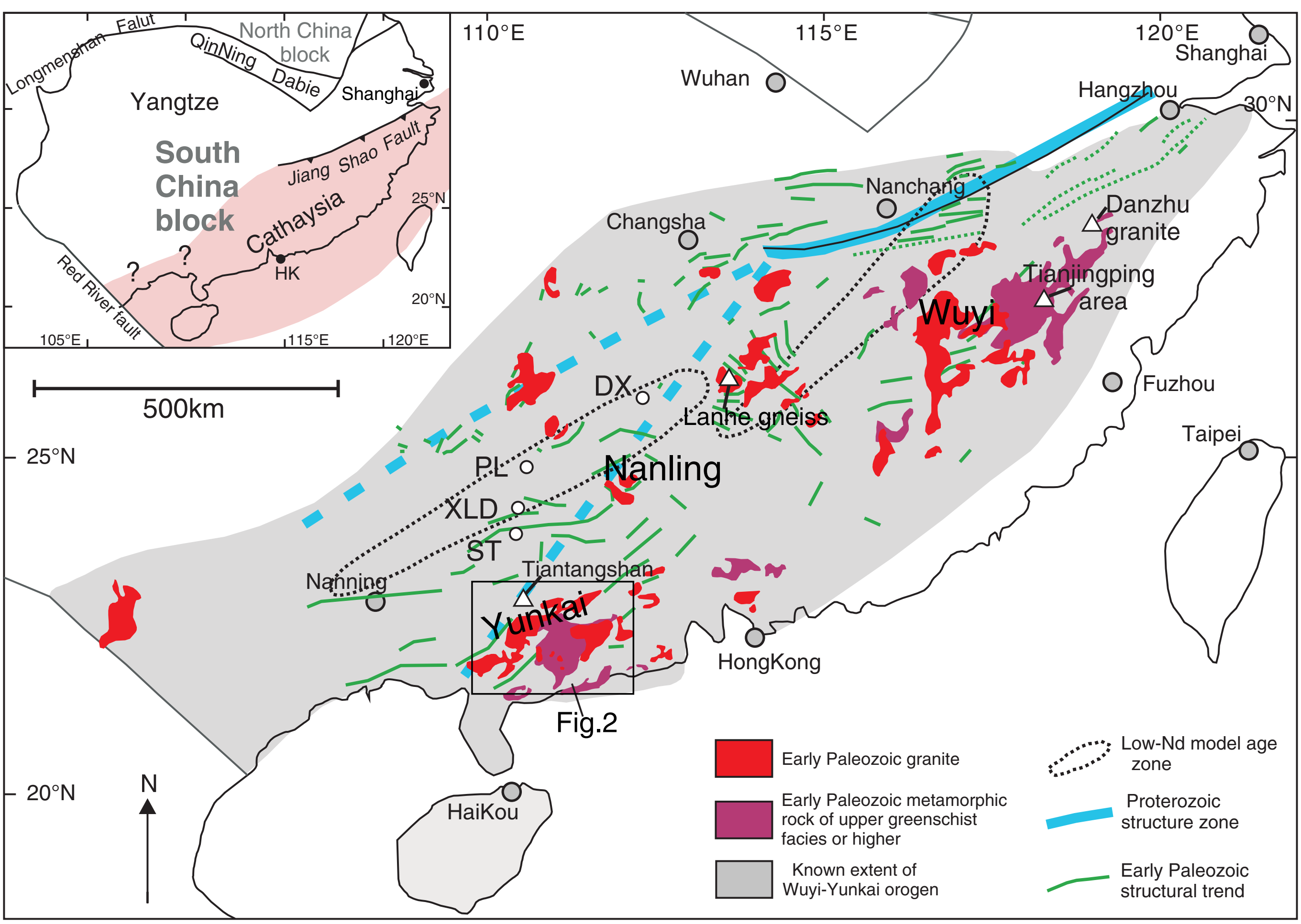

Fig. 1. Simplified regional map highlighting the regional extent of the early Paleozoic Wuyi–Yunkai orogen, early Paleozoic metamorphic and granitic rocks (modified after Li et al., 2010; Shu et al., 2013). Distribution of "low-Nd model age belt" is based on Chen and Jahn (1998). PL, Pingle; ST, Shuangtian; XLD, Xiaoliudian; DX, Daoxian. The inset figure shows that the South China block is made of the Yangtze and Cathaysia blocks.