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Neoproterozoic plate tectonic process and Phanerozoic geodynamic evolution of the South China Block

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Abstract

The South China Block is situated in the Eastern Asian margin. Since the Neoproterozoic, its tectonic evolution was constrained by successive consumption-closure processes of the Paleo-South China, Proto-Tethys, Paleo-Tethys, and Paleo-Pacific oceans. Studies suggest that this block was initially formed by the Neoproterozoic assembly of the Yangtze and Cathaysia blocks following the subduction-accretion of the Paleo South China Ocean. Then after, it experienced three tectonic-magmatic events in the Phanerozoic. Among these events, the Late Mesozoic tectonism-magmatism was linked with the consumption of the Paleo-Pacific Ocean, while the Silurian and Early to Middle Triassic events took place in intracontinental settings that were related to far-field effects of the closure of the remote Proto-Tethys and Paleo-Tethys oceans, respectively. The subduction-accretion of the Paleo-South China Ocean, and collision at 980-820 Ma between the Yangtze and Cathaysia blocks formed the Jiangnan Orogenic Belt and the Proto-South China Continent, followed by a rifting tectonics and bimodal volcanism at 810-760 Ma. From 760 Ma to 460 Ma, the South China Block was situated under shore, shallow sea to slope depositional environments. During Late Ordovician to Early Devonian (460-400 Ma), an intracontinental orogeny occurred mainly in the Cathaysia Block as a response to the

closure of the Proto-Tethys Ocean. Shortly afterwards, this block underwent a stable carbonate deposition during Early Devonian- Middle Triassic (400-230 Ma) and was thus under a shore or shallow sea environment. In the Middle-Late Triassic (240-220 Ma), the South China Block was affected by the closure of the Paleo-Tethys Ocean, intracontinental deformation and S-type granitic magmatism. During the Cretaceous, a multi-stage basin-and-range framework occurred in the western shore of the Paleo-Pacific Plate.

Keywords

Neoproterozoic Paleo-South China Ocean; Proto-Tethys Ocean; Paleo-Tethys Ocean; Paleo-Pacific Ocean; subduction and accretion; far-field effects of plate collision; South China Block.

1. Introduction

The South China Block is located in the western margin of the Pacific Plate and consists of the Yangtze and Cathaysia blocks and the Jiangnan Orogenic Belt (Fig. 1). Comprehensive analyses on the available tectonic and magmatic data, along with sedimentary structures from the Jiangnan Orogenic Belt and Cathaysia Block, suggest that the evolution of the South China Block was constrained and affected by the Paleo-South China, Proto-Tethys, Paleo-Tethys and Paleo-Pacific oceans (Gilder et al., 1991,1996; Ren JS, 2001; Ren and Chen, 1989; Ren and Li, 2016; Ren JS et al., 1998; Li XH et al., 1994; Charvet et al., 1996; Li ZX et al., 1999, 2008; Xu ZQ et al., 2010; Xu and Zhang, 2013; Faure et al., 2009, 2016a, b; Wang YJ et al., 2010, 2013).

The Paleo-South China Ocean is a NE-trending Neoproterozoic tectonic unit separating the Yangtze and Cathaysia continental blocks and was evidenced by the ophiolite suite extending 1500 km and ranging in age from 980 Ma to 820 Ma (Guo LZ et al., 1989; Shu LS et al., 1994, 1995, 2014; Wang XL et al., 2006; Yao JL et al., 2014; Zhang GW et al., 2013; Dong YP et al., 2017). The Proto-Tethys Ocean existed from the latest Ediacaran to the Carboniferous (550-330 Ma). It formed when Laurentia, Baltica, and Siberia drifted away from each other. This ocean was bordered by the Kazakhstan microcontinent and Panthalassic Ocean to the north, by Siberia to the west, and by Gondwana to the east. Since the Late Silurian, the northward drift of North China and South China blocks away from Gondwana, and subsequent collision between the North China and Siberia-Kazakhstan in the Carboniferous resulted in the closure of the Proto-Tethys Ocean (Stampfli and Borel, 2002; Zhao GC et al., 2018). The Paleo-Tethys Ocean was a precursor to the Neo-Tethys Ocean and was located between Gondwana and the Hun super-terranes (including Armorica-Iberia in Europe and East-Central Asia). It opened as the Proto-Tethys Ocean subducted under these terranes and closed at about 290-180 Ma as the Cimmerian terranes rifted from Gondwana landmasses to form the Neo-Tethys Ocean at ~250 Ma (Stampfli and Borel, 2002; Keppie, 2015; Huang BC et al., 2018). The Paleo-Pacific Plate, also known as the Izanagi or Kula Plate, was an oceanic plate existed during the Late Mesozoic. From the Jurassic to Cretaceous, with the expanding of the Pacific Plate and the closure of the Okhotsk Ocean, the Paleo-Pacific Plate subducted northwestwards beneath the Eurasian continent. Until the latest Mesozoic the Izanagi-Pacific Ridge subducted and the Paleo-Pacific Plate totally submerged beneath the Eurasian and North American continents (Lapierre et al., 1997).

In the middle Neoproterozoic, the South China Block was initially formed by the subduction-accretion of the Paleo-South China Ocean and the convergent margin successions between the Yangtze and Cathaysia blocks, but with largely varied timing of the final assembly (Xu B et al., 1992; Shu and Charvet, 1996; Li XH et al., 2003, 2009; Wang XL et al., 2006; Zhao and Cawood, 2012; Yao JL et al., 2014, 2016, 2019a). Shortly after, a within-plate extensional event occurred and formed the rifting magmatic and sedimentary sequences dated at 850-760 Ma in South China (Wang and Li, 2003; Li WX et al., 2005; Shu LS et al., 2011). This rifting magmatism ceased at some time in the Late Tonian and the South China Block was in a stable depositional environment since then (Shu LS, 2012). The Cryogenian to Early Paleozoic stratigraphic sequences and fossil features in the South China Block are comparable to those of the Tarim Block (Zhou and Deng, 1996), and detrital zircon U-Pb geochronological results suggest that the South China Block was once adjacent to Northwest Australia, Tarim, Eastern India and East Antarctica in the Neoproterozoic (Yu JH et al., 2008; Xiang and Shu, 2010; Yao JL et al., 2011). In addition, paleomagnetic results show that the South China Block was a member of the Rodinia supercontinent (Yang ZY et al., 2004; Li ZX et al., 2004, 2008; Han ZR et al., 2015; Jing XQ et al., 2015; Niu JW et al., 2016).

In the Phanerozoic time, the South China Block experienced multiple stages of extensive tectono-magmatism, including the within-plate Early Paleozoic and Early –Middle Triassic tectonic and magmatic events (or Indochina event) which are correlated with the evolution of the Proto-Tethys and Paleo-Tethys oceans, respectively (Li ZX et al., 2010; Wang YJ et al., 2010; Charvet et al., 2010; Shu LS et al., 2014, 2015, 2018; Zhao et al., 2018), along with the Early Mesozoic tectono-magmatic event generated by the subduction of the Paleo-Pacific Ocean (Zhou XM et al., 2006; Shu LS et al., 2004; Li JH et al., 2016). However, an Appalachian-style multi-terrane Wilson cycle model has also been hotly discussed for the Early Paleozoic and Early Mesozoic orogenic events in South China (Lin SF et al., 2018; Shu et al., 2018; Faure et al., 2018a). These Phanerozoic events strongly reworked the Precambrian basement of the South China Block and also the traces of earlier orogenic events, leading to a less well constrained overall tectonic and paleogeographic evolution of the South China Block.

With the development of high quality geochemical and dating technologies, increasing new results were documented (Wang YJ et al., 2010, 2014; Zhao GC, 2015; Li JH et al., 2016; Yao JL et al., 2019a). In spite of the significant advances, controversies still exist on some major issues related to the pre-Jurassic geological features of the South China Block, including the western continuation of the

Neoproterozoic suture zone, the formation ages of the Jiangnan Orogenic Belt and Proto-South China Continent, the nature of the basement of the Cathaysia Block and driving forces of the intracontinental tectono-magmatic events, as well as the genesis of the Late Mesozoic South China basin-and-range tectonics (Zhou XM et al., 2006; Li XH et al., 2003, 2009; Faure et al., 2009; Li and Li, 2007; Yan DP et al., 2002; Charvet et al., 2010; Wang and Shu, 2012).

This paper aims to analyze the available field observations and results, to discuss controversial issues, to draw further attention and to promote understanding on fundamental geology of the South China Block.

2. Tectonic setting

2.1 Relics of the Paleo-South China Ocean

The NE- to ENE-extending Shaoxing–Pingxiang–Longsheng fault is a suture zone formed in the Neoproterozoic along the southeastern margin of the Jiangnan Orogenic Belt in the SE Yangtze Block (Fig. 1, 2). Ophiolitic mélanges occur along this suture zone, mainly composed of various-sized lenses of basalt, chert, marble, turbidite and ultramafic-mafic rocks dated at 980-840 Ma (Li XH et al., 1994; Shu LS et al., 1994, 2015, 2019; Yao JL et al., 2019), which were derived from the Paleo-South China Oceanic crust.

Meters to decameters-scale exotic blocks of ultramafic-mafic rocks dated at 2028±18 Ma and 1962±20 Ma (Han QS et al., 2017) and 973±15 Ma, 999±17 Ma and 1002±19 Ma (Deng H et al., 2017) are scatteredly distributed near the Yichang City of the northern Yangtze Block (Fig. 2), and are inferred as relics of the Paleoproterozoic and Early Neoproterozoic ophiolitic mélanges (Han QS et al., 2017; Deng H et al., 2017), symbolizing the northern suture of the Paleo-South China Ocean. The detrital zircons from sandstones of the Cryogenian Liantuo Formation and Nantuo tillite layers in the northern Yangtze Block also yielded similar U-Pb ages as mentioned above (Gao S et al., 2011; Zhao GC et al., 2012).

2.2 The Yangtze Block

The Yangtze Block is mostly covered by Mesozoic-Cenozoic sediments and its margins mainly consist of Neoproterozoic magmatic rocks and sandy–muddy slates and phyllites. The oldest rocks were dated at ca. 3.5-3.0 Ga by zircon U-Pb dating on orthogneiss and amphibole-schist (Gao and Zhang, 1990; Qiu YM et al., 2000; Zhang SB et al., 2006; Wu YB et al., 2009), whereas Late Archean rocks are limitedly exposed in the southwestern Yangtze Block, forming an ancient continental core. Detrital zircon ages from the southeastern Yangtze Block indicate that the metamorphosed clastic rocks were deposited at some time after 1.0 Ga (Wang XL et al., 2007, 2014; Yao JL et al., 2013).

During 980-860 Ma, the Paleo-South China oceanic lithosphere subducted northwestwards beneath the Yangtze Block and formed the Neoproterozoic Jiangnan trench-arc system of 80-200 km in width and 1500 km in length (Xu B et al., 1992; Li XH et al., 2009; Shu LS et al., 1995, 2006; Wang XL et al., 2006; Zhang YZ and Wang YJ, 2016; Yao JL et al., 2014b). This trench-arc system was overprinted by the Yangtze-Cathaysia collision dated at ca. 860-820 Ma (Shu LS et al., 1994, 2019; Shu and Charvet, 1996; Wang XL et al., 2006; 2012; Zhao JH et al., 2013; Yao JL et al., 2016, 2019a; Yan CL et al., 2021), forming the Proto-South China Continent (Shu LS et al., 2020), which was unconformably covered by an Upper Tonian terrigenous molasse sequence.

An intracontinental rifting within the Proto-South China Continent took place during 810-760 Ma, generating mafic dyke swarms and intracontinental rifting basins that were filled by molasses and bimodal volcanic rocks. According to dating data of bimodal magmatic rocks in both the eastern Jiangnan and eastern Cathaysia segments, the initial rifting likely happened at ca. 850 Ma (Li WX et al., 2005; Li XH et al., 2008; Shu LS et al., 2011).

2.3 The Cathaysia Block

2.3.1 Age of the Cathaysia basement

The Cathaysia Block is located to the southeast of the Shaoxing-Pingxiang-Longsheng fault (Fig. 2). This block consists of Paleoproterozoic basement (Yu JH et al., 2009) and Neoproterozoic to Early Paleozoic sedimentary covers. Recent studies suggest that the age of the basement in the Cathaysia Block is older than those of the Jiangnan Orogenic Belt and the patterns of deformation are much more complicated. More than 2000 detrital zircon ages from Ordovician and Devonian sandstones were obtained and can be divided into five groups (Xiang and Shu, 2010; Yao JL et al., 2011; Yan CL et al., 2015). The first one, 2.56-2.38 Ga (peak at 2.46 Ga), represents the formation time of global continental nucleus. These zircons are mostly euhedral, indicating a possible Archean basement beneath the Cathaysia Block. The second one, 1.93-1.52 Ga (peak at 1.8 Ga), is likely derived from the granitic plutons and amphibolites in the northern Wuyi terrane, corresponding to the Columbia supercontinent cycle. The third group, 1.3-0.9 Ga (peak at 0.97 Ga), is indicative of assembly of the Rodinia supercontinent, and the related magmatic rocks are sporadically exposed in the Wuyi, Nanling and Yunkai terranes (Fig. 2; Wang YJ et al., 2014). The fourth one, 0.85-0.73 Ga, corresponds to the breakup of Rodinia. The Last group 0.68-0.55 Ga (peak at ca. 0.65 Ma) records a magmatic event, contemporaneous with the Pan-African orogeny, which was formed by the assembly of the west and east Gondwana, but no magmatic rock of this age was reported from the whole South China Block. The Late Neoproterozoic age population therefore indicates that the South China Block was a member of the Gondwana Continent, with the upper part of the upper Proterozoic-lower Paleozoic sediments in the block sourced from the interior of Gondwana (Yao JL et al., 2011; Xu YJ et al., 2014; Zhao GC et al., 2018; Cawood et al., 2018). This argument is also supported by recent paleomagnetic data (Han ZR et al., 2015).

Several sub-euhedral detrital zircon grains from Proterozoic and Paleozoic meta-sandstones and migmatites in Cathaysia yielded SHRIMP U-Pb ages of 4.1-3.8 Ga (Xu XS et al., 2005; Xiang and Shu, 2010; Yao JL et al., 2011; Xing GF et al., 2014), but coeval magmatic rocks have not been reported. The oldest magmatic rocks are scatteredly exposed in the northern Wuyi terrane (Fig. 2). Twelve samples of granite, amphibolite and migmatite were dated at 1890-1740 Ma (Li XH, 1998; Yu JH et al., 2009). These rocks are inferred to be reliable arguments for the Cathaysia continental core that may extend westwards to the Nanling and Yunkai terranes (Shu LS et al., 2020).

2.3.2 Geological history of the Cathaysia Block

Middle Proterozoic rocks are rare in the Cathaysia Block, the Mesoproterozoic setting is therefore unclear. The lower part of upper Proterozoic metamorphic muddy and sandy rocks with interlayers of marble and meta-rhyolitic rocks occur in the Wuyi, Nanling and Yunkai terranes and are associated with orthogneiss and meta-gabbro dated at ca. 980-910 Ma (Shu LS et al., 2008a; Wang YJ et al., 2012a, 2014). The amphibolite, dolerite and orthogneiss occur in the Wuyi and Yunkai terranes and yielded ages at 969±13 Ma, 964±6 Ma, 978±11 Ma, 970±10 Ma and 980±8 Ma (Wang YJ et al., 2012a). Gneissic granite and meta-rhyolite in the Nanling terrane yielded zircon U-Pb ages of 996±29 Ma (Liu BX et al. 2001) and 972±8 Ma (Shu LS et al., 2008a), respectively. In addition, several plutons of gneissic granitoids show geochemical fingerprints of arc and back-arc settings. Given their ages and compositional characteristics, these plutons were formed in two stages: ca. 965 Ma (982±27 Ma, 963±11 Ma, 954±14 Ma) and ca. 915 Ma (916±6 Ma and 909±10 Ma; Wang YJ et al., 2014), corresponding to the magmatic arc age and the closure time of back-arc basin, respectively. These magmatic rocks indicate a Neoproterozoic subduction and accretion process, leading to the westward expansion of Cathaysia from the Wuyi continental core to the Nanling and Yunkai domains.

The sedimentary cover on the top of the aforementioned metamorphic rocks is composed of terrigenous rocks intercalated with carbonate and carbonaceous rocks, ranging from the Upper Tonian (referred to as the Banxi Group, or Nanhua System in Chinese literature) to Upper Ordovician strata (at ca. 800-460 Ma). The Late Tonian mantle-derived mafic rocks (gabbro and basalt) along the Zhenghe-Dapu fault zone (Fig. 2) display geochemical characteristics of continental rift (Li WX et al., 2005). Minor basalt, diabase and gabbro also occur in the southwestern Yunkai terrane and yielded zircon U-Pb ages of ca. 850-780 Ma (Wang YJ et al., 2010). These magmatic rocks show geochemical signatures that are comparable to within-plate basalt, therefore, implying an extensional event during ca. 850-780 Ma (Late Tonian) which was related to the generation of the Late Tonian rifting basins.

The South China Block was situated in a stable depositional environment at ca. 750-460 Ma, with little magmatic activity. Moreover, although ages ranging from 650 Ma to 500 Ma were obtained from detrital zircons within pre-Devonian clastic rocks in Cathaysia, there is no geological and magmatic trace for the Pan-African event (Xiang and Shu, 2010; Yao JL et al., 2011), and the reasonable interpretation of these ages requires more work in future.

2.4 Multi-terrane framework in the Paleo-South China Ocean

Studies suggest that numerous tectono-stratigraphic terranes with various origins and distinct geological history were distributed in the Paleo-South China Ocean in the Neoproterozoic. Five Neoproterozoic tectono-stratigraphic terranes (Fig. 2) were identified in the NW part of the Paleo-South China Ocean domain (now to the SE margin of the Yangtze Block). They are the oceanic crustal-type Huaiyu terrane, the continental crustal-affinity Zhanggong and northern Hunan terranes, and the arc-type Jiuling and northern Guangxi terranes (Guo LZ et al., 2000; Shu LS et al., 1995, 2019; Xu B et al., 1992; Charvet et al., 1996).

The Huaiyu terrane (Fig. 2) is composed of Neoproterozoic ophiolitic mélange, volcanic and turbidite sequences, belonging to an intraoceanic back-arc marginal sea with a tectonic affinity of oceanic crust, whereas the Zhanggong and northern Hunan terranes (Fig. 2) mainly consist of quartz-sandstone, sandstone and mudstone, showing continental crustal affinities (Shu LS et al., 1995, 2019; Wang XL et al., 2012). The Jiuling and northern Guangxi terranes (Fig. 2) incorporate Neoproterozoic ophiolitic mélange and 870-840 Ma basaltic-andesitic rocks with positive εHf(t) values (Yao JL et al., 2016; Sun JJ et al., 2017) which were correlated to trench-arc setting (Charvet et al., 1996; Zhou MF et al., 2002; Wang XL et al., 2007; Yao JL et al., 2014a, 2016a; Sun JJ et al., 2017).

These five terranes are bounded by major fault zones, namely, the Dongxiang–Dexing-Shexian fault zone between the Zhanggong and Huaiyu terranes, the northern Ganjiang fault zone between the Zhanggong and Jiuling terranes, the Miluo-Xiangtan fault zone between the Jiuling and northern Hunan terranes, and the Jishou-Longsheng fault zone between the northern Hunan and northern Guangxi terranes (Fig. 2; Shu LS et al., 1995, 2000, 2019). The Huaiyu, Zhanggong and Jiuling terranes constitute the eastern Jiangnan Orogenic Belt while the northern Hunan and northern Guangxi terranes form the western Jiangnan Orogenic Belt.

Three tectono-stratigraphic terranes have been recognized in the SE part of the Paleo-South China Ocean domain (now to the NW margin of the Cathaysia Block), namely, the Wuyi, Nanling and Yunkai terranes. The NE-trending Wuyi terrane (Fig. 2) is the oldest one among them, and consists of gneiss, migmatite, amphibole schist, and meta-granitoid with protolith zircon U-Pb ages around 1800 Ma (Li XH, 1998; Yu JH et al., 2009). These lower Proterozoic strata are overlain by middle and upper Proterozoic sequences of meta-arkose, phyllite, slate and interlayers of meta-tuffaceous rocks. The boundary between the Wuyi and Nanling terranes (Fig. 2) is marked by the sub-S-N-trending southern Ganjiang fault zone.

The sub-E-W-trending Nanling terrane is composed of the upper Proterozoic sandy-muddy slate and phyllite intercalated with meta-rhyolite and meta-rhyolitic wacke dated at 972±8 Ma (SHRIMP U-Pb age), showing characteristics of arc magmatism (Shu LS et al., 2008a). The NE-trending Yunkai terrane (Fig. 2), located in the southwestern segment of the Cathaysia Block, mainly comprises sandy-muddy slate, sericite-chlorite phyllite, biotite schist, S-type granite or orthogneiss, along with minor meta-basalt and gabbroic rocks. These rock suites are dated at 984-909 Ma (Wang YJ et al., 2014). The boundary between the Nanling and Yunkai terranes is unclear because it is completely covered by younger formations.

3. Proterozoic plate tectonics

3.1 Subduction and closure of the Paleo-South China Ocean

3.1.1 Ophiolitic mélange (980-860 Ma) To the southeast margin of the Yangtze Block, two Early Neoproterozoic ophiolitic mélange zones were identified along the Shaoxing-Pingxiang-Longsheng and Dongxiang-Dexing-Shexian zones (Fig. 1; Guo LZ et al., 1989; Shu LS et al., 1995, 2019; Zhang SB et al., 2012; Yao JL et al., 2016a, 2019a; Sun ZM et al., 2018). The former resulted from the closure of the Paleo-South China Ocean, following a collision between the Yangtze and Cathaysia blocks, and the latter was formed by the accretion of the Huaiyu and Zhanggong terranes following the closure of the Huaiyu back-arc marginal sea (Shu LS et al., 2019). Ultramafic-mafic blocks are well preserved within both ophiolitic mélange zones, especially along the Dongxiang-Dexing-Shexian suture zone. The main rock types include ultramafic rocks (pyroxenite, harzburgite, lherzolite), mafic rocks (cumulative gabbro, pillow lava, diabase, meta-basalt), chert, red chert, marble and metamorphosed muddy-sandy flysches. Ophiolitic anorthosite and plagio-granite have also been reported in the Shexian (Shu LS et al., 2019) and Dexing (Li WX et al., 2008) segments. In the field, the ophiolites have been involved into a disrupted and disordered mélange. Most of the ophiolitic rocks have been deformed to form elongated blocks lying parallel to the shear foliation.

More than 200 outcrops of ophiolitic mélanges were reported along the Dongxiang-Dexing-Shexian fault zone, whereas only 20 sites are distributed along the Shaoxing-Pingxiang-Longsheng fault zone (Shu LS et al., 1995, 2020). Previous geochemical results on the ophiolitic rocks suggest that the mafic-ultramafic members of the ophiolite have E-MORB fingerprints and the ophiolite was formed at around 900 Ma (Table S1). For example, plagiogranite of Dexing at 968±23 Ma (Li XH et al., 1994) or 970 ±21 Ma (Gao J et al., 2009), gabbro of Dexing at 930±34 Ma (Xu and Qiao, 1989), mafic rocks of SW Dexing at 935±10 Ma (Chen JF et al., 1991) and mafic rocks of Shexian at 874±10 Ma and 857±5 Ma (Cui X et al. 2017; Shu LS et al., 2019) (Figs. 3 and 4; Table S1).

3.1.2 Magmatic arc (910-840 Ma)

Arc-type magmatic rocks consist of basalt, andesite, gabbro dated at ca. 910 Ma and I-type granite dated at 880-840 Ma (Fig. 4; Zhang SB et al., 2012; Yao JL et al., 2016b; Shu LS et al., 2019), rhyolite and tuffaceous breccia. These rocks are widely distributed in the Jiangnan Orogenic Belt (Guo LZ et al., 1989; Shu et al., 1994, 1996, 2000; Wang XL et al., 2007, 2012; Yao JL et al., 2016b; Zhang and Wang, 2019). In addition, arc type hornblende-bearing granites dated at 913±15 Ma and 905±14 Ma (Ye MF et al., 2007), along with rhyolite and gabbro dated at 891±12 Ma (Li XH et al., 2009) and 879±10 Ma (Yao JL et al., 2014c), respectively, are widely developed in the Huaiyu terrane. In the Longyou area along the Shaoxing-Pingxiang fault zone, the Neoproterozoic magmatic zircons from mafic rocks dated at 879±11 Ma were reworked and replaced by metamorphic zircons dated at around 430 Ma (Wang JQ et al., 2017). The arc-type granitic plutons in Shexian of the Huaiyu terrane emplaced during 848-843 Ma (Shu LS et al., 2019). The andesite, basaltic andesite and dacite of the western Jiuling terrane yielded U-Pb ages of 837±4 Ma and 835±7 Ma, respectively (Zhang YZ and Wang YJ, 2019). Furthermore, the continental arc-type gabbros in the Longsheng of the northern Guangxi terrane yielded crystalline ages of 855±5 Ma and 867±10 Ma (Yao JL et al., 2014a, 2016a; Figs. 3 and 4; Table S1).

In the Cathaysia Block, only a few outcrops of gabbro, orthogneiss and meta-rhyolite dated at 980-910 Ma (Figs. 3 and 4) are distributed and were considered as evidence for a Neoproterozoic magmatic arc (Shu LS et al., 2008a; Wang YJ et al., 2014; Zhang AM et al., 2012).

3.1.3 The HP/LT metamorphism

Several exposures of high-pressure (HP) and low-temperature (LT) metamorphic rocks, such as glaucophane-jadeite schist, were reported along the Dexing-Shexian fault zone in the eastern Jiangnan Orogenic Belt (Shu LS et al., 1994; Zhou and Zhou, 1996). The largest relics of blueschist crops out in the Dexing ophiolitic mélange and is only 2-3 meters wide and 20-30 meters long. From the glaucophane-jadeite schist, metamorphic conditions were estimated at 0.9-1.3 GPa and 250-450°C (Zhou and Zhou, 1996). The glaucophane grains yielded K-Ar ages of 864.5±15 and 867.5±13.5 Ma (Fig. 3), representing the timing of initial closing of the Paleo-South China Ocean and the Huaiyu marginal sea (Shu LS et al. 1995, 2019).

3.2 Collision and assembly of the Yangtze and Cathaysia blocks

3.2.1 Ductile shear zones

The closure of the Paleo-South China Ocean caused the collision of the Yangtze and Cathaysia blocks and regional-scale ductile deformation. The above-mentioned ophiolitic mélange zones were ductilely deformed and then unconformably covered by brittlely deformed conglomerate and quartz-sandstone of the Upper Tonian strata. The Shaoxing-Pingxiang shear zone is 10-30 km wide, extending E-W for more than 800 km, and the Dongxiang-Dexing-Shexian shear zone is 5-10 km wide and extends along a NE strike for about 250 km. Within both shear zones, felsic, granitic and phyllitic mylonites show clear stretching lineation, shearing foliation and various asymmetric kinematic indicators, indicating an early top-to-the-SE thrusting and a late sinistral strike-slip shearing, corresponding to a geodynamic evolution of oblique sudduction-collision (Shu LS et al., 1995; Shu and Charvet, 1996).

3.2.2 Regional greenschist facies metamorphism

Coeval with the ductile shearing, the amalgamated continent of the Yangtze and Cathaysia blocks, namely, the Proto-South China Continent experienced a regional greenschist facies metamorphism, forming large-scale low-grade metamorphic rocks that occupy an area of more than 300,000 km^2, including slate, phyllite and meta-volcanic rocks. Meanwhile, middle to high-grade garnet-bearing schist, amphibole schist and orthogneiss also occur along the margins and on the top parts of coeval S-type granites. The U-Pb ages of metamorphic rims of zircon grains were obtained at around 840 Ma, which were considered as fingerprints of the middle Neoproterozoic metamorphic timing (Yan CL et al., 2015; Yao JL et al., 2017).

3.2.3 Collisional S-type granitoids (845-815 Ma)

More than 15 granite plutons (about 12,000 square kms in total) are exposed along the Jiangnan Orogenic Belt. These plutons contain commonly cordierite, muscovite and tourmaline minerals, indicative of peraluminous granites that coincide well with their negative εHf(t) values (-5 to -12) of zircons and A/CNK values of 1.3-1.5, suggesting a partial melting of supra-crustal sedimentary rocks, most likely due to crustal thickening caused by the collision of the Cathaysia and Yangtze blocks. These S-type granitic plutons yielded numerous zircon U-Pb ages ranging from 845 Ma to 815 Ma, with a peak at 830 Ma, and they are covered by the Upper Tonian coarse-grained clastic rocks (Fig. 4, Table S1; Li ZX et al., 1999; Zeng W et al., 2005； Zhong YF et al., 2013; Wang XL et al., 2006; Zheng YF et al., 2007; Yao JL et al., 2014a, 2016; Wang YJ et al., 2019; Yan CL et al., 2021).

3.2.4 Regional-scale angular unconformity (820-795 Ma)

The Upper Tonian (or Nanhua System) coarse-grained clastic rocks were unconformably deposited above the pre-Upper Tonian (or Sibao Group) strata and are widespread in the Jiangnan Orogenic Belt. The youngest detrital zircon population in the Upper Tonian clastic rocks varies between 820 Ma and 795 Ma (Sun JJ et al., 2018; Yan CL et al., 2019), constraining the uplifting, eroding, transportation and accumulation processes at the Late Tonian period. Along the Jiangnan Orogenic Belt, the Neoproterozoic unconformity can be clearly observed in many sites (Fig. 5). However, a contemporaneous unconformity does not exist in the Cathaysia Block

(Shu LS et al., 2020).

Below the unconformity, the Lower Tonian (or Sibao Group) greenschist facies meta-volcanic and meta-sedimentary sequences have been deformed into tight, disharmonic and asymmetric folds, and above the unconformity, the Upper Tonian (or Nanhua System) consists of undeformed conglomerates and sandstones (Fig. 6) that were occasionally intruded by diabase dykes. The Upper Tonian System is disconformably covered by the Cryogenian tillite layer and Ediacaran to lower Paleozoic neritic sedimentary sequences.

3.3 Rifting and bimodal magmatism (810-760 Ma)

Shortly after the assembly of the Yangtze and Cathaysia blocks, several foreland basins were formed in the eastern Zhejiang, northern Jiangxi and northern Fujian areas. Meanwhile, a regional-scale rifting took place in the Proto-South China Continent (Gilder et al., 1991). This event is characterized by the formation of sedimentary basins and bimodal igneous rocks (gabbro, diabase, basalt, and granite dykes, felsic volcanic rocks) with geochemical characteristics of continental rift (Gilder et al., 1991) and probably resulted from a mantle plume (Li ZX et al., 1999; Li XH et al., 2003).

The bimodal magmatism is diachronous in different areas. The initial rifting is dated as early as ~850 Ma in the Cathaysia Block (Li WX et al., 2005; Li XH et al., 2008; Shu LS et al., 2011), whereas the widespread bimodal dyke swarms and rifting basins were formed at 810-760 Ma in the Jiangnan Orogenic Belt, with a peak age of 790 Ma (Li ZX et al., 1999, 2003; Wang XL et al., 2012; Yao JL et al., 2014b; Fig. 4; Table S1).

Many bimodal diabasic and granitic dykes of several meters width and several hundred meters length, often occur in the S-type granite plutons as seen in the eastern and western Jiangnan segments (Fig. 2). In the northern Guangxi terrane, the bimodal volcanic rocks, consisting of vesicular alkaline basalt and rhyolite, occur as interlayers within the Upper Tonian quartz sandstone strata. In the Jiuling terrane, zircons from E-W-extending diabase dykes yielded a U-Pb age of 812±5 Ma (Wang XL et al., 2006), whereas zircons in basalt and rhyolite from the Huaiyu terrane were dated at 794±9 Ma and 792±5 Ma, respectively (Wang and Li, 2003; Li XH et al., 2008). Our field investigations suggest that these bimodal igneous rocks were initially developed along the previous suture zone, namely, the Shaoxing-Pingxiang-Longsheng fault zone (Shu LS et al., 2019). In the Jiuling terrane, this early-middle Neoproterozoic suture zone was rifted into two branches, namely, the Nanchang-Wenjiashi and the Dongxiang-Pingxiang rifting zones (Fig. 7). A Late Tonian Dongxiang-Pingxiang rifting basin was formed in between these two branches as is inferred from a 100 m thick meta-spilite layer dated at ca. 780 Ma (Shu LS et al.,1995; Charvet et al., 1996). Two extensional regions were filled by coarse clastic rocks, bimodal volcanic rocks and associated alkaline basaltic dykes (Li XH et al., 2003). The previous foreland basins were involved into this event and became components of the above-mentioned two depositional regions. A coeval rifting basin and diabasic dykes were also formed in the Cathaysia region to the south (Fig. 7).

In addition, tillites and muddy-sandy clastic rocks were deposited and were well preserved in the NE-SW extending western Jiangnan and the N-S extending Kangdian (SW Sichuan) rifting basins (Ren and Chen, 1989; Wang and Li, 2003). Thus, the rifting ended at ~760 Ma and then was covered by the Cryogenian tillite layer in both the Yangtze and Jiangnan areas.

On the basis of the above geological features, a Neoproterozoic lithospheric evolution model for the South China Block is summarized in Fig. 8.

4. The Ediacaran to Early Paleozoic evolution: influence of the closure of the Proto-Tethys Ocean

Studies suggest that the Pan-African aged subduction did not obviously affect the South China Block (Yao JL er al., 2011, 2019). From the Ediacaran to Early Paleozoic (760-460 Ma), the sediments from the Jiangnan Orogenic Belt, the Cathaysia Block and neighboring areas were deposited in a stable neritic-slope environment (Fig. 9), and no trans-lithosphere fault and oceanic crust were found (Ren and Chen, 1989; Rong JY et al., 2003, 2010, 2018, 2020; Chen X et al., 2012; Rong JY, 2018; Wang Y et al., 2018, 2020a). Neither mappable volcanic lava or volcaniclastic rocks, nor deep-sea sedimentary rocks or turbidite with Bouma sequence were observed from lower Paleozoic strata in both the Jiangnan and Cathaysia regions (Shu LS et al., 2008c, 2014; Shen WZ et al., 2009).

4.1 Ediacaran - Ordovician stable sedimentation

Since the Ediacaran, two stable depositional regions occurred in South China, namely, the Cathaysia one to the south and the Jiangnan one to the north, with the Shaoxing-Pingxiang-Longsheng fault zone in between. The Ediacaran System in the Cathaysia depositional region mainly consists of sandy and muddy rocks whereas that in the Jiangnan depositional region is composed of limestone, dolomite and chert sequence intercalated with sandy-muddy rocks. The lower Paleozoic sedimentary sequences in the Jiangnan region are also composed of neritic carbonate rocks and chert, whereas neritic-slope sandstone and siltstone with limestone lenses are well developed in the Cathaysia region. The lower Paleozoic strata in the Jiangnan region contain abundant *trilobite, cephalopoda, armenoceras, coral and brachiopoda* fossils, whereas those in the Cathaysia region are marked by abundant *graptolite* fossils (Figs. 9 and 10; Rong JY et al., 2010, 2018; Chen X et al., 2012; Rong JY 2018). In terms of the Ediacaran to Early Paleozoic sedimentary and paleobiological differences, the Shaoxing-Pingxiang-Qidong-Longsheng fault zone is roughly considered as the boundary between the Jiangnan and the Cathaysia depositional regions whereas gradual sedimentary transition can be still observed in several segments (Chen X et al., 2012; Shu LS et al., 2015, 2019, 2020).

Lithostratigraphic sequences from 9 segments in 7 provinces (Fig. 10) show that both the Jiangnan and Cathaysia depositional regions were situated in a platform-shallow sea depositional environment (Shu LS et al., 2008c, 2014; Shen WZ et al., 2009; Wang YJ et al., 2010). The lower Paleozoic siliceous carbonate sequences, 3000-5400m thick, were accumulated in the Jiangnan region (Figs. 9 and 10). The coeval stratigraphic sequences deposited in the Cathaysia depositional region are graptolite-bearing sandy-muddy sequences interlayered with carbonaceous layers and limestone lenses with a thickness of 5600-7000m (Figs. 9 and 10).

Lower Paleozoic clastic sequences are widely distributed in the Wuyi, Nanling and Yunkai terranes. Sedimentary structures and rocks such as ripple mark, mudstone clasts in sandstone, sandstone blocks in mudstone, arkose and limestone lenses are well preserved, indicative of a neritic to slope depositional environment (Fig. 11).

4.2 The Early Paleozoic tectono-magmatic events responses to the closure of the Proto-Tethys Ocean

4.2.1 Paleogeographic differences of the Cathaysia and Jiangnan regions since the Late Ordovician

Since the Late Ordovician (~460 Ma), paleogeographic variations within the South China Block can be observed from sedimentary features (Rong JY et al., 2010). In the Jiangnan depositional region, the Upper Ordovician to Silurian muddy-sandy sequences were well developed, whereas the whole Cathaysia region has no coeval stratum due to strong uplifting and erosion. The major Yangtze Block has few outcrops of clastic rocks due to the large-scale Quarternary cover. In the E-W-trending sedimentary depression between the Cathaysia and Jiangnan depositional regions, a 4,000-5,000 m-thick Silurian molasse sequence with variable detritus compositions was accumulated, displaying a northward transition from coarse-grained and less rounded clastic rocks in the south to fine-grained ones in the north (Shu LS et al., 2008c, 2014). The thickness of Silurian strata in the depression shows a northward increasing trend from 2,000 m to 3,000 m, and then to 6,000 m (Fig. 9). Detrital zircon age spectra also indicate a northward transportation of detritus from the provenances in the south (Li HB et al., 2013), consistent with northwestward expansion of the Cathaysia Block (Rong JY et al., 2010, 2020; Wang Y et al., 2020).

Fig. 10 also shows an obvious difference in tectonic-sedimentary environment during the Silurian. Deposition in the west Jiangnan and Yunnan areas to the west of Xuefeng Mts. formed a continuous and thick Silurian sequence (Ren JS et al. 1990). In the Xuefeng Mts. (Fig. 2), the thick Silurian clastic sequence was folded and thrusted during the Triassic period (Chu Y et al., 2012a). However, to the southeast of the Xuefeng Mts., Silurian strata in the Cathaysia Block are lacked and an angular unconformity exists between the Devonian and Ordovician strata (Figs. 9 and 10; Wang Y et al., 2020). The Ediacaran-Ordovician strata were intensively deformed to form tight folding and thrusting structures. The eroded detritus was transported and deposited in the northern and western margins of the Cathaysia Block, forming thick olistostromes (Fig. 10; Rong JY et al., 2003, 2010).

4.2.2 Silurian deformation and metamorphism

During the Silurian, the Cathaysia Block experienced intensive folding-surface uplift and metamorphism. Asymmetric or recumbent folds are common with maximum shortening up to 67% (Shu LS et al. 2008c). Major fold axes display ca. E-W and NE-direction orientation, associated with thrust-type and strike-slip-type ductile shear deformation, and their ages are dated at ca. 430-390 Ma, coeval with or slightly younger than the peak age of granitic magmatism (Figs. 7 and 12; Wang YJ et al., 2010; Shu LS et al., 2015). Along the fold axial folded zone in the Wuyi terrane, kinematic indicators suggest top-to-the SE shearing on the southeastern side and top-to-the NW shearing on the northwestern side, forming a regional fan-like thrusting structure (Shu LS et al. 2008c; Charvet et al. 2010; Li JH et al., 2016, 2017).

The Early Paleozoic tectonic event strongly reworked the Proterozoic rocks of the Cathaysia Block. All pre-Silurian sandy and muddy rocks were metamorphosed into slates and phyllites, indicating a regional low-grade metamorphism which is dated at 453±7 Ma (monazite U/Th-Pb chemical dating; Faure et al, 2009) and 433±1 Ma, 428±1 Ma to 391±3 Ma (^{40}Ar/^{39}Ar; Shu LS et al., 2015). Thick Middle-Upper

Devonian molasse beds unconformably cover the aforementioned deformed and metamorphosed Cambrian-Ordovician strata and Silurian plutonic rocks.

Some orthogneiss, granitic gneiss and migmatite with mylonitic foliation and stretching lineation are locally developed around the margins of some Silurian plutons (Shu LS et al., 2008c, 2018; Wang YJ et al., 2010; Zhang GW et al., 2013). Far away from the plutons, only regional lower-greenschist facie slate and phyllite occur, without any high temperature metamorphic rocks. There is also barrowian metamorphism with biotite-garnet-kyanite relics (Zhao and Cawood, 1999; Faure et al., 2009; Charvet et al., 2010). For example, in some segments of the northern Wuyi and southwestern Yunkai terranes, rock assemblages of schist, granitic gneiss and migmatite are locally observed along the margins of S-type granitic plutons with ages of 440-420 Ma and disappear in areas away from the plutons. Thus, the high-grade metamorphic rocks within the Cathaysia Block are related to thermal input from granitic magma in an overall intracontinental setting (Shu LS et al., 2015, 2018). These observations are incompatible with models that favor continental collision to generate large-scale high-grade metamorphic rocks (Lin SF et al., 2018).

In the Jiangnan region, neither Silurian thrusting-type mylonite was reported nor carbonate rocks were metamorphosed into marble (Shu LS et al., 2014; Xu XB et al., 2018). The mylonitic rocks are only observed within several large strike-slip shearing zones (Li JH et al., 2017; Xu XB et al., 2018), no large-scale ductile thrusting was observed. Locally, decameters-scale ductile decollements developed within the Ediacaran strata occur in the northeastern Jiangxi (Shu LS et al., 1995; Faure et al. 2009).

4.3 Silurian peraluminous granitic plutonism

As tectono-magmatic responses to the closure of the Proto-Tethys Ocean, the Cathaysia Block underwent widespread folding-faulting, partial melting and granitic magmatism in the Silurian. More than 200 Silurian granitic plutons with total a total area of 20,900 km^2 are distributed in an area of 1,200 km long and 800 km wide, covering both the Cathaysia and Jiangnan regions. Granitoids mainly consist of two-mica granite, cordierite-bearing granite and tourmaline-bearing muscovite granite. Negative zircon εHf(t) values (-5.1 to -12.5) and 1.23-2.43 Ga model ages suggest that these granites were generated by partial melting of Paleo-Mesoproterozoic crustal material without input of mantle-derived melt. Much less coeval I-type granites with lower εHf(t) values (-1.4 to +7.2) only occur occasionally in several areas (<400 km^2 namely, <2% of total area) in the Cathaysia Block, they were considered as the result of partial melting of mafic rocks in the lower crust (Shu LS et al., 2018). Minor mafic rocks or mafic-intermediate enclaves in the granitoids have also been reported in a few localities and are dated at ca. 450 Ma and ca. 435 Ma (Fig. 12, Table S2), the former was also interpreted as partial melting of a metasomatized subcontinental lithospheric mantle and the latter was formed by partial melting of the mafic crust, both in an intracontinental setting (Zhang XS et al., 2017).

Ductile deformed and middle to high-grade metamorphosed rocks can be observed along margins of some plutons in the Wuyi and Nanling terranes of the Cathaysia Block, the augen orthogneisses, mylonitic and gneissic granites display shearing foliation, stretching lineation and plentiful asymmetric kinematic indicators including asymmetric feldspar porphyroclasts, augens and S-C shear bands (Faure et al., 2009; Charvet et al., 2010; Xu XB et al., 2011; Wang B et al., 2014). Neither mappable lower Paleozoic arc magmatic rocks nor subduction-related accretionary complex were recognized in the Cathaysia or Jiangnan regions. These deformation, metamorphism and granitic magmatism are inferred to be a far-field behavior of intracontinental responses to the closure of the Proto-Tethys Ocean, which is a coeval ocean between the South China-North Vietnam and the South Vietnam blocks that is called as the Tam Ky-Phuoc Son Ocean (Faure et al., 2018b).

All the undeformed and deformed plutons have similar age ranges without any apparent spatial and temporal evolutionary regularity (Song MJ et al., 2015; Shu LS et al., 2015, 2018). The zircon U-Pb and mica $^{40}Ar/^{39}Ar$ ages from 246 samples show that the ages of crystallization of granitoids and diabase (at 460-390 Ma, peak at 440-420 Ma) are comparable with the timing of mylonitic rocks and metamorphic rocks (at 430-390 Ma by $^{40}Ar/^{39}Ar$ on muscovite; Fig. 12; Table S2**;** Zhang Y et al., 2011; Wang YJ et al., 2012b, 2013b; Shu LS et al., 2014, 2015; Song MJ et al., 2015; Wang B et al., 2014; Zhang XS et al., 2017; Yan CL et al. 2017).

4.4 Tonian-Early Paleozoic dynamic evolution of the South China Block

In the Early Neoproterozoic (980-850 Ma), a northwestward (current coordinates) subduction of the Paleo-South China Oceanic plate occurred, forming accretionary complexes and arc magmatic rocks. The final closure of the Paleo-South China Ocean was followed by a collision between the Yangtze and Cathaysia blocks, and the accretion of the aforementioned five terranes along the southeastern margin of the Yangtze Block, leading to metamorphism, ductile deformation, granitic magmatism dated at 840-820 Ma and formation of the Jiangnan Orogenic Belt and Proto-South China Continent at 825-800 Ma (Fig. 8C and 13A). Thereafter, an intracontinental rifting event occurred in the Proto-South China Continent, leading to the formation of the extensional Jiangnan and Cathaysia depositional regions. This event was characterized by mantle-derived magmatic intrusion and bimodal volcanism dated at 810-760 Ma in the Nanhua rifting basin (Fig. 8D), namely, a part of the initial Proto-Tethys Ocean. From the Neoproterozoic to the Late Ordovician (760-460 Ma), a stable neritic depositional platform was developed in the South China Block. In the Cambrian-Ordovician period, the South China Block became a member of the northern Gondwana Continent (Fig. 13B) and is characterized by carbonate sequences containing plenty of *trilobite, brachiopoda* and *coral* fossils in the northern Nanhua sea basin that belongs to the Jiangnan depositional region (NR in Fig. 13B). The coeval *graptolite*-bearing sandy-muddy sedimentary successions in the southern Nanhua sea basin belongs to the Cathaysia depositional region.

Since the Late Ordovician, the closure of the Early Paleozoic Qinglin Ocean (a branch of the Proto-Tethys Ocean) along the northern margin of the South China Block caused a collisional orogeny along the Shangdan suture zone (Fig. 13C) associated with HP/LT blueschist and UHP eclogite facies metamorphism (Mattauer et al., 1985; Dong YP and Santosh, 2016). To the southeast of the South China Block, the subduction of Proto-Tethys Ocean and subsequent collision took place between the South China-North Vietnam-Laos Block and the South Vietnam-Khmer Block along the Tam Ky-Phuoc Son suture (Tran et al., 2014; Gardner CJ et al., 2017; Faure et al., 2018a,b; Wang YJ et al., 2020a) and generated an ophiolite-bearing mélange zone, arc-type granitoids and eclogites dated at 480-450 Ma in the Kontum Massif of Center Vietnam (Nagy et al., 2001; Roger et al., 2007; Nakano et al., 2013; Tran et al., 2014; Faure et al., 2018b). The assemblage of the Indochina Block (IC in Fig. 13C) might have been initiated since the Late Ordovician to Early Silurian and terminated in the Early-Middle Devonian. This was coeval with the intracontinental folding and thrusting, lower greenschist facies metamorphism, syn-tectonic S-type granitic magmatism and migmatization along the Wuyi-Yunkai domain within the Cathaysia Block (Fig. 13C) (Faure et al., 2018b; Wang YJ et al., 2020b). Finally, the Cathaysia region evolved into the Early Paleozoic South China Fold Belt (Guo LZ et al., 1965; Cawood et al., 2018). This orogeny was followed by deposition of thick sequences of Middle-Upper Devonian molasse and quartz sandstone, which unconformably coverred the folded and metamorphosed pre-Devonian strata. Thus, the subduction- and collision-related compressive stress on both the southern and northern margins of the South China Block might be significant driving-forces triggering the folding/thrusting of the pre-Devonian strata and the Silurian granitic magmatism within the South China Block.

In addition, paleomagnetic data indicate that the Viet-Khmer Block in the Southeast Asian region was previously distributed along an E-W strike and the rotation involved not only the Viet-Khmer Block but also the entire the Indochina region. This block was rotated clockwise for 30°-40° in the Cenozoic (Sato et al., 2001; Yang and Besse, 1993; Yang ZY et al., 2001) due to the extrusion tectonism in the eastern margin of the Tibet Plateau, well interpreting its present occurrence of the NW-trending Songma-Ailaoshan orogenic belt.

5. Late Paleozoic-Early Mesozoic evolution: responses to the closure of the Paleo-Tethys Ocean

5.1 Late Paleozoic–Early Mesozoic sedimentary environment

From the Middle Devonian (in Cathaysia) or Late Devonian (in Jiangnan) to the Middle Triassic period, the South China Block was situated in a stable coastal–neritic depositional environment of an archipelagic framework (Fig. 13D). In the Middle Devonian, the depressions of the northern Cathaysia depositional region were commonly filled by terrestrial coarse-grained clastic rocks such as conglomerate, quartz sandstone, arkose and sandstone (Fig. 14).

From the Early Carboniferous to Middle Triassic, the sedimentary sequences of the Jiangnan and Cathaysia depositional regions were similar, and characterized by platform-facies and coastal–neritic-facies carbonates (limestone, bioclastic limestone and dolomite) intercalated with cherts (Fig. 14), containing abundant floral fossils of *Leptophloeum rhombicum Dawson*, and faunal ones such as *Fusulina, Coral, Brachiopoda* and neritic *Radiolarian*, which are observed in the Jiangnan depositional region and the Yongan-Meizhou basin and the Shaoguan-Zhaoqing-Maoming basin of the Cathaysia region. Neither large-scale volcanism nor slices of oceanic crust were documented in the Upper Devonian to Middle Triassic strata. Occasionally, intraplate meter-scale basaltic layers intercalated in the Upper Paleozoic strata were reported (Shu LS et al., 2006, 2008b).

Our studies suggest that the depth of the basins and the thickness of strata gradually increase from the northeast to the southwest (Shu LS et al., 2008c). In the Qinzhou Bay area (QZB in Fig. 13D) of the southwestern Cathaysia region, the thickness of Upper Paleozoic strata is more than 10,000 m. Meanwhile, a short-term uplift took place in the Middle Permian, leading to formation of coastal swamps, as represented by arkoses and coal layers (Shu LS et al., 2009). Whereas, in the southwestern Yangtze Block, the Late Permian mantle plume activity has generated the huge-scale Emeishan flood basalts known as the Emeishan Large Igneous Province (Xu YG et al., 2001).

5.2 The Early Mesozoic deformation: a response to the closure of the Paleo-Tethys Ocean

In the Early-Middle Triassic period, the closure of the Paleo–Tethys Ocean (Wang YJ et al., 2007; Zhao GC et al., 2018) led to a strong tectono–magmatism within the South China Block (Fig. 13E, 14). The Upper Paleozoic coastal-neritic carbonates and clastic rocks were folded and brittlely faulted, deformed by strike-slip ductile deformation.

An Early Mesozoic continental deep-subduction took place in the northern margin of the Yangtze Block along the E-W-trending Dabie-Qinling Orogenic Belt (Fig. 1) between the South China and North China blocks (Hacker et al., 1998; Faure et al., 1999; Dong YP et al., 2011; Li SZ et al., 2012). At the southwestern margin of the South China Block, the collision between the South China and Indochina blocks occurred along the Songma (in northern Vietnam)-Ailaoshan (in Yunnan) suture zone (Figs. 1 and 13E), generating the Songma-Ailaoshan ophiolitic mélange. Ductile strike-slip shear zones and peraluminous granitic plutons dated at 250-220 Ma were also developed (Lepvrier et al., 1997, 2004; Roger et al., 2012; Faure et al., 2014, 2016a, b).

Within the South China Block, several Neoproterozoic phyllite klippens were thrusted southwards onto the Carboniferous-Permian limestone strata along a low-angle fault as seen in the Pingxiang-Leping basin (Shu LS et al., 2009). On the northern and southern slopes of the Wuyi terrrane and within the Yunkai terrane, ductile strike-slip shearing structures are developed, partly replacing the previous thrusting structures. The single-grain ^{40}Ar/^{39}Ar dating of newly formed mica from mylonitic rocks yielded ages of 240–200 Ma (peak age at ca. 230 Ma), coeval with the peak age of regional granitic plutonism (Fig. 15; Wang YJ et al., 2007; Lin W et al., 2008; Charvet et al., 2010; Shu LS et al., 2015).

This tectonic event intensively reworked the pre–Devonian deformed structures (Shu LS et al., 2009) and is widely recorded in rocks in the eastern Jiangnan Orogenic Belt and the southwestern Yunkai terrane. To the northwest of the Xuefeng mountains, large-scale thin-skinned structures including box folds, fold-and-thrust structures are well developed (Figs. 2 and 13E; Chu Y et al., 2012a, b; Zhang GW et al., 2013). Furthermore, at depth, a syn-metamorphic, NW-directed ductile shearing developed to accommodate the km-scale displacement of the entire Neoproterozoic to Middle Triassic sedimentary cover of the South China Block, leading to refolding of the Early Paleozoic structures during the Triassic intracontinental orogeny. To the southeast of the Xuefeng mountains, the Early Paleozoic folds were almost totally reworked by the

Early Mesozoic deformation structures (Shu LS et al., 2008c, 2009). In the Nanling terrane, three E-W-trending granite zones with an average width of 40-50 km were generated and dated at 228-205 Ma (Zhou XM et al., 2006; Shu LS et al., 2008b). The Lower-Middle Triassic are unconformably covered by a several kilometers thick molassic sequence (Shu LS et al., 2006, 2008b).

5.3 Early Mesozoic magmatic response to the closure of the Paleo-Tethys Ocean

Under the aforementioned compressional setting, widespread magmatism took place in the Jiangnan and Cathaysia regions, forming a 600-800 km wide and 1,200 km long granitic domain. The Early Mesozoic granite exposures occupy a surficial area of more than 15,000 km^2 (Song MJ et al., 2017). A lot of zircon U-Pb and mica ^{40}Ar/^{39}Ar ages ranging from 240 to 220 Ma were obtained from 189 granite samples (Table S3), which might be the timing of the Early Mesozoic intracontinental orogeny. From several NW-SE and NE-SW trending sections across the Jiangnan and Cathaysia regions, the Early Mesozoic granites show an overlapping age range without any regular trend (Shu LS et al., 2008b; Wang YJ et al., 2010, 2012b; Song MJ et al., 2017).

About 97% granitic plutons show peraluminous geochemical signatures and are rich in muscovite and tourmaline. The magmatic zircons yielded negative εHf(t) values (-2.2 to -14.3 with an average of -7.3) (Table S3) and two-stage model ages from 1.41 to 2.28 Ga, suggesting that they were generated by partial melting of ancient continental crust (Wang YJ et al., 2010, 2012b; Song MJ et al., 2015; Shu LS et al., 2014，2015). Several I-type plutons (<3% of all Early Mesozoic granites) were also identified and yielded positive εHf(t) values (+0.5 to +3.2), which were considered to have been derived from partial melting of mafic lower crust (Song MJ et al., 2015). The magmatic zircon U–Pb ages range from 245 to 205 Ma (Zhou XM et al., 2006) with a peak at 240-220 Ma. These S-type plutons also display syn-magmatic deformation fabrics and syn-magmatic metamorphism. Gneissic granites, augen granites and granitic gneiss commonly developed along the margins of some plutons, whereas the country rocks away from plutons were not subjected to middle-high-grade metamorphism (Shu LS et al., 2015), comparable to the Early Paleozoic granites.

5.4 Late Triassic – Early Jurassic widespread angular unconformity

The Early Mesozoic tectonism displays variations across the South China Block (Shu LS et al., 2008c, Wang YJ et al., 2013). In the western Cathaysia Block, close to the Ailaoshan-Songma suture zone, the Upper Triassic strata consist of purple-red conglomerate-sandstone layers and overlie the Upper Permian strata with an angular unconformity. In the middle Cathaysia Block, the Upper Triassic strata consist of coarse-grained terrestrial clastic rocks and covers the Lower Triassic carbonates by an angular unconformity. In the eastern Cathaysia Block, the Upper Triassic coarse-grained sandstones overlie unconformably the Permian carbonate strata. Locally, the Lower Jurassic conglomerate and quartz sandstone contact with the pre-Mesozoic strata by an angular unconformity (Fig. 14; Shu LS et al., 2008c, 2009; Wang YJ et al., 2013).

In the western Jiangnan Orogenic Belt, the Middle Triassic granitic plutons dated at ca. 230 Ma are overlain by the Upper Triassic granite-derived conglomerate and arkose sequences (Shu L S et al., 2008c). In the middle Jiangnan Orogenic Belt, the Upper Triassic is composed of purple coal-bearing coarse-grained clastic rocks, and they overlie unconformably the Middle Triassic and Permian carbonates (Fig. 14). In the eastern Jiangnan Orogenic Belt, the Upper Triassic coal-bearing coarse-grained clastic rocks cover unconformably the Neoproterozoic schist and gneiss (Shu LS et al., 1995; Xiao and He, 2005). Near the Nanjing city of the northeastern Yangtze Block, the Upper-Middle Triassic conglomerate and quartz sandstone strata overlie unconformably the Early Triassic thin-bedded limestone (Fig. 14).

The aforementioned arguments suggest that the Early Mesozoic closure of Paleo-Tethys Ocean has strongly affected the South China Block, and terminated the marine environment, entering a fluvial-lacustrine sedimentary environment.

5.5 Continental dynamic mechanism for the Early Mesozoic tectonism

As mentioned above, the Upper Devonian to Middle Triassic stratigraphic sequences in the South China Block are composed of limestone, dolomite, chert, mudstone, coal-bearing sandstone and arkose with various fossils, indicative of stable sedimentary environments of continental shelf, coast, lacustrine and river-delta (Fig. 14; Shu LS et al., 2008b). The Early to Middle Triassic magmatic rocks are mostly peraluminous, with rare or no mantle-derived components, suggesting that there was no subduction of oceanic crust at this period (Song MJ et al., 2015, 2017; Shu LS et al., 2018).

The Early Mesozoic compression resulted in folding of all the pre-Middle Triassic strata and associated faulting that crosscut the pre-Triassic strata. The Upper Triassic conglomerate and coarse-grained sandstone overlie unconformably the Lower Devonian to Lower Triassic strata (Fig. 14), suggesting that the tectonic event took place in the Middle Triassic period. Some researchers proposed a hypothesis of flat-slab subduction to interpret wide and strong deformation in the Early Mesozoic in the inland areas of South China (Li and Li, 2007).

Available data indicate that in the Early Mesozoic, the South China Block subducted beneath the North China Block and generated the Dabie-Qinling UHP metamorphic-deformed zone (Fig. 1; Gilder et al., 1999; Faure et al., 1999, 2003; Zheng YF et al., 2003; Li XH et al., 2006; Li SZ et al., 2012; Zhang GW et al., 2013; Wu and Zheng, 2013). Meanwhile, the Paleo-Tethys Ocean subducted beneath the Indochina Block, followed by the assembly of the South China Block with the Indochina Block (Carter A et al., 2001; Faure et al., 2014; Shu et al., 2015). These two compressive stress fields on both the northern and southern sides of the South China Block might be the driving forces for the Early Mesozoic intracontinental folding, faulting and crustal thickening as evidenced by partial melting of crust and S-type granitic magmatism (Fig. 13E, 15; Shu et al., 2008b; Wang YJ et al., 2007, 2012b; Faure et al., 2016b; Song MJ et al., 2017; Li JH et al., 2017). Therefore, the Early Mesozoic tectono-magmatic event within the South China Block is an intracontinental reworking event due to far-field effects of plate convergence surrounding the South China Block (Fig. 13E; Shu LS et al., 2008b, 2009, 2018; Charvet et al., 2010; Zhang GW et al., 2013; Faure et al., 2016b, 2018b).

6. Consumption of the Paleo-Pacific Ocean: the active continental margin and basin-and-range tectonics

6.1 Tectonic transition from the E-W-trending to NE-trending regimes

Following the Early Mesozoic tectono-magmatic responses to the closure of the Paleo-Tethys Ocean, a regional-scale tectonic transition from the E-W-trending tectonic regime with Paleo-Tethys affinity into the NE-trending regime with Paleo-Pacific affinity happened in the East Asia region (Ren JS et al., 1990, 1998; Wang and Shu, 2012). In the Late Triassic-Early Jurassic period, uplift and erosion took place in the southeastern region of the South China Block and is evidenced by the absence of Upper Triassic strata and formation of Lower Jurassic conglomerate layers with a thickness of 50-80 m (Shu LS et al., 2009; Wei W et al., 2016). Meanwhile, crustal extension and thinning happened in the western Wuyi terrane and formed a sub-E-W-extending Middle Jurassic volcanic-sedimentary basin (Shu LS et al., 2009) of 30-40 km wide and 250 km long, referred to as the western Fujian-southern Jiangxi-northern Guangdong or the Yongding-Meizhou half-graben basin zone (Fig. 16), in which 180-160 Ma greenish vesicular alkaline basalt and reddish rhyolitic rocks of 300-800 m thick were accumulated (Shu LS et al., 2009). This was the most intensive volcanic eruption in South China since the Late Tonian.

In the Nanling terrane of southern Hunan Province, three phases of intrusion of mantle-derived mafic magma took place at ~175 Ma, 150-125 Ma and 95-80 Ma along the Chenzhou-Linwu fault which was interpreted as a Late Mesozoic upwelling path of mantle-sourced magma (Fig. 16; Wang YJ et al., 2003). In the Jiangnan region, intrusion of diabase and granitic dykes mainly occurred during 150-145 Ma and were asssociated with huge-scale skarn-type scheelite polymetallic deposits (Chen GH et al., 2016). Meter-scale mafic dykes and coeval alkaline granites of 180-150 Ma also occur along the margins of half-graben basins in the Nanling terrane (Deng P et al., 2004; Zhou and Chen, 2001; Shu LS et al., 2009).

The E-W to NE-SW trending Late Jurassic peraluminous granitic zone is generally oblique to the E-W-trending Middle Triassic plutonic zone in the Nanling terrane (Zhou XM et al., 2006). Therefore, the Nanling terrane could be the most reasonable place that documents the tectonic transition from the E-W-trending to NE-SW trending regime in the Middle Jurassic (180–160 Ma; Deng P et al., 2004; Shu LS et al., 2009, 2012) when the low–angle subduction of the Paleo-Pacific Ocean (Izanagi) lithosphere beneath the East Asian continental margin started.

The subduction zone of Paleo-Pacific Ocean in the Late Mesozoic was recorded in various rocks (ophiolitic rocks and blueschists) in many areas, such as the Sanbagawa zone of southwestern Japan, the Longitudinal Valley of Taiwan of China, and the Mindoro-Palawan of western Philippines (Faure et al., 1989; Ichikawa et al., 1990; Shu and Zhou, 2002). Recently, field observations and tectonic analyses suggest that the time of tectonic transformation from the Tethys to Paleo-Pacific tectonic domain probably took place in the Early-Middle Jurassic in the South China Block (Shu and Zhou, 2002; Zhou et al., 2006; Zhou et al., 2009; Shu LS etr al., 2009; Wu FY et al., 2011; Guo F et al., 2015). As a part of the Paleo-Pacific tectonic regime, a wide back-arc extensional region developed in the Southeast China, forming a huge-scale NE-SW trending volcanic and plutonic complex zone dated at 140-110 Ma, and numerous contemporaneous rift basins (Fig. 16; Wang and Shu, 2012). The Ganjiang and Sihui-Yangchun-Wuchuan fault zones (Fig. 16) were identified as the terminal line of the Late Mesozoic volcanic rocks (Zhou XM et al., 2006; Wang and Shu, 2012).

The NE-SW trending Lower Cretaceous volcanoclastic, volcanic and intrusive rocks occupy almost the whole southeast China coastal region, and overprinted the previous E-W trending structures in the inland areas as seen in the Nanling and Yunkai domains (Charvet et al., 1994; Lapierre et al., 1997; Wang and Zhou, 2002; Zhou XM et al., 2006).

6.2 Tectonic effects of the Paleo-Pacific Ocean subduction

In the Late Jurassic-Early Cretaceous, the subduction of the Paleo–Pacific Plate accelerated along a low-angle subduction zone (Zhou and Li, 2000; Kato and Saka, 2006), forming a broad active continental margin in the East Asian region. The Japanese islands belonged to a volcanic arc while Southeast China was mainly in a back-arc extension region (Ichikawa, 1990; Faure et al., 1986, 1992; Wang and Zhou, 2002; Shu and Zhou, 2002; Wang and Shu, 2012). Consequently, the Early Cretaceous rhyolitic volcanic rocks, bimodal magmatic dykes, metamorphic core complexes, co-existing I- and S-type granites dated at 140-100 Ma, rift basins and thinning lithosphere occurred in both the southeast coastal region and the inland areas, evidencing a back-arc extensional setting (Zhou et al., 2006; Shu LS et al., 2009).

Meanwhile, a major tectono-magmatic event affected the East Asian margin and formed the ophiolitic mélange and HP/LT metamorphic zone in the southwestern Japan, Central Taiwan, Mindoro and Palawan areas (e.g. Ichikawa, 1990; Lo and Yui, 1996). In Japan, this event is assigned by some authors to the collision of the

Proto-Japan Block with the South Kitakami-Kurosegawa Block (Faure, 1985; Faure et al., 1986; Faure and Natal'in, 1992; Otsuki, 1992; Kato and Saka, 2003, 2006). This collision was possibly responsible for the formation of the NE–SW trending Changle-Nan'ao ductile shear zone in the southeast coast of South China (Fig. 16), which was dated at 120–100 Ma by muscovite ^{40}Ar/^{39}Ar method (Wang ZH et al., 1997). This event formed a regional angular unconformity between the Late Cretaceous coarse-grained clastic rocks and the underlying Early Cretaceous volcanic rocks in the SE China coastal areas (Lapierre et al., 1997; Wang and Shu, 2012).

Possible break off of the subducted oceanic lithosphere might have resulted in the roll-back of the subducting slab and induced a shift from low-angle to high-angle subduction of the Pacific lithosphere since the Late Cretaceous (Uyeda, 1983; Zhou and Li, 2000; Guo F et al., 2021). Such a change corresponded to a large-scale crustal thinning and further continental extension, forming a series of NE-SW rift basins in South China and Northeast China. These basins were filled by the Late Cretaceous–Paleogene red clastic rocks of thousands of meters thickness, interbedded with alkaline basalts and were intruded by mafic dykes (Fig. 16). An alkaline granite zone dated at 100–70 Ma was also developed well along the East Asian continental margin (Zhou XM et al., 2006; Shu LS et al., 2009; Li JH et al., 2020).

Based on the above-mentioned field observations and data patterns across South China, we suggest that the Early Cretaceous low–angle subduction of the Paleo-Pacific plate caused partial melting of the subducted slab. In the depth, an upwelling of mantle-derived magma, and basaltic underplating along fault zones, led to softening and partial melting of middle-lower crust, along with granitic plutons emplacement in the upper plate (Fig. 17). These processes generated the Cretaceous rift structures, leading to the basin-and-range tectonics in South China (see below).

6.3 Extensional tectonics and related magmatism

6.3.1 Basin-and-range tectonics

In the Early Cretaceous, when a hypothetical low-angle subduction of Paleo-Pacific slab happened, the southeast China coastal zone was situated in the back-arc region behind the Japanese volcanic arc (Wang and Shu, 2012). The southeast China coastal back-arc extensional zone is characterized by lithospheric thinning, namely, the thickness of the crust is only 29 km, and the lithosphere is 80 km thick (Zhou XM et al., 2006). The extensional basins were filled by 2-3 km-thick Cretaceous rhyolite–pyroclastic rocks and terrigenous clastic rocks. Coeval metamorphic core complexes and normal-fault-bounded granitic domes were also reported in the Wugongshan (Faure et al., 1996; Wang DZ et al., 2001), Lushan (Lin W et al., 2000), Zhuguangshan (Fig. 16) and Hengshan areas (Shu LS et al., 2004; Wei W et al., 2016). A distinctive Late Mesozoic high-Nd abnormal zone occurred and corresponds to a coeval granitic and poly-metal metallogenic zone (Gilder et al., 1996). The volumes of plutons increase and their ages show a younging direction gradually from the inland to the coast (Zhou XM et al., 2006).

The Late Mesozoic basins in Southeast China have a total surficial area of 128,000 km^2 (Shu LS et al., 2009), comparable to the total exposure of the coeval magmatic rocks (140,000 km^2; Fig. 16; Zhou XM et al., 2006). Most of the rift basins were formed in the Middle Jurassic (180-160 Ma) and have a total surficial area of 4,600 km^2. The Late Jurassic-Early Cretaceous volcanic grabens occupy a total area of 85,500 km^2, and total area of the non-volcanic ones (called the redbed basins) formed in the Late Cretaceous to Paleogene is 37,900 km^2 (Shu LS et al., 2009).

The basin-and-range tectonics is a distinct character of the Southeast China region during the Cretaceous. From the coast to inland, a series of magmatic ridges is closely associated with the extensional basins, forming the South China basin-and-range tectonics (Gilder et al., 1991; Shu LS et al., 2004, 2009, 2020; Wang and Shu, 2012). The major basin-and-range systems are: (1) in the southern Wuyi domain, the NE-trending Early Cretaceous granitic batholiths in the Daiyunshan-Bopingling range (peak altitude of 1,856 m) coupled with contemporaneous volcanic basins on both sides of the range; (2) in the Wuyi mountains, the NE-trending Early Cretaceous granitic batholiths (peak altitude of 2,157 m; Fig. 16) coupled with a Late Cretaceous-Paleogene rift basin zone on its northwestern side and an Early Cretaceous volcanic basin on its southeastern side; (3) in the northern Wuyi domain, the E-W-trending Early Cretaceous granitic plutons (peak altitude of 1,918 m) coupling with the Pingxiang and Anfu rift basins, formed the Wugongshan metamorphic core complex which was superimposed on a Triassic dome; (4) in the Nanling domain, the E-W-trending Late Triassic-Early Jurassic granitic zone (peak altitude of 1,902 m) coupled with coeval sedimentary basins was intruded by the NE-trending Early Cretaceous plutons, forming the famous Five Ranges landform (Wang and Shu, 2012; Shu et al., 2020).

6.3.2 Multi-sourced igneous rocks

The Zhenghe-Dapu fault zone (Fig. 2) is a boundary between I-type (140-110 Ma) and S-type (170-150 Ma) magmatic domains. Rhyolitic volcanic rocks and alkaline granites, as well as mafic plutons/dykes, are widespread on its southeast side, i.e., the coastal area; whereas, S-type plutons mostly outcrop on its northwest side, i.e., the inland region (Fig. 17). This fault zone was a normal one dipping to the southeast and was formed in the Mesozoic.

The bimodal igneous rocks were formed in two stages, i.e., mainly in the Middle Jurassic and secondly in the Early Cretaceous. The E-W-trending Middle Jurassic bimodal igneous rocks are mainly distributed in the Yongding-Dingnan-Shixing zone of the western Wuyi-Nanling domain (Figs. 16 and 17) where the basalts and rhyolites have approximately equal thickness. The cryptocrystalline and vitric textures reflect a rapid extensional setting (Deng P et al., 2004). Small scale aegirine-bearing granites were also observed. The NE-SW trending Early Cretaceous bimodal igneous rocks are mainly distributed in the southeastern China coastal areas and are mainly composed of rhyolites and basalts, with an exposure ratio of 10:1. The basalts belong to continental tholeiites, which are distinctively different from the Middle Jurassic alkaline basalts in the Nanling domain. The positive εHf(t) values (+2 to +5) of rhyolites reflect the involvement of mantle-derived material or crust-mantle interaction (Zhou XM et al., 2006).

The Late Cretaceous alkaline granites occur in an 800 km-long southeast coastal area (Wang and Shu, 2012). A–type granites were emplaced during 160–150 Ma in the Nanling and at 100–90 Ma in the coastal region (Zhou XM et al., 2006; Wang and Shu, 2012), whereas I–type granites mainly range in age between 140 and 110 Ma (Wang and Zhou, 2002). Alkaline granites usually have many geodes that are often filled by quartz, muscovite and alkaline mafic minerals, indicating a shallow emplacement depth. Geochemical data suggest that the alkaline granites were all produced by crust–mantle interaction in an extensional setting (Wang and Zhou, 2002; Zhou XM et al., 2006).

To the west of the Zhenghe-Dapu fault zone, granites are mostly peraluminous and were emplaced at 170–150 Ma (Wang and Shu, 2012). Porphyritic texture and massive structure were commonly developed. The long axes of granitic batholiths are mostly oriented NE-SW, occasionally accompanied by volcanic basins. Sometimes, the granitic batholiths are covered by rhyolite and welded tuff, constituting a volcanic and intrusive complex (Zhou JC et al., 2006; Wang and Shu, 2012). These rocks may be derived from deep melting of subducted slab, upwelling of mantle material and partial melting of continental crust (Zhou and Li, 2000).

7. Discussion on some controversial issues

7.1 The location of the Neoproterozoic suture/rifting zone in the middle segment of the Jiangnan Orogenic Belt

The Neoproterozoic rocks within the Shaoxing-Pingxiang fault zone (the eastern Jiangnan segment) and the Quanzhou-Longsheng fault zone (the western Jiangnan segment) comprise ophiolites, arc-type andesites and rhyolites with ages of 980-840 Ma, documenting a suture zone between the Yangtze and Cathaysia blocks. However, it is difficult to identify the location of the suture zone in the middle Jiangnan segment situated in the Hunan Province due to the absence of Neoproterozoic magmatic rock and other geological evidence. According to our recent field investigations covering both the Jiangnan Orogenic Belt and Cathaysia Block, we have identified that the litho-stratigraphic sequences on each side of the Pingxiang-Qidong-Quanzhou fault zone (Fig. 2) show distinctive rock assemblages from upper to lower. (1) The Cambrian and Ordovician sequences are characterized by *trilobite-sinoceras*-bearing carbonate rocks and graphitic bearing material layers in the Jiangnan region to the north of the fault zone (Fig. 18A-C) whereas the Cathaysia region to the south of the fault zone is marked by *graptolite*-bearing sandy-muddy slate and phyllites (Fig. 18D-F). The lower Paleozoic graphitic material bearing layers and limestone are absent in the Cathaysia region. (2) The Ediacaran sequence in Jiangnan is characterized by black chert, dolomite, siliceous limestone and limestone while in Cathaysia it is a suite of sandstone and mudstone. (3) The Cryogenian tillite layers are well developed in Jiangnan, but are absent in Cathaysia. (4) The Upper Tonian (corresponding to the Nanhua System) contains bimodal volcanic rocks in the Jiangnan region, but is rare in the Cathaysia region. (5) The Lower Tonian (corresponding to the Sibao Group) in the Jiangnan region is marked by sandy-muddy flysch slates intercalated with meta-volcanic and mafic-ultramafic rocks; whereas the equivalent strata in the Cathaysia region are characterized by various sandy-muddy slates and phyllites with no or only sporadic mafic rocks.

The above-mentioned distinct features of the Jiangnan and Cathaysia regions indicate that since the Late Tonian (or Nanhua period), this fault zone divided the united Yangtze-Cathaysia tectonic unit, namely, the Proto-South China Continent into two tectono-stratigraphic regions, Jiangnan to the north and Cathaysia to the south. We interpret that these differences as the results of the Late Tonian rifting event along the previous suture zone (Shu LS et al., 2020). Here, we define the Pingxiang-Qidong-Quanzhou fault zone as the location of the Neoproterozoic rift zone, which most probably re-activated the pre-existing Neoproterozoic suture zone in the middle Jiangnan segment. This result has been recently confirmed by a geophysical investigation which presents obvious gravity and magnetic anomalies along this fault zone (Guo and Gao, 2018).

7.2 The nature of the “Cathaysia Oldland”

7.2.1 Study history of the “Cathaysia Oldland”

The term “Cathaysia Oldland” was firstly proposed by Grabau (1924) and refers to a hidden crustal block beneath the South China Sea, whereas the Wuyi domain, composed of pre-Devonian metamorphic rocks, was defined as a geosyncline region (Grabau, 1924). The term was adopted by Huang JQ et al. (1945) in their studies. In the 1960-1970’s, some researchers identified the Cambrian and Ordovician *graptolite* fossils from the Cathaysia Block which was originally assigned to the “Cathaysia Oldland”. Thus, the term “Cathaysia Oldland” was re-defined as the South China Early Paleozoic Fold Belt (Guo LZ et al., 1965) or the Ediacaran to Early Paleozoic fold belt (Ren JS, 1964, 2001). Since the 1980’s, with the application of advanced dating techniques, a large number of Proterozoic ages were obtained from meta-igneous rocks in the Wuyi terrane (Gan XC et al., 1993; Wan YS et al., 2007; Yu JH et al., 2009), leading to re-use of the concept “Cathaysia Oldland” (Shui T, 1988), which is, however, not accepted by other researchers (Wang and Zhou, 2002; Shu, 2006, 2012; Ren and Li, 2016). Therefore, the Cathaysia Oldland became a major debated issue.

The Cathaysia Block was recently considered as a geological unit consisting of widely exposed Precambrian sandy-argillaceous slate-phyllite series interlayered with meta-mafic rocks, along with Early Paleozoic *graptolite*-bearing clastic rocks, both are intruded by Silurian peraluminous granitoids. The pre-Silurian strata are up to 10,000 meters thick and occupy an area of 80,000 km^2 of the Cathaysia Block, and are covered by a 300-500 m thick Middle Devonian conglomerate, coarse sandstone and quartz sandstone.

7.2.2 Re-evaluation of usability of "Cathaysia Oldland"

As mentioned above, the geological features of Cathaysia can be summarized as several aspects as the follows. (1) Very limited occurrence of old continental core. Although an unexposed Archean basement might exist in Cathaysia as revealed by 4.1-3.8 Ga detrital zircons (Xu XS et al., 2005; Xiang and Shu, 2010; Yao JL et al., 2011; Xing GF et al., 2014), the in-situ Paleoproterozoic basement (1.8-1.9 Ga) occurs only in the northern Wuyi terrane (Yu JH et al., 2009). (2) Complex genesis of sporadic Neoproterozoic magmatic rocks dated at 980-910 Ma. Neoproterozoic magmatic rocks were recognized in several isolated terranes and formed in different tectonic settings, including (a) the continental arc-type rhyolites in the Nanling terrane (Shu LS et al., 2008a), the subduction-related gneissic granites (Liu BX et al., 2001) and amphibolite and dolerite in the Wuyi and Yunkai terranes (Wang YJ et al., 2012a, 2013a); (b) gneissic granitoids related to the formation and closure of back-arc basins in the Yunkai terrane (Wang YJ et al., 2014); and (c) mantle-derived mafic rocks generated in continental rifts, such as gabbro and basalt along the Zhenghe-Dapu fault zone of the Wuyi terrane (Shu LS et al., 2011), and basalt, diabase and gabbro in the Yunkai terrane (Wang YJ et al., 2010). (3) Intense Phanerozoic tectonic and magmatic reworking. Most importantly, all the pre-Devonian rocks were involved into a Late Ordovician to Silurian syn-metamorphic deformation and thrusting system documented in the Wuyi, Nanling, Yunkai and Xuefeng domains (Shu LS et al., 2008c; Ren and Li, 2016), associated with intrusion of S-type granitic plutons with ages of

440-420 Ma (Shu LS et al., 2015, 2018; Wang YJ et al., 2010).

Based on the above-mentioned geological facts, the Cathaysia Block seems to be characterized by small-scale exposures of ancient rocks, weakly crystallized basement, and poor rigidity. Considering the definition of an oldland, we propose that the previous term “Cathaysia Oldland” is not suitable to be used for Cathaysia.

7.3 Initial formation age of the South China Block

7.3.1 History of studies

The formation of the South China Block (or the Proto-South China Continent; Zhang GW et al., 2013) has long been debated. In 1990’s, the timing of initial stabilization was inferred as Meso-Neoproterozoic according to litho-stratigraphic comparison, structural correlation and isotopic dating (Guo LZ et al., 1989; Shu LS et al., 1995; Charvet et al., 1996), and was linked with the global Greenville period subduction and collision (Li ZX et al., 1999). Nevertheless, Hsu et al. (1990) proposed that the South China Block was an Appalachian-type Mesozoic orogenic belt and experienced a long-term depositional and tectonic evolution. Since the 21th century, with increasing geochronological data, the formation of the Proto-South China Continent once again was re-determined as at 860-800 Ma (Shu LS et al., 1994, 2011; Li ZX et al., 1999; Li XH et al., 2003; Li WX et al., 2008), 830-800 Ma (Yao JL et al., 2013, 2019; Zhang YZ et al., 2012, 2015; Yan CL et al., 2017, 2021) and 820-795 Ma (Sun JJ et al., 2018; Shu LS et al., 2019). Hence, the initial assembly of the South China Continent is essentially important in understanding the geology of the South China Block.

7.3.2 The tectono-magmatism prior to the Proto-South China Continent

The aforementioned dating data suggest that the Archean magmatic rocks dated at around 3.0 Ga only occur locally in the northern Yangtze Block (Fig. 5; Qiu YM et al., 2000; Zhang SB et al., 2006; Wu YB et al., 2009). They are assigned to the Kongling complex which is composed of schist, biotite-plagioclase gneiss, trondhjemite, granodiorite and a few mafic-ultramafic rocks (Gao S et al., 2011, Han

QS et al., 2017). The early-middle Neoproterozoic mafic-ultramafic rocks, intermediate-mafic intrusive rocks and turbidites are mainly distributed in the southern, southeastern and western margins of the Yangtze Block and are dated at 980-845 Ma in the eastern Jiangnan (Xu B et al., 1992; Li XH et al., 1994) and 870-840 Ma in the western Jiangnan (Yao JL et al., 2016). Upper Tonian cover consisting of conglomerate and quartz sandstone sequences is widely exposed along the margins of the Yangtze Block.

As mentioned above, within the Cathaysia Block, no mappable Archean rocks are observed. The Paleoproterozoic magmatic rocks dated at around 1.9 Ga are exposed only in the northern Wuyi terrane. The widespread Upper Proterozoic sandy slate and phyllite interlayered with meta-mafic and granitic rocks dated at 980-910 Ma are commonly exposed in the Cathaysia Block (Shu LS et al., 2008a; Li ZX et al., 2010; Wang YJ et al., 2012a, 2014).

Recent studies indicate that the earliest plate tectonics in South China occurred in the Paleoproterozoic, as is evidenced by 2.1-1.9 Ga MORB-type ophiolite in the northern Yangtze (Han QS et al., 2017) and the 1.9-1.8 Ga arc-type granitoids and amphibolite in the northern Wuyi terrane (Li XH, 1998; Yu JH et al., 2009), suggesting that the subduction of oceanic plate occurred in the Paleoproterozoic along the northern Yangtze Block and the northern Cathaysia Block.

Along the southeastern margin of the Yangtze Block, a subduction initiated at the earliest Neoproterozoic and continued to the middle Neoproterozoic, as documented by the 940-900 Ma cumulate gabbro and plagiogranite of the SSZ-type ophiolite mélange along the Dexing-Shexian fault zone (Li XH et al., 1994; Li WX et al., 2003), the 980 Ma EMORB-type mafic rocks along the Shaoxing-Pingxiang fault zone (Wang XL et al., 2014a), the 870-845 Ma SSZ-type ophiolite and arc-type granite in the Huaiyu terrane (Zhang SB et al., 2012; Shu LS et al., 2019), the 870-840 Ma ophiolite and continental arc-type gabbro, diorite and granodiorite in the northern Guangxi terrane (Yao JL et al., 2016), and the 866±14 Ma high-pressure blueschist along the Dexing-Shexian fault zone (Shu LS et al., 1994, 1995; Zhou and Zhou, 1996). In addition, the 980-910 Ma arc magmatic rocks demonstrate that another subduction in the Cathaysia Block was also initiated at the earliest Neoproterozoic (Shu LS et al., 2008a; Li ZX et al., 2010; Zhang AM et al., 2012; Wang YJ et al., 2014), which were also considered as evidence of bi-direction subduction (Zhao GC, 2015).

7.3.3 Forming time of the Proto-South China Continent

The aforementioned Neoproterozoic peraluminous granites distributed linearly over 1,500 km within the Jiangnan Orogenic Belt and were mostly formed during 840-810 Ma, constraining the timing of crustal thickening and partial melting related to the collision of the Yangtze and Cathaysia blocks, which is also the formation of the Proto-South China Continent (Wang XL et al., 2014a; Xin YJ et al., 2017; Yao JL et al., 2019).

The regional-scale middle Neoproterozoic angular unconformity is well developed in the southeastern margin of the Yangtze Block as shown in Figs. 5 and 6. It recorded a consistent sedimentation shortly after the formation of the Proto-South China Continent. The bentonitic silty tuff within the basal conglomerate from the lowest Banxi Group or the lowest Danzhou Group above the unconformity yielded a youngest age peak at ca. 797 Ma (803-791 Ma) that could constrain the oldest depositional age of the Banxi and Danzhou groups (Gao LZ et al., 2011; Yan CL et al., 2015; Wang LJ et al., 2010; Xu YJ et al., 2014; Wang XL et al., 2014b; Sun JJ et al., 2018; Yao JL et al., 2019). Similar youngest age peaks have also been obtained from the equivalent strata in the Cathaysia Block, indicating that the assembly of the Yangtze and Cathaysia blocks took place prior to ~797 Ma. The dating of the bentonites and sandstones in the uppermost Lengjiaxi Group below the unconformity yielded a youngest age population of 829-820 Ma with a peak at ~825 Ma (Gao LZ et al., 2011; Yan CL et al., 2015; Wang XL et al., 2014b; Li JY et al., 2016; Sun JJ et al., 2018). Consequently, the regional unconformity was formed during 820-797 Ma, which indicates the interval from uplifting and erosion to accumulation for the Jiangnan Orogenic Belt. Thus, the time of initial formation of the Proto-South China Continent was most likely at 820-800 Ma.

7.4 The nature of the Early Paleozoic orogeny in Cathaysia

The aforementioned geological facts suggest that in the Early Paleozoic the Jiangnan-Cathaysia region was in a stable littoral-neritic-slope depositional environment, with no oceanic or arc-type magmatic record. Folding, uplifting and peraluminous granitic magmatism initiated at ca. 460 Ma and ended at ca. 390 Ma.

Three large-type Early Paleozoic orogenic belts were documented in the Scotland-Norway, East Greenland and Appalachians belts that resulted from the collision between Laurentia, Baltica and Avalonia blocks (Williams, 1995; Mai et al., 1988; Mckerrow et al., 2000). Other five large-scale Early Paleozoic orogenic belts are exposed in the East Australia, the southern Siberian margin, the Central-South Tianshan of NW China and the Qinling-Kunlun belt of the central China, and the South China Fold Belt. In contrast to the other orogenic belts, the Early Paleozoic South China orogenic belt has not recorded any oceanic subduction features, such as ophiolitic mélange, arc magmatic rocks, UHP-HP eclogite and HP-type granulite, as well as HP-LT blueschist. Contribution of mantle material is rare or absent in the Late Ordovician-Early Devonian peraluminous granites (460-390 Ma) which were strongly deformed and show a dispersive distribution with no regular migration of magmatism, associated with regional lower greenschist facies metamorphism. These facts comprise the distinctive characters of the South China intracontinental orogenic belt as compared to other coeval subduction-collisional orogens (Table 1).

Table 1 Comparison of geological features of the Early Paleozoic South China intracontinental orogen with typical subduction-collision-type orogenic belts

	Intracontinental-type orogen in South China	Subduction-collison-type orogens
Location	Far away from plate subduction zone and collision	Along the subduction and collision zone of convergent plate margins

	zone	
Depositional environment	Intracontinental environment, terrigenous muddy-sandy sediments with rare or no pyroclastic rocks, no deep-sea sediments, and depositional sequences with gradual transition within basins	Active continental margin setting, varied lithological features, turbidite with Bouma sequence, abrupt change of sedimentary facies within basins
Tectonic units on two sides of orogen	Having same or similar geological history	Showing quite different geological history
Trench-arc-type rocks	No	Arc magmatic rocks, SSZ-type ophiolites and accretionary complex however absence of arc magma in the Alps
UHP and HP metamorphic rocks	Occasional and small-scale occurrence of high-temperature granulite	HP-LT-type blueschist, UHP-HP -type eclogite and HP-type granulite
Magmatic rocks	Two-mica granite, muscovite granite, tourmaline and cordierite-bearing granites with syn- or post-collisional settings	Calk-alkaline volcanic rocks and intrusive rocks, I-type granite, juvenile crustal rocks like basalts, gabbros, and post-collisional peraluminous granitoids
Magma source and evolution	Significant partial melting of supra-crustal rocks with rare or no mantle input, concentrated age values, dispersive distribution with no regular migration of magmatism	Mantle-derived compositions with various degrees of crustal contamination, regular polar distribution and migration of magmatism from plate margin to inland both in composition and age, and crustal melting
Deformation and metamorphism	Widespread folding, thrusting and ductile shear zones, crustal thickening and lower to medium-grade metamorphism	Widespread folding, thrusting and ductile shearing zones, crustal thickening and lower to high-grade metamorphism
Geodynamics	Far-field effects of plate collision, leading to crustal-scale intraplate compression and shortening (e.g. Tianshan, South China)	Continental collision and subduction, resulting in underthrusting of continental crust after the closure of the oceanic basin

The Early Paleozoic orogeny of the South China Block was most likely induced by a far-field effect of a collisional event, comparable with the Cenozoic intracontinental Tianshan orogen in NW China, the Neoproterozoic-Early Paleozoic intracontinental Alice Springs orogen in central Australia (Buick et al., 2008； Raimondo et al., 2014), the Mesozoic Qinling belt (Zhang GW et al., 2013; Dong YP et al., 2011) and the intracontinental Damara orogen in Namibia in the late stage of Neoproterozoic (Nex et al., 2001). In South China, the driving force of the Early Paleozoic intracontinental orogeny was likely resulted from the collision of the South China Block with a southern continent. A collision between the main part of the South China Block and Australia, a piece of which is supposed to be located in the Hainan island, has been proposed (Xu YJ et al., 2016). However, the geological record for the Early Paleozoic arc magmatism and ophiolitic suture is missing in the Hainan island. Another possibility would be to consider that the Early Paleozoic orogeny of South China is a far-field consequence of the collision between the North Vietnam or Viet-Lao Block with a southern continent presently represented by the South Vietnam or Viet-Cambodia block (Faure et al., 2018b).

7.5 The "Late Paleozoic South China Ocean"

7.5.1 Upper Paleozoic radiolarian cherts

The Late Paleozoic geological setting of the South China Block has long been debated (Hsu et al., 1990; Zhao CH et al., 1995; Xiao and He, 2005). In the 1990's, Late Paleozoic radiolarians were reported from the Dexing-Shexian ophiolitic zone (Zhao CH et al., 1995), thus the previously defined Neoproterozic ophiolitic zone was changed into a Late Paleozoic suture zone derived from the Late Paleozoic South China Ocean (He KZ et al., 2000), which was inferred to be a branch of the Paleo-Tethys Ocean. Thus, some researchers adopted the view of a Late Paleozoic South China Ocean (Xiao and He, 2005), although others disagree (Li XH, 2000; Wang and Shu, 2001; Yang Q et al., 2005; Shu LS et al., 2006). The debates are focused on the Late Paleozoic depositional environment (Lin SF et al., 2018; Shu LS et al., 2018; Faure et al., 2018a) and the significance of the radiolarian-bearing cherts.

As marine plankton and radiolarians can live in the sea and ocean environments with different depths, and then be buried in sediments of various depths after their death and sinking. For example, the radiolarian might live in continental shelf of the East China Sea (Shu LS et al., 2006), and in shallow sea to the fjords of Norway (Caridroit M, 2012). After their death, most of the relics of radiolarians were accumulated in a shallow sea environment whereas a few may be transported to a deep-sea basin where the preservation is always more difficult because of the dissolution of the radiolarian body during transportation to the sea floor (Caridroit M, 2012). In addition, the Ce content has been proven to be useful for identifying depositional setting of radiolarian-bearing cherts and most deep-sea radiolarians display an obvious Ce negative anomaly (Shimizu and Masuda, 1977).

The Late Paleozoic radiolarian bearing cherts are widely distributed in South China. Permian radiolarian-bearing cherts have been identified in many places of the Yangtze Block. Radiolarian fossils of seven generas and sixteen species have been identified from the Lower Permian strata in the Lower Yangtze region (Yang Q et al., 2005). These chert layers are mostly black and interlayered with Permian *fusulina*-bearing limestone and arkose, suggesting that they were surely formed in a neritic environment (Yang Q et al., 2005).

Geochemical characters of cherts within the Neoproterozoic Dexing-Shexian ophiolitic mélange zone indicate that these cherts were formed in an active continental margin (Li XH, 2000; Wang and Shu, 2001). From 1998 to 2002, Yang Q et al. (2005) studied 306 chert samples from the Neoproterozoic Dexing-Shexian ophiolitic mélange zone, concluding that no radiolarians could be observed, instead, Neoproterozoic *acritarchs* were identified from 74 out of 306 samples. Given these results on cherts, we consider that the previously inferred “Late Paleozoic radiolarian-bearing cherts” could either be incorrectly identified, or they were tectonically mixed with the Neoproterozoic ophiolitic mélanges during the Triassic or younger events. The true Neoproterozoic Dexing-Shexian ophiolite mélanges do not contain any radiolarian fossil (Yang Q et al., 2005; Shu LS et al., 2006).

7.5.2 Upper Paleozoic stratigraphic sequences and depositional environment

From the Late Devonian to Middle Triassic, the Yangtze, Jiangnan and Cathaysia depositional regions became identical, characterized by unified sedimentary assemblages of limestone, bioclastic limestone interlayered with sandstone and siltstone, enriched with coal layers, marine fossils and land flora fossils (Fig. 14; Shu LS et al., 2006, 2008b). The general stratigraphic sequences and rock assemblage may be described from upper to lower as follows.

The Upper Triassic strata are composed of conglomerate, sandy conglomerate, sandstone and coal-bearing siltstone. They overlie unconformably the underlying pre-Triassic strata as shown in Pingxiang (Fig. 14). The Middle and Lower Triassic strata consist of siliceous mudstone, *ammonoid*-bearing limestone, brecciated limestones, and gypsum beds. The Upper Permian is composed arkose, plant fossils-bearing sandstone, carbonaceous mudstone interlayered with coal beds, *fusulina*-bearing limestone and marlite. The Lower Permian sequence consists of *asphaltene*-bearing limestone and dolomite, *radiolarian*-bearing banded cherts and *fusulina*-bearing limestone. The Carboniferous is a sequence of limestone, dolomitic limestone interlayered with dolomite and marlite, enriched in brachiopoda, coral and *fusulina* fossils. The Upper-Middle Devonian strata are the assemblages of conglomerate, sandstone and mudstone, enriched plant, fish and fusulina fossils and overlie unconformably the underlying pre-Devonian strata.

The aforementioned strata sequences and lithotectonic assemblages indicate that the upper Paleozoic sedimentary rocks in South China were formed in a coastal marsh-tidal and flat-shelf neritic environment (Figs. 9 and 14). They reflect a true paleogeographic evolution from the Late Devonian short-term continental onshore, via Early Carboniferous to Early Permian long-term neriticand and Middle Permian short-term uplifting and subsidence, then Early to Middle Triassic neritic-coastal environment. Finally, a Late Triassic crustal uplift took place in the whole South

China, following the end of marine setting and beginning of the lake and river delta environment as a response to the closure of the Paleo-Tethys Ocean in the Early Mesozoic. These conclusions are consistent with our field-investigations

Actually, no mappable deep-sea (>3,000 m depth) sediment existed during the Late Paleozoic to Early Mesozoic times (Shu LS et al., 2006, 2008b, 2009). The available geological data and micro-paleontological results disagree with the hypothesis of a “Late Paleozoic South China Ocean”.

7.6 Geodynamics of Mesozoic magmatism in the southeast coastal region

Undoubtedly, the Mesozoic magmatism is widespread in the southeast China coastal region (Fig. 16) with ages ranging from the Late Triassic to Cretaceous and up to ~30-40% of the exposure cropping out over 127,000 km^2 (Zhou XM et al., 2006). Several models have been proposed to explain the geodynamic cause of this general Mesozoic magmatism, essentially based on petrological, geochronological and geochemical studies (e.g. Hsu et al., 1990; Zhou and Li., 2000; Li and Li, 2007; Chen CH et al., 2008; Faure et al., 2016a, Chu et al, 2019). Nevertheless, each of them presents some weaknesses on several fundamental questions, such as the petrogenesis and related regional tectonic setting of the magmatism. For instance, the mantle plume model was proposed according to the circular distribution of bimodal (mafic-acidic) volcanic rocks dated at 130-120Ma and 100-90Ma, which are dominated by andesite-dacite-rhyolite suites, along with a few basaltic rocks (Xie GQ et al., 2001; Mao JW et al., 1998, 2013). However, the Late Triassic-Early Jurassic volcanism is rarely recorded in South China. Moreover, mantle plume is considered as a short duration event, usually less than 10 Ma (Campbell and Griffiths 1990). Whereas the Mesozoic magmatism in South China lasted for ~130 Ma.

Based on the gradually temporal and spatial distribution of granitoids from inland (older) to costal area (younger) as well as the rough parallel relationship between the regional NE-trending fold-fault system and continental margin, several reseachers have proposed a model of the low-angle flat slab subduction and subsequent roll back of subducting slab (Zhou and Li, 2000; Zhou XM et al., 2006; Li and Li, 2007; Jiang YH et al., 2015). However, neither reliable ophiolite, nor arc-type magmatism has been found to prove the existence of oceanic slab subduction. Moreover, numerous recent geochronological studies show that Late Jurassic plutons are widely distributed in the Southeast China region with a planar distribution in map view (Liu Q et al., 2012, Cui JJ et al., 2013, Zhang Y et al., 2015).

Given the E-W trending OIB-like mafic rock series developed from 180 to 110 Ma in the interior of the Cathaysia Block, Chen CH et al. (2008) considered that they were due to the Indosinian post-orogenic magmatism. But the Indosinian orogeny was terminated in the Late Triassic (ca. 220 Ma), much older than the Jurassic mafic rock series (ca. 175 Ma). The E-W trending magmatism during 180-160 Ma was considered as a product of intracontinental rifting (Deng P et al., 2004; Shu et al., 2009). Moreover, the Jurassic extension- or shortening-related E-W-trending faults are not observed in the magmatic zone. The large-scale extension was probably triggered by roll back of the Paleo-Pacific subduction. Another hypothesis concerns the intracontinental crustal subduction (Faure et al., 2016a). This model suggests that a Triassic oceanward continental subduction was accommodated by a large-scale décollement within the Cathaysia Block as that recognized in the Xuefeng Mts. (Chu et al., 2012a). Nevertheless, the contemporary sedimentary basins are lacking. Furthermore, the subducted cold continental crust would hinder the thermal conduction from the mantle to lower crust.

In brief, no existing model can satisfactorily explain the features of the Mesozoic magmatism, consequently the tectonic setting and geodynamics for the Mesozoic magmatism in the Southeast China region are still enigmatic. An integrated petrological, geochemical, rock magnetic and paleomagnetic study should be a good approach (Manning and Elmore, 2015; Zhang Y et al., 2018).

8. Conclusions

Synthesizing aforementioned analyses on the geological and tectonic evolution of the South China Block, the following guidelines seem to be clear.

1. The South China Block was formed by the assembly of the Yangtze and Cathaysia blocks in the Neoproterozoic. It experienced a long-term tectonic evolution, including (a) the early to middle Neoproterozoic subduction-collision (at 980-840 Ma) and rifting (at 810-760 Ma), (b) the Early Paleozoic intracontinental orogeny, granitic magmatism and migmatization (at 440-420 Ma), (c) the Early Mesozoic intracontinental reworking and granitic magmatism (at 240-220), and (d) the Late Mesozoic back-arc volcanism and magma intrusion (at 180-100 Ma). The tectonic process was constrained and affected by the closures of the Paleo-South China, Proto-Tethys, Paleo-Tethys and Paleo-Pacific oceans.

2. The Cathaysia Block has a pre-Late Tonian basement dominated by Neoproterozoic rocks. Although some Paleoproterozoic magmatic rocks are reported, the geological, paleogeographic and crustal structural features do not fit with the concept of the Cathaysia Oldland. In the 980-840 Ma period, the subduction of the Paleo-South China Ocean beneath the Yangtze Block resulted in the South China trench, volcanic arc and back-arc basin system. The collision of the Cathaysia and Yangtze blocks during 860-820 Ma yielded regional metamorphism, ductile deformation and magmatism along the southeast Yangtze margin, forming the Jiangnan Orogenic Belt. Shortly afterwards, continental rifting during 810-760 Ma occurred nearby the previous suture zone.

3. The initial formation of the Proto-South China Continent likely took place in the interval of 825-800 Ma, marked by a regional-scale anglar unconformity. During the Cryogenian to Late Ordovician interval, the Cathaysia Block was in a stable neritic to slope depositional environment, dominated by *graptolite*-bearing mudstone and sandstone sequences. In the period of 460-400 Ma, as response to the closure of the remote Proto-Tethys Ocean, intense ductile deformation and S-type granitic magmatism took place and formed the South China intracontinental orogenic belt. This orogen shows distinctive characteristics and is comparable with several

intracontinental orogens worldwide. The Early Paleozoic South China intracontinental orogeny was most likely a result of far-field effects related to a collisional event in the south of the South China Block.

4. During the Cryogenian to Middle Jurassic, neither trans-lithosphere faulting nor mantle–derived magmatism was documented. In the Early–Middle Jurassic (ca. 180-150 Ma), with the tectonic transition from the E-W-trending Paleo-Tethys regime to the NE-SW trending Paleo-Pacific one, the Southeast China region evolved into a part of the western Paleo-Pacific active continental margin. The Late Mesozoic back-arc extension with a peak age at 140-110 Ma resulted in the formation of the South China basin-and-range tectonics.

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Figure captions

Fig. 1 Simplified tectonic framework map of the South China Block

1, Dongxiang-Dexing-Shexian Neoproterzoic fault zone; 2, Songma-Ailaoshan-Jinshajiang early Mesozoic suture zone.

Fig. 2 Simplified regional geological map of South China

1, Shaoxing-Pingxiang-Longsheng fault zone; 2, Zhenghe-Dapu fault zone; 3, Dongxiang-Dexing-Shexian fault zone; 4, Ganjiang fault zone; 5, Miluo-Xiangtan fault zone; 6, Jishou-Longsheng fault zone; 7, Shitai-Jiujiang-Jishou buried fault zone; 8, Sihui-Yangchun-Wuchuan fault zone; 9, Tan-Lu fault zone.

Fig. 3 Distribution map of Neoproterozoic igneous rocks and their isotopic ages in the Jiangnan Orogenic Belt. Reference data can be found in Table S1.

Fig. 4 A comparison of crystallization ages of Neoproterozoic igneous suites from various units of South China. Reference data can be found in Table S1.

Fig. 5 The distribution map of the well-exposed Neoproterozoic unconformity in the Jiangnan Orogenic Belt

Abbreviations for names of provinces: AH, Anhui; FJ, Fujian; GD, Guangdong; GX, Guangxi; GZ, Guizhou; HB, Hubei; HN, Hunan; JS, Jiangsu; JX, Jiangxi; YN, Yunnan; ZJ, Zhejiang.

Fig. 6 Field-photographs of the well-exposed Neoproterozoic unconformity in the Jiangnan Orogenic Belt (located in Fig. 5)

Notes: 1, Lantian of Xiuning County (Southern Anhui); 2, Renjiapu of Xiushui County (Northern Jiangxi); 3, Yunxi of Linxiang City (Northern Hunan); 4, Madiyi of Yuanling County (Western Hunan); 5, Sibao of Luocheng County (Northern Guangxi); 6, Fangjingshan of Jiangkou County (Eastern Guizhou). Pt_3*lk*, Likou Group; Pt_3*sx*, Shangxi Group; Pt_3*ss*, Upper Shuangqiaoshan Group; Pt_3*xs*, Lower Shuangqiaoshan Group; Pt_3*bx*, Banxi Group; Pt_3*lj*, Lengjiaxi Group; Pt_3*d*, Danzhou Formation; Pt_3*sb*, Sibao Group; Pt_3*xj*, Xiajiang Group; Pt_3*fj*, Fanjingshan Group.

Fig. 7 Distribution map of the Upper Tonian to lower Paleozoic strata and of the early Paleozoic granitoids with isotopic data

1, Shaoxing-Pingxiang-Longsheng fault zone; 2, Zhenghe-Dapu fault zone; 3, Dongxiang-Dexing- Shexian fault zone; 4, Nanchang-Wenjiashi fault zone；The number in bracket of dating value indicates the isotopic dating method: 1, SHRIMP zircon U-Pb; 2, SIMS zircon U-Pb; 3, LA-ICPMS zircon U-Pb.

Fig. 8 Neoproterozoic lithospheric dynamic evolution model of the South China Block (non-scale for thicknesses of continental crust and lithosphere)

Fig. 9 Comparisons of the Paleozoic sedimentary rock assemblages and of the depositional environments for the lower Yangtze, the Jiangnan and the southeast China regions

Fig. 10 Comparisons of the lower Paleozoic stratigraphic sequences in the nine segments in South China

Fig. 11 Field-photographs for the lower Paleozoic sedimentary rocks and structures, indicating a coastal–neritic-bathyal depositional environment of South China

A. Lower Cambrian sandy and muddy flysch rocks; B. Ripple mark in the Lower Cambrian sandstone; C. Flute cast in the Upper Cambrian sandstone; D. Lenticular mudstone blocks in the Upper Cambrian sandstone layer; E. Cross-bedding in the Middle Ordovician sandstone; F. Big quartz sandstone block wrapped by the Upper Ordovician mudstone; G. Upper Cambrian feldspar sandstone with oblique bedding; H. Intercalated limestone layers in the Lower Cambrian sandstone. L, limestone; M, mudstone; S, Sandstone; QS, quartz sandstone.

Fig. 12 A comparison of crystallization ages of the early Paleozoic igneous suites and ages of coeval ductile deformation in the Cathaysia and Yangtze regions. Reference data can be found in Table S2.

Fig. 13 Tectonic and paleogeographic reconstruction of the South China Block from the late Neoproterozoic to the Middle Triassic (modified from Yu JH et al., 2008; Xu et al., 2016, Zhao GC et al., 2018 and Shu LS et al., 2019).

Abbreviations for microcontinental blocks: Al, Alax; Ca, Cathaysia; C-Qil, Central Qilian; IC, Indochina; NC, North China; N-Qt, North Qiangtang; Qai, Qaidam; SC, South China; Sbms, Sibumasu; S-Qt-Ls, South Qiangtang – Lhasa; Ta, Tarim; Yz, Yangtze.

Abbreviations for special tectonic units: JN, Jiangnan Orogenic Bbelt; NR, Nanhua rift basin; SM, Songma suture zone; SS, Shangdan suture zone; TS, Tianshan Orogenic Belt; WY, Wuyi-Yunkai Orogenic Belt; XF, Xuefeng Mountains; QZB, Qinzhou Bay.

Fig. 14 Upper Paleozoic to lower Mesozoic stratigraphic columns from Anhui, Zhejiang, Jiangxi, Fujian provinces of Southeast China, reflecting their sedimentary environments

Fig. 15 A comparison of crystallization ages of the early Mesozoic granitoids and ages of coeval ductile deformation in the Cathaysia and Jiangnan regions. Reference data are listed in Table S3.

Fig. 16 Simplified geological map of the Southeast China region, showing the distribution of Mesozoic-Cenozoic basins and granitic plutons

1, Shaoxing-Pingxiang-Longsheng fault zone; 2，Dongxiang-Dexing-Shexian fault zone; 3. Zhenghe-Dapu fault zone; 4, Ganjiang River fault zone; 5, Sihui-Yangchun-Wuchuan fault zone; 6, Wuzhou-Sihui buried fault zone; 7, Chalin-Guangchang buried fault zone; 8, Changle-Nanao fault zone; 9, Chenzhou-Linwu fault zone.

Fig. 17 Geological section traversing the Late Mesozoic Southeast China magmatic complex zone

Fig. 18 Field-photographs of lower Paleozoic sedimentary rocks from the Jiangnan (A-C) and Cathaysia (D-F) regions

A, Middle Ordovician limestome (Chalin of Quanzhou City); B, Lower Cambrian graphitic bearing material layers (10 km North of Qidong County); C, Lower Cambrian carbonaceous rock (Shuiche of Guanyang County); D, Cambrian sandy-muddy slate (20 km South of Qidong County); E, Lower Cambrian carbonaceous slate (12 km West of Nankang City), F, Middle Ordovician sandy slate and muddy phyllite (Chalin of Quanzhou City)

Table captions

Table S1 Summary of ages and isotopic ratios for the Neoproterozoic magmatic rocks in South China

Table S2 Summary of ages and isotopic ratios for the Early Paleozoic magmatic rocks from Jiangnan and Cathaysia regions

Table S3 Summary of ages and isotopic ratios for the Early Mesozoic magmatic rocks from Jiangnan and Cathaysia regions

Table 1 Comparison of geological features of the Early Paleozoic South China intracontinental orogen with typical subduction-collision-type orogenic belts

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.