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**Early Neoproterozoic (~840 Ma) arc magmatism: geochronological and
geochemical constraints on the metabasites in the Central Jiangnan Orogen**

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Abstract The Jiangnan Orogen is traditionally considered the suture zone, along which the Yangtze and Cathaysia blocks collided to form the united South China Block. There are still major controversies surrounding the pre-collisional tectonic pattern and amalgamation process along the Orogen and the relationship of the united South China Block (SCB) with the Rodinia. Our recent field investigations identified the presence of the volcano-sedimentary unit of the Lengjiaxi Group at Jianxichong, with the thickness of over 1700 m. A set of new zircon U-Pb geochronological, whole-rock elemental and Sr-Nd isotopic data for the metabasites have been obtained and presented in this paper. The layered diabase and tuffaceous samples from the Jianxichong volcano-sedimentary unit yielded the weighted mean ages of 837 ± 5 Ma and 835 ± 6 Ma, respectively. The U-Pb ages of detrital zircons from the phyllite interlayer form a main age-cluster at the peak age of 870 Ma with the youngest apparent age of 845 ± 23 Ma. This indicates that the metabasites in the Jianxichong volcano-sedimentary unit formed at ~ 845 -835 Ma rather than in the previously-thought Neoproterozoic in the Central Jiangnan Orogen. The metabasitic samples have SiO_2 ranging from 48.78 wt.% to 53.72 wt.% and MgO from 7.71 wt.% to 12.74 wt.% with mg-number of 63-71, and hence can be classified as tholeiitic basalt and basaltic andesite. They demonstrate a sub-parallel and right-sloping chondrite-normalized REE pattern with slightly negative Eu anomalies and sub-parallel spiky PM-normalized patterns with enrichment in LILEs, depletion in HFSEs and P-Ti negative anomalies, similar to those of arc volcanic rocks. Their $\epsilon_{\text{Nd}}(t)$ values range from -1.64 to -0.37 and initial $^{87}\text{Sr}/^{86}\text{Sr}$ values from 0.7046 to 0.7081, respectively. Such crust-like geochemical characteristics might have been inherited from a sub-arc source modified by fluid/melt released from the subduction sedimentary component. In conjunction with available data and geological observations, we herein propose the development of the early Neoproterozoic (~ 840 Ma) continental arc-basin system along the Central Jiangnan Orogen in response to an arc-continent accretionary assembly along the Rodinia exterior.

Key words Early Neoproterozoic; Metabasites; Continental arc-basin system;

1. Introduction

The assemblage of the Yangtze with Cathaysia Blocks created the SCB along the Jiangnan Orogen during the Neoproterozoic period (e.g., Charvet et al., 1996; Li et al., 2002, 2008, 2009; Wang et al., 2006, 2013a, 2014; Yu et al., 2012; Zhang and Zheng, 2013; Zhang et al., 2012a, 2013a, 2015; Yao et al., 2014, 2015; Zhao, 2015). The Shaoxing-Jiangshan fault has been widely accepted as the suture in the Eastern Jiangnan Orogenic zone due to the preservation of oceanic remnants, arc igneous rocks and related geological signatures (e.g., Li et al., 2002, 2008, 2009; Wang et al., 2006, 2007a; Ye et al., 2007; Zhang et al., 2012b). Numerous studies have been done on the Neoproterozoic igneous and sedimentary rocks along the Central (NW Jiangxi and NE Hunan Provinces) and Western (western Hunan and northern Guangxi Provinces) Jiangnan Orogen (Fig. 1a; Gan et al., 1996; Li, 1997; Wang et al., 2004, 2007b; Zhou et al., 2004, 2009; Zheng et al., 2006, 2007, 2008; Zhao et al., 2011; Zhang et al., 2013a, 2015).

Main attention has been paid to the Neoproterozoic (830-750 Ma) igneous rocks along the Central and Western Jiangnan Orogen, for example, the <830 Ma mafic-ultramafic rocks that are traditionally considered the oceanic remnants (e.g., Wang et al., 2004, 2006, 2012a, 2012b; Zhou et al., 2009; Zhao et al., 2011). In contrast, >830 Ma igneous rocks, especially mafic rocks, have been poorly reported along the Jiangnan orogenic belt. Zhang et al. (2013a) reported 860-838 Ma basalts and dolerites generated in a back-arc or fore-arc basin setting in the Wenjiashi-Fangxi areas along the Central Jiangnan Orogen. Yao et al. (2014) identified ~850 Ma arc-related magmatic rocks in northern Guangxi along the western Jiangnan Orogen. In general, the pre-collisional tectonic pattern and initial collisional timing for the Central Jiangnan Orogen are still in dispute and remain unsolved. This leads to further controversies over the amalgamation process along the Jiangnan Orogen. For example, some researchers considered that the amalgamation of the SCB along the Jiangnan Orogen occurred at 1.0-0.9 Ga (named "Sibao orogeny"), equivalent with the global

Grenvillian orogeny, and the subsequent (~830-750 Ma) rifting geodynamically related to the mantle plume or superplume in response to the breakup of the supercontinent Rodinia (e.g., Li et al., 1995, 1999, 2003, 2009; Greentree et al., 2006; Wang et al., 2007a; Ye et al., 2007). Other researchers believed that the SCB was created by the oceanic subduction and subsequent arc/continental-continental collision at ~1.0-0.8 Ma along the periphery of Rodinia (e.g., Zhou et al., 2002, 2009; Wang et al., 2004, 2013a, 2014; Zheng et al., 2006, 2007, 2008; Zhao et al., 2011; Zhao and Cawood, 2012; Zhang et al., 2012a, 2013a, 2015; Cawood et al., 2013).

The Jiangnan Orogen is accepted to be an important tectonic boundary between the Yangtze and Cathaysia Blocks (e.g., Shu and Charvet, 1996; Li et al., 1999; Zhao and Cawood, 2012; Zhang et al., 2012a, 2013a, 2015 and reference therein). It extends along the NE-trending with a length of >1000 km and a width of 80-120 km (Fig. 1a; e.g., Jiangxi BGMR, 1984; Hunan BGMR, 1988). Along this Orogen, there exposed abundant Neoproterozoic sequences involving the Lengjiaxi Group and Banxi Group as well as their equivalents, along with small amount of the Neoproterozoic igneous rocks, especially mafic-ultramafic rocks (e.g., Jiangxi BGMR, 1984; Hunan BGMR, 1988; Zhang et al., 2012a, 2013a). These Neoproterozoic mafic and ultramafic rocks are critical to understanding the tectonic evolution of the SCB and its relationship with Rodinia supercontinent. It is especial that the mafic rocks with the formation ages of >830 Ma along the Central Jiangnan Orogen play a key role in better unraveling the pre-collisional tectonic setting and testing various different tectonic models of the SCB. Our recent field investigations identified the metamorphic volcano-sedimentary unit in the Lengjiaxi Group with the thickness of over 1700 m at the Jianxichong area (named herein the Jianxichong unit), Liuyang (Hunan Province, China). The unit is characterized by metabasites, sandstone, phyllite and tuffaceous rocks, as shown in Fig. 2. In this paper, we document field observation, zircon U-Pb geochronological, whole-rock elemental and Sr-Nd isotopic data for the metabasites, along with zircon U-Pb geochronological data for the tuff and phyllite from the Jianxichong unit in the Central Jiangnan Orogen. Our data reveal the development of an early Neoproterozoic (~840 Ma) arc environment along the Central Jiangnan

Orogen of the SCB arc-continent accretionary regime along the exterior Rodinia.

2. Geological background and petrology

The outcropped strata along the Jiangnan Orogen include the Neoproterozoic sequence, Paleozoic shallow marine package and Mesozoic terrestrial sequence (e.g., Hunan BGMR, 1988; Wang et al., 2005; Dong et al., 2014; Li et al., 2014). The Paleozoic package is composed of Cambrian slaty shale, sandstone and limestone, Ordovician limestone and argillaceous siltstone, Silurian shale and sandstone, Middle and Upper Devonian sandstone and siltstone, Carboniferous and Permian limestone, and Lower Triassic carbonatite. The upper Paleozoic Devonian -lower Triassic sedimentary sequence is angular unconformably underlain by the lower Paleozoic Cambrian-Silurian sequence, and overlain by the Upper Triassic- Cretaceous terrestrial siliciclastic strata.

The Neoproterozoic sequence in the Jiangnan Orogen comprises the Lengjiaxi, and Banxi Groups, as well as their equivalents, along with the Sinian tillite and limestone (e.g., Jiangxi BGMR, 1984; Hunan BGMR, 1988; Zhang et al., 2012a, 2013a). The Lengjiaxi Group and its equivalents (e.g., Shuangqiaoshan Group in NW Jiangxi and Sibao Group in NE Guangxi Provinces) experienced multiple-phase structural overprinting and are traditionally regarded as the folded basement of the Jiangnan orogenic belt. The rock package is dominated by a volcano-sedimentary sequence with tholeiitic mafic lavas and flysch turbidite at the lower and upper segment, respectively. The turbidite sequence shows a sediment thickness of >25,000 m and consists mainly of metamorphic sandstone, siltstone, tuff, schist, phyllite and slate. Available data show that the Lengjiaxi Group and its equivalents likely formed at ~860-835 Ma (e.g., Gao et al., 2008, 2010, 2011; Zhou et al., 2009; Zhao et al., 2011; Zhang et al., 2011a, 2013a, 2015). The Banxi Group and its equivalents were previously considered to be the representative of the Mesozoic Banxi ophiolite mélangé (Hsü et al., 1990). However, lines of evidence argue that the Banxi Group and its equivalents represent a continuous Neoproterozoic sedimentary succession,

which is mainly composed of a well-bedded greywacke– slate–schist sedimentary association intruded by the igneous plutons. Its deposition time is likely at 810–720 Ma (Wang and Li, 2003; Wang et al., 2003; Yin et al., 2003; Zhang et al., 2015 and reference therein).

The Neoproterozoic igneous rocks along the Jiangnan Orogen include a small amount of tholeiitic volcanic rocks in the Lengjiaxi and Cangshuipu Groups, mafic and ultramafic plutons and voluminous peraluminous granites (e.g., Hunan BGMR, 1988; Wang and Li, 2003; Zhang et al., 2012a, 2013a, 2015; Su et al., 2014). The granitic batholiths are dominated by peraluminous K-feldspar granites and two-mica granites with porphyritic to porphyroid textures. Their mineral assemblage includes quartz, K-feldspar, plagioclase, biotite, muscovite and accessory minerals. Available geochronological data show that the Neoproterozoic granites give zircon U-Pb crystallization age of 828-745 Ma with two peaks at ~770 and ~820 Ma (e.g., Xu and Zhou, 1992; Tang et al., 1997; Liu, 1997; Li, 1999; Li et al., 1999, 2002, 2003; Wu et al., 2006; Zheng et al., 2007, 2008 and references therein). The mafic and ultramafic plutons are mainly exposed in the Wanzai-Nanchang area in NW Jiangxi, the Huaihua-Yuanling and Yiyang-Liuyang area in western Hunan and the Longsheng-Yuanbaoshan area in southern Guangxi. They are preserved as dykes, intrusive and layered sill mainly in the Lengjiaxi Group (Fig. 1a, e.g., Hunan BGMR, 1988; Wang et al., 2004, 2007a). The Neoproterozoic volcanic rocks are characterized by tholeiitic basalt and predominantly preserved in the lower segment of the Lengjiaxi Group and its equivalents in the Jiangnan Orogen. Pillow basalt is additionally observed in the Fanjingshan (Guizhou) and Yiyang (Hunan) areas, with the primary mineral association of plagioclase, pyroxene and few magnetite (Che et al., 2005; Wang et al., 2007a; Zhao et al., 2011; Zhao and Zhou, 2013). In addition, ~814-824 Ma high-mg intermediate and acid volcanic rocks have recently been identified in the Cangshuipu Group between the Lengjiaxi and Banxi Groups, which show enrichment in LILEs and depletion in HFSEs and negative $\epsilon_{\text{Nd}}(t)$ values (Zhang et al., 2012a; Zhao, 2015).

The Neoproterozoic mafic rocks from the Central Jiangnan Orogen crop out in

Liuyang in NE Hunan Province and Tonggu in NW Jiangxi Province. They are characterized by basaltic lavas or mafic dykes consisting of pillow basalt, spilite, basaltic andesite, tuff, gabbro and diabase (e.g., Jiangxi BGMR, 1984; Hunan BGMR, 1988; Wang et al., 2008; Zhou et al., 2009; Zhang et al., 2013a). These rocks occurred mainly as layered basalts in the Lengjiaxi Group and partly as diabase dykes truncating or parallel to the bedding of the Lengjiaxi Group (Fig. 1b; Zhang et al., 2013a). They have undergone similar metamorphism with the Lengjiaxi sedimentary sequence (e.g., Jiangxi BGMR, 1984; Hunan BGMR, 1988). Zhang et al. (2013a) recently reported the occurrence of 860-838 Ma mafic rocks in the Lengjiaxi Group at Nanqiao, Shuikou and Zhonghuayuan villages (NE Hunan and NW Jiangxi), which show N-MORB geochemical signature, interpreted as the product in a back-arc setting.

In the Qingfengting-Jianxichong-Nanpeng area of Wenjiashi (Liuyang, NE Hunan), there preserved a metamorphic volcano-sedimentary package. This package has been traditionally mapped as the Lengjiaxi Group (Fig. 1b; e.g., Hunan BGMR, 1988), which have received very little research attention so far. Che et al. (2005) defined it as the "Jianxichong Group" containing the Qingfengting and Nanpengxia Formations at the lower and upper segments, respectively (Wu et al., 2004, 2005). Our field investigation shows that the volcano-sedimentary package has an outcrop area of ~70 km² (Fig. 1b-c; Che et al., 2005). This package have experienced greenschist- to low-grade amphibolite-facies metamorphism, generally higher grade metamorphism than that of the typical Lengjiaxi Group. It mainly consists of metamorphic basalt, basaltic andesite, phyllite and sandstone (Fig. 2). It is observed of a small amount of diabase dykes, which are parallel to the bedding planes of the "Jianxichong Group" (Figs. 1c and 2). At the top of the Jianxichong volcano-sedimentary unit, there are small amounts of tuffaceous rocks. Pillow lavas are also observed in the unit, which are brecciated with chilled margins with vesicular and amygdaloidal structures. Our investigated results show that the Jianxichong volcano-sedimentary unit is constituted by a series of thrust sheets with a total apparent thickness of more than 2000 m and overlain by the upper Triassic sequences with a fault contact (Fig. 2). Its lower

segment is generally characterized by the metamorphic basaltic rocks with the sedimentary interlayer and the upper segment by phyllite and sandstone with small amounts of volcanic rocks (Fig. 2).

These basaltic rocks have mineral compositions of plagioclases, pyroxenes, diopside and minor magnetite. The matrix shows an intergranular texture, in which the triangular interstices among plagioclase laths are filled with pyroxene, magnetite and altered mineral. Acicular pyroxene in such texture is less than 4 mm in grain size and occurs in a quenched devitrified matrix. The massive metabasitic rocks are grayish green and show blastoophitic texture with a mineral assemblage of plagioclases, pyroxenes, chalcopyrite, pyrite, ilmenite and titanite (Fig. 3a-b). Tuffaceous sample 12WS-70 is mainly composed of quartz in a tuffaceous texture (Fig 3c). Phyllite sample 13WS-7B has fine-grained mica flacks with a preferred orientation and is composed of mineral assemblage of quartz, sericite mica and chlorite (Fig. 3d). In this study, nineteen metabasaltic samples were collected from the Yanjiatan-Nanpeng–Jianxichong area (Fig. 2; Wenjiashi, NE Hunan) and selected for geochemical analyses. One representative metabasaltic, one tuffaceous and one phyllite sample were selected for zircon U-Pb dating analyses.

3. Analytical methods

Zircon grains were separated using standard density and magnetic separation techniques, and then handpicked under a binocular microscope. The grains were mounted in epoxy, polished and coated with gold. The reflected and transmitted light and cathodoluminescence (CL) imaging was carried out using a JXA-8100 electron probe microanalyzer at the Guangzhou Institute of Geochemistry (GIG), Chinese Academy of Sciences (CAS) to investigate the internal texture of zircons.

Zircon U-Pb isotope analysis for tuffaceous sample 12WS-70 was carried out by the Nu Instruments MC-ICPMS, attached to the Resonetics RESolution M-50-HR Excimer Laser Ablation System, at the University of Hong Kong (HKU), and metadiabase (13WS-4A) and phyllite (13WS-7B) by a 193 nm Geolas 2005M

laser-ablation system coupled with an Agilent 7500a ICP-MS at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (CUG) in Wuhan. Analyses were performed with a beam diameter of ca. ~30 μm , 6 Hz repetition rate, which yielded a signal intensity of 0.03 V at ^{238}U for the standard zircon 91500. Typical ablation time is 40 s for each measurement, resulting in pits of 30–40 μm depth. The data acquisition mode involved peak jumping and raw count rates were measured for ^{29}Si , ^{204}Pb , ^{206}Pb , ^{207}Pb , ^{208}Pb , ^{232}Th and ^{235}U . The instrumental setting and detailed analytical procedures for the dating techniques were described in Xia et al. (2011) and Liu et al. (2010), respectively. The off-line selection and background integration, analyzed signals, drift correction and quantitative calibration were conducted by ICPMSDataCal (Liu et al., 2010). U–Pb ages and concordia diagrams were carried out using the SQUID 1.03 and Isoplot/Ex 2.49 programs (Ludwig, 2001). 2σ errors were documented for the individual U–Pb analyses. The analyzed data are presented in Table 1.

Major oxides were measured by a wavelength X-ray fluorescence spectrometry at GIG, CAS. The relative standard derivations (RSD) are within 5%, and totals are 100 ± 1 %. Details of procedures were described by Li et al. (2005). Trace element abundances were analyzed using inductively coupled plasma mass spectrometer (ICP-MS) at the Institute of Geochemistry (IG), CAS. Detailed sample preparation and analytical procedure followed Qi et al. (2000). About 100- mg samples were digested with 1 ml of HF and 0.5 ml HNO_3 in screw top PTFE-lined stainless steel bombs at 190°C for 12 hours. The analytical precision is better than 5% for elements >10 ppm, less than 8% for those <10 ppm, and about 10% for transition metals from repetitive analyses of USGS standards BHVO-2, MRG-1 basalt and W-2 diabase.

Samples powders for Sr and Nd isotopic analyses were spiked with mixed isotope tracers, dissolved in Teflon capsules with $\text{HF}+\text{HNO}_3$ acids, and separated by the conventional cation-exchange technique and then run on single W and Ta-Re double filaments, respectively. Sr-Nd Isotope ratios were measured by a multicollector inductively coupled plasma mass spectrometry (MC-ICP-MS) at the GIG, CAS. Sample preparation and chemical separation followed Liang et al. (2003).

The total procedure blanks were $<5 \times 10^{-10}$ g for Sr and $>5 \times 10^{-11}$ g for Nd. The mass fractionation corrections for Sr and Nd isotopic ratios were based on $^{86}\text{Sr}/^{88}\text{Sr}=0.1194$ and $^{146}\text{Nd}/^{144}\text{Nd}=0.7219$, respectively. The measured $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of the (NIST) SRM 987 standard and the $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of the La Jolla standard are 0.710265 ± 12 (2σ) and 0.511862 ± 10 (2σ), respectively. $^{87}\text{Rb}/^{86}\text{Sr}$ and $^{147}\text{Sm}/^{144}\text{Nd}$ ratios were calculated using the Rb, Sr, Sm and Nd abundances measured by ICP-MS. The analytical results of whole-rock major oxides, element and Sr-Nd isotopes for the representative samples are listed in Table 2.

4. Analytical results

4.1 Zircon U-Pb dating results

Laser zircon U-Pb dating result for layered metadiabase (13WS-4A), tuff (12WS-70) and phyllite (13WS-7B) are shown in Table 1 and Fig. 4.

13WS-4A metadiabase: The sample was taken from a layered diabase dyke developed along the bedding of the Jianxichong unit. The separated zircons are mostly subhedral and spindly in morphology, transparent and light yellow in color and have weakly oscillatory zonation in CL images (insert in Fig. 4a). Twenty-two spots on 22 grains give Th/U ratios of 0.90-6.23 with the majority ranging from 1.40 to 2.56 (Table 1), indicative of an igneous origin. Nineteen analyses yield a weighted mean age of 837 ± 5 Ma with MSWD=0.1 (Fig. 4a), interpreted as the crystallization age of the sample. The remaining three grains (13WS-4A-3, -4 and -5) show an internal texture of inherited cores surrounded by heterogeneous rims and give $^{207}\text{Pb}/^{206}\text{Pb}$ apparent ages of 1057-2518 Ma, interpreted as xenocrysts.

12WS-70 tuff: This sample was collected from the top of the Jianxichong volcano-sedimentary unit, probably equivalent to the upper segment of the lower Lengjiaxi Group. The separated grains are mainly prismatic, transparent and colorless, and exhibit well-developed concentric zoning in CL images. Forty-four spots on 44 grains have been analyzed and 40 of which are plotted on the concordant line (Fig. 4b). Fourteen analyses of these spots yield $^{206}\text{Pb}/^{238}\text{U}$ apparent age of 831-840 Ma

with a weighted mean age of 835 ± 6 Ma (MSWD=0.1, Fig. 4b), representing the formation age of the coeval felsic rocks. Twenty-three analyses have $^{207}\text{Pb}/^{206}\text{Pb}$ apparent ages ranging from 1361 Ma to 2606 Ma with three age-peaks of 2478 ± 13 Ma (n=10), 2024 ± 14 Ma (n=10) and 1821 ± 27 Ma (n=3), respectively. Spots 12WS-70-05 and -32 give $^{207}\text{Pb}/^{206}\text{Pb}$ apparent ages of 1361 ± 50 Ma and 1546 ± 48 Ma, respectively, and Spot 12WS-70-11 has $^{206}\text{Pb}/^{238}\text{U}$ apparent age of 939 ± 23 Ma.

13WS-7B phyllite: This sample is a phyllite from the lower segment of the Jianxichong unit. Thirty analyses of 30 grains are concordant, as shown in Fig. 4c, and have Th/U ratios of 0.20-1.31. Twenty-five of the spots constitute an age-cluster with the peak at 870 Ma, along with the youngest $^{206}\text{Pb}/^{238}\text{Pb}$ apparent age of 845 ± 23 Ma (13WS-7B-29). Five analyzed spots (13WS-7B-9, -21, -23, -28 and -30) give older apparent ages of 1072-1906 Ma.

4.2 Geochemical results

Our metabasaltic samples have $\text{SiO}_2=48.78\text{-}53.72$ wt.% (volatile free), $\text{MgO}=7.71\text{-}12.74$ wt.%, $\text{CaO}=8.80\text{-}12.09$ wt.%, $\text{Al}_2\text{O}_3=12.31\text{-}14.78$ wt.%, $\text{TiO}_2=0.69\text{-}0.82$ wt.% and $\text{FeOt}=9.79\text{-}12.05$ wt.%. They show mg-numbers ranging from 63 to 71, Ni from 52 ppm to 277 ppm and Cr from 279 ppm to 793 ppm, respectively. These samples are plotted into the fields of basalt and basaltic andesite in the $\text{Na}_2\text{O}+\text{K}_2\text{O}$ vs. SiO_2 diagram (Fig. 5a) and exhibit the trend of the tholeiitic series in the AFM diagram (Fig. 5b). Their K_2O contents range from 0.18 wt.% to 0.99 wt.% and can be classified as low-K tholeiitic with the exception of a few samples as medium-K calc-alkaline basalts. In the plots of major oxides vs. SiO_2 (Fig. 6a-f) and trace elements vs. MgO (Fig. 6g-h), MgO, FeOt and CaO decrease with increasing SiO_2 , and Cr, Ni increase with increasing MgO.

The chondrite-normalized rare earth element (REE) patterns are shown in Fig. 7a. These samples generally demonstrate a sub-parallel and right-sloping pattern with more depleted HREEs relative to LREEs and weak Eu negative anomalies ($\text{Eu}/\text{Eu}^*=0.72\text{-}0.93$ with the exception of 12WS-76D. The $(\text{La}/\text{Sm})_{\text{cn}}$ ratios range from 1.94 to

2.87, (La/Yb)_{cn} from 2.65 to 4.49 and (Gd/Yb)_{cn} from 1.23 to 1.34. In the primitive mantle-normalized multi-elemental patterns (Fig. 7b), they exhibit "spiky" patterns that are characterized by pronounced enrichment in large-ion lithophile elements (LILEs) and a strong depletion in high-field strength elements (HFSEs). The negative Nb-Ta ((Nb/La)_n= 0.35-0.53), P and Ti and positive Th-U anomalies are similar to those of the Hokkaido arc volcanic rocks (Fig. 7b; Takanashi et al., 2011). Our samples give the measured ⁸⁷Sr/⁸⁶Sr ratios ranging from 0.70810 to 0.71545 and ¹⁴³Nd/¹⁴⁴Nd ratios from 0.51227 to 0.51237, respectively. When back-calculating to the eruption age of 840 Ma, their initial ⁸⁷Sr/⁸⁶Sr ratios are in range of 0.704582-0.708108 and the ε_{Nd}(*t*) values of -1.64 to -0.37 (Fig. 8a).

5. Discussion

5.1 Formation time of the Jianxichong metabasites: early Neoproterozoic

The Jianxichong volcano-sedimentary unit is traditionally mapped as the Lengjiaxi Group (e.g., Hunan BGMR, 1988). Wu et al. (2004, 2005) and Che et al. (2005) suggested it formed in the Neoarchean period on the basis of the whole-rock Sm-Nd isochron age of 2594±48 Ma and the higher grade metamorphism relative to the typical Lengjiaxi Group in western Hunan Province. Our dating results show that the metadiabase (13WS-4A) with the parallel occurrence to the basaltic rocks gives a weighted mean age of 837±5 Ma (n=19, MSWD=0.1). This age is consistent with 847 ±18 Ma for the Fangxi dolerite in the Shuangqianshan Group and 838±12 Ma for the Nanqiao basalt in the Lengjiaxi Group (Zhang et al., 2013a). The tuffaceous sample (12WS-70) at the top of the unit has a weighted mean age of 835±6 Ma. 13WS-7B phyllite sample in the lower segment of the unit, yields an age-peak of 870 Ma and the youngest ²⁰⁶Pb/²³⁸Pb apparent age of 845±23 Ma (13WS-7B-29). This provides a reliable constrain on the maximum depositional age at ~845-870 Ma for the Jianxichong unit. Available data show that the detrital zircons from the sandstones in the exposed Lengjiaxi Group and its equivalents have the youngest age-peak at ~860 Ma, and the associated bentonite, tuff, dacite and tholeiitic mafic lava formed at

~860-830 Ma (Li et al., 2003; Wang et al., 2006, 2007b, 2012c; Gao et al., 2008, 2010; Ma et al., 2009; Zhou et al., 2009; Dong et al., 2010; Zhao et al., 2011; Zhang et al., 2011a, 2012a, 2013a, 2015). The synthesis of these data indicates that the metabasites of the Jianxichong unit probably formed at ~835-845 Ma. The volcano-sedimentary unit should have formed in the early Neoproterozoic rather than previously-thought Neoarchean, temporally and spatially equivalent to the extensively-exposed Lengjiaxi Group in the Central Jiangnan Orogen.

5.2 Petrogenesis: sub-arc mantle modified by the recycled sediment component

Our samples have content of loss on ignition ranging from 2.13 wt.% to 3.40 wt.% and linear correlations in the plots of incompatible elements vs. Zr (Fig. 9; e.g. Nd, Th, Y and Nb) and major oxides vs. SiO₂ (Fig. 6). They show scattered distributions between LOI and Na₂O, K₂O, Rb, Sr and Sr–Nd isotopic ratios. These signatures, together with the consistency of the dataset in the REE- and PM-normalized patterns in Fig. 7a–b, suggest an insignificant low-temperature alteration. Significant crustal assimilation during magma process can be ruled out on the basis of the following observations: 1) high MgO contents (7.71-12.74 wt%), mg-number (63-71) and Cr (279-793) and Ni (52-277) contents; 2) relatively constant Nb/La ratios (0.37-0.55) and $\epsilon_{\text{Nd}}(t)$ values (-1.64 to -0.37) irrespective of MgO (Fig. 10a-b); and 3) lower Ce/Pb (1.40-5.64) and Nb/U (4.83-7.36) ratios than those of average continental crust, and similar moderately-incompatible element contents with those of the average E-MORB (Fig. 7a-b). These features, together with the similarity of the incompatible element patterns (Fig. 7a-b), are in contrary to what would be expected for a scenario where the Jianxichong metabasites have been affected by significant crustal assimilation during magma ascending.

As shown above, the studied samples have mg-number of 63–71, indicating that the magma might have experienced crystallization fractionation of olivine and pyroxene. This is further supported by the decrease of MgO, FeO_t and CaO and increase of Al₂O₃ with increasing SiO₂ (Fig. 6a-d), along with the positive

correlations between compatible elements and MgO (e.g., Cr and Ni; Fig. 6g-h). The linear relationship in Fig. 6 is consistent with what would be expected for the crystallization fractionation of olivine. Plagioclase fractionation might have played an insignificant role as suggested by slightly negative Eu anomalies and insignificant Ba enrichments (Fig. 7a-b). Fe–Ti oxides fractionation should be minor in accordance with relatively constant TiO₂ contents (Figs. 6e). The depletion of P in Fig. 7b might be related to the apatite crystallization fractionation, as additionally suggested by the increasing P₂O₅ with increasing SiO₂ and Zr. However, the crust-like elemental signatures (e.g., high LREE and LILE contents, La/Nb and Ba/La ratios and negative Nb-Ta anomalies) and Sr-Nd isotopic compositions for these samples should not be the result of the crystallization fractionation but reflective of source nature. According to the variation trends in the plots of La/Sm vs. La and La/Yb vs. Yb diagrams (Fig. 10c-d), source heterogeneity is a most likely alternative.

Negative $\varepsilon_{\text{Nd}}(t)$ values, marked Nb-Ta but absence of Ce negative anomalies for the Jianxichong metabasites indicate an impossibility for these rocks being derived from the hot and young subducted oceanic crust (e.g., Kelemen et al., 1993; Gertisser and Keller, 2003; Guo et al., 2005). The melting of the eclogitic crust usually generates the magma with high-Al₂O₃ (>17%) and low mg-number and transitional metal contents (Rapp et al., 1991, 1999; Sen and Dunn, 1994; Klemmen et al., 2002). This contradicts to the features observed for the Jianxichong metabasites. The crust-like geochemical signatures, such as high LREE and LILE contents, high Th/Ta, La/Nb, Cs/La, Ba/Th and Ba/La ratios, and significant Nb-Ta-Ti negative anomalies, are likely inherited from a mantle source modified by melt/fluid released from a subducting slab and recycled sediments (or their mixture), once the possibility for significant crustal assimilation en route is discarded (e.g., Turner et al., 1992; Gertisser and Keller, 2003; Kovalenko and Savatenkov, 2003; Smithies et al., 2007; Oliveira et al., 2009). For these samples, (Ta/La)_n ratios range from 0.54 to 1.18 and (Hf/Sm)_n ratios are from 1.00 to 1.18, suggesting an involvement of fluid-related subduction metasomatism (Fig. 11a, LaFlèche et al., 1998). They have low Nb/Y (0.18–0.23) and Nb/Zr ratios (0.005–0.06), and scattered Rb/Y (0.28–2.70) and Th/Zr

ratios (0.03–0.05), in accordance with the fluxing trend of slab-derived aqueous fluids (Fig. 11b-c, e.g., Zhao and Zhou, 2007). However, slab-derived fluid/melt is generally marked by high $\epsilon_{\text{Nd}}(t)$ positive values and Ba/Th ratios (e.g., Gertisser and Keller, 2003; Guo et al., 2005), contradicting to our observations. Therefore, it is inferred that our samples probably originated from a metasomatized source with the involvement of fluid/melt released from recycled sediments. These samples show low Sr/Ce (4.5–17.3), Ba/Th (10.3–100.0), Ce/Pb (1.4–5.6), Pb/Nd (0.3–1.3), Ba/Rb (4.2–8.4) and Sr/Y (4.1–16.1) but high Th/Ce (0.13–0.22), Nb/Zr (0.05–0.06) and Th/Nb (0.52–0.95), also suggesting the addition of the recycled sediments (Fig. 11d; e.g., Shimoda et al., 2003; Seghedi et al., 2004; Wang et al., 2007b). Our modeling calculation for $\epsilon_{\text{Nd}}(t)$ versus SiO_2 shows that an addition of 10–15% recycled sediments (i.e. the SCB continental crust) into the MORB source (resembling the synchronous Nanqiao N-MORB component) could reasonably explain the observed geochemical compositions of the Jianxichong metabasites (Fig. 8b). Based on all the evidences above, it is concluded that the crust-like geochemical characteristics of the Jianxichong metabasites in the Central Jiangnan Orogen are inherited from a sub-arc source modified by fluid/melt released from the recycled sedimentary component.

5.3 Tectonic implication: ~840 Ma arc setting along the Central Jiangnan Orogen

The Jiangnan Orogen is commonly accepted as the Neoproterozoic amalgamation belt of the Yangtze with Cathaysia Blocks (e.g., Li et al., 2002, 2008, 2009; Wang et al., 2006, 2013a, 2014; Zhang and Zheng, 2013; Zhang et al., 2012a, 2013a, 2015; Zhao et al., 2011; Zhao, 2015). A series of investigations on the igneous and sedimentary rocks in the SCB led to a number of competing models for the development of the Jiangnan Orogen, involving the ~1.0 Ga Sibaoian vs. ~820 Ma Jinningian orogenic events by distinct amalgamation styles (eastward vs. westward vs. divergent; e.g., Zhou et al., 2002; Shu et al., 2006; Wang et al., 2006, 2007a, 2013a; Li et al., 2007, 2008; Ye et al., 2007; Zheng et al., 2007, 2013; Zhao and Zhou, 2013; Cawood et al., 2013; Yao et al., 2013, 2014; Zhang et al., 2013a, 2013b, 2015; Zhao, 2015).

The Lengjiaxi Group and its equivalents are characterized by an abysmal flysch- and turbidite-facies volcano-sedimentary sequence with strong deformation and higher-grade metamorphism relative to the Banxi Group and its equivalents. This rock package along the Central Jiangnan Orogen is angular-unconformably overlain by the Cangshuipu or Banxi groups and their equivalents (Zhang et al., 2015). The detrital zircons from the sandstones in the Lengjiaxi Group commonly give the youngest and overwhelming age-cluster of 850-880 Ma with the peak age at ~860 Ma (e.g., Wang et al., 2007b; Zhou et al., 2009; Zhao et al., 2011; Zhang et al., 2011a, 2015). In contrast, the Banxi Group and its equivalents experienced relatively low-grade metamorphism, constituted by a greywacke-slate-schist-tuff sequence in a rift environment (e.g., Hunan BGMR, 1988; Wang et al., 2003, 2008; Zhao et al., 2011; Zhao, 2015). Its maximum deposition age is ~800 Ma along the Central Jiangnan Orogen (Zhang et al., 2015 and reference therein). In addition, the granites intruding the Lengjiaxi Group have zircon U–Pb ages of <828 Ma and the oldest granite in the Banxi Group is dated at 806 ± 9 Ma (e.g., Zhong et al., 2005; Wang et al., 2007b; Ma et al., 2009; Xue et al., 2010; Bai et al., 2010; Gao et al., 2010; Zhao et al., 2011). Based on these data and stratigraphic contact relationships, more and more researchers believe the amalgamation time along the Central Jiangnan Orogen occurred at ~830-800 Ma, although this remains a hotly debated issue (Wang et al., 2006, 2007a, 2008, 2012c, 2013b; Zheng et al., 2007; Zhao et al., 2011; Zhang et al., 2013a, 2015). Zhang et al. (2015) further proposed that initial collision and final assemblage occurred at ~830 Ma and ~810 Ma for the Yangtze and Cathaysia Blocks along the Central Jiangnan Orogen, respectively. However, the tectonic regime prior to the initial collision remains poorly constrained since previous works focused on the Neoproterozoic igneous rocks of 830-750 Ma along the Central Jiangnan Orogen, and the 828–810 Ma intermediate-mafic rocks with arc-like geochemical signatures (e.g., Wang et al., 2004, 2006, 2012b; Zhou et al., 2009; Zhang et al., 2011b, 2012a; Zhao et al., 2011). In contrast, the igneous rocks with the crystallization age of >830 Ma, especially mafic rocks, have received less attention and been poorly studied so far. As mentioned above, our Jianxichong metabasites formed at ~845-835 Ma and exhibit

arc-like geochemical signatures, indicating the derivation of a sub-arc source modified by the input of the recycled sedimentary component. Such characteristics suggest an island-arc setting rather than a plume environment. This is further supported by the following observations (Fig. 12): 1) On the Th-Hf-Ta and MnO-TiO₂-P₂O₅ plots, they fall into the fields of arc volcanics and island-arc tholeiites (Fig. 12a-b). 2) They have low Ti and Zr contents, resembling to arc volcanics (Fig. 12c). 3) The majority of these samples plot into the arc volcanic range, with only several samples bridging between the MORB and arc-volcanic rocks in the Ba/Nb vs La/Nb discrimination diagram (Fig. 12d).

A question remains as to whether the Neoproterozoic Jianxichong metabasites occurred on an active continental margin or in an intra-oceanic arc setting. In general, magmas from the active continental margin show higher Th/Yb and Ta/Yb ratios relative to those of oceanic arc setting (Pearce, 2008). Our samples have high Th/Yb and Ta/Yb ratios, plotting into the field of active continental marginal setting (Fig. 12e). Their high (Th/Ta)_n ratios and relatively low (Tb/Ta)_n ratios are similar to that of the basalt from active continental marginal setting (Fig. 12f). This is further supported by the feature of negative $\epsilon_{\text{Nd}}(t)$ values and presence of the xenocrysts grains of 1057-2518 Ma in Sample 13WS-4A. Zhang et al. (2013a) and Yao et al. (2014) also suggested the development of the continental basement beneath the Central and Western Jiangnan Orogen. This finding, together with available observations, suggests the development of an early Neoproterozoic (~840 Ma) continental-arc system along the Central Jiangnan Orogen.

For the Yiyang pillow high-MgO mafic-ultramafic rocks in the Lengjiaxi Group, Wang et al. (2007a) considered these rocks with spinifex texture as can be classified as komatiitic rocks, representative of the Neoproterozoic (~825 Ma) SCB mantle plume. However, these pillow basalts have quenched and devitrified matrix of less than 4 mm acicular olivine or pyroxene pseudomorphs (Zhao and Zhou, 2013) and show arc-like geochemical signature with low TiO₂, P₂O₅ and Nb/La (Wang et al., 2004; Zhao and Zhou, 2013), distinct from those of komatiitic rock (e.g. Anderson, 1994; Arndt et al., 2008). Thus, Zhao and Zhou (2013) defined them as high-mg basalt originating from

fertile peridotite source at 1440–1500°C. As shown in Figs. 6-7, our samples 12WS-73J and 12WS-73K from the Jianxichong unit have high MgO (~12.6 wt%), low TiO₂ (~0.70 wt %) and P₂O₅ (~0.05 wt %), Nb/La (~0.48) and negative $\epsilon_{\text{Nd}}(t)$ values (-0.37), similar to those of the Yiyang “komatiitic rocks” (Wang et al., 2004; Zhao and Zhou, 2013). In addition, Wang et al. (2007a) and Zhao and Zhou (2013) considered that the Yiyang pillow “komatiitic rock” probably erupted at 823-829 Ma according to the zircon U-Pb dating result for the high-mg andesite at the adjacent area. However, the dating andesite is geochemically and geochronologically identical to the high-mg andesite in the Cangshuipu Group, which is underlain by the Lengjiaxi Group with an ~830 Ma angular conformity (Zhang et al., 2012a, 2015). These observations suggest that the eruption time of the Yiyang “komatiitic rocks” should be older than ~830 Ma. Our Jianxichong unit formed at ~835-845 Ma, lithologically and temporally similar to the extensively-exposed ~860-830 Ma Lengjiaxi Group in the Central Jiangnan Orogen (Zhang et al., 2015 and reference therein). In fact, Xiao et al. (1983, 1988) and Hunan BGMR (1988) believed the Yiyang “komatiitic rocks” occurred in the middle-lower segment of the Lengjiaxi Group. Thus it is boldly inferred that the Yiyang “komatiitic rocks” formed in an early Neoproterozoic arc environment, equivalent to the Jianxichong metabasites. In the Guangxi Province of the Western Jiangnan Orogen, Yao et al. (2014) reported the presence of the ~855 Ma arc igneous rocks. Shu et al. (1994) and Charvet et al. (1996) also defined the Huaiyu and Jiuling terranes of the Jiangnan Orogen as the Neoproterozoic arc system in South China (Shu and Charvet, 1996). Yao et al. (2015) considered that the Daolinshan dolerite and Dengshan intermediate-mafic rocks (~860 Ma) are the product of arc magmatism in the Eastern Jiangnan Orogen. Therefore, arc magmatism occurred in the Jiangnan Orogen (Shu et al., 1994; Charvet et al., 1996; Zhou et al., 2003; Zhao and Zhou, 2013; Yao et al., 2014, 2015; Zhang et al., 2015 and references therein).

At the Nanqiao and Shuikou areas of the Central Jiangnan Orogen, the reported ~860-838 Ma basalts and dolerites show the N-MORB- and arc-like geochemical signatures, which are interpreted as the product in the back-arc (e.g., Zhou et al., 2003; Wang et al., 2004; Zhang et al., 2013a) or fore-arc (Yao et al., 2014) settings. The

gabbro in the Fuchuan ophiolite (South Anhui Province) suite exhibits the geochemical affinity to the back-arc basalt and is dated at 848 ± 12 Ma (e.g., Ding et al., 2008). These data support the development of the ~860-838 Ma back-arc setting along the Central Jiangnan Orogen. The synthesis of the data above indicates the development of the Neoproterozoic arc-basin system along the Central Jiangnan Orogen. The closure of the arc-basin system should be the result of the Jinningian (~830 Ma) orogenic events (e.g., Cawood et al., 2013; Wang et al., 2013, 2014; Zhang et al., 2015 and reference therein), significantly later than the ~1.0 Ga global Grenvillian orogenic event that created the Rodinia assemblage (e.g., McLelland et al., 1996; Rivers, 2008). The development of ~840 Ma arc magmatism along the Central Jiangnan Orogen argue for the model that the SCB was situated along the periphery of Rodinia facing Australia-India or East Antarctica (e.g., Torsvik et al., 2001; Yang et al., 2004; Evans, 2009; Cawood et al., 2013; Wang et al., 2013a). These data, together with the absent high-grade metamorphism and extensively- exposed Neoproterozoic (~830–800 Ma) peraluminous granite (with positive $\epsilon_{\text{Hf}}(t)$ values and high $\delta^{18}\text{O}$ values; e.g., Wu et al., 2006; Ma et al., 2009; Zhang et al., 2011b, 2013b), allow us to propose a model of an early Neoproterozoic arc-continent accretionary assembly along the Jiangnan Orogen as a part of an exterior accretionary orogen of Rodinia.

6 Conclusions

(1) The metabasites in the Jianxichong volcano-sedimentary unit formed at ~845-835 Ma rather than in the previously-thought Neoarchean in the Central Jiangnan Orogen.

(2) The metabasites have arc-like elemental and isotopic geochemical signatures, originated from a sub-arc source modified by the recycled sedimentary component..

(3) The Jianxichong metabasites formed in a continental arc setting. These data synthetically indicate an early Neoproterozoic arc-continent accretionary assembly of the SCB.

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References

- Anderson, D.L., 1994. Komatiites and picrites: evidence that the 'plume' source is depleted. *Earth Planet. Sci. Lett.* 128, 303 – 311.
- Arndt, N., Leshar, C.M., Barnes, S.J., 2008. *Komatiite*. Cambridge University Press.
- Bai, D.Y., Jia, B.H., Liu, W., Chen, B.H., Liu, Y.R., Zhang, X.Y., 2010. Zircon SHRIMP U-Pb dating of the igneous rocks from Chengbu, Hunan: constraint on the Neoproterozoic tectonic evolution of the Jiangnan Orogenic Belt. *Acta Geologica Sinica* 12, 1715–1726 (in Chinese with English Abstract).
- Cawood, P.A., Wang, Y.J., Xu, Y.J., Zhao, G.C., 2013. Locating South China in Rodinia and Gondwana: a fragment of greater India lithosphere? *Geology*, <http://dx.doi.org/10.1130/G34395.1>.
- Charvet, J., Shu, L.S., Shi, Y.S., Guo, L.Z., Faure, M., 1996. The building of South China: collision of Yangzi and Cathaysia blocks, problems and tentative answers. *J. Southeast Asian Earth Sci.* 13 (3-5), 223–235.
- Che, Q.J., Wu, G.Y., Tang, X.S., Peng, H.Q. 2005. Disintegration of the Mesoproterozoic Lengjiaxi Group in Northeast Hunan Province. *Geology and Mineral Resource of South China* 47-53. doi:10.3969/j.issn.1007-3701.2005.01.009 (in Chinese with English Abstract).
- Chen, J.F., Jahn, B.M., 1998. Crustal evolution of Southeast China: Nd and Sr isotopic evidence. *Tectonophysics* 284, 101–133.

602 Ding, B.H., Shi, R.D., Zhi, X.C., Zheng, L., Chen, L., 2008. Neoproterozoic (~850
 603 Ma) subduction in the Jiangnan Orogen: evidence from the SHRIMP U-Pb dating
 604 of the SSZ-type ophiolite in southern Anhui Province. *Acta Petrologica et*
 605 *Mineralogica* 27(5), 375-388 (in Chinese with English Abstract).
 606 Dong, S.W., Xue, H.M., Xiang, X.K., Ma, L.C., 2010. The discovery of
 607 Neoproterozoic pillow lava in spilite-ceratophyre of Lushan area, northern Jiangxi
 608 Province, and its geological significance. *Chin. Geol.* 37(4), 1021–1033 (in
 609 Chinese with English Abstract).
 610 Dong, Y.P., Xiao, A.C., Wu, L., Li, X.Y., 2014. New Conceptual Fold-Fracture
 611 Model Including Prefolding Fractures, Based on Fuyang-Lin'an Anticline,
 612 Zhejiang Province. *J. Earth Sci.* 25(5): 901–911.
 613 Evans, D.A.D., 2009, The palaeomagnetically viable, long-lived and all-inclusive
 614 Rodinia supercontinent reconstruction, in Murphy, J.B., et al., eds., *Ancient*
 615 *orogens and modern analogues: Geological Society of London Special Publication*
 616 327, 371–404.
 617 Fan, W.M., Guo, F., Wang, Y.J., Zhang, M., 2004. Late Mesozoic volcanism in
 618 thenorthern Huaiyang tectono-magmatic belt, central China: partial melts from
 619 alithospheric mantle with subducted continental crust relicts beneath the
 620 Dabieorogen? *Chem. Geol.* 209, 27–48._
 621 Fekkak, A., Pouclet, A., Ouguir, H., Ouazzani, H., Badra, L., Gasquet, D., 2001.
 622 Geochemistry and geotectonic significance of Early Cryogenian volcanics of
 623 Saghro (Eastern Anti-Atlas, Morocco). *Geodin. Acta* 14,373–385.
 624 Gan, X.C., Li, X.H., Zhao, F.Q., Huang, H.B., 1996. Zircon U-Pb and Sm-Nd
 625 isochron ages of spilite from Danzhou group, Guangxi Zhuang Autonomous
 626 region. *Geochimica* 25 (3), 270–276 (in Chinese with English abstract).
 627 Gao, L.Z., Yang, M.G., Ding, X.Z., Liu, Y.X., Liu, X., Ling, L.H., Zhang, C.H., 2008.
 628 SHRIMP U–Pb zircon dating of tuff in the Shuangqiaoshan and Heshangzhen
 629 groups in South China - constraints on the evolution of the Jiangnan
 630 Neoproterozoic Orogenic belt. *Geol. Bull. China* 27, 1744–1751 (in Chinese with
 631 English Abstract).

- Gao, L.Z., Dai, C.G., Liu, Y.X., Wang, M., Wang, X.H., Chen, J.S., Ding, X.Z., Zhang, C.H., Gao, C.Q., Liu, J.H., 2010. Zircon SHRIMP U-Pb dating of tuff bed of the Sibao Group in Southeastern Guizhou-Northern Guangxi area, China and its stratigraphic implication. *Geol. Bull. China* 29, 1259–1267 (in Chinese with English Abstract).
- Gao, L.Z., Chen, J., Ding, X. Z., Liu, Y.R., Zhang, C.H., Zhang, H., Liu, Y.X., Pang, W.H., Zhang, Y.H., 2011. Zircon SHRIMP U-Pb dating of the tuff bed of Lengjiayi and Banxi groups, northeastern Hunan: constraints on the Wuling Movement. *Geol. Bull. China* 30, 1001–1008 (in Chinese with English Abstract).
- Gao, S., Ling, W. L., Qiu, Y., Zhou, L., Hartmann, G., and Simon, K., 1999, Contrasting geochemical and Sm-Nd isotopic compositions of Archean metasediments from the Kongling high-grade terrain of the Yangtze craton: Evidence for cratonic evolution and redistribution of REE during crustal anatexis. *Geochim. Cosmochim. Acta* 63, 2071–2088, doi:10.1016/S0016-7037(99)00153-2.
- Gertisser, R., Keller, J., 2003. Temporal variations in magma composition at Merapi Volcano (Central Java, Indonesia): magmatic cycles during the past 2000 years of explosive activity. *J. Volcanol. Geotherm. Res.* 123, 1–23.
- Greentree, M.R., Li, Z.X., Li, X.H., Wu, H.C., 2006. Late Mesoproterozoic to earliest Neoproterozoic basin record of the Sibao orogenesis in west South China and relationship to the assembly of Rodinia. *Precambrian Res.* 151, 79–100.
- Guo, L.T., Hong, Y.R., Huang, J.C., Chen, Y.H., Huang, Y.H., Xu, H.S., 2005. Discovery of the Kengping spilite-keratophyre series in Xinyi, western Guangdong, China and its geological significance. *Geol. Bull. China* 24 (7), 648–654 (in Chinese with English abstract).
- Hunan BGMR (Bureau of Geology and Mineral Resources of Hunan Province), 1988. Regional Geology of Hunan Province. Geological Publishing House, Beijing (in Chinese).
- Irvine, T.N., Baragar, W.R.A., 1971. A guide to the chemical classification of common volcanic rocks. *Can. J. Earth Sci.* 8, 523–548.
- Jiangxi BGMR (Bureau of Geology and Mineral Resources of Jiangxi province),

1984. Regional Geology of Jiangxi Province. Geological Publishing House, Beijing (in Chinese).

Kelemen, P.B., Shimuzu, N., Dunn, T., 1993. Relative depletion of niobium in some arc magmas and the continental crust: partitioning of K, Nb, La and Ce during melt-rock reaction in the upper mantle. *Earth Planet. Sci. Lett.* 120, 111–134.

Kepezhinskas, P., McDermott, F., Defant, M.J., Hochstaedter, A., Drummond, M.S., 1997. Trace element and Sr–Nd–Pb isotopic constraints on a three-component model of Kamchatka Arc petrogenesis. *Geochim. Cosmochim. Acta* 61 (3), 577–600.

Klemmen, S., Blundy, J.D., Wood, B.J., 2002. Experimental constraints on major and trace element partitioning during partial melting of eclogite. *Geochim. Cosmochim. Acta* 66 (17), 3109 – 3123.

Kovalenko, A.V., Savatkov, V.M., 2003. Sm–Nd and Rb–Sr isotopic data on the sanukitoid intrusions of the Karelia, Baltic shield. *Eur. Geophys. Soc., Geophys. Res. Abs.* 5, 01508.

LaFlèche, M.R., Camire, G., Jenner, G.A., 1998. Geochemistry of post-Acadian, Carboniferous continental intraplate basalts from the Maritimes basin, Magdalen islands, Quebec. *Canada Chem. Geol.* 148, 115–136.

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

Li, X.H., 1997. Geochemical and Sm–Nd isotopic study of the Longsheng Ophiolite from the southern margin of Yangtze Craton: implications for Proterozoic tectonic evolution in SE China. *Geochem. J.* 31, 323–337.

Li, X.H., 1999. U–Pb zircon ages of granites from the southern margin of the Yangtze Block: timing of the Neoproterozoic Jinning Orogeny in SE China and implications for Rodinia Assembly. *Precamb. Res.* 43–57.

Li, X.H., Li, Z.X., Ge, W.C., Zhou, H.W., Li, W.X., Liu, Y., Wingate, M.T.D., 2003. Neoproterozoic granitoids in South China: crustal melting above a mantle plume at ca. 825Ma? *Precamb. Res.* 122, 45–83.

- Li, X.H., Su, L., Chung, S.L., Li, Z.X., Liu, Y., Song, B., Liu, D.Y., 2005. Formation of the Jinchuan ultramafic intrusion and the world's third largest Ni–Cu sulfide deposit: associated with the ~825 Ma south China mantle plume? *Geochem. Geophys. Geosyst.* 6, Q11004. doi:10.1029/2005GC 001006.
- Li, X.H., Li, W.X., Li, Z.X., Lo, C.H., Wang, J., Ye, M.F., Yang, Y.H., 2009. Amalgamation between the Yangtze and Cathaysia Blocks in South China: Constraints from SHRIMP U–Pb zircon ages, geochemistry and Nd–Hf isotopes of the Shuangxiwu volcanic rocks. *Precamb. Res.* 174, 117–128.
- Li, Y.J., Chen, L.W., Tan, P., Li, H., 2014. Lower Crustal Flow and Its Relation to the Surface Deformation and Stress Distribution in Western Sichuan Region, China. *J. Earth Sci.* 25(4): 630–637.
- Li, Z.X., Zhang, L.H., Powell, C.M.A., 1995. South China in Rodinia: part of the missing link between Australia-East Antarctica and Laurentia? *Geology* 23 (5), 407–410.
- Li, Z.X., Li, X.H., Kinny, P.D., Wang, J., 1999. The breakup of Rodinia: did it start with a mantle plume beneath South China? *Earth Planet. Sci. Lett.* 173, 171–181.
- Li, Z.X., Li, X.H., Zhou, H., Kinny, P.D., 2002. Grenvillian continental collision in South China: new SHRIMP U–Pb zircon results and implications for the configuration of Rodinia. *Geology* 30, 163–166.
- Li, Z.X., Wartho, J.A., Occhipinti, S., Zhang, C.L., Li, X.H., Wang, J., Bao, C.M., 2007. Early history of the eastern Sibao Orogen (South China) during the assembly of Rodinia: new mica $^{40}\text{Ar}/^{39}\text{Ar}$ dating and SHRIMP U–Pb detrital zircon provenance constraints. *Precamb. Res.* 159, 79–94.
- Liang, X.R., Wei, G.J., Li, X.H., Liu, Y., 2003. Precise measurement of $^{143}\text{Nd}/^{144}\text{Nd}$ and Sm/Nd ratios using multiple-collectors inductively couple plasma-mass spectrometer (MC-ICP-MS). *Geochimica* 32(1), 91–96.
- Liu, B.G., 1997. Analysis on the evolutionary features and origin of Shi'ershan superunit granite in Western Zhejiang. *Geology of Zhejiang* 13, 39–46 (in Chinese with English Abstract).
- Liu, Y.S., Gao, S., Hu, Z.C., Gao, C.G., Zong, K.Q., Wang, D.B., 2010. Continental

and oceanic crust recycling-induced melt-peridotite interactions in the Trans-North China Orogen: U – Pb dating, Hf isotopes and trace elements in zircons from mantle xenoliths. *J. Petrol.* 51, 537 – 571.

Ludwig, K. R. 2001. Users manual for Isoplot/Ex rev. 2.49: A Geochronological Toolkit for Microsoft Excel. , Berkeley Geochronology Center, Special Publication, No.1a, 55 pp.

Ma, T.Q., Chen, L.X., Bai, D.Y., Zhou, K.J., Li, G., Wang, X.H., 2009. Zircon SHRIMP dating and geochemical characteristics of Neoproterozoic granites of southeastern Hunan. *Geol. China* 36(1), 65–73 (in Chinese with English Abstract).

Maitre, R.W.L., Bateman, P., Dudek, A., Keller, J., Lemeyre, J., Bas, M.J.L., Sabine, P.A., Schmid, R., Sorensen, H., Streckeisen, A., Wooley, A.R., Zanettin, B., 1989. A Classification of Igneous Rocks and Glossary of Terms. Blackwell, Oxford.

McLelland, J., Daly, J.S., McLelland, J.M., 1996. The Grenville Orogenic Cycle (ca.1350–1000 Ma): an Adirondack perspective. *Tectonophysics* 265, 1–28.

Mullen, E.D., 1983. MnO/TiO₂/P₂O₅: a minor element discrimination for basaltic rocks of oceanic environments and its implications for petrogenesis. *Earth Planet. Sci. Lett.* 62, 53-63.

Oliveira, M.A., Agnol, R.D., Althoff, F.J., da Silva Leite, A.A., 2009. Mesoarchean sanukitoid rocks of the Rio Maria Granite-Greenstone Terrane, Amazonian craton, Brazil. *J. S. Am. Earth. Sci.* 27, 146–160.

Pearce, J.A., Cann, J.R., 1973. Tectonic setting of basic volcanic rocks determined using trace element analyses. *Earth Planet. Sci. Lett.* 19, 290–300.

Pearce, J.A., 2008. Geochemical fingerprinting of oceanic basalts with applications to ophiolite classification and the search for Archean oceanic crust. *Lithos* 100, 14–48.

Qi, L., Hu, J., Gregoire, D., 2000. Determination of trace elements in granites by inductively coupled plasma mass spectrometry. *Talanta* 51, 507–513.

Rapp, R.P., Watson, E.B., Miller, C.F., 1991. Partial melting of amphibole, eclogite and the origin of Archean trondhjemites and tonalites. *Precamb. Res.* 51, 1–25.

Rapp, R.P., Shimizu, N., Norman, M.D., 1999. Reaction between slab-derived melts

- and peridotite in the mantle wedge: experimental constraints at 3.8 GPa. *Chem. Geol.* 160, 335–356.
- Rivers, T., 2008. Assembly and preservation of lower, mid, and upper orogenic crust in the Grenville Province—implications for the evolutions of large hot long duration orogens. *Precamb. Res.* 167, 237–259.
- Seghedi, I., Downes, H., Szakács, A., Mason, P.R.D., Thirlwall, M.F., Rosu, E., Pécskay, Z., Márton, E., Panaiotu, C., 2004. Neogene–Quaternary magmatism and geodynamics in the Carpathian–Pannonian region: a synthesis. *Lithos* 72, 117–146.
- Sen, C., Dunn, T., 1994. Dehydration melting of a basaltic composition amphibolite at 1.5 and 2.0 GPa: implications for the origin of adakites. *Contrib. Mineral. Petrol.* 117, 394–409.
- Shen, W.Z., Ling, H.F., Li, W.X., Wang, D.Z., 1998. Sr and Nd isotope of Mesozoic granitoids in Jiangxi Province. *Chin. Sci. Bull.* 43, 2653–2657.
- Shimoda, G., Tatsumi, Y., Nohda, S., Ishizaka, K., Jahn, B.M., 1998. Setouchi high-Mg andesite revisited; geochemical evidence for melting of subducting sediments. *Earth Planet. Sci. Lett.* 160, 479–492.
- Shu, L.S., Zhou, G.Q., Shi, Y.S., Yin, J., 1994. Study of the high-pressure metamorphic blueschist and its Late Proterozoic age in the Eastern Jiangnan belt. *Chin. Sci. Bull.* 39, 1200–1204.
- Shu, L.S., Charvet, J., 1996. Kinematics and geochronology of the Proterozoic Dongxiang - Shexian ductile shear zone, With HP metamorphism and ophiolitic mélange (Jiangnan Region, South China). *Tectonophysics*, 267, 291–302.
- Shu, L.S., Faure, M., Jiang, S.Y., Yang, Q., Wang, Y.J., 2006. SHRIMP zircon U-Pb age, litho- and biostratigraphic analyses of the Huaiyu Domain in South China — evidence for a Neoproterozoic Orogen, not Late Paleozoic–Early Mesozoic collision. *Episodes* 29, 244–252.
- Smithies, R.H., Van Kranendonk, M.J., Champion, D.C., 2007. The Mesoproterozoic emergence of modern-style subduction. *Gondwana Res.* 11, 50–68.
- Su, J.B., Zhang, Y.Q., Dong, S.W., Chen, X.H., Li, Y., Cui, J.J., 2014.

Geochronology and Hf Isotopes of Granite Gravel from Fanjingshan, South China:
Implication for the Precambrian Tectonic Evolution of Western Jiangnan Orogen.
J. Earth Sci. 25(4): 619–629.

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

Takanashi, K., Shuto, K., Sato, M., 2011. Origin of Late Paleogene to Neogene
basalts and associated coeval felsic volcanic rocks in Southwest Hokkaido,
northern NE Japan arc: Constraints from Sr and Nd isotopes and major- and
trace-element chemistry. *Lithos* 125, 368–392.

Tang, X.S., Huang, J.Z., Guo, L.Q., 1997. Hunan Banxi Group and its tectonic
environment. *Hunan Geology* 16, 219–226 (in Chinese with English Abstract).

Torsvik, T.H., Carter, L.M., Ashwal, L.D., Bhushan, S.K., Pandit, M.K., and Jamtveit,
B., 2001, Rodinia refined or obscured: Palaeomagnetism of the Malani igneous
suite (NW India). *Precamb. Res.* 108, 319–333.

Turner, S.P., Foden, J.D., Morrison, R.S., 1992. Derivation of some A-type magmas
by fractionation of basaltic magma: an example from the Padthaway Ridge, South
Australia. *Lithos* 28, 151–179.

Wang, J., Li, Z.X., 2003. History of Neoproterozoic rift basins in South China:
implications for Rodinia break-up. *Precambrian Res.* 122, 141–158.

Wang, J., Li, X.H., Duan, T.Z., Liu, D.Y., Song, B., Li, Z.W., Gao, Y.H., 2003.
Zircon SHRIMP U–Pb dating for the Cangshuipu volcanic rocks and its
implications for the lower boundary age of the Nanhua strata in South China. *Chin.*
Sci. Bull. 48, 1663–1669.

Wang, X.C., Li, X.H., Li, W.X., Li, Z.X., 2007a. Ca. 825 Ma komatiitic basalts in
South China, first evidence for >1500°C mantle melts by a Rodinia mantle plume.
Geology 35, 1103–1106.

Wang, X. C., Li, X. H., Li, Z. X., Li, Q.L., Tang, G. Q., Gao, Y. Y., Zhang, Q. R., Liu,
Y., 2012a. Episodic Precambrian crust growth: Evidence from U-Pb ages and

812 Hf-O isotopes of zircon in the Nanhua Basin, central South China. *Precamb. Res.*
813 222–223, 386–403.

814 Wang, X.L., Zhou, J.C., Qiu, J.S., Gao, J.F., 2004. Geochemistry of the Meso- to
815 Neoproterozoic basic-acid rocks from Hunan Province, South China: implications
816 for the evolution of the western Jiangnan Orogen. *Precamb. Res.* 135, 79–103.

817 Wang, X.L., Zhou, J.C., Qiu, J.S., Zhang, W.L., Liu, X.M., Zhang, G.L., 2006.
818 LA-ICP-MS U–Pb zircon geochronology of the Neoproterozoic igneous rocks
819 from Northern Guangxi, South China: implications for petrogenesis and tectonic
820 evolution. *Precamb. Res.* 145 (1–2), 111–130.

821 Wang, X.L., Zhou, J.C., Griffin, W.L., Wang, R.C., Qiu, J.S., O’Reilly, S.Y., Xu,
822 X.S., Liu, X.M., Zhang, G.L., 2007b. Detrital zircon geochronology of
823 Precambrian basement sequences in the Jiangnan Orogen: dating the assembly of
824 the Yangtze and Cathaysia blocks. *Precamb. Res.* 159 (1–2), 117–131.

825 Wang, X.L., Zhou, J.C., Qiu, J.S., Jiang, S.Y., Shi, Y.R., 2008. Geochronology and
826 geochemistry of Neoproterozoic mafic rocks from western Hunan, South China:
827 implications for petrogenesis and post-orogenic extension. *Geol. Mag.* 145 (2),
828 215–233.

829 Wang, X.L., Shu, L.S., Xing, G.F., Zhou, J.C., Tang, M., Shu, X.J., Qi, L., Hu, Y.H.,
830 2012b. Post-orogenic extension in the eastern part of the Jiangnan Orogen:
831 Evidence from ca 800–760 Ma volcanic rocks. *Precamb. Res.* 222–223, 404–423.

832 Wang Y.J., Zhang, Y.H., Fan, W.M., Peng, T.P., 2005. Structural signatures and
833 $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology of the Indosinian Xuefengshan tectonic belt, South
834 China Block. *J. Struct. Geol.* doi: 10.1016/j.jsg. 2005.04.004.

835 Wang, Y.J., Zhang, A.M., Cawood, P.A., Fan, W.M., Xu, J.F., Zhang, G.W., Zhang,
836 Y.Z., 2013a. Geochronological, geochemical and Nd-Hf-Os isotopic
837 fingerprinting of an early Neoproterozoic arc-back-arc system in South China and
838 its accretionary assembly accretionary assembly along the margin of Rodinia.
839 *Precamb. Res.* 231, 343–371

840 Wang, Y.J., Zhang, Y.Z., Fan, W.M., Geng, H.Y., Zou, H.P., Bi, X.W., 2014. Early
841 Neoproterozoic accretionary assemblage in the Cathaysia Block:

- Geochronological, Lu–Hf isotopic and geochemical evidence from granitoid gneisses. *Precamb. Res.* 249: 144–161.
- Wang, W., Zhou, M. F., Yan, D. P., Li, J. W., 2012c. Depositional age, provenance, and tectonic setting of the Neoproterozoic Sibao Group, southeastern Yangtze Block, South China. *Precamb. Res.* 192–195, 107–124.
- Wang, W., Zhou, M. F., Yan, D. P., Li, L., Malpas, J., 2013b. Detrital zircon record of Neoproterozoic active-margin sedimentation in the eastern Jiangnan Orogen, South China. *Precamb. Res.* 235, 1–19.
- Wood, D.A., 1980. The application of a Th–Hf–Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary volcanic province. *Earth Planet. Sci. Lett.* 50, 11–30.
- Wu, G.Y., Li, J.D., Che, Q.J., Xiao, Q.H., Tang, X.S., Peng, H.Q., 2004. Sm–Nd dating and genesis of the Jianxichong Group metamorphic volcanic rocks in Northeast Hunan. *Geoscience* 18(3), 339–345 (in Chinese with English Abstract).
- Wu, G.Y., Li, J.D., Tang, X.S., Huang, J.Z., Xiao, Q.H., Che, Q.J., Peng, H.Q., 2005. Mineralogy, petrology and geochemistry of the Neoarchean metasedimentary-volcanic rocks at Jianxichong, Northeast Hunan. *Geology in China* 32(1), 82–89 (in Chinese with English Abstract).
- Wu, R.X., Zheng, Y.F., Wu, Y.B., Zhao, Z.F., Zhang, S.B., Liu, X.M., Wu, F.Y., 2006. Reworking of juvenile crust: element and isotope evidence from Neoproterozoic granodiorite in South China. *Precamb. Res.* 146, 179–212.
- Xia, X.P., Sun, M., Geng, H.Y., Sun, Y.L., Wang, Y.J., Zhao, G.C., 2011. Quasi-simultaneous determination of U–Pb and Hf isotope compositions of zircon by excimer laser-ablation multiple-collector ICPMS. *J. Anal. At. Spectrom.* 26, 1868–1871.
- Xiao, X.D., 1983. On the basaltic komatiite and its formative environment in Yiyang, Hunan. *J. Central-South Inst. Min. Metall.* 38, 106–113 (in Chinese with English Abstract).
- Xiao, X.D., 1988. Spinifex was found in Mesoproterozoic komatiites of Yiyang,

872 Hunan. Chin. Sci. Bull. 4, 286–288 (in Chinese).

873 Xu, X.S., Zhou, X.M., 1992. Precambrian S-type granitoids in South China and their
874 geological significance. Journal of Nanjing University 28, 423-430 (in Chinese
875 with English Abstract.).

876 Xue, H.M., Ma, F., Song, Y.Q., Xie, Y.P., 2010. Geochronology and geochemistry of
877 the Neoproterozoic granitoid association from eastern segment of the Jiangnan
878 orogen, China: Constraints on the timing and process of amalgamation between
879 the Yangtze and Cathaysia blocks. Acta Petrologica Sinica 26, 3215- 3244 (in
880 Chinese with English Abstract).

881 Yao, J.L., Shu, L.S., Santosh, M., Li, J.Y., 2013. Geochronology and Hf isotope of
882 detrital zircons from Precambrian sequences in the eastern Jiangnan Orogenic belt:
883 con-straining the assembly of Yangtze and Cathaysia blocks in South China. J.
884 Asian Earth Sci. 74, 225–243.

885 Yao, J.L., Shu, L.S., Santosh, M., Zhao, G.C., 2014. Neoproterozoic arc-related
886 mafic-ultramafic rocks and syn-collision granite from the western segment of the
887 Jiangnan Orogen, South China: constraints on the Neoproterozoic assembly of the
888 Yangtze and Cathaysia blocks. Precamb. Res. 243, 39–62.

889 Yao, J.L., Shu, L.S., Santosh, M., Li, J.Y., 2015. Neoproterozoic arc- related andesite
890 and orogeny-related unconformity in the eastern Jiangnan orogenic belt:
891 Constraints on the assembly of the Yangtze and Cathaysia blocks in South China.
892 Precamb. Res. 262, 84-100.

893 Yang, Z., Sun, Z., Yang, T., and Pei, J., 2004. A long connection (750–380 Ma)
894 between South China and Australia: Paleomagnetic constraints. Earth Planet. Sci.
895 Lett. 220, 423–434.

896 Ye, M.F., Li, X.H., Li, W.X., Liu, Y., Li, Z.X., 2007. SHRIMP zircon U–Pb
897 geochronological and whole-rock geochemical evidence for an early
898 Neoproterozoic Sibaoan magmatic arc along the southeastern margin of the
899 Yangtze Block. Gondwana Res. 12, 144–156.

900 Yin, C.Y., Liu, D.Y., Gao, L.Z., Wang, Z.Q., Xing, Y.S., Jian, P., Shi, Y.R., 2003.
901 Lower boundary age of the Nanhua System and the Gucheng glacial stage:

evidence from SHRIMP II dating. *Chin. Sci. Bull.* 16, 1657–1662.

Yu, J.H., O'Reilly, S.Y., Zhou, M.F., Griffin, W.L., Wang, L.J., 2012. U–Pb geochronology and Hf–Nd isotopic geochemistry of the Badu Complex, Southeastern China: Implications for the Precambrian crustal evolution and paleogeography of the Cathaysia Block. *Precamb. Res.* 222–223, 424–449.

Zhang, S.B., Zheng, Y.F., 2013. Formation and evolution of Precambrian continental lithosphere in South China. *Precamb. Res.* 23, 1241–1260.

Zhang, Y.Z., Wang, Y. J., Fan, W. M., Zhang, A. M., Zhang, F. F., 2011a. Geochronological constraints on the Neoproterozoic collision along the Jiangnan uplift: Evidence from studies on the Neoproterozoic basal conglomerates at the Cangshuipu area, Hunan Province. *Geotecton. Metallog.* 35(1), 32–46 (in Chinese with English Abstract).

Zhang, Y.Z., Wang, Y. J., Fan, W. M., Zhang, A. M., Ma, L.Y., 2012a. Geochronological and geochemical constraints on the metasomatised source for the Neoproterozoic (~825 Ma) high-mg volcanic rocks from the Cangshuipu area (Hunan Province) along the Jiangnan domain and their tectonic implications. *Precamb. Res.* 220–221, 139–157.

Zhang, Y.Z., Wang, Y.J., Geng, H.Y., Zhang, Y.H., Fan, W.M., Zhong, H., 2013a. Early Neoproterozoic (~850 Ma) back-arc basin in the Central Jiangnan Orogen (Eastern South China): Geochronological and petrogenetic constraints from meta-basalts. *Precamb. Res.* 231, 325–342.

Zhang, Y.Z., Wang, Y.J., Zhang, Y.H., Zhang, A.M., 2015. Neoproterozoic assembly of the Yangtze and Cathaysia blocks: Evidence from the Cangshuipu Group and associated rocks along the Central Jiangnan Orogen, South China. *Precamb. Res.* 269, 18–30.

Zhang, F.F., Wang, Y.J., Fan, W.M., Zhang, A.M., Zhang, Y.Z., 2011b. Zircon U–Pb geochronology and Hf isotopes of the Neoproterozoic granites in the central of Jiangnan Uplift. *Geotecton. et Metallog.* 35(1), 73–84 (in Chinese with English Abstract).

Zhang, C.L., Santosh, M., Zou, H.B., Li, H.K., Huang, W.C., 2013b. The Fuchuan

ophiolite in Jiangnan Orog. Geochemistry, zircon U–Pb geochronology, Hf isotope, implications for the Neoproterozoic assembly of South, China. *Lithos* 179, 263–274.

Zhang, S.B., Wu, R.X., Zheng, Y.F., 2012b. Neoproterozoic continental accretion in South China: Geochemical evidence from the Fuchuan ophiolite in the Jiangnan Orogen. *Precamb. Res.* 220–221, 45–64.

Zhao, G.C., Cawood, P.A., 2012. Precambrian Geology of China. *Precamb. Res.* 222–223, 13–54.

Zhao, G.C., 2015. Jiangnan Orogen in South China: Developing from divergent double subduction. *Gondwana Res.* 27, 1173–1180.

Zhao, J.H., Zhou, M.F., 2007. Geochemistry of Neoproterozoic mafic intrusions in the Panzihua district (Sichuan Province, SW China): implications for subduction related metasomatism in the upper mantle. *Precamb. Res.* 152, 27 – 47.

Zhao, J.H., Zhou, M.F., Yan, D.P., Zheng, J.P., Li, J.W., 2011. Reappraisal of the ages of Neoproterozoic strata in South China: no connection with the Grenvillian Orogeny. *Geology* 39, 299–302.

Zhao, J.H., Zhou, M.F., 2013. Neoproterozoic high-Mg basalts formed by melting of ambient mantle in South China. *Precamb. Res.* 233, 193 – 205.

Zheng, Y.F., Zhao, Z.F., Wu, Y.B., Zhang, S.B., Liu, X.M., Wu, F.Y., 2006. Zircon U–Pb age, Hf and O isotope constraints on protolith origin of ultrahigh-pressure eclogite and gneiss in the Dabie Orogen. *Chem. Geol.* 231, 135–138.

Zheng, Y.F., Zhang, S.B., Zhao, Z.F., Wu, Y.B., Li, X.H., Li, Z.X., Wu, F.Y., 2007. Contrasting zircon Hf and O isotopes in the two episodes of Neoproterozoic granitoids in South China: implications for growth and reworking of continental crust. *Lithos* 96, 127–150.

Zheng, Y.F., Wu, R.X., Wu, Y.B., Zhang, S.B., Yuan, H.L., Wu, F.Y., 2008. Rift melting of juvenile arc-derived crust: geochemical evidence from Neoproterozoic volcanic and granitic rocks in the Jiangnan Orogen, South China. *Precamb. Res.* 163, 351–383.

Zheng Y.F., Xiao, W.J., Zhao, G.C., 2013. Introduction to tectonics of China.

Gondwana Res. 23, 1189-1206.

Zhong, Y.F., Ma, C.Q., She, Z.B., Lin, G.C., Xu, H.J., Wang, R.J., Yang, K.G., Liu, Q., 2005. SHRIMP U-Pb zircon geochronology of the Jiuling granitic complex batholith in Jiangxi Province. *Earth Sci.* 30(6), 685–691 (in Chinese with English Abstract).

Zhou, J.C., Wang, X.L., Qiu, J.S., Gao, J.F., 2003. The discovery of Nanqiao highly depleted N-MORB and geological significance. *Acta Petrologica et Mineralogica* 22 (3), 211–216 (in Chinese with English Abstract).

Zhou, J.C., Wang, X.L., Qiu, J.S., Gao, J.F., 2004. Geochemistry of Meso- and Neoproterozoic mafic-ultramafic rocks from northern Guangxi, China: arc or plume magmatism? *Geochem. J.* 38, 139–152.

Zhou, J.C., Wang, X.L., Qiu, J.S., 2009. Geochronology of Neoproterozoic mafic rocks and sandstones from northeastern Guizhou, South China: Coeval arc magmatism and sedimentation. *Precamb. Res.* 170, 27–42.

Zhou, M.F., Yan, D.P., Kennedy, A., Li, Y.Q., Ding, J., 2002. SHRIMP U–Pb zircon geochronological and geochemical evidence for Neoproterozoic arc magmatism along the western margin of the Yangtze Block, South China. *Earth Planet. Sci. Lett.* 196, 51–67.

Figure caption

Fig. 1 Simplified geological maps of (a) the Precambrian basement of the Yangtze and Cathaysia Blocks separated by the Jiangnan Orogen (Zhang et al., 2012a), (b) the Wenjiashi region (modified after Hunan BGMR, 1988), and (c) the Jianxichong region showing the location of a cross section A-B in Liuyang, Hunan.

Fig. 2 Cross section of the Jianxichong metamorphic volcano-sedimentary unit on section A-B with field occurrence photos and locations of sampling.

Fig. 3 Microscope photographs for the metabasaltic rocks (a), layered metadiabase (b),

tuff (c) and phyllite (d) from the Jianxichong metamorphic volcano-sedimentary unit (Liuyang, Hunan) in the Central Jiangnan Orogen.

Fig. 4 Concordia diagrams of zircon U-Pb data for (a) 13WS-4A layered diabase, (b) 12WS-70 tuff, and (c) 13WS-7B phyllite from the Jianxichong metamorphic volcano-sedimentary unit (Liuyang, Hunan) in the Central Jiangnan Orogen. Insert in a note the representative CL images for zircons from the layered diabase 13WS-4A.

Fig. 5 Rock classification diagram of (a) TAS (after Maitre et al., 1989), and (b) $\text{Na}_2\text{O}+\text{K}_2\text{O}-\text{FeOt}-\text{MgO}$ diagram (after Irvine and Baragar, 1971) for the early Neoproterozoic metabasites from the Jianxichong metamorphic volcano-sedimentary unit (Liuyang, Hunan) in the Central Jiangnan Orogen.

Fig. 6 Plots of (a) MgO , (b) FeOt , (c) CaO , (d) Al_2O_3 , (e) TiO_2 , (f) P_2O_5 vs. SiO_2 and (g) Cr and (h) Ni vs. MgO for the early Neoproterozoic metabasites from the Jianxichong metamorphic volcano-sedimentary unit (Liuyang, Hunan) in the Central Jiangnan Orogen.

Fig. 7 (a) The chondrite normalized rare-earth elemental patterns and (b) primitive mantle-normalized spidergram for the early Neoproterozoic metabasites from the Jianxichong metamorphic volcano-sedimentary sequence (Liuyang, Hunan) in the Central Jiangnan Orogen. Chondrite- and primitive mantle-normalize values are from Sun and McDonough (1989). Data for the E-MORB, Yiyang high-MgO basalt and Hokkaido (NE Japan) arc volcanic rocks are from Sun and McDonough (1989), Zhao and Zhou (2013) and Takanashi et al. (2011), respectively.

Fig. 8 Plots of (a) $\epsilon_{\text{Nd}}(t)$ ($t = 840 \text{ Ma}$) vs. initial $^{87}\text{Sr}/^{86}\text{Sr}(t)$, (b) $\epsilon_{\text{Nd}}(t)$ vs. SiO_2 showing the modeling results for crustal assimilation en route and source involvement for the early Neoproterozoic metabasites from the Jianxichong metamorphic volcano-sedimentary unit (Liuyang, Hunan) in the Central Jiangnan Orogen. The data for the Wenjiashi N-MORB and the derived melt, MORB and the derived melt, SCB upper and middle crustal materials are from Zhang et al. (2013a), Wang et al. (2003, 2004), Shen et al. (1998), Chen and Jahn (1998) and Gao et al. (1999).

Fig. 9 Plots of (a) Nd , (b) Th , (c) Y , and (d) Nb vs. Zr for the early Neoproterozoic metabasites from the Jianxichong metamorphic volcano-sedimentary unit (Liuyang,

Hunan) in the Central Jiangnan Orogen.

Fig. 10 Plots of (a) Nb/La and (b) $\epsilon_{\text{Nd}}(t)$ vs. MgO, (c) La/Sm vs. La, and (d) La/Yb vs. Yb for the early Neoproterozoic metabasites from the Jianxichong metamorphic volcano-sedimentary unit (Liuyang, Hunan) in the Central Jiangnan Orogen.

Fig. 11 Plots of (a) (Hf/Sm)_n vs. (Ta/La)_n (after LaFlèche et al., 1998), (b) Rb/Y vs. Nb/Y (after Kepezhinskis et al., 1997), (c) Nb/Zr vs. Th/Zr (after Kepezhinskis et al., 1997), and (d) Ba/Th vs. $\epsilon_{\text{Nd}}(t)$ for the early Neoproterozoic metabasites from the Jianxichong metamorphic volcano-sedimentary unit (Liuyang, Hunan) in the Central Jiangnan Orogen.

Fig. 12 Plots of (a) Th-Hf-Ta (after Wood, 1980), (b) MnO-TiO₂- P₂O₅ (after Mullen, 1983), (c) Ti vs Zr. (after Pearce and Cann, 1973), (d) Ba/Nb vs. La/Nb (after Fan et al., 2004), (e) Th/Yb vs. Ta/Yb (after Pearce, 2008), and (f) (Tb/Ta)_n vs. (Th/Ta)_n (after Fekkak et al., 2001) for the early Neoproterozoic metabasites from the Jianxichong metamorphic volcano-sedimentary unit (Liuyang, Hunan) in the Central Jiangnan Orogen. OIT: ocean-island tholeiite or seamount tholeiite; OIA: ocean-island alkali basalt; CAB: island-arc calc-alkaline basalt; IAT: island-arc tholeiite. N-MORB: normal MORB; E-MORB: enriched MORB; BAB: back-arc basin basalts; CFB: continental flood basalts; OIA: Mariana-type intra-oceanic arc; IAB: intermediate arc basalts; OIB: ocean island basalts; CWPAB: continental within-plate alkali and transitional basalts; and CAMB: active continental margin basalts.

Table 1 LA-ICP-MS zircon U-Pb dating results for the representative metadiabase, tuff and phyllite from the Jianxichong region (Liuyang, Hunan), Central Jiangnan Orogen

Spot	Th/U	Isotopic ratios						Apparent age (Ma)						Con. %
		$^{207}\text{Pb}/^{206}\text{Pb}$	$\pm 2\sigma$	$^{207}\text{Pb}/^{235}\text{U}$	$\pm 2\sigma$	$^{206}\text{Pb}/^{238}\text{U}$	$\pm 2\sigma$	$^{207}\text{Pb}/^{206}\text{Pb}$	$\pm 2\sigma$	$^{207}\text{Pb}/^{235}\text{U}$	$\pm 2\sigma$	$^{206}\text{Pb}/^{238}\text{U}$	$\pm 2\sigma$	
		Pb		U		U		Pb		U		U		
13WS-4A: layered diabase dyke along the bedding of the Jianxichong unit														
13WS-4A-1	6.23	0.0664	0.00424	1.29732	0.08385	0.13951	0.00377	820	133	845	37	842	21	100
13WS-4A-2	2.85	0.06755	0.00388	1.30764	0.07827	0.13849	0.00385	854	119	849	34	836	22	98
13WS-4A-3	1.39	0.07455	0.00410	1.78202	0.10073	0.17121	0.00441	1057	111	1039	37	1019	24	98
13WS-4A-4	3.32	0.16607	0.00906	10.7028	0.5786	0.46456	0.01251	2518	92	2498	50	2460	55	98
13WS-4A-5	0.9	0.07461	0.00512	1.8715	0.12754	0.18100	0.00493	1057	134	1071	45	1072	27	100
13WS-4A-6	1.92	0.06766	0.00588	1.28959	0.11142	0.13801	0.00399	857	181	841	49	833	23	99
13WS-4A-7	0.9	0.07024	0.00527	1.35288	0.10293	0.13946	0.00382	1000	156	869	44	842	22	97
13WS-4A-8	1.51	0.07102	0.00395	1.36688	0.07637	0.13929	0.00346	967	147	875	33	841	20	96
13WS-4A-9	1.57	0.06468	0.00463	1.23777	0.08711	0.13861	0.00372	765	152	818	40	837	21	102
13WS-4A-10	3.91	0.06908	0.00412	1.32639	0.07963	0.13864	0.00371	902	124	857	35	837	21	98
13WS-4A-11	0.55	0.07147	0.00474	1.36987	0.09262	0.13832	0.00404	972	136	876	40	835	23	95
13WS-4A-12	1.59	0.0658	0.00793	1.26777	0.15343	0.13967	0.00415	800	256	831	69	843	23	101
13WS-4A-13	2.48	0.06506	0.00342	1.25282	0.06636	0.13895	0.00342	776	111	825	30	839	19	102
13WS-4A-14	1.85	0.06858	0.00912	1.29549	0.16904	0.13864	0.00486	887	278	844	75	837	28	99
13WS-4A-15	2.6	0.06428	0.00552	1.22615	0.10456	0.13816	0.00388	750	179	813	48	834	22	103
13WS-4A-16	2.56	0.06712	0.00479	1.28408	0.09116	0.13867	0.00381	843	148	839	41	837	22	100
13WS-4A-17	3.51	0.06701	0.0063	1.29101	0.12789	0.13854	0.00434	839	203	842	57	836	25	99
13WS-4A-18	4.36	0.06387	0.00351	1.22846	0.06715	0.13867	0.00355	739	117	814	31	837	20	103
13WS-4A-19	0.82	0.06577	0.00674	1.25772	0.12913	0.13767	0.00387	798	221	827	58	831	22	100
13WS-4A-20	1.4	0.06737	0.01055	1.27786	0.19293	0.13827	0.00658	850	331	836	86	835	37	100
13WS-4A-21	2.11	0.06921	0.00579	1.33487	0.11328	0.13823	0.00414	906	205	861	49	835	23	97

13WS-4A-22	1.44	0.0667	0.00888	1.27393	0.16718	0.13845	0.00687	828	280	834	75	836	39	100
12WS-70: tuffaceous sample from the top of the Jianxichong volcano-sedimentary unit														
12WS-70-01	1.26	0.12348	0.00318	5.93493	0.17035	0.3485	0.00976	2007	46	1966	25	1927	47	98
12WS-70-02	0.98	0.06823	0.00176	1.30578	0.03614	0.13874	0.00369	876	54	848	16	838	21	99
12WS-70-03	0.29	0.16447	0.00414	10.5322	0.29289	0.46426	0.01281	2502	43	2483	26	2458	56	99
12WS-70-04	0.66	0.16191	0.00409	10.3868	0.293	0.46504	0.01294	2476	43	2470	26	2462	57	100
12WS-70-05	0.66	0.08705	0.00225	2.60397	0.07225	0.21692	0.00592	1361	50	1302	20	1266	31	97
12WS-70-06	0.56	0.06574	0.00185	1.26252	0.03909	0.1392	0.00378	798	59	829	18	840	21	101
12WS-70-07	0.63	0.07207	0.00189	1.37081	0.03896	0.13779	0.00364	987	20	877	17	832	21	95
12WS-70-08	0.51	0.06898	0.00181	1.32148	0.03761	0.13889	0.0038	898	54	855	16	838	22	98
12WS-70-09	0.7	0.16102	0.00407	7.08158	0.20818	0.31918	0.00956	2466	38	2122	26	1786	47	84
12WS-70-10	0.73	0.06664	0.00171	1.26533	0.03712	0.13765	0.00393	828	54	830	17	831	22	100
12WS-70-11	0.61	0.06743	0.00173	1.45773	0.03911	0.15677	0.00411	850	53	913	16	939	23	103
12WS-70-12	0.66	0.06757	0.00174	1.2931	0.03626	0.1388	0.00386	855	45	843	16	838	22	99
12WS-70-13	1.69	0.06763	0.00181	1.28778	0.0434	0.13812	0.0045	857	39	840	19	834	25	99
12WS-70-14	0.02	0.1662	0.00419	10.8767	0.34233	0.47457	0.01491	2519	42	2513	29	2504	65	100
12WS-70-15	0.9	0.06684	0.00176	1.27319	0.03455	0.13812	0.00359	833	56	834	15	834	20	100
12WS-70-16	0.79	0.1647	0.00416	10.5698	0.30987	0.46544	0.01366	2506	42	2486	27	2464	60	99
12WS-70-17	0.46	0.15236	0.00385	7.05115	0.18604	0.33564	0.00886	2373	44	2118	23	1866	43	88
12WS-70-18	0.04	0.12332	0.00313	5.97398	0.16473	0.35125	0.00955	2006	46	1972	24	1941	46	98
12WS-70-19	0.35	0.1607	0.00406	10.2998	0.27406	0.46475	0.01226	2465	43	2462	25	2461	54	100
12WS-70-20	1.56	0.12393	0.00315	5.54483	0.15292	0.32441	0.00879	2013	45	1908	24	1811	43	95
12WS-70-21	0.43	0.06739	0.00173	1.2891	0.03561	0.13868	0.00373	850	54	841	16	837	21	100
12WS-70-22	1.09	0.12516	0.00317	6.05557	0.16401	0.35079	0.00937	2031	44	1984	24	1938	45	98
12WS-70-23	0.29	0.17506	0.00441	11.305	0.29795	0.46824	0.01227	2606	42	2549	25	2476	54	97
12WS-70-24	0.64	0.06523	0.00172	1.24263	0.03343	0.13814	0.00357	783	56	820	15	834	20	102

12WS-70-25	0.58	0.15551	0.00392	9.90065	0.27056	0.46173	0.01266	2409	42	2426	25	2447	56	101
12WS-70-26	0.34	0.06614	0.00169	1.26559	0.03321	0.13876	0.0036	811	49	830	15	838	20	101
12WS-70-27	0.15	0.06652	0.00172	1.26437	0.03625	0.13781	0.00383	833	54	830	16	832	22	100
12WS-70-28	1.26	0.12352	0.00315	6.20829	0.17728	0.36441	0.01027	2009	46	2006	25	2003	49	100
12WS-70-29	0.39	0.12632	0.00319	6.35629	0.17844	0.36483	0.01019	2047	44	2026	25	2005	48	99
12WS-70-30	0.61	0.06779	0.00173	1.28775	0.03666	0.13775	0.00389	861	52	840	16	832	22	99
12WS-70-31	0.62	0.15861	0.00405	10.1993	0.31475	0.46515	0.01352	2443	43	2453	29	2462	59	100
12WS-70-32	0.49	0.09589	0.00243	3.60759	0.09692	0.27274	0.00723	1546	48	1551	21	1555	37	100
12WS-70-33	0.39	0.181	0.0046	10.7693	0.32634	0.43141	0.01309	2662	42	2503	28	2312	59	92
12WS-70-34	0.6	0.12156	0.00306	5.88774	0.16315	0.35118	0.0097	1989	44	1959	24	1940	46	99
12WS-70-35	0.36	0.15558	0.00393	9.93173	0.27087	0.4628	0.01254	2409	43	2428	25	2452	55	101
12WS-70-36	0.48	0.15805	0.00401	10.0952	0.26262	0.46309	0.01194	2435	43	2444	24	2453	53	100
12WS-70-37	0.39	0.11447	0.00291	5.27109	0.14709	0.33381	0.00918	1872	46	1864	24	1857	44	100
12WS-70-38	0.6	0.11456	0.00292	5.08544	0.13386	0.32182	0.00831	1873	45	1834	22	1799	41	98
12WS-70-39	0.64	0.06917	0.00191	1.31638	0.03818	0.13799	0.00375	906	53	853	17	833	21	98
12WS-70-40	0.16	0.12852	0.00326	6.63257	0.18713	0.37412	0.01042	2080	45	2064	25	2049	49	99
12WS-70-41	0.45	0.16339	0.00414	9.12138	0.23689	0.40474	0.01043	2491	43	2350	24	2191	48	93
12WS-70-42	0.55	0.12292	0.0031	6.33191	0.17381	0.37346	0.01017	1999	45	2023	24	2046	48	101
12WS-70-43	1.81	0.12304	0.00315	6.32701	0.18922	0.37287	0.01101	2067	50	2022	26	2043	52	101
12WS-70-44	1.14	0.10451	0.00267	3.90745	0.10957	0.27112	0.00751	1706	48	1615	23	1546	38	96
13WS-7B: phyllite from the lower segment of the Jianxichong unit														
13WS-7B-1	0.34	0.0688	0.0035	1.3752	0.0693	0.1444	0.004	892	106	878	30	869	22	99
13WS-7B-2	0.31	0.068	0.0038	1.3634	0.0737	0.145	0.0037	878	119	873	32	873	21	100
13WS-7B-3	0.39	0.0693	0.0035	1.3908	0.0712	0.1445	0.0035	907	106	885	30	870	20	98
13WS-7B-4	0.47	0.0692	0.0036	1.3975	0.0731	0.1453	0.0039	906	107	888	31	874	22	98
13WS-7B-5	0.41	0.0679	0.004	1.3599	0.0792	0.1446	0.0038	865	119	872	34	871	21	100

13WS-7B-6	0.57	0.0717	0.0053	1.4333	0.1036	0.144	0.004	976	150	903	43	867	23	96
13WS-7B-7	0.85	0.0698	0.0045	1.4306	0.0919	0.1476	0.0042	922	133	902	38	888	24	98
13WS-7B-8	0.71	0.0694	0.0045	1.3771	0.0855	0.1433	0.0039	909	132	879	37	863	22	98
13WS-7B-9	0.72	0.1003	0.0048	3.9705	0.1886	0.2852	0.007	1631	89	1628	39	1618	35	99
13WS-7B-10	0.53	0.0681	0.0038	1.3623	0.0756	0.1443	0.0038	872	115	873	33	869	21	100
13WS-7B-11	0.1	0.0685	0.0044	1.3695	0.0907	0.1443	0.0043	883	131	876	39	869	24	99
13WS-7B-12	0.72	0.0686	0.0044	1.3702	0.0906	0.1441	0.0043	887	131	876	39	868	24	99
13WS-7B-13	0.39	0.0675	0.0054	1.3485	0.112	0.1441	0.0045	854	167	867	48	868	25	100
13WS-7B-14	0.8	0.0775	0.0074	1.5362	0.148	0.1437	0.0047	1144	192	945	59	866	26	92
13WS-7B-15	0.38	0.0701	0.0057	1.3929	0.1136	0.1437	0.0041	931	173	886	48	865	23	98
13WS-7B-16	0.83	0.069	0.0039	1.3722	0.0774	0.1434	0.0037	898	118	877	33	864	21	99
13WS-7B-17	0.42	0.0693	0.0048	1.3919	0.0982	0.1447	0.004	909	139	886	42	871	22	98
13WS-7B-18	0.63	0.0704	0.0043	1.4155	0.0859	0.1446	0.0039	939	125	895	36	871	22	97
13WS-7B-19	1.03	0.0706	0.0048	1.4155	0.0969	0.1445	0.0047	946	60	895	41	870	27	97
13WS-7B-20	0.23	0.0724	0.0043	1.4444	0.0867	0.1437	0.0043	998	125	908	36	866	24	95
13WS-7B-21	0.86	0.1155	0.007	5.3618	0.3276	0.3349	0.0101	1888	110	1879	52	1862	49	99
13WS-7B-22	0.89	0.0683	0.0047	1.3739	0.097	0.1446	0.0042	880	144	878	42	871	24	99
13WS-7B-23	1.31	0.0751	0.0051	1.7583	0.1187	0.1685	0.0044	1072	168	1030	44	1004	24	97
13WS-7B-24	0.98	0.0715	0.0059	1.4379	0.1183	0.1452	0.0042	972	169	905	49	874	24	97
13WS-7B-25	0.53	0.074	0.0057	1.5503	0.1198	0.1513	0.0043	1040	157	951	48	908	24	95
13WS-7B-26	0.53	0.075	0.0056	1.5559	0.1191	0.1496	0.0045	1133	150	953	47	899	25	94
13WS-7B-27	0.53	0.0702	0.0049	1.3943	0.1002	0.1434	0.0046	1000	144	887	43	864	26	97
13WS-7B-28	0.91	0.0982	0.006	3.4781	0.2136	0.2562	0.0067	1591	115	1522	48	1471	35	97
13WS-7B-29	0.2	0.0672	0.005	1.2966	0.0968	0.1397	0.004	843	156	844	43	845	23	100
13WS-7B-30	0.56	0.1167	0.006	5.4194	0.2885	0.3359	0.0092	1906	91	1888	46	1867	44	99

Table 2 Major oxides, elemental and Sr-Nd isotopic analyses for the Neoproterozoic metabasites from the Jianxichong region (Liuyang, Hunan), Central Jiangnan Orogen

	12WS-73H	12WS-73J	12WS-73K	12WS-73L	12WS-73N	12WS-74B	12WS-74C	12WS-74D	12WS-74G	12WS-75C	12WS-75D	12WS-75G	12WS-76D	12WS-76E	13WS-4A	13WS-4E	13WS-4F	13WS-5A	13WS-7A
SiO ₂	49.93	47.01	48.15	51.31	51.89	48.72	50.32	49.79	51.91	51.71	48.92	49.30	48.82	47.92	51.38	52.12	51.10	50.87	50.82
TiO ₂	0.72	0.68	0.69	0.70	0.75	0.72	0.69	0.75	0.67	0.70	0.75	0.68	0.74	0.79	0.73	0.71	0.74	0.79	0.69
Al ₂ O ₃	12.78	11.86	12.05	13.03	13.18	12.98	13.12	13.19	13.27	13.53	13.16	13.77	13.09	13.55	14.32	14.03	14.34	13.36	13.83
CaO	11.65	11.41	10.45	11.20	9.58	11.47	11.21	10.37	10.95	10.28	10.94	8.78	11.08	10.23	10.83	9.36	8.55	9.74	9.23
FeOt	9.90	10.43	10.32	9.27	9.23	10.10	9.32	10.12	8.54	9.04	10.19	8.78	10.14	10.48	8.85	8.80	9.54	8.80	8.49
MgO	8.64	12.28	12.24	8.40	8.19	9.35	8.87	9.08	8.39	8.01	9.28	7.92	9.68	9.91	7.50	7.63	7.87	9.51	9.26
K ₂ O	0.18	0.36	0.80	0.29	0.59	0.36	0.39	0.45	0.42	0.59	0.18	0.33	0.36	0.18	0.55	0.89	0.34	0.53	0.99
Na ₂ O	1.25	0.97	0.74	1.82	2.03	1.44	1.55	1.58	1.65	2.05	1.70	3.33	1.19	2.15	1.98	2.29	3.32	1.66	1.71
MnO	0.15	0.16	0.16	0.14	0.14	0.15	0.15	0.16	0.14	0.14	0.15	0.16	0.14	0.15	0.15	0.15	0.15	0.15	0.13
P ₂ O ₅	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.07	0.05	0.06	0.07	0.07	0.07	0.06	0.05
LOI	3.02	3.00	2.56	2.13	2.71	2.89	2.74	2.70	2.59	2.31	2.90	5.75	3.00	2.78	2.21	2.50	2.47	3.13	3.40
Total	99.37	99.37	99.37	99.37	99.37	99.37	99.47	99.37	99.56	99.45	99.37	99.85	99.42	99.37	99.57	99.52	99.55	99.59	99.53
mg-number	65	71	71	66	65	66	67	65	67	65	66	65	67	66	64	65	63	69	70
Sc	41	38	39	38	41	40	41	42	29	39	40	41	39	44	35	36	34	33	26
V	246	232	235	228	246	251	248	253	236	216	229	253	258	259	242	233	244	205	178
Cr	468	754	793	436	491	491	447	483	483	392	487	320	454	495	279	304	280	430	370
Co	48	60	61	43	49	44	50	49	43	42	47	35	33	46	31	31	29	32	30
Ni	127	277	262	126	142	143	139	140	154	126	150	52	120	138	82	87	73	148	86
Ga	14.9	13.1	12.9	12.4	13.8	14.9	13.7	13.8	13.9	13.8	13.9	14.2	18.7	14.9	14.7	13.0	13.7	13.0	12.7
Rb	7.1	14.8	25.6	12.5	25.1	13.6	18.0	18.0	16.3	29.1	25.4	11.9	4.6	7.2	21.9	34.7	11.6	28.3	37.5
Sr	136	106	94	96	105	124	109	117	113	106	104	76	264	119	127	110	96	124	110
Y	16.8	15.3	15.9	15.9	16.3	16.7	16.5	17.1	16.7	18.1	18.1	18.8	16.4	17.8	19.8	19.2	19.5	19.4	13.9
Zr	63.2	59.5	60.0	60.9	63.7	62.8	66.2	66.4	57.2	75.7	80.5	64.9	59.3	69.5	61.5	60.8	63.0	68.6	51.4
Nb	3.32	3.08	3.20	3.20	3.38	3.27	3.44	3.45	3.68	4.07	4.14	3.94	3.10	3.72	3.65	3.76	3.87	4.13	3.21
Cs	0.43	0.80	1.77	0.61	1.27	0.76	1.25	1.26	0.70	2.21	1.77	2.05	0.27	0.42	0.94	1.46	0.48	1.19	2.66
Ba	37	62	142	73	138	78	101	98	116	139	109	98	23	41	162	231	97	124	206

La	7.40	6.33	6.72	7.15	6.82	7.29	7.28	7.33	6.65	10.71	11.23	8.40	6.95	7.99	8.48	7.95	7.88	10.95	7.95
Ce	16.29	14.22	14.99	15.39	15.55	15.95	16.38	16.73	14.25	22.57	23.31	15.30	15.27	17.67	17.18	16.80	16.95	16.67	16.28
Pr	2.12	1.89	2.00	2.03	2.03	2.12	2.16	2.19	1.88	2.90	2.86	2.36	2.00	2.30	2.13	2.09	2.16	2.66	1.92
Nd	9.21	8.38	8.73	8.81	8.86	9.21	9.47	9.62	7.81	11.94	11.82	9.43	8.75	9.97	9.11	8.93	9.20	10.60	7.77
Sm	2.40	2.10	2.17	2.21	2.24	2.31	2.38	2.41	1.99	2.78	2.73	2.27	2.21	2.50	2.28	2.20	2.32	2.47	1.79
Eu	0.72	0.67	0.69	0.65	0.68	0.78	0.73	0.72	0.61	0.69	0.72	0.70	0.89	0.75	0.71	0.67	0.71	0.65	0.51
Gd	2.91	2.63	2.77	2.78	2.78	2.86	3.01	3.12	2.32	3.05	3.21	2.55	2.78	3.13	2.72	2.63	2.76	2.72	1.98
Tb	0.50	0.45	0.46	0.47	0.49	0.50	0.51	0.53	0.40	0.54	0.54	0.44	0.47	0.53	0.47	0.46	0.48	0.47	0.33
Dy	3.16	2.87	3.04	2.95	3.00	3.17	3.15	3.28	2.66	3.33	3.39	2.81	3.00	3.37	3.00	2.97	3.10	2.97	2.11
Ho	0.68	0.62	0.64	0.67	0.67	0.69	0.69	0.72	0.54	0.76	0.73	0.59	0.65	0.73	0.62	0.61	0.63	0.61	0.44
Er	1.91	1.76	1.84	1.80	1.85	1.95	1.99	2.02	1.62	2.03	2.02	1.75	1.83	2.00	1.83	1.78	1.86	1.84	1.30
Tm	0.28	0.26	0.27	0.27	0.28	0.28	0.30	0.29	0.23	0.31	0.31	0.25	0.27	0.30	0.26	0.25	0.27	0.27	0.19
Yb	1.88	1.71	1.78	1.72	1.83	1.93	1.88	1.92	1.51	2.01	2.03	1.67	1.77	2.01	1.71	1.68	1.75	1.75	1.27
Lu	0.30	0.27	0.27	0.28	0.29	0.30	0.31	0.32	0.22	0.32	0.33	0.24	0.28	0.32	0.25	0.25	0.26	0.26	0.18
Hf	1.75	1.66	1.63	1.64	1.72	1.71	1.77	1.82	1.41	2.28	2.20	1.62	1.65	1.88	1.58	1.57	1.64	1.76	1.30
Ta	0.29	0.25	0.26	0.27	0.26	0.27	0.28	0.29	0.47	0.39	0.36	0.31	0.27	0.33	0.29	0.34	0.29	0.38	0.39
Pb	4.17	3.15	2.66	3.25	2.98	3.53	3.21	3.55	10.20	5.62	4.40	8.77	7.95	4.53	10.30	7.82	6.16	7.20	8.11
Th	2.29	2.07	2.10	2.17	2.17	2.21	2.30	2.31	1.92	3.86	3.92	2.81	2.19	2.51	2.32	2.31	2.36	3.67	2.63
U	0.48	0.43	0.47	0.44	0.57	0.44	0.48	0.51	0.52	0.84	0.86	0.62	0.45	0.53	0.52	0.55	0.56	0.76	0.55
⁸⁷ Rb/ ⁸⁶ Sr	0.153		0.792		0.694			0.447				0.451		0.174	0.500				
⁸⁷ Sr/ ⁸⁶ Sr	0.708100		0.715447		0.712907			0.710090				0.713524		0.709312	0.711014				
2 σ	11		9		10			8				18		9	14				
⁸⁷ Sr/ ⁸⁶ Sr(i)	0.706267		0.705941		0.704582			0.704722				0.708108		0.707219	0.705015				
¹⁴⁷ Sm/ ¹⁴⁴ Nd	0.157		0.151		0.153			0.151				0.146		0.151	0.151				
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512362		0.512365		0.512359			0.512360				0.512273		0.512340	0.512353				
2 σ	7		7		8			8				10		7	6				
ε _{Nd} (<i>t</i>)	-1.14		-0.37		-0.75			-0.57				-1.64		-0.94	-0.68				

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Fig.1 Zhang Y-Z and coauthors

Fig. 2 Zhang Y-Z and coauthors

Fig. 3 Zhang Y-Z and coauthors

Fig. 4 Zhang Y-Z and coauthors

Fig. 5 Zhang Y-Z and coauthors

Fig. 6 Zhang Y-Z and coauthors

Fig. 7 Zhang Y-Z and coauthors

Fig. 8 Zhang Y-Z and coauthors

Fig. 9 Zhang Y-Z and coauthors

Fig. 10 Zhang Y-Z and coauthors

Fig. 11 Zhang Y-Z and coauthors

Fig. 12 Zhang Y-Z and coauthors