1 **I-type granitoids associated with the early Paleozoic intracontinental**
2 **orogenic collapse along pre-existing block boundary in South China**

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8

9 **Abstract**

10 The early Paleozoic Wuyi-Yunkai orogeny resulted in extensive magmatism in the
11 Cathaysia and eastern Yangtze blocks, South China. Identifying the nature of related
12 magmatism is essential for understanding the orogeny that remains enigmatic with regard
13 to its tectonic setting and geodynamic driving force. The Zhangjiafang pluton (438±3 Ma)
14 in western Jiangxi province is composed of predominant granodiorite with abundant
15 coeval mafic-intermediate microgranular enclaves (MMEs) (~433±5 Ma). The
16 granodiorite samples are weakly peraluminous (A/CNK = 1.05–1.09) and have low SiO₂
17 (61.9–64.9 wt %) and high Fe₂O₃ (4.6–5.6 wt %), MgO (2.2–2.8wt %) and CaO (4.3–4.8
18 wt %), belonging to I-type suite due to abundant amphibole in the rocks. They exhibit
19 strongly negative whole-rock $\epsilon_{\text{Nd}}(t)$ values (-11 to -9) and zircon $\epsilon_{\text{Hf}}(t)$ values (-14 to -4),
20 similar to the basement of the Cathaysia Block, but distinguishable from simultaneous I-
21 type granites of the Banshanpu and Hongxiaqiao plutons in eastern Yangtze Block in

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much lower Sr, Ba, Th and U. The MME samples show pronounced negative Nb-Ta-Ti anomalies and have overall less negative whole-rock $\epsilon_{\text{Nd}}(t)$ (-9 to -7) and zircon $\epsilon_{\text{Hf}}(t)$ values (-9 to -4) than the host granodiorite, which are best interpreted as products of mantle-derived melts that mixed insufficiently with crust-derived magma.

The block boundary between the eastern Yangtze and Cathaysia blocks should pass through the nearby west area (i.e., Pingxiang City) of the Zhangjiafang pluton. The Early Paleozoic I-type granitic rocks near the block boundary have all negative $\epsilon_{\text{Nd}}(t)$ and $\epsilon_{\text{Hf}}(t)$ values, demonstrating an overall ancient basement of the two blocks prior to the Wuyi-Yunkai orogeny, preferring an intracontinental orogeny model. However, the early Paleozoic mafic rocks and I-type granites with coeval MMEs were frequently present along the Jiangshan-Shaoxing-Pingxiang Fault zone, illustrating widespread modification of the ancient basement adjacent to the block boundary by mantle-derived melt during the orogenic collapse. The pre-existing block boundary might have promoted asthenosphere upwelling and basaltic underplating during the intracontinental orogenic collapse.

Key words: mafic microgranular enclaves; I-type granite; pre-existing block boundary; intracontinental orogen; eastern Yangtze Block; Cathaysia Block

39 1. Introduction

40 The South China Block (SCB) consists of the Yangtze Block in the northwest and
41 the Cathaysia Block in the southeast, which have distinct basements (e.g., Zhao and
42 Cawood, 2012; Zhang et al., 2012) and were amalgamated during the Early
43 Neoproterozoic (e.g., Li et al., 2006, 2008, 2009; Wang et al., 2007). After that, it
44 underwent at least three major tectonothermal events of the Wuyi-Yuankai orogeny
45 (early-middle Paleozoic), Indosinian event (Triassic) and Yanshanian event (Jurassic–
46 Cretaceous) (e.g., Charvet, 2013; Charvet et al., 2010; Faure et al., 2009; Li et al., 2010;
47 Shu et al., 2014; Wang et al., 2013a). The early Paleozoic Wuyi-Yunkai orogeny, as the
48 first extensive tectonothermal event in South China since the Neoproterozoic break-up of
49 the Rodinia supercontinent (e.g., Chen et al., 1991; Li et al., 2010; Shu et al., 2014; Wang
50 et al., 2011), resulted in the remobilization of basement of the eastern Yangtze and
51 Cathaysia blocks. The reactivation would be due to orogenic collapse, which is
52 progressively revealed by recent investigation on early Paleozoic mafic rocks (Fig. 1b)
53 (Yao et al., 2012; Wang et al., 2013b; Zhang et al., 2015) and I-type granites in the
54 eastern SCB (Fig. 1b) (Huang et al., 2013; Guan et al., 2014; Xia et al., 2014; Zhang et al.,
55 2015). Alternatively, the Wuyi-Yunkai orogeny has been regarded as a consequence of
56 continental or arc collisions with closure of a proposed Huanan Ocean between the
57 eastern Yangtze and Cathaysia blocks (Shui, 1987; Guo et al., 1989; Hsü, 1994; Hsü et al.,
58 1990). However, the most recent work interpreted it as an intraplate orogenic event (e.g.,
59 Charvet et al., 2010; Faure et al., 2009; Li et al., 2010; Wang et al., 2007, 2011, 2013a).
60 Nevertheless, the orogeny remains enigmatic with regard to its tectonic setting and
61 geodynamic driving force (Li et al., 2010; Wang et al., 2013a, 2013b). Identifying the

nature of related magmatism and tectonic boundary between the eastern Yangtze and Cathaysia blocks is essential for understanding the processes responsible for the orogeny.

Fig. 1

The early Paleozoic northeastern boundary between the Yangtze and Cathaysia blocks is commonly accepted as the northeasterly striking Jiangshan-Shaoxing Fault (Fig. 1b) for evidence including Neoproterozoic ophiolites (Chen et al., 1991; Yao et al., 2014), arc-type granites (Li et al., 2008) and HP/LT blueschists (Li et al., 2009). However, the middle part of the boundary is still ambiguous and has been largely debated (Fig. 1b) due to poor exposure and strong modification by young tectonic events (Li et al., 2010; Wang et al., 2013a). Recent studies about sedimentology, biofacies and lithofacies suggest that the tectonic boundary would extend from the Shaoxing-Jiangshan-Pingxiang fault zone to the Hengyang and Longsheng areas (Fig. 1b) (Chen et al., 2012; Shu et al., 2015). Whereas, Wang et al. (2003) proposed that the Chenzhou-Linwu Fault could represent the southwestern part of the boundary between the two blocks (Fig. 1b) because the mafic rocks across the fault show distinct geochemical characteristics and define different lithosphere mantle sources across the fault. This is also consistent with recent geophysical data that exhibit different geophysical properties in the crust across the Chenzhou-Linwu Fault (Rao et al., 2012). The early Paleozoic I-type granites in the eastern Yangtze and Cathaysia blocks could record geochemical characteristics of the basements of the two blocks because most of them have resisted the impacts of the later tectonic-thermal events. A cluster of early Paleozoic I-type granites, including the Banshanpu and Hongxiaiqiao

plutons to the west, Xinyu pluton to the north and Zhangjiafang pluton to the east of Pingxiang City, are likely outcrops along the middle part of the boundary between the Yangtze and Cathaysia blocks (Fig. 1b), which would be a good opportunity for investigation of the block boundary. Guan et al. (2014) had proposed that the Banshanpu and Hongxiaqiao plutons were derived from partial melting of lower crust with residual garnet in the eastern Yangtze Block. The Zhangjiafang pluton was suspected to be an early Paleozoic I-type granite in the Cathaysia Block (Fig. 1b) (Zhang et al., 2012). If so, the middle part of the block boundary between the eastern Yangtze and Cathaysia blocks would pass through the narrow area between the Zhangjiafang pluton and the Banshanpu and Hongxiaqiao plutons. However, there is still no geochemical data available for the Zhangjiafang pluton. In this study, we report both the geochronological and geochemical characteristics of the granites and coexisting mafic microgranular enclaves (MMEs) of the Zhangjiafang pluton in order to elucidate the magma sources and petrogenetic processes of the rocks. The results allow us to explore geochemical difference of the basements and outline the block boundary between the eastern Yangtze and Cathaysia blocks, which would also offer new perspectives on the early Paleozoic magmatism associated with the Wuyi-Yunkai orogenic collapse in the SCB.

2. Geological background and sample descriptions

The SCB is bounded by the Qinling-Dabie-Sulu orogenic belt to the north, the Longmenshan Fault to the northwest, the Red River Fault to the southwest, and the continental slope of the East China Sea and the South China Sea to the southeast (Fig. 1a). The basement of the Yangtze Block in the northwest of the SCB consists predominantly

of Proterozoic 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 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). In the eastern Yangtze Block, the oldest outcropped rocks are represented by early Neoproterozoic metamorphosed volcanic-sedimentary units, such as Sibao Group in north Guangxi, Fanjingshan Group in northeast Guizhou, Lengjiaxi Group in central Hunan, Shuangqiaoshan/Jiuling Group in northwest Jiangxi and Shangxi Group in south Anhui (Zhao and Cawood, 2012; and references therein). The Precambrian basement of the Cathaysia Block can be divided into the Wuyishan terrane to the northeast and the Nanling-Yunkai terrane to the southwest (Fig. 1b) (Xu et al., 2005; Yu et al., 2010). Paleoproterozoic granites, meta-sedimentary and volcanic rocks outcropped in northeastern Wuyishan were supposed to be the basement of the Wuyishan terrane (Yu et al., 2010; Liu et al., 2014). The Silurian strata were missing, and a widespread angular unconformity between the overlying upper Paleozoic terrestrial deposits (Devonian and younger) and the lower Paleozoic meta-sedimentary successions (typically Ordovician and older) could be recognized in the southeast part of the SCB (Shu et al., 2014).

The Zhangjiafang pluton to the east of Pingxiang City (Fig. 1b) intruded into the Neoproterozoic metasedimentary sequence or early Paleozoic gneissic granites (Fig. 2) with ages mainly of 440–456 Ma (Wang et al., 2011). The Zhangjiafang pluton is predominantly composed of granite in the eastern part and granodiorite in the western

part (Fig. 2) that are gradual transition without sharp boundary. There are abundant mafic microgranular enclaves (MMEs) hosted in the granodiorite (Fig. 3a, b). The granodiorite samples are porphyritic, and plagioclase phenocrysts are mostly euhedral-subhedral and zoned (Fig. 3c). The common mineral assemblage is biotite (20–30%), amphibole (~15%), plagioclase (25–30%), K-feldspar (10–15%) and quartz (10–15%) (Fig. 3c), with minor accessory minerals of apatite, sphene and magnetite. The fine-grained MMEs are generally elliptic and contact sharply with the host granodiorite (Fig. 3a, b). However, the MMEs often contain variable amounts of large-grained xenocrysts or clots of quartz and feldspars, and some locally show intrusion of host granitoid veinlets (Fig. 3b). The mineral assemblage of MMEs is similar to that of the host granodiorite but has higher proportions of biotite (25–30%), amphibole (~20%) and plagioclase (30–35%) with equal K-feldspar (10–15%) and lower quartz (~10%) (Fig. 3d).

Fig. 2

Fig. 3

3. Analytical methods

Zircons were separated using conventional heavy liquid and magnetic techniques and purified by the handpicking under a binocular microscope, and cast into an epoxy mount. The mount was then polished to exposure the grain centers and carbon-coated. The internal structures of the zircons were examined using cathodoluminescence (CL) image prior to U-Pb isotopic analysis. Zircon U-Pb analyses were performed using an Agilent 7500a ICP-MS, equipped with a RESolution M-50 laser-ablation system at the

Guangzhou Institute of Geochemistry, Chinese Academy of Sciences (GIG-CAS). Spot sizes of 30 μm with a laser frequency of 8 Hz were used. U-Th-Pb ratios and U concentration were determined relative to TEMORA zircons (Black et al., 2003) and the standard NIST610 (Pearce et al., 1997), respectively. Raw count rates were measured for ^{29}Si , ^{204}Pb , ^{206}Pb , ^{207}Pb , ^{208}Pb , ^{232}Th and ^{238}U , $^{207}\text{Pb}/^{206}\text{Pb}$, $^{206}\text{Pb}/^{238}\text{U}$, $^{207}\text{Pb}/^{235}\text{U}$ and $^{208}\text{Pb}/^{232}\text{Th}$ ratios, and then calculated using the ICP-MS DataCal 6.7 (Liu et al., 2008). The detailed analytical techniques are described in Tu et al. (2011). Uncertainties of individual analyses are reported at the 1σ level, and data reduction was carried out using Isoplot (ver. 3.23) (Ludwig, 2003).

In situ zircon Hf isotopic analyses were carried out on the dated sites using a Neptune MC-ICPMS, equipped with a 193 nm laser, at the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGG-CAS). Spot sizes of 44 μm with a laser repetition rate of 8 Hz were used, which obtained a signal intensity of ~ 5 V at ^{180}Hf mass with the energy density of 15 J/cm^2 . The detailed analytical technique and data correction procedures are described in Wu et al. (2006). The mean β_{Yb} ($^{172}\text{Yb}/^{173}\text{Yb}$) value obtained from zircon itself was applied for the interference correction of ^{176}Yb and ^{176}Lu on ^{176}Hf (Wu et al., 2006). $^{176}\text{Yb}/^{172}\text{Yb} = 0.5886$ and $^{176}\text{Lu}/^{175}\text{Lu} = 0.02655$ were used for the elemental fractionation correction. Due to the extremely low $^{176}\text{Lu}/^{177}\text{Hf}$ in zircon (normally < 0.002 in the studied samples), the isobaric interference of ^{176}Lu on ^{176}Hf is negligible (Iizuka and Hirata, 2005). No relationship between $^{176}\text{Yb}/^{177}\text{Hf}$ and $^{176}\text{Hf}/^{177}\text{Hf}$ ratios was observed in the studied samples, indicating that the correction of ^{176}Yb interference on ^{176}Hf is precise for obtaining accurate $^{176}\text{Hf}/^{177}\text{Hf}$ values. During analysis of the unknown samples, the zircon standard (GJ-1) and Mud Tank gave $^{176}\text{Hf}/^{177}\text{Hf}$

ratios of 0.282002 ± 25 (2σ ; $n=9$) and 0.252496 ± 18 (2σ ; $n=9$), respectively, which are identical with the preferred mean values measured using the LA-MC-ICPMS method (Gerdes and Zeh, 2006; Woodhead et al., 2004). The uncertainties of calibrated isotope ratios, including those from the sample, standards, and reference values, are given at $\pm 2\sigma$. The measured $^{176}\text{Lu}/^{177}\text{Hf}$ ratios and the ^{176}Lu decay constant of $1.865 \times 10^{-11} \text{ yr}^{-1}$ (Scherer et al., 2001) were used to calculate initial $^{176}\text{Hf}/^{177}\text{Hf}$ ratios. The chondritic values of $^{176}\text{Hf}/^{177}\text{Hf}=0.0332$ and $^{176}\text{Lu}/^{177}\text{Hf}=0.282772$ (Blichert-Toft and Albarede, 1997) were used for the calculation of ϵ_{Hf} values.

Whole rock geochemical and Sr-Nd isotopic analyses were carried out at the GIG-CAS. Major element oxides were analyzed using a Rigaku RIX 2000 X-ray fluorescence spectrometer (XRF), and analytical uncertainties are mostly between 1% and 5% (Li et al., 2006). Trace elements were obtained by inductively coupled plasma-mass spectrometry (ICP-MS) after acid digestion of samples in high-pressure Teflon vessels, and detailed procedures are same as those described by Li et al. (2006). The USGS and Chinese National standards AGV-2, GSR-1, GSR-2, MRG-1, BCR-1, W-2 and G-2 were chosen for calibrating element concentrations of the analyzed samples. Analytical precision of REE and other incompatible element analyses is typically 1–5%. Sr and Nd isotopic ratios were measured on a subset of whole-rock samples using a Micro mass Isoprobe multicollector ICP-MS (MC-ICP-MS). Detailed procedures of sample preparation and chemical separation are same as those described by Liang et al. (2003) and Wei et al. (2002). The procedure blanks were in the range of 200–500 pg for Sr and ≤ 50 pg for Nd. REEs were separated using the cation exchange columns, and the Nd fractions were further separated by HDEHP-coated Kef columns. Measured $^{143}\text{Nd}/^{144}\text{Nd}$ ratios were

normalized to $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$. Reference standards were analyzed along with samples and gave $^{87}\text{Sr}/^{86}\text{Sr} = 0.710273 \pm 18$ (2σ) for NBS987 and $^{143}\text{Nd}/^{144}\text{Nd} = 0.512094 \pm 11$ (2σ) for Shin Etsu JNdi-1, which are comparable to the recommended values of NBS987 ($^{87}\text{Sr}/^{86}\text{Sr} = 0.710248$; [McArthur, 1994](#)) and Shin Etsu JNdi-1 ($^{143}\text{Nd}/^{144}\text{Nd} = 0.512115 \pm 7$; [Tannaka et al., 2000](#)).

4. Results

4.1. Zircon U-Pb geochronology and Hf isotope

Two granodiorite samples (XQ10-3 and XQ10-13) and one MME sample (XQ10-15) were selected for zircon U-Pb dating (Supplemental Table 1) and Hf isotope analysis (Supplemental Table 2). Zircons are all euhedral prismatic grains, and CL images show strong oscillatory zoning, indicating the magmatic origin.

4.1.1. Granodiorite

The zircons from granodiorite sample XQ10-3 contain variable Th and U contents (39–185 ppm and 132–1050 ppm, respectively) with Th/U ratios of 0.10–0.57 (Supplemental Table 1). Spot 18 on the inherited zircon has an old $^{206}\text{Pb}/^{238}\text{U}$ age of 760 ± 27 Ma with high U (1050 ppm; Supplemental Table 1). Spots 04, 05 and 21 have slightly old $^{206}\text{Pb}/^{238}\text{U}$ ages ranging from 465 ± 8 Ma to 482 ± 9 Ma (Fig. 4), which would be mixture between inner inherited zircon and outer magmatic zircon based on the CL images (Fig. 4b). Spots 08 and 11 show slightly young $^{206}\text{Pb}/^{238}\text{U}$ ages (403 ± 6 Ma and

415±7 Ma, respectively; Supplemental Table 1), possibly due to the later thermal disturbance of U-Pb isotopic system. The other 18 analyses show similar $^{206}\text{Pb}/^{238}\text{U}$ ages ranging from 427±6 Ma to 451±8 Ma (Supplemental Table 1) with a weighted mean value of 438±3 Ma (MSWD = 0.83; Fig. 4a, b), identical to the age of biotite granite in eastern part of the pluton (440±2 Ma; Fig. 2; Zhang et al., 2012) within errors. All zircons have negative $\varepsilon_{\text{Hf}}(t)$ values from -14 to -7 (Fig. 5; Supplemental Table 2).

Twenty-five zircons from granodiorite sample XQ10-13 have variable Th and U contents (50–665 ppm and 165–1805 ppm, respectively) with Th/U of 0.2–0.8 (Supplemental Table 1). Spots 01, 04 and 13 show slightly older apparent $^{206}\text{Pb}/^{238}\text{U}$ ages (456±7 Ma, 459±7 Ma and 465±9 Ma, respectively; Supplemental Table 1) than the others, which would be derived from the surrounding gneissic granites that have abundant zircons with the crystallization age of > 450 Ma (Wang et al., 2011). The other 22 zircon grains have similar $^{206}\text{Pb}/^{238}\text{U}$ ages (422±6 to 446±7 Ma; Supplemental Table 1) with a weighted mean value of 438±3 Ma (MSWD = 0.98; Fig. 4c), identical to weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of sample XQ10-13 and was interpreted as the crystallization age of the Zhangjiafang granodiorite. These zircons show wide range of negative $\varepsilon_{\text{Hf}}(t)$ values (-14 to -4; Fig. 5; Supplemental Table 2).

Fig. 4

Fig. 5

4.1.2. MME

The zircon grains of MME sample XQ10-15 contain variable Th and U contents (37–229 ppm and 93–1049 ppm, respectively) with relatively low Th/U ratios of 0.1–0.4

(Supplemental Table 1). Spot 09 has older age (462 ± 9 Ma) with much higher Th (229 ppm) and U (1049 ppm) compared to the others, and would be an inherited zircon captured from the surrounding rocks similar to those in granodiorite samples XQ10-3 and XQ10-13. The other ten zircon grains give a weighted mean value of 433 ± 5 Ma (MSWD = 1.06; Fig. 4d), interpreted as the crystallization age of the MMEs, which is equal to the crystallization age of the host granodiorite (438 ± 3 Ma; Fig. 4b, c) within errors. The zircons of the MME sample show overall less negative $\varepsilon_{\text{Hf}}(t)$ values (-9 to -4; Fig. 5; Supplemental Table 2) than those of the granodiorite samples.

4.2. Geochemistry

4.2.1. Major and trace elements

Whole-rock major and trace element concentrations of nine granodiorite samples and three MME samples from the Zhangjiafang pluton (Supplemental Table 3) are plotted in Fig. 6, together with surrounding gneissic granites (Wang et al., 2011) and the I-type granite and MMEs from the Banshanpu and Hongxiaqiao plutons in the eastern Yangtze Block (Guan et al., 2014). The Zhangjiafang granodiorites contain low SiO_2 (62–65 wt %; Supplemental Table 3) and high Al_2O_3 (16.3–17.3 wt %; Supplemental Table 3), and show a general trend of decreasing TiO_2 , Al_2O_3 , MgO , CaO , Fe_2O_3 and P_2O_5 with increasing SiO_2 but within narrow ranges (Fig. 6). The MME samples have slightly higher MgO , CaO , Fe_2O_3 and Na_2O but lower P_2O_5 , K_2O , SiO_2 and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ than the host granodiorites (Fig. 6). The granodiorite samples are weakly peraluminous

(A/CNK = 1.00–1.09; Fig. 7), while three MME samples are all metaluminous (A/CNK ≤ 1; Fig. 7), corresponding to higher proportion of amphibole in the MMEs (Fig. 3d).

Fig. 6

Fig. 7

The Zhangjiafang granodiorites show fractionated chondrite-normalized REE patterns ($[La/Yb]_N = 6–29$; Supplemental Table 3) with moderately to weakly negative Eu anomalies ($Eu/Eu^* = 0.67–1.0$; Supplemental Table 3; Fig. 8a). The MME samples have variable REE concentrations and chondrite-normalized REE patterns ($[La/Yb]_N = 3–21$; $[Dy/Yb]_N = 1.8–2.4$; Supplemental Table 3) with strongly negative Eu anomalies ($Eu/Eu^* = 0.49–0.63$; Supplemental Table 3; Fig. 8a). On the primitive mantle-normalized multi-element variation diagram, all samples exhibit pronounced negative Nb, Ta, Ti, Sr and Ba anomalies but positive Pb anomaly, similar to the I-type granite and MMEs from the Banshanpu and Hongxiaqiao plutons (Fig. 8b).

Fig. 8

4.2.2. *Sr-Nd isotopes*

The Zhangjiafang granodiorites have lower $^{143}Nd/^{144}Nd$ ratios (0.511886–0.511959; Supplemental Table 4) and more negative $\epsilon_{Nd}(t)$ values (from -11 to -9; Supplemental Table 4) than coeval I-type granites in the eastern Yangtze (Guan et al., 2014; Zhang et al., 2012) and surrounding early Paleozoic gneissic granites (Fig. 9). Initial $^{87}Sr/^{86}Sr$

ratios of the Zhangjiafang granodiorite samples are high in a narrow range of 0.7138–0.7145 (Supplemental Table 4). The MME samples show higher $^{143}\text{Nd}/^{144}\text{Nd}$ ratios (0.512043–0.512163), less negative $\varepsilon_{\text{Nd}}(t)$ values (-9 to -7) and lower initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.7127–0.7136) than the host granodiorites (Supplemental Table 4; Fig. 9). All samples likely plot along a mixing curve (Fig. 9) between the Taishan I-type granites (Huang et al., 2013) and Xinyi gabbro (Wang et al., 2013b).

Fig. 9

5. Discussion

5.1. Petrogenesis of granodiorite: lower crustal dehydration melting

The Zhangjiafang granodiorite samples show negative $\varepsilon_{\text{Nd}}(t)$ values and high $(^{87}\text{Sr}/^{86}\text{Sr})_i$ ratios with negative zircon $\varepsilon_{\text{Hf}}(t)$ values (Figs. 5, 9), which is clearly distinguished from M-type granite that formed from juvenile mantle-derived materials (Whalen, 1985). The studied samples contain abundant early-crystallizing biotite and amphibole but lack of any peraluminous minerals such as cordierite, muscovite or garnet (Fig. 3c), indicating an overall hydrated and metaluminous feature of their initial magma. Therefore, both petrological and geochemical features denote clearly that the Zhangjiafang granodiorite is not S- or A-type granite but belongs to I-type suite.

Weakly peraluminous or metaluminous feature of the Zhangjiafang granodiorite contradicts with a supracrustal sedimentary source that generally produces strongly peraluminous melts (Lebreton and Thompson 1988; Vielzeuf and Montel., 1994).

314 Evidently, the studied samples have more negative $\epsilon_{\text{Nd}}(t)$ and higher $(^{87}\text{Sr}/^{86}\text{Sr})_i$ (Fig. 9)
315 than the surrounding gneissic granites (i.e., Wugongshan area) that were generated
316 through partial melting of a supracrustal sedimentary source (Wang et al., 2011).

317 The studied granodiorite samples show narrow ranges of all major elements and
318 uniform trace elements characteristics (Fig. 6, 8), suggesting that they would be products
319 through similar degree of partial melting of the source and have undergone similar
320 fractional crystallization. The rocks might be derived from partial melting of an
321 intermediate to mafic source (e.g., amphibolite; Beard and Lofgren, 1991) according to
322 their high MgO and Fe₂O₃ but low SiO₂ (Fig. 6). Hydrous melting of an intermediate-
323 mafic source usually generates strongly peraluminous melts with extremely high Al₂O₃
324 (generally > 20 wt% at SiO₂ = 60 wt%) due to breakdown of plagioclase with amphibole
325 residue in the source (Beard and Lofgren, 1991; Wolf and Wyllie, 1994). Thus, weakly
326 peraluminous feature of the Zhangjiafang granodiorite suggests an overall water-
327 unsaturated partial melting of the source. Low Sr and negative Eu anomalies are
328 consistent with insignificant contribution of plagioclase (Fig. 8a, b), which can also attest
329 to a dehydration melting process.

330 During dehydration melting of an intermediate-mafic rock (e.g., amphibolite; Beard
331 and Lofgren, 1991), the hydrous phase such as amphibole would break down following
332 different reactions under varying P-T conditions (Wolf and Wyllie, 1994; Wyllie and
333 Wolf, 1993) and supply water for initial melting (Beard and Lofgren, 1991; Douce et al.,
334 1995; Wolf and Wyllie, 1994). Garnet together with plagioclase and orthopyroxene
335 would be major residual phase at a high pressure (>8–11 kbar; the pressure varies with
336 the temperature and source composition; Beard and Lofgren, 1991; Wolf and Wyllie,

1994; Wyllie and Wolf, 1993). Nevertheless, the possibility of a high pressure (>8–11 kbar) magma source can be excluded for relatively flat HREE pattern ($[\text{Dy/Yb}]_{\text{N}} = 1.22\text{--}1.52$; Supplemental Table 3) and high HREE concentration in the Zhangjiafang granodiorite (Fig. 8a). For a mafic source such as amphibolite, amphibole would be a residual phase in the source if thermal gradient is low (Rapp and Watson, 1995; Wolf and Wyllie, 1994), which will induce concave-upward REE patterns between the middle and heavy REEs in the melts (e.g., Huang et al., 2009). The Zhangjiafang granodiorite show a progressive decrease from middle to heavy REEs with increasing atomic number (Fig. 8a), thus suggesting the breakdown of amphibole in the source. For a water-unsaturated source in the middle to lower crust (< 8 kbar), an extremely high temperature (thermal gradient > 35 °C/km) would be required for the breakdown of amphibole (Huang et al., 2013). However, the Zhangjiafang granodiorite samples have low Zr contents, corresponding to low zircon saturation temperatures (722–780 °C; Supplemental Table 3). Therefore, the Zhangjiafang granodiorite would not be a typical dehydration melting product of the crustal source. The water and heat from mantle-derived melts might have triggered partial melting in the crustal source, which is consistent with variable $\epsilon_{\text{Nd}}(\text{t})$ values of the granodiorite samples (Fig. 9) and abundant MMEs in the pluton (Fig. 3).

5.2. The block boundary between the eastern Yangtze and Cathaysia blocks

The eastern Yangtze and Cathaysia blocks amalgamated during the Early Neoproterozoic (e.g., Li et al., 2006, 2008 2009) and have distinct basements (e.g. Zhao and Cawood, 2012; Zhang et al., 2012). Guan et al (2014) proposed that the Banshanpu and Hongxiaqiao plutons were derived from partial melting of lower crust of the eastern

Yangtze Block in the garnet stability field. In general, the lower crust has low Sr, Ba, Th and U contents because previous partial melting may have extracted such incompatible elements (Rudnick and Fountain, 1995). However, the Banshanpu and Hongxiaqiao plutons show particular high Sr, Ba, Th and U (Fig. 10). In addition, the Daning I-type granite nearby west of Chenzhou-Linwu fault (Fig. 1b) is also characterized by relatively high Ba, Th and U (Fig. 10). The eastern Yangtze Block had been highly modified by extensive juvenile materials during the Neoproterozoic time (e.g., Li et al., 2008 2009; Wang et al., 2004; Yao et al., 2014). The juvenile materials are probably related to the activity of mantle plume associated with breakup of the Rodinia supercontinent (e.g., Li et al., 2009) or breakoff of subducted slab during the post-collision of the Jiangnan orogeny (e.g., Wang et al., 2004). Such a process would be responsible for particular enrichment of Sr, Ba, Th and U in the Banshanpu and Hongxiaqiao plutons (Fig. 10) and overall higher $\epsilon_{\text{Nd}}(t)$ and $\epsilon_{\text{Hf}}(t)$ values of the I-type granites in the eastern Yangtze Block than those in the western Cathaysia Block (Figs. 5, 9).

The Zhangjiafang samples show low Sr, Ba, Th and U contents (Fig. 10), which contradicts with an origin of partial melting of recently modified lower crust similar to the Banshanpu and Hongxiaqiao plutons which is enriched in such incompatible elements. Additionally, the Zhangjiafang granodiorite and MME samples have more negative $\epsilon_{\text{Nd}}(t)$ and $\epsilon_{\text{Hf}}(t)$ values than the Banshanpu and Hongxiaqiao plutons in the eastern Yangtze Block, but are similar to the Taishan I-type granitoid rocks in the Cathaysia Block (Figs. 5, 9). The latter was typically derived from partial melting of ancient middle to lower crust of the Cathaysia Block without significant input of juvenile materials (Huang et al., 2013). Although Neoproterozoic event might have significantly

affected the eastern part of the Cathaysia Block, as revealed by the Neoproterozoic bimodal volcanic rocks along the Zhenghe-Dapu Fault (Shu et al., 2011; Wang et al., 2011), lack of Neoproterozoic rocks in the studied area also suggests an overall undisturbed basement in the western part. Therefore, the Zhangjiafang pluton is mostly produced by partial melting of the basement of the Cathaysia Block. According to contrastive geochemical characteristics of simultaneous I-type granites near the Pingxiang City, we speculated that the block boundary between the Cathaysia and eastern Yangtze blocks would pass through Pingxiang area between the Zhangjiafang pluton and the Banshanpu and Hongxiaqiao plutons (Fig. 1b).

Fig. 10

5.3. Origin of the MMEs: insufficient digestion of mantle-derived melts during mixing process

The MMEs would be restite of the source during partial melting (e.g., Chappell et al., 1987; Chappell and White, 1991), “cognate” mafic accumulation in the felsic host (e.g., Dahlquist, 2002; Wall et al., 1987), or mantle-derived melts that injected into and/or mixed insufficiently with felsic magmas (e.g., Barbarin and Didier, 1992; Clemens and Stevens, 2012; Silva et al., 2000). If the MMEs are refractory or residual portions of the source, they should be older than the host rocks and have complementary compositions to the host (e.g., Chappell et al., 1987; Chappell and White, 1991). The Zhangjiafang MMEs show identical crystallization age (Fig. 4d) and similar REE pattern and trace element spiderdiagram to the host granodiorite (Fig. 8), which is inconsistent with the restite

model. The model of “cognate” mafic accumulation would not be preferred because the MME samples have distinguishable higher zircon $\varepsilon_{\text{Hf}}(t)$ and whole rock $\varepsilon_{\text{Nd}}(t)$ but lower whole rock ($^{87}\text{Sr}/^{86}\text{Sr}$)_i than the granodiorite samples (Figs. 5, 9).

The Zhangjiafang MMEs and host granodiorites show significant linear trends on the Harker diagrams (Fig. 6) and the diagrams of Nd isotopes versus $\text{MgO}/\text{Fe}_2\text{O}_3$ and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ (Fig. 11), which would indicate a mixing process between mantle-derived and crust-derived melts. The Taishan I-type granites in southern Guangdong (~436 Ma; Fig. 1b) produced by partial melting of ancient middle to lower crust without significant input of juvenile melts (Huang et al., 2013) would be regarded as “pure” melt from the basement of the Cathaysia Block. One Zhangjiafang granodiorite sample has similar $\varepsilon_{\text{Nd}}(t)$ value to the Taishan I-type granites (Huang et al., 2013), suggesting similar ancient basement in the north and south parts of the Cathaysia Block. The other granodiorite samples and all MME samples from the Zhangjiafang pluton show less negative $\varepsilon_{\text{Nd}}(t)$ values and higher $\text{MgO}/\text{Fe}_2\text{O}_3$ ratios but slightly lower $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios than the Taishan I-type granites (Fig. 11), reflecting the input of mantle-derived melt. The reported early Paleozoic mafic rocks at present include the nearby appinites in Wugongshan area on the east of Piangxiang (Zhong et al., 2015) and gabbros and basalts in Guangdong and Fujian provinces (Wang et al., 2013b; Yao et al., 2012; Zhang et al., 2015) (Fig. 1b). They all have negative $\varepsilon_{\text{Nd}}(t)$ values (Fig. 9) and show pronounced negative Nb-Ta-Ti anomalies (Fig. 8), indicating that they were derived from partial melting of predominant metasomatism mantle source. The Wugongshan appinites, originating from an ancient metasomatised mantle but undergoing crustal assimilation and fractional crystallization (AFC) process (Zhong et al., 2014), have relatively lower $\varepsilon_{\text{Nd}}(t)$ values than the gabbros

and basalts in Guangdong and Fujian provinces (Fig. 11). The mafic rocks in the inner Cathaysia Block, including the Dakang gabbros, Xinchuan gabbros and Chayuanshan basalts (Fig. 1b), are characterized by variable but overall high $\text{MgO}/\text{Fe}_2\text{O}_3$ and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios and negative $\epsilon_{\text{Nd}}(t)$ values (Fig. 11). The Xinyi gabbros adjacent to the block boundary in the Yunkai domain (Fig. 1b) show overall lower $\text{MgO}/\text{Fe}_2\text{O}_3$ and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios and less negative $\epsilon_{\text{Nd}}(t)$ values than the mafic rocks in the inner Cathaysia Block (Fig. 11), indicating a “younger” lithosphere mantle source beneath the marginal region compared with the inner Cathaysia Block. The Zhangjiafang granodiorites and MMEs have relatively low $\text{MgO}/\text{Fe}_2\text{O}_3$ and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios and plot on the mixing trend between the Xinyi gabbros and Taishan I-type granites (Figs. 9, 11), indicating that they would be insufficient mixture of similar ultimate sources. Evidently, the Zhangjiafang MMEs contain irregular granitoid veinlets (Fig. 3b) and variable amounts of large-grained xenocrysts or clots of quartz and feldspar. Therefore, the Zhangjiafang MMEs were likely mantle-derived melts injected into felsic magmas without complete digestion.

5.4. Implication for the collapse of the Wuyi-Yunkai Orogen

The Wuyi–Yunkai orogen has been regarded as a consequence of continental or arc collisions with closure of a proposed Huanan Ocean in the SCB interior (e.g., Guo et al., 1989; Hsü, 1994; Hsü et al., 1990). But most recent work interpreted the Wuyi-Yunkai orogen as an intracontinental event (Charvet, 2013; Charvet et al., 2010; Faure et al., 2009; Guan et al., 2014; Huang et al., 2013; Li et al., 2010; Wang et al., 2007, 2011, 2013b; Yao et al., 2012). Lack of juvenile component in the early Paleozoic crust of the

SCB (e.g., Wang et al., 2011, 2013a; Huang et al., 2013) suggests an overall undisturbed crust prior to orogeny but distinctly contradicts the model of an early Paleozoic Huanan Ocean between the Cathaysia and Yangtze blocks (e.g., Guo et al., 1989; Hsü, 1994; Hsü et al., 1990). A far-field-type intracontinental orogenic collapse would have occurred in the early Paleozoic (Li et al., 2010), which had a strong heat influence on crustal mobilization beneath the inner Cathaysia Block (Huang et al., 2013). The Zhangjiafang pluton adjacent to the block boundary between the eastern Yangtze and Cathaysia blocks also show insignificant juvenile materials in its crustal source prior to the orogeny, obviously preferring an intracontinental orogeny model.

Intracontinental orogeny is closely related to the reactivation of ancient thrusting structures or pre-existing lithospheric weak zones (Hand and Sandiford, 1999; Sandiford and Hand, 1998), such as the Cenozoic Tianshan Belt in Central Asia (Yin et al., 1998), the late Neoproterozoic Peterman orogen and the Paleozoic Alice Springs orogen in Central Australia (Hand and Sandiford, 1999; Sandiford and Hand, 1998). The Wuyi-Yunkai orogen had experienced a clockwise P-T path with rapid pressure drop from >8 kbar during 460–440 Ma to ~4 kbar after 440 Ma (Li et al., 2010), suggesting a tectonic transition from compression to extension in accordance with a far-field-type intracontinental orogenic collapse in the early Paleozoic (Li et al., 2010). Asthenosphere upwelling during post-orogenic collapse could input significant heat and mafic melts into the crust and might result in large-scale granitic magmatism (Gorczyk and Vogt, 2015; Huang et al., 2013; Smithies et al., 2011). The early Paleozoic I-type granites and mafic rocks in the SCB all occurred after 440 Ma, which would be a witness for the remobilization of the crustal basement associated with partial melting of lithospheric

mantle during post-orogenic collapse (Fig. 1b). The mixing process recorded in the Zhangjiafang pluton reflects the direct modification of mantle-derived melt on the ancient basement in the northern margin of the Cathaysia Block due to the collapse of the Wuyi-Yunkai orogen. It is noteworthy that the early Paleozoic mafic rocks (Zhong et al., 2014; Wang et al., 2013b) and I-type granites with coeval MMEs (Guan et al., 2014; this study) were frequently present along the Jiangshan-Shaoxing-Pingxiang-Chenzhou-Linwu Fault zone which would be in juxtaposition with the block boundary (Fig. 1b). This strongly suggests that the pre-existing block boundary or fault might have played an important role on the collapse of the Wuyi-Yunkai orogen. Actually, most of the I-type granites near the block boundary show the mixing process between mafic and felsic melts (Guan et al., 2014; Xia et al., 2014; Zhang et al., 2012; this study). Therefore, the pre-existing block boundary may be a proper location for the juxtaposition of asthenospheric upwelling and basaltic underplating (Fig. 12) during the collapse of an intracontinental orogen.

Fig. 12

6. Conclusion

- (1) The Zhangjiafang granodiorites in the northern margin of the Cathaysia Block are typical early Paleozoic I-type granitoid rocks derived from dehydration melting of the basement of the Cathaysia Block.

(2) The MMEs in the Zhangjiafang pluton were ultimately mantle-derived melts but had experienced incomplete mixing process.

(3) The basement of Cathaysia Block is more ancient than that of the eastern Yangtze Block. The block boundary between the Cathaysia and eastern Yangtze blocks passes through the nearby west area (i.e., Pingxiang City) of the Zhangjiafang pluton.

(4) Pre-existing block boundary is a proper location for juxtaposition of asthenosphere upwelling and basaltic underplating during the collapse of an intracontinental orogen.

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References

Barbarin, B., Didier, J., 1992. Genesis and evolution of mafic microgranular enclaves through various types of interaction between coexisting felsic and mafic magmas. Transactions of the Royal Society of Edinburgh: Earth Sciences 83, 145–153.

519 Beard, J.S., Lofgren, G.E., 1991. Dehydration melting and water-saturated melting of
520 basaltic and andesitic greenstones and amphibolites at 1, 3, and 6.9 kbar. *Journal*
521 *of Petrology* 32, 365–401.

522 Black, L.P., Kamo, S.L., Allen, C.M., Aleinikoff J.N., Davis D.W., Korsch R.J.,
523 Foudoulis C., 2003. TEMORA 1: a new zircon standard for Phanerozoic U-Pb
524 geochronology. *Chemical Geology* 200, 155–170.

525 Blichert-Toft, J., Albarede, F., 1997. The Lu-Hf geochemistry of the chondrites and the
526 evolution of the mantle-crust system. *Earth and Planetary Science Letters* 148,
527 243–258.

528 Chappell, B.W., White, A.J.R., Wyborn, D., 1987. The importance of residual source
529 material (restite) in granite petrogenesis. *Journal of Petrology* 28, 1111–1138.

530 Chappell, B.W., White, A.J.R., 1991. Restite enclaves and the restite model. In: Didier, J.,
531 Barbarin, B. (Eds.), *Enclaves and Granite Petrology*, Developments in Petrology.
532 Elsevier, Amsterdam, pp. 375–381.

533 Charvet, J., Shu, L.S., Faure, M., Choulet, F., Wang, B., Lu, H.F., Breton, N.L., 2010.
534 Structural development of the Lower Paleozoic belt of South China: genesis of an
535 intracontinental orogen. *Journal of Asian Earth Sciences* 39, 309–330.

536 Charvet, J., 2013. The Neoproterozoic-Early Paleozoic tectonic evolution of the South
537 China Block: an overview. *Journal of Asian Earth Sciences* 74, 198–209.

538 Chen, C.H., Lee, C.Y., Hsieh, P.S., Zeng, W., Zhou, H.W., 2008. Approaching the age
539 problem for some metamorphosed Precambrian basement rocks and Phanerozoic
540 granitic bodies in the Wuyishan area: The application of EMP monazite age
541 dating. *Geological Journal of China Universities* 14 (1), 1–15.

542 Chen, J.F., Foland, K.A., Xing, F.M., Xu, X.A., Zhou, T.X., 1991. Magmatism along the
543 southeast margin of the Yangtze block: Precambrian collision of the Yangtze and
544 Cathaysia blocks of China. *Geology* 19, 815–818.

545 Chen X, Zhang Y,D, Fan J.X., Tang L., Sun H.Q., 2012, Onset of the Kwangsi
546 Orogeny as evidenced by biofacies and lithofacies. *Science in China (Earth*
547 *Sciences)*, 55: 1592–1600.

548 Cheng, S.B., Fu, J.M., Xu, D.M., Chen, X.Q., Ma, L.Y., Wang, X.D., Pang, Y.C., 2009.
549 Zircon SHRIMP U-Pb dating and geochemical characteristics of Daning batholith

550 in northeast Guangxi. *Geology in China* 36 (6), 1278–1288 (in Chinese with
551 English abstract).

552 Clemens, J.D., Stevens, G., 2012. What controls chemical variation in granitic magmas?
553 *Lithos* 134, 317–329.

554 Dahlquist, J.A., 2002. Mafic microgranular enclaves: early segregation from
555 metaluminous magma (Sierra de Chepes), Pampean Ranges, NW Argentina.
556 *Journal of South America Earth Science* 15, 643–655.

557 Douce, A.E.P., Beard, J.S., 1995. Dehydration-melting of Biotite Gneiss and Quartz
558 Amphibolite from 3 to 15 kbar. *Journal of Petrology* 36, 707–738.

559 Faure, M., Shu, L.S., Wang, B., Charvet, J., Choulet, F., Monié, P., 2009. Intracontinental
560 subduction: a possible mechanism for the Early Paleozoic Orogen of SE China.
561 *Terra Nova* 21, 360–368.

562 Gan, X.C., Li, H.M., Sun, D.Z., Zhuang, J.M., 1993. Geochronological study on the
563 Precambrian metamorphic basement in Northern Fujian. *Geology of Fujian* 17,
564 17–32 (in Chinese with English abstract).

565 Gao, S., Yang, J., Zhou, L., Li, M., Hu, Z.C., Guo, J.L., Yuan, H.L., Gong, H.J., Xiao,
566 G.Q., Wei, J.Q., 2011. Age and growth of the Archean Kongling terrain, South
567 China, with emphasis on 3.3 Ga granitoid gneisses. *American Journal of Science*
568 311, 153–182.

569 Gerdes, A., Zeh, A., 2006. Combined U-Pb and Hf isotope LA-(MC-)ICP-MS analyses of
570 detrital zircons: Comparison with SHRIMP and new constraints for the
571 provenance and age of an Armorican metasediment in Central Germany. *Earth
572 and Planetary Science Letters* 249, 47–61.

573 Griffin, W.L., Pearson, N.J., Belousova, E., Jackson S.E., Van Achterbergh, E., O'Reilly,
574 S.Y., Shee, S.R., 2000. The Hf isotope composition of cratonic mantle: LAM-
575 MC-ICPMS analysis of zircon megacrysts in kimberlites. *Geochimica et
576 Cosmochimica Acta* 64, 133–147.

577 Gorczyk, W., Vogt, K., 2015. Tectonics and melting in intra-continental settings.
578 *Gondwana Research* 27, 196–208.

579 Guan, Y.L., Yuan, C., Sun, M., Wilde, S., Long, X.P., Huang, X.L., Wang, Q., 2014. I-
580 type granitoids in the eastern Yangtze Block: implications for the Early Paleozoic
581 intracontinental orogeny in South China. *Lithos* 206, 34–51.

582 Guo, L.Z., Shi, Y.S., Lu, H.F., Ma, S.R., Dong, H.G., Yang, S.F., 1989. The pre-
583 Devonian tectonic patterns and evolution of South China. *Journal of Southeast*
584 *Asian Earth Sciences* 3, 87–93.

585 Hand, M., Sandiford, M., 1999. Intraplate deformation in central Australia, the link
586 between subsidence and fault reactivation. *Tectonophysics* 305, 121–140.

587 Huang, X.L., Xu, Y.G., Lan, J.B., Yang, Q.J., Luo, Z.Y., 2009. Neoproterozoic adakitic
588 rocks from Mopanshan in the western Yangtze Craton: Partial melts of a
589 thickened lower crust. *Lithos* 112, 367–381.

590 Huang, X.L., Yu, Y., Li, J., Tong, L.X., Chen, L.L., 2013. Geochronology and
591 petrogenesis of the early Paleozoic I-type granite in the Taishan area, South China:
592 Middle-lower crustal melting during orogenic collapse. *Lithos* 177, 268–284.

593 Hsü, K.J., Li, J.L., Chen, H.H., Wang, Q.C., Sun, S., Sengör, A.M.X., 1990. Tectonics of
594 South China: key to tectonics of South China: key to understanding west Pacific
595 geology. *Tectonophysics* 193, 9–39.

596 Hsü, K.J., 1994. Tectonic facies in an archipelago model of intra-plate orogenesis. *GSA*
597 *Today* 4(12), 289–293.

598 Iizuka, T., Hirata, T., 2005. Improvements of precision and accuracy in in-situ Hf isotope
599 microanalysis of zircon using the laser ablation-MC-ICPMS technique. *Chemical*
600 *Geology* 220, 121–137.

601 Lebreton, N., Thompson, A.B., 1988. Fluid-absent (dehydration) melting of biotite in
602 metapelites in the early stages of crustal anatexis. *Contributions to Mineralogy*
603 *and Petrology* 99, 226–237.

604 Li, W.X., Li, X.H., Li, Z.X., Lou, F.S., 2008. Obduction-type granites within the NE
605 Jiangxi Ophiolite: Implications for the final amalgamation between the Yangtze
606 and Cathaysia Blocks. *Gondwana Research* 13, 288–301.

607 Li, X.H., Li, Z.X., Wingate, M.T.D., Chung, S.L., Liu, Y., Lin, G.C., Li, W.X., 2006.
608 Geochemistry of the 755Ma Mundine Well dyke swarm, northwestern Australia:

609 part of a Neoproterozoic mantle superplume beneath Rodinia? Precambrian
 610 Research 146, 1–15.

611 Li, X.H., Li, W.X., Li, Z.X., Lo, C.H., Wang, J., Ye, M.F., Yang, Y.H., 2009.
 612 Amalgamation between the Yangtze and Cathaysia Blocks in South China:
 613 Constraints from SHRIMP U-Pb zircon ages, geochemistry and Nd-Hf isotopes of
 614 the Shuangxiwu volcanic rocks. Precambrian Research 174, 117–128.

615 Li, Z.X., Li, X.H., Wartho, J.A., Clark, C., Li, W.X., Zhang, C.L., Bao, C., 2010.
 616 Magmatic and metamorphic events during the Early Paleozoic Wuyi-Yunkai
 617 Orogeny, southeastern South China: new age constraints and pressure-temperature
 618 conditions. Geological Society of America Bulletin 122, 772–793.

619 Liang, X.R., Wei, G.J., Li, X.H., Liu, Y., 2003. Precise measurement of $^{143}\text{Nd}/^{144}\text{Nd}$ and
 620 Sm/Nd ratios using multiple-collectors inductively couple plasma-mass
 621 spectrometer (MC-ICP-MS). Geochimica 32, 91–96 (in Chinese with English
 622 abstract).

623 Liu, Q., Yu, J.H., O'Reilly, S.Y., Zhou, M.F., Griffin, W.L., Wang, L.J., Cui, X., 2014.
 624 Origin and geological significance of Paleoproterozoic granites in the northeastern
 625 Cathaysia Block, South China. Precambrian Research 248, 72–95.

626 Liu, Y.S., Hu, Z.C., Gao, S., Gunther, D., Xu, J., Gao, C.G., Chen, H.H., 2008. In situ
 627 analysis of major and trace elements of anhydrous minerals by LA-ICP-MS
 628 without applying an internal standard. Chemical Geology 257, 34–43.

629 Lou, F.S., Shen, W.Z., Wang, D.Z., Shu, L.S., Wu, F.J., Zhang, F.R., Yu, J.H., 2005.
 630 Zircon U-Pb isotopic chronology of the Wugongshan dome compound granite in
 631 Jiangxi Province. Acta Geologica Sinica 5, 636–644 (in Chinese with English
 632 abstract).

633 Ludwig, K.R., 2003. Isoplot: a geochronological toolkit for Microsoft Excel. Berkeley
 634 Geochronology Center Special Publication, No. 4, 1–67.

635 McArthur, J.M., 1994. Recent trends in strontium isotope stratigraphy. Terra Nova 6,
 636 331–358.

637 Pearce, N.J.G., Perkins, W.T., Westgate, J.A., Grrton, M.P., Jackson, S.E., Neal C.R.,
 638 Chenery, S.P., 1997. A compilation of new and published major and trace element

639 data for NIST SRM 610 and NIST SRM 612 glass reference materials.
 640 Geostandards Newsletter 21, 115–144.

641 Peng, S.B., Jin, Z.M., Liu, Y.H., Fu, J.M., He, L.Q., Cai, M.H., Wang, Y.B., 2006.
 642 Petrochemistry, chronology and tectonic setting of strong peraluminous anatectic
 643 granitoids in Yunkai Orogenic Belt, Western Guangdong Province, China. Journal
 644 of China University of Geosciences 17, 1–12 (in Chinese with English abstract).

645 Qiu, Y.M., Gao, S., McNaughton, N.J., Groves, D.J., Ling, W.L., 2000. First evidence of
 646 ≥ 3.2 Ga continental crust in the Yangtze craton of South China and its
 647 implications for Archean crustal evolution and Phanerozoic tectonics. Geology 28,
 648 11–14.

649 Rao, J.R., Xiao, H.Y., Liu, Y.R., Bai, D.Y., Deng, Y.Y., 2012. Location of the Yangtze-
 650 Cathaysia plate convergence zone in Hunan. Chinese Journal of Geophysics-
 651 Chinese Edition 55, 484–502.

652 Rapp, R.P., Watson, E.B., 1995. Dehydration melting of metabasalt at 8–32 kbar:
 653 implications for continental growth and crust–mantle recycling. Journal of
 654 Petrology 36, 891–931.

655 Rudnick, R.L., Fountain, D.M., 1995. Nature and composition of the continental crust: A
 656 lower crustal perspective. Review of Geophysics 33, 267–309.

657 Sandiford, M., Hand, M., 1998. Controls on the locus of intraplate deformation in central
 658 Australia. Earth and Planetary Science Letters 162, 97–110.

659 Scherer, E., Munker, C., Mezger, K., 2001. Calibration of the Lutetium-Hafnium clock.
 660 Science 293, 683–687.

661 Shen, W.Z., Zhang, F.R., Shu, L.S., Wang, L.J., Xiang, L., 2008. Formation age,
 662 geochemical characteristics of the Ninggang granite body in Jiangxi Province and
 663 its tectonic significance. Acta Petrologica Sinica 24, 2244–2254 (in Chinese with
 664 English abstract).

665 Shu, L.S., Faure, M., Yu, J.H., Jahn, B.M., 2011. Geochronological and geochemical
 666 features of the Cathaysia block (South China): New evidence for the
 667 Neoproterozoic breakup of Rodinia. Precambrian Research 187, 263–276.

668 Shu, L.S., Jahn, B.M., Charvet, J., Santosh, M., Wang, B., Xu, X.S., Jiang, S.Y., 2014.
 669 Early Paleozoic depositional environment and intraplate tectono-magmatism in

670 the Cathaysia Block (South China): Evidence from stratigraphic, structural,
671 geochemical and geochronological investigations. *American Journal of Science*
672 314, 154–186.

673 Shu L.S., Wang B., Cawood P.A., Santosh M., Xu Z.Q., 2015. Early Paleozoic and early
674 Mesozoic intraplate tectonic and magmatic events in the Cathaysia Block, South
675 China. *Tectonics*, 34, Doi.org/10.1002/2015TC003835

676 Shui, T., 1987. Tectonic framework of the southeastern China continental basement.
677 *Scientia Sinica B*30, 414–422.

678 Silva, M.M.V.G., Neiva, A.M.R., Whitehouse, M.J., 2000. Geochemistry of enclaves and
679 host granites from the Nelas area, central Portugal. *Lithos* 50, 153–170.

680 Smithies, R.H., Howard, H.M., Evins, P.M., Kirkland, C.L., Kelsey, D.E., Hand, M.,
681 Wingate, M.T.D., Collins, A.S., Belousova, E., 2011. High-temperature granite
682 magmatism, crust-mantle interaction and the Mesoproterozoic intracontinental
683 evolution of the Musgrave Province, Central Australia. *Journal of Petrology* 52,
684 931–958.

685 Sun, S.S., McDonough, W.F., 1989. Chemical and isotopic systematics of oceanic basalts:
686 implication for mantle composition and process. In: Saunders, A.D., Norry, M.J.
687 (Eds.), *Magmatism in the ocean Basins*. Geological Society Special Publications
688 42, 313–345.

689 Söderlund, P., Söderlund, U., Möller, C., Gorbachev, R., Rodhe, A., 2004. Petrology and
690 ion microprobe U-Pb chronology applied to a metabasic intrusion in southern
691 Sweden: a study on zircon formation during metamorphism and deformation.
692 *Tectonics* 23, 1–16.

693 Taylor, S.R., McLennan, S.M., 1985. *The Continental Crust: Its Composition and*
694 *Evolution*. Blackwell, Oxford.

695 Tannaka, T., Togashi, S., Kamioka, H., Amakawa, H., Kagami, H., Hamamoto, T.,
696 Yuhara, M., Orihashi, Y., Yoneda, S., Shimizu, H., Kunimaru, T., Takahashi, K.,
697 Yanagi, T., Nakano, T., Fujimaki, H., Shinjo, R., Asahara, Y., Tanimizu, M.,
698 Dragusanu, C., 2000. JNdi-1: a neodymium isotopic reference in consistency with
699 LaJolla neodymium. *Chemical Geology* 168, 279–281.

700 Tu, X.L., Zhang, H., Deng, W.F., Ling, M.X., Liang, H.Y., Liu, Y., Sun, W.D., 2011.
 701 Application of RESOLUTION in-situ laser ablation ICP-MS in trace element
 702 analyses. *Geochemica* 40(1), 83–98 (in Chinese with English abstract).
 703 Vielzeuf, D., Montel, J.M., 1994. Partial melting of metagreywackes, Part II.
 704 Compositions of minerals and melts. *Contributions to Mineralogy and Petrology*
 705 117, 375–393.
 706 Wall, V.J., Clemens, J.D., Clarke, D.B., 1987. Models for granitoid evolution and source
 707 compositions. *Journal of Geology* 95, 731–749.
 708 Wan, Y.S., Liu, D.Y., Xu, M.H., Zhuang, J.M., Song, B., Shi, Y.R., Du, L.L., 2007.
 709 SHRIMP U-Pb zircon geochronology and geochemistry of metavolcanic and
 710 metasedimentary rocks in North western Fujian, Cathaysia block, China: Tectonic
 711 implications and the need to redefine lithostratigraphic units. *Gondwana Research*
 712 12, 166–183.
 713 Wan, Y.S., Liu, D.Y., Simon, A.W., Cao, J.J., Chen, B., Dong, C.Y., 2010. Evolution of
 714 the Yunkai Terrane, South China: Evidence from SHRIMP zircon U-Pb dating,
 715 geochemistry and Nd isotope. *Journal of Asian Earth Sciences* 37, 140–153.
 716 Wang, X.L., Zhou, J.C., Qiu, J.S., Gao, J.F., 2004. Geochemistry of the Meso- to
 717 Neoproterozoic basic-acid rocks from Hunan Province, South China: implications
 718 for the evolution of the western Jiangnan orogen. *Precambrian Research* 135, 79–
 719 103.
 720 Wang, X.L., Shu, L.S., Xing, G.F., Zhou, J.C., Tang, M., Shu, X.J., Qi, L., Hu, Y.H.,
 721 2012. Post-orogenic extension in the eastern part of the Jiangnan orogen:
 722 Evidence from ca 800–760 Ma volcanic rocks. *Precambrian Research* 222–223,
 723 404–423.
 724 Wang, Y.J., Fan, W.M., Guo, F., Peng, T.P., Li, C.W., 2003. Geochemistry of Mesozoic
 725 mafic rocks around the Chenzhou-Linwu fault in South China: implication for the
 726 lithospheric boundary between the Yangtze and the Cathaysia Blocks.
 727 *International Geology Review* 45, 263–286.
 728 Wang, Y.J., Fan, W.M., Zhao, G.C., Ji, S.C., Peng, T.P., 2007. Zircon U-Pb
 729 geochronology of gneissic rocks in the Yunkai massif and its implications on the
 730 Caledonian event in the South China Block. *Gondwana Research* 12, 404–416.

731 Wang, Y.J., Zhang, A.M., Fan, W.M., Zhao, G.C., Zhang, G.W., Zhang, F.F., Zhang,
 732 Y.Z., Li, S.Z., 2011. Kwangsiian crustal anatexis within the eastern South China
 733 Block: geochemical, zircon U-Pb geochronological and Hf isotopic fingerprints
 734 from the gneissoid granites of Wugong and Wuyi-Yunkai Domains. *Lithos* 127,
 735 239–260.

736 Wang, Y.J., Fan, W.M., Zhang, G.W., Zhang, Y.H., 2013a. Phanerozoic tectonics of the
 737 South China Block: Key observations and controversies. *Gondwana Research* 23,
 738 1273–1305.

739 Wang, Y.J., Zhang, A.M., Fan, W.M., Zhang, Y.H., Zhang, Y.Z., 2013b. Origin of
 740 paleosubduction-modified mantle for Silurian gabbro in the Cathaysia Block:
 741 geochronological and geochemical evidence. *Lithos* 160–161, 37–54.

742 Wang, Y.J., Zhang, A.M., Cawood, F.A., Fan, W.M., Xu, J.F., Zhang, G.W., Zhang, Y.Z.,
 743 2013c. Geochronological, geochemical and Nd–Hf–Os isotopic fingerprinting of
 744 an early Neoproterozoic arc–back-arc system in South China and its accretionary
 745 assembly along the margin of Rodinia. *Precambrian Research* 231, 343–371.

746 Wei, G.J., Liang, X.R., Li, X.H., Liu, Y., 2002. Precise measurement of Sr isotopic
 747 compositions of liquid and solid base using (LA) MC-ICP-MS. *Geochimica* 31,
 748 295–305 (in Chinese with English abstract).

749 Wolf, M.B., Wyllie, P.J., 1994. Dehydration-melting of amphibolite at 10 kbar: the
 750 effects of temperature and time. *Contributions to Mineralogy and Petrology* 115,
 751 369–383.

752 Woodhead, J., Hergt, J., Shelley, M., Eggins, S., Kemp, R., 2004. Zircon Hf-isotope
 753 analysis with an excimer laser, depth profiling, ablation of complex geometries,
 754 and concomitant age estimation. *Chemical Geology* 209, 121–135.

755 Wu, F.J., Zhang, F.R., 2003. Features and genesis of Caledonian granites in the Wugong
 756 in the eastern segment of the northern margin of South China. *Geology in China*
 757 30, 166–172 (in Chinese with English abstract).

758 Wu, F.Y., Yang, Y.H., Xie, L.W., Yang, J.H., Xu, P., 2006. Hf isotopic compositions of
 759 the standard zircons and baddeleyites used in U-Pb geochronology. *Chemical*
 760 *Geology* 234, 105–126.

761 Wyllie, P.J., Wolf, M.B., 1993. Amphibolite dehydration-melting: sorting out the solidus.
762 Geological Society, London, Special Publications 76, 405–416.

763 Xia, Y., Xu, X.S., Zou, H.B., Liu, L., 2014. Early Paleozoic crust-mantle interaction and
764 lithosphere delamination in South China Block: evidence from geochronology,
765 geochemistry, and Sr-Nd-Hf isotopes of granites. *Lithos* 184–187, 416–435.

766 Xie, Z.D., Yang, Y.G., 2000. Isotopic age of zircon in Anxi pluton of Xinfeng, Jiangxi,
767 and its geological implications. *Jiangxi Geology* 14 (3), 172–175 (in Chinese with
768 English abstract).

769 Xu, W.J., Xu, X.S., 2015. Early Paleozoic intracontinental felsic magmatism in the South
770 China Block: Petrogenesis and geodynamics. *Lithos*, 234–235, 79–92.

771 Xu, X.B., Zhang, Y.Q., Shu, L.S., Jia, D., Wang, R.R., Xu, H.Z., 2009. Zircon LA-ICP-
772 MS U-Pb Dating of the Weipu granitic pluton in southwest Fujian and the
773 Changpu migmatite in South Jiangxi: Constrains to the timing of Caledonian
774 movement in Wuyi mountains. *Geological Review* 55, 277–285 (in Chinese with
775 English abstract).

776 Xu, X.S., O'Reilly, S.Y., Griffin, W.L., Deng, P., Pearson, N.J., 2005. Relict Proterozoic
777 basement in the Nanling Mountains (SE China) and its tectonothermal
778 overprinting. *Tectonics* 24, 1–16.

779 Yao, J.L., Shu, L.S., Santosh, M., 2014. Neoproterozoic arc-trench system and breakup of
780 the South China Craton: Constraints from N-MORB type and arc-related mafic
781 rocks, and anorogenic granite in the Jiangnan orogenic belt. *Precambrian*
782 *Research* 247, 187–207.

783 Yao, W.H., Li, Z.X., Li, W.X., Wang, X.C., Li, X.H., Yang, J.H., 2012. Post-kinematic
784 lithospheric delamination of the Wuyi-Yunkai orogen in South China: evidence
785 from ca. 435 Ma high-Mg basalts. *Lithos* 154, 115–129.

786 Yin, A., Nie, S., Craig, P., Harrison, T.M., Ryerson, F.J., Xianglin, Q., Geng, Y., 1998.
787 Late Cenozoic tectonic evolution of the southern Chinese Tian Shan. *Tectonics* 17,
788 1–27.

789 Yu, J.H., Wang, L.J., O'Reilly, S.Y., Griffin, W.L., Zhang, M., Li, C.Z., Shu, L.S., 2009.
790 A Paleoproterozoic orogeny recorded in a long-lived cratonic remnant (Wuyishan
791 terrane), eastern Cathaysia Block, China. *Precambrian Research* 174, 347–363.

792 Yu J.H., O'Reilly S.Y., Wang L.J., Griffin W.L., Zhou M.F., Zhang M., Shu L.S., 2010.
 793 Components and episodic growth of Precambrian crust in the Cathaysia Block,
 794 South China: Evidence from U-Pb ages and Hf isotopes of zircons in
 795 Neoproterozoic sediments. *Precambrian Research* 181, 97–114.
 796 Zhang, F.F., Wang Y.J., Zhang A.M., Fan W.M., Zhang Y.Z., Zi J.W., 2012.
 797 Geochronological and geochemical constraints on the petrogenesis of Middle
 798 Paleozoic (Kwanghsian) massive granites in the eastern South China Block. *Lithos*
 799 150, 188–208.
 800 Zhang, Q., Jiang, Y.H., Wang, G.C., Liu, Z., Ni, C.Y., Qing, L., 2015. Origin of Silurian
 801 gabbros and I-type granites in central Fujian, SE China: Implications for the
 802 evolution of the early Paleozoic orogen of South China. *Lithos* 216–217, 285–297.
 803 Zhao, G.C., Cawood, P.A., 2012. Precambrian geology of China. *Precambrian Research*
 804 222–223, 13–54.
 805 Zhao, L., Zhou, X.W., Zhai, M.G., Santosh, M., Geng, Y.S., 2014. Zircon U-Th-Pb-Hf
 806 isotopes of the basement rocks in northeastern Cathaysia block, South China:
 807 Implications for Phanerozoic multiple metamorphic reworking of a
 808 Paleoproterozoic terrane. *Gondwana Research* 28, 246–261.
 809 Zhong, Y. F., Ma, C. Q., Liu, L., Zhao, J. H., Zheng, J. P., Nong, J. N., Zhang, Z. J., 2014.
 810 Ordovician appinites in the Wugongshan Domain of the Cathaysia Block, South
 811 China: Geochronological and geochemical evidence for intrusion into a local
 812 extensional zone within an intracontinental regime. *Lithos* 198, 201–216.
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814 **Figure Captions**

815 Fig. 1. (a) Simplified regional map highlighting the tectonic framework of the South
816 China Block (SCB) that is made of the Yangtze and Cathaysia blocks (revised
817 from [Li et al., 2010](#)). (b) Sketch map showing the known extent of the early
818 Paleozoic Wuyi-Yunkai orogen, the metamorphic core of the orogen, the early
819 Paleozoic granitic rocks of the eastern SCB and the location of known mafic
820 rocks (revised from [Li et al., 2010](#); [Wang et al., 2011](#); [Huang et al., 2013](#)). Insert
821 geochronology histogram show the age range of the early Paleozoic mafic and
822 granitic rocks in the eastern SCB. Geochronology data are according to the
823 literatures ([Chen et al., 2008](#); [Gan et al., 1993](#); [Guan et al., 2014](#); [Huang et al.,](#)
824 [2013](#); [Li et al., 2010](#); [Lou et al., 2005](#); [Peng et al., 2006](#); [Shen et al., 2008](#); [Wan](#)
825 [et al., 2007](#); [2010](#); [Wang et al., 2007, 2011](#); [2013b](#); [Wu and Zhang, 2003](#); [Xie](#)
826 [and Yang, 2000](#); [Xu et al., 2009](#); [Zhang et al., 2012, 2015](#); [Xia et al., 2014](#);
827 [Zhong et al., 2014](#); [Xu and Xu, 2015](#))

828 Fig. 2. Simplified geological map of the Zhangjiafang pluton (modified after Yichun
829 and Zhuzhou Geological Maps at 1:200,000 scale), showing rock types and
830 sample location.

831 Fig. 3. Field photographs and petrographic characteristics of the Zhangjiafang
832 granodiorite and coexisting mafic microgranular enclave (MME): (a, b) outcrops
833 of elongated MME in the granodiorite; (c) petrographic characteristics of
834 granodiorite (XQ-1); and (d) petrographic characteristics of MME (XQ-15).
835 Mineral abbreviations: Amphibole (Amp), Biotite (Bt), Plagioclase (Pl), K-

feldspar (Kfs) and Quartz (Qz). The length of the marker pen in (a) and (b) is ca 14 cm.

Fig. 4. Concordia diagrams for LA-ICP-MS zircon analyses and diagrams for weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of Zhangjiafang granodiorites and MME: (a, b) granodiorite (XQ10-3); (c) granodiorite (XQ10-13); and (d) MME (XQ10-15). The circles on representative CL images denote the locations for *in situ* zircon U-Pb dating (dotted line) or Lu-Hf isotopic analyses (solid line). Uncertainties of individual analyses are at the 1σ level.

Fig. 5. Diagrams of zircon Hf isotope evolution for Zhangjiafang granodiorites and MMEs. The data sources: the early Paleozoic I-type granites (Zhang et al., 2012) and Precambrian basements (Shu et al., 2011; Liu et al., 2014; Wang et al., 2012, 2013c; Yu et al., 2009; Zhao et al., 2014) of the eastern Yangtze and western Cathaysia blocks, Zhenghe Neoproterozoic mafic rocks (Shu et al., 2011; Wang et al., 2013), Hongxiaqiao-Banshanpu (HXQ-BSP) granites (Guan et al., 2014) and Zhangjiafang (ZJF) granite (Zhang et al., 2012).

Fig. 6. Harker diagrams for Zhangjiafang (ZJF) granodiorites and MMEs. The data of gneissic granites are from Wang et al. (2011), and those of Banshanpu (BSP) and Hongxiaqiao (HXQ) plutons are from Guan et al. (2014). Gneissic granites include the samples from the Wugongshan, North Wuyi and South Wuyi areas in the Cathaysia Block.

Fig. 7. A/NK vs. A/CNK plots showing metaluminous to weak peraluminous nature of Zhangjiafang (ZJF) granodiorites and MMEs. The data of gneissic granites are from Wang et al. (2011), and those of Banshanpu (BSP) and Hongxiaqiao (HXQ)

plutons are from Guan et al. (2014). Gneissic granites include the samples from the Wugongshan, North Wuyi and South Wuyi areas in the Cathaysia Block.

Fig. 8. Chondrite-normalized REE patterns and primitive mantle-normalized trace elements variation diagrams for Zhangjiafang (ZJF) granodiorites and MMEs. Chondrite and PM normalization factors from Taylor and McLennan (1985) and Sun and McDonough (1989), respectively. The data of appinites from Zhong et al. (2014), and those of Banshanpu (BSP) and Hongxiaqiao (HXQ) plutons are from Guan et al. (2014).

Fig. 9. Initial $\epsilon_{Nd}(t)$ vs. $(^{87}Sr/^{86}Sr)_i$ for Zhangjiafang granodiorites and MMEs. The data sources: appinites from the Wugongshan area (Zhong et al., 2014), gneissic granites from the Wugongshan, North Wuyi and South Wuyi areas (Wang et al., 2011), I-type granites and coexisting mafic enclave from the Banshanpu and Hongxiaqiao plutons (Guan et al., 2014), other I-type granites of the eastern Yangtze Block (Zhang et al., 2012) and the Taishan pluton (Huang et al., 2013), Xinyi gabbros, and mafic rocks in the inner Cathaysia Block (Wang et al., 2013b; Yao et al., 2012; Zhang et al., 2015). The curve show mixing between mantle derived melts (represented by Xinyi gabbros: Sr = 60 ppm, Nd = 15 ppm, $(^{87}Sr/^{86}Sr)_i = 0.7049$, $\epsilon_{Nd}(t) = -0.6$) and crustal magma (represented by average value of Taishan I-type granite at Shamaoshi: Sr = 163 ppm, Nd = 33.3 ppm, $(^{87}Sr/^{86}Sr)_i = 0.7158$, $\epsilon_{Nd}(t) = -11.2$).

Fig. 10. The diagrams of SiO₂ versus trace elements of Sr, Ba, Th, U, Cr and Co for Zhangjiafang (ZJF) granodiorites and MMEs. The data sources: appinites from the Wugongshan (WGS) area (Zhong et al., 2014), gneissic granites from the

Wugongshan (WGS), North Wuyi and South Wuyi areas in the Cathaysia Block (Wang et al., 2011), Daning granite in northeastern Guangxi (Cheng et al., 2009), I-type granites and coexisting mafic enclave from the Banshanpu (BSP) and Hongxiaqiao (HXQ) plutons (Guan et al., 2014).

Fig. 11. Initial $\epsilon_{\text{Nd}}(t)$ versus $\text{MgO}/\text{Fe}_2\text{O}_3$ and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ for Zhangjiafang (ZJF) granodiorites and MMEs. Data source: appinites from the Wugongshan (WGS) area (Zhong et al., 2014), I-type granites and coexisting mafic enclave from the Banshanpu (BSP) and Hongxiaqiao (HXQ) plutons (Guan et al., 2014), Daning granite in northeastern Guangxi (Cheng et al., 2009), Xinyi gabbros and other mafic rocks in the inner Cathaysia Block (Wang et al., 2013b; Yao et al., 2012; Zhang et al., 2015). The curves show mixing trend between mantle-derived melts (represented by Xinyi gabbros: $\text{Nd} = 15$ ppm, $\epsilon_{\text{Nd}}(t) = -0.6$, $\text{MgO} = 7.0$ wt%, $\text{Fe}_2\text{O}_3 = 10.0$ wt%, $\text{K}_2\text{O} = 0.8$ wt%, $\text{Na}_2\text{O} = 2.4$ wt%) and crustal magma (represented by average value of Taishan I-type granite at Shamaoshi: $\text{Nd} = 33.3$ ppm, $\epsilon_{\text{Nd}}(t) = -11.2$, $\text{MgO} = 2.23$ wt%, $\text{Fe}_2\text{O}_3 = 6.86$ wt%, $\text{K}_2\text{O} = 2.49$ wt%, $\text{Na}_2\text{O} = 2.29$ wt%).

Fig. 12. Cartoon showing the asthenospheric upwelling, basaltic underplating and associated magmatism along the pre-existing boundary between eastern Yangtze and Cathaysia blocks during the collapse of the Wuyi-Yunkai orogen.

Fig 03

Fig 07

Fig 08

Sample/Chondrite

Sample/Primitive Mantle

Fig 09

Fig 01 200 Ma