



Pre-Neoproterozoic continental growth of the Yangtze Block: From continental rifting to subduction–accretion

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ABSTRACT

The Yangtze Block exemplifies the gradual formation of cratons since the Archean, and its pre-Neoproterozoic basement constitution needs to be clarified by a study of the combination of spatiotemporal relationship, geochemistry, and radiogenic isotopes of pre-Neoproterozoic rocks within and around the continent. It is suggested that the Yangtze Block could be divided into the north (NYB) and south (SYB) parts before the Neoproterozoic due to distinct rock configuration and tectonic evolution. The NYB consists of extensive Archean lithosphere and witnessed nascent stage (~2.0 Ga) of Columbia (Nuna)-assembly tectonics and was less involved in subsequent supercontinent breakup. It was then surrounded by a series of early Neoproterozoic (1.0–0.93 Ga) intra-oceanic accretionary system, which facilitated the tectonic emplacement of ~1.1–0.95 Ga ophiolite suites and the accretion of allochthonous terranes. The SYB, as well as the south Qinling Orogenic Belt and western Cathaysia Block, in part or in whole, may serve as one of the accretionary terranes around the NYB. These accreted terranes were generally involved in the extensional tectonics in response to the breakup of Columbia supercontinent, with the post-1.5 Ga rift locally evolved to seafloor spreading as evidenced by the occurrences of relic oceanic lithosphere in some areas. We highlight the progressive continental growth from a large-scale, long-term continental rifting during Columbia breakup to subsequent Rodinia-assembly-related tectonics around the NYB. The former stage is characterized by the consuming of ancient continental lithosphere and creation of thick, juvenile volcanic-sedimentary rocks within continents (failed rift) or along passive margins (successful rift). In contrast, the latter stage may have driven the subduction–accretion of allochthonous rift terranes around the NYB and promoted the emplacement of circum-NYB 1.1–0.9 Ga ophiolite suites and island-arc units. We suggest that the significant mantle input in both extension and convergence stages and the successive lateral accretion of terranes may have contributed to the continental growth and reshaping of the Yangtze Block.

1. Introduction

A craton is commonly the rigid ancient nucleus of a particular continent and is composed of old, strong, thick, and stable remnants of ancient crystalline basement that survived from long-term amalgamation and breakup of (super)continents (Jordan, 1975; Pollack, 1986; Hirth et al., 2000; James and Fouch, 2002; Kamber and Tomlinson, 2019). Cratons stabilized mainly in late Archean (Rogers and Santosh, 2003; Zhai, 2011; Pehrsson et al., 2015) and are generally subjected to little deformation, overlain by sediments, and surrounded by accreted terranes and orogenic belts (Griffin et al., 2003; Lee et al., 2011; Zhai, 2011). After the craton stabilization, the growth and reshaping of

continents continuously operated throughout the Earth's history, with the former process being determined by the balance between mantle input and recycling of crust into the mantle, while the latter defined by continental rifting and accretionary orogenesis.

The Yangtze Block in East Asia has long been regarded as a craton with an Archean basement (Gao et al., 1999; Zheng et al., 2006; Guo et al., 2015; Zhang et al., 2020) and thick lithosphere (An and Shi, 2006). Abundant mid-Neoproterozoic igneous and sedimentary rocks are distributed along its periphery (Zhao et al., 2011; Wang et al., 2014), and in particular those in the southeastern margin may record the amalgamation with the Cathaysia Block along the Jiangnan Orogen (e. g., Wang et al., 2007, 2014; Zhao and Cawood, 2012) (Fig. 1a). It is

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noted that the Mesozoic collision between the North China Craton and the Yangtze Block significantly reshaped the northern margin of the Yangtze Block (Dong and Santosh, 2016; Liu et al., 2016), and the Neoproterozoic to Phanerozoic thick sediment coverage and multi-stage overprinting (An and Shi, 2006) have restricted access to the Archean–Mesoproterozoic basement of the Yangtze Block (Fig. 1b). The rock distribution and continental evolution of the Yangtze Block prior to the Neoproterozoic are hence poorly constrained. Here, in combination of spatiotemporal relationships, geochemistry, and radiogenic isotopes of the pre-Neoproterozoic rocks within and around the Yangtze Block, we infer the pre-Neoproterozoic Yangtze Block was not a unified block, and the early Neoproterozoic accretionary orogenesis has played a crucial role in continental amalgamation and growth of the Yangtze Block.

2. Compiled data sources, sample descriptions, and new analytical results

To explore the pre-Neoproterozoic rock configuration and continent evolution, we made a compilation of published zircon U–Pb–Hf isotopes and whole-rock elemental and isotopic data for the pre-Neoproterozoic rocks throughout the Yangtze Block, with some additional references to the pre-Neoproterozoic rocks from the western Cathaysia Block and the Qinling Orogenic Belt. Additionally, we present new zircon U–Pb–Hf results from the metasedimentary rocks of the Huodiya Group and the Baiyu granites in northwestern Yangtze Block. The brief introduction of the pre-Neoproterozoic rock units and early Neoproterozoic rocks within or around the Yangtze Block are given in the Fig. 1b and

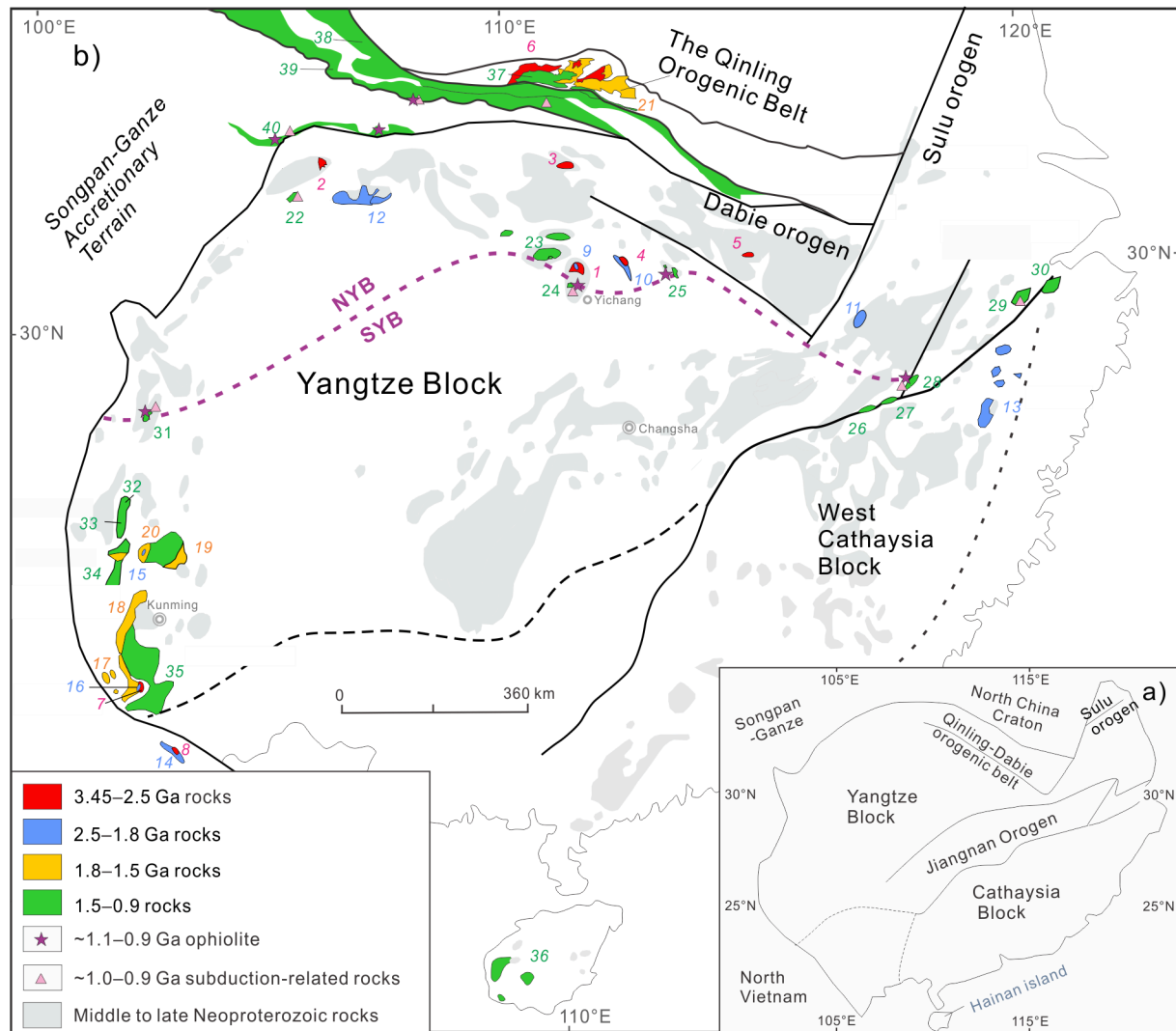


Fig. 1. Simplified geological maps showing the distribution of the pre-Neoproterozoic rocks around the South China Block. (a) Sketch tectonic map showing the division of the South China Block and the location of the Yangtze Block; (b) Pre-Neoproterozoic rock distribution within the Yangtze and western Cathaysia blocks and the Qinling Orogenic Belt. The Yangtze Block was divided into NYB and SYB in this study. Major geological units are marked with numbers. Archean (3.45–2.5 Ga) basements/rocks include: 1– Kongling Complex; 2– Yudongzi Complex; 3– Douling Complex; 4– Zhongxiang Complex and Yangpo Group; 5– Huangtuling Complex; 6– Taihua Group; 7– Cuoque Complex (Archean rocks); 8– Phan Si Pan Complex (Archean rocks). Paleoproterozoic (2.5–1.8 Ga) rocks include: 9– Quanyishang granite; 10– Lengshui Complex and Huashanguan granite; 11– Dongling Complex; 12– Baiyu granite, Houhe Complex and Mawozi Formation; 13– Badu, Chencai and Mayuan Complexes; 14– North Vietnam granite; 15– ~2.3 Ga dolerite; 16– Cuoque 2.36–2.22 Ga granites. Paleo- to Meso- Proterozoic (1.8–1.5 Ga) rocks include: 17– Dahongshan Group; 18– Haizi igneous rock; 19– Dongchuan Group; 20– Hekou Group and Tong’an Formation; 21– Xiong’er Group, Longwangzhuang and Mapin granites. Meso- to early Neoproterozoic (1.5–0.9 Ga) rocks include: 22– Tongmuliang Group; 23– Shennongjia and Macaoyuan groups; 24– Miaowan Ophiolite; 25– Dagushi Group and Huashan Ophiolite; 26– Tieshajie volcanic rock; 27– Tianli Schist; 28– Northeastern Jiangxi Ophiolite; 29– Shuangxiwu Group; 30– Chencai Group; 31– Shimian Ophiolite; 32– Dengxiangying Group; 33– Huili Group, Caiziyuan Ophiolite; 34– Julin Group; 35– Kunyang Group; 36– Baoban Complex, Shilu Group and Shihuiding Formation; 37– Taowan and Guandaokou Groups; 38– Kuanping Group (including Kuanping Ophiolite); 39– Qinling Group and Songshugou Ophiolite; 40– Sanchazi Ophiolite (and island arc rocks).

Supplementary Information. The compiled zircon results from the pre-Neoproterozoic sedimentary sequences and igneous rocks are given in the Supplementary Table S1 and S2. Age data for the main pre-Neoproterozoic strata and associated intrusive bodies in the Yangtze Block are shown in the Supplementary Figs. S1 and S2. The sample locations, zircon U–Pb–Hf isotopic results and CL images, field and microscope observations and analytical procedures of this study are provided in the Supplementary Fig. S5b, Table S3 and Supplementary Information. Compiled whole rock elements of the 1.8–0.9 Ga mafic rocks and ophiolite suites (not all) are given in the Supplementary Table S4. Zircon $\epsilon_{\text{Hf}}(t)$ values and whole-rock $\epsilon_{\text{Nd}}(t)$ values of the Mesoproterozoic to early Neoproterozoic ophiolite suites and island-arc rocks are provided in the Supplementary Table S5.

3. Different pre-Neoproterozoic evolution processes between the north (NYB) and south (SYB) parts of the Yangtze Block

3.1. Extensive Archean basement in NYB but lack in SYB

According to the compiled data, Archean rocks were extensively reported within the NYB from west to east (present coordinate) (Fig. 1b). Paleoproterozoic (2.03–1.95 Ga) metamorphism remarkably behaved in the NYB (Zhang et al., 2006; Wu et al., 2008; Yin et al., 2013) in response to the assembly of two or more Archean terranes (Wang et al., 2018a). The occurrence of 1.85 Ga A-type granites indicates tectonic extension and craton stabilization before 1.85 Ga (Peng et al., 2009). The 2.00–1.93 Ga syn- and post-collisional granitoids and the subsequent A-

type granites throughout the NYB all exhibit strong geochemical evidence of the existence of Archean lithosphere (Fig. 2a, b). The mid-Neoproterozoic granitoids that intruded into the Kongling Complex also show clear Archean source affinity by zircon Hf isotopes (Zhang et al., 2008; Zhao et al., 2013). In addition, several Cenozoic basalts exposed in the NYB territory captured Archean xenoliths (Zhang, 2004). Lithosphere in north part of Yangtze Block is thick at present (~170 km) (An and Shi, 2006). The above lines of evidence suggest that the NYB has an extensive thick Archean basement.

On the contrary, few Archean rock outcrops have been reported in the SYB, with the only occurrences in the Cuoke and Phan Si Pan areas of the southwestern margin of the SYB (Lan et al., 2001; Nam et al., 2003; Zhao et al., 2020). A few early Paleoproterozoic (2.36–2.22 Ga) granitoids in the SYB (Cui et al., 2020) documented the reworking of an Archean crustal source by zircon Hf isotopes (Fig. 2a, b). However, abundant ca. 1.8–0.8 Ga igneous rocks within the SYB uniformly exhibit dominant derivations from post-Archean sources in terms of zircon Hf isotopes (Fig. 2a; Cai et al., 2015; Wang et al., 2016a). Similarly, the proportion of Archean detrital zircon from the late Mesoproterozoic (1.1–1.0 Ga) strata within the SYB is only ~3% (n = 548) from the SYB, in comparison to that of ~38% (n = 723) around the NYB (Supplementary Table S1; Fig. 3a, b), implying a scarce Archean basement in the SYB relative to the NYB during the late Mesoproterozoic. From detrital zircon Hf isotopic perspective (Fig. 4d), ~90% (468 in 519) Paleoproterozoic zircon (2.5–1.6 Ga) but ~3% (3 in 109) Mesoproterozoic

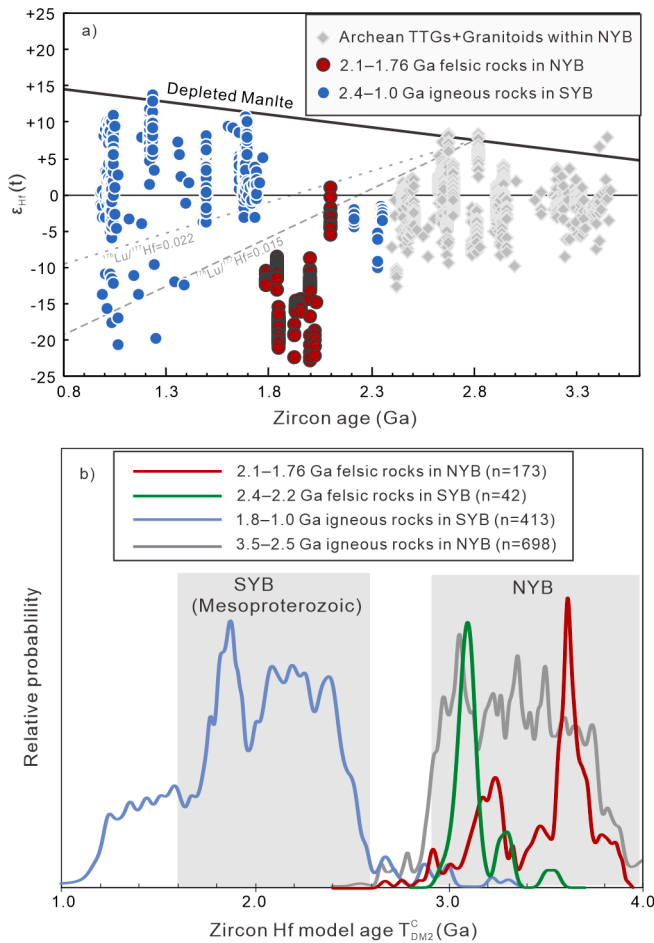


Fig. 2. Zircon U–Pb vs $\epsilon_{\text{Hf}}(t)$ (a) and relatively distribution frequency of Hf model age (b) of zircons from the Pre-Neoproterozoic igneous rocks within the NYB and SYB (data sources are given in the Supplementary Table S2).

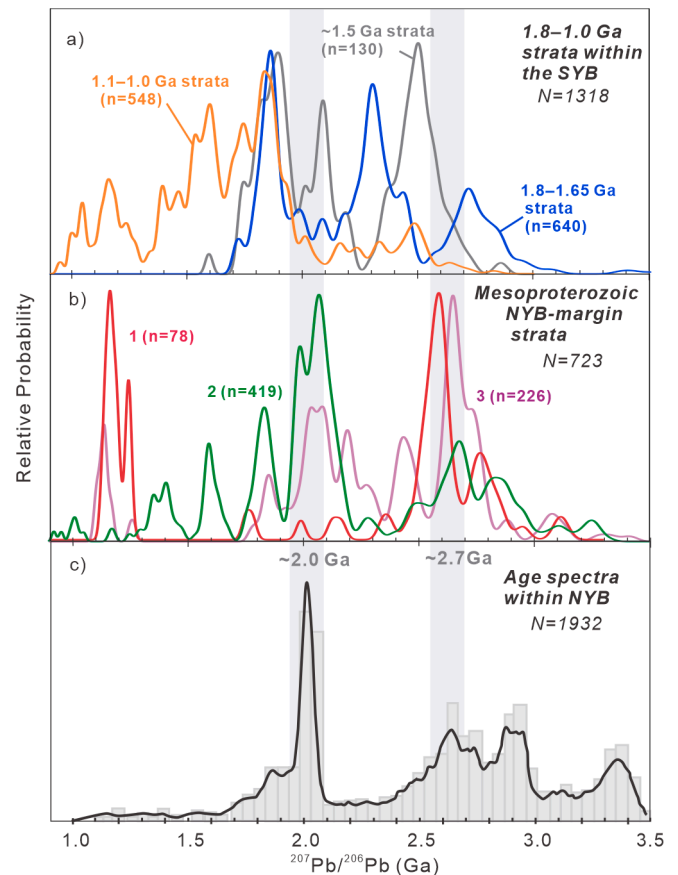


Fig. 3. Comparisons of detrital zircon age spectra from the Paleoproterozoic to Mesoproterozoic strata around the NYB and SYB. (a) Detrital zircon age spectrum from the 1.85–1.65 Ga, ~1.5 Ga and 1.1–1.0 Ga strata within the SYB. Three stages strata were divided based on their age ranges (Fig. S2); (b) Mesoproterozoic continental-margin strata edged the NYB (1–Macaoyuan Group; 2–Shennongjia Group; 3–Dagushi Group); (c) Histogram of U–Pb ages within the NYB (modified after Li et al., 2016a). Data sources are given in the Supplementary Table S1.

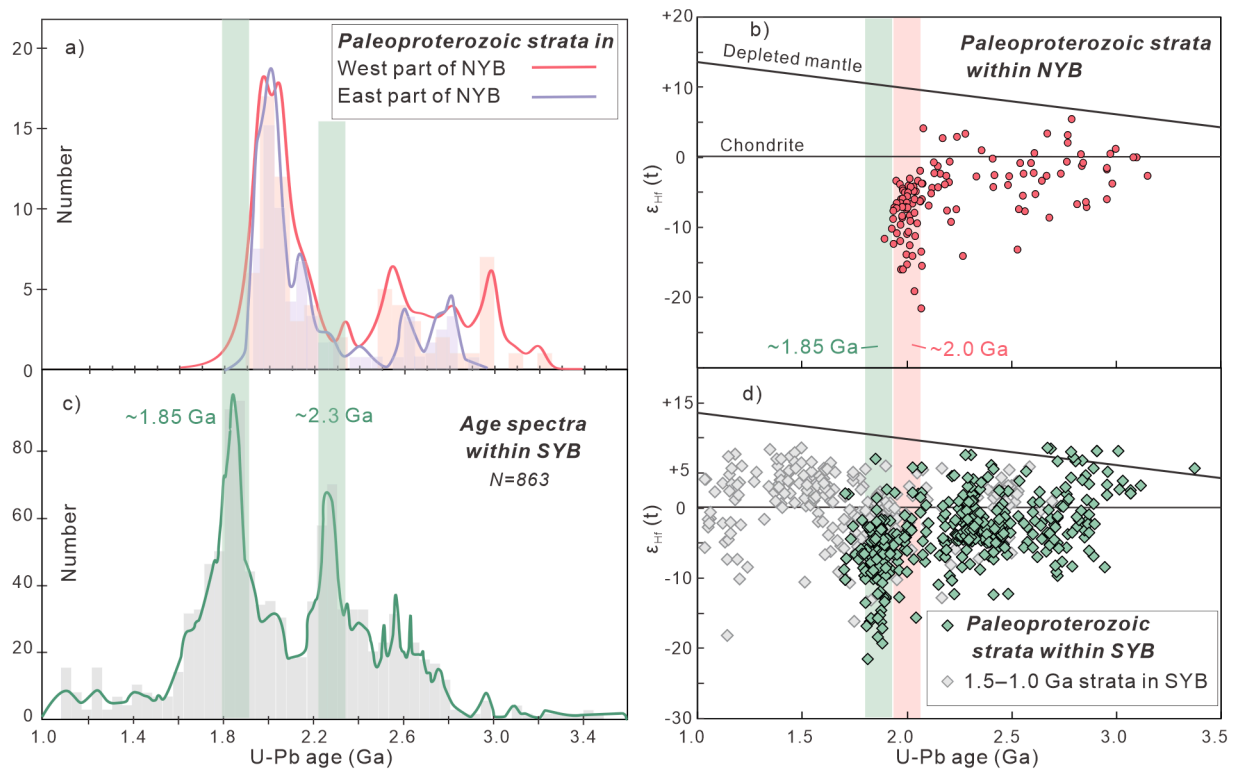


Fig. 4. U-Pb age frequency and $\epsilon_{\text{Hf}}(t)$ -age distribution of detrital zircons from the Pre-Neoproterozoic strata within the NYB and SYB. (a) Detrital zircon U-Pb age spectra of the Paleoproterozoic strata in western NYB (conglomerate in Mawozi Formation; this study) and eastern NYB (2.1–2.0 Ga metapelite in Kongling Complex; Li et al., 2016a); (b) $\epsilon_{\text{Hf}}(t)$ -age distribution of zircon from the NYB Paleoproterozoic strata; (c) Age spectra of the SYB (modified after Li et al., 2016a); (d) $\epsilon_{\text{Hf}}(t)$ -age distribution of detrital zircon from the Paleoproterozoic (1.85–1.65 Ga) and 1.5–1.0 Ga strata within the SYB. (Data sources are given in the Supplementary Tables S1 and S3).

zircon (1.6–1.0 Ga) in the 1.8–1.0 Ga strata have Archean (>2.5 Ga) model ages (Table S1). That hints that the Archean lithosphere within the SYB might have been largely consumed during the Paleoproterozoic so that there was a lack of Archean component within the SYB after Paleoproterozoic. The consumption of Archean lithosphere might have contributed to the thin lithosphere in nowadays SYB (An and Shi, 2006). In general, from both igneous and sedimentary perspectives, the post-Paleoproterozoic SYB was likely featured by the lack of Archean crust.

3.2. Distinct convergence and extension histories linked with Columbia supercontinent between the NYB and SYB

The assembly of the Columbia supercontinent occurred during the Paleoproterozoic time (Zhao et al., 2004), with three main stages at 2.20–1.95 Ga, 1.95–1.88 Ga, and 1.88–1.78 Ga behaved in different continental fragments (Pehrsson et al., 2015). After the formation of the supercontinent, slab subduction mainly occurred on its western margin till ~1.3 Ga (Condie, 2013), while the interior of the supercontinent was generally in an extension-dominated tectonic regime.

The NYB preserved comprehensive rock assemblages related to Columbia-assembly tectonics that include ~2.1 Ga subduction, ~2.0 Ga collision and subsequent post-collision extension (Zhang et al., 2006; Li et al., 2014a; Han et al., 2017, 2018). The Paleoproterozoic strata within the NYB received a large proportion of ~2.0 Ga detrital zircon grains with negative $\epsilon_{\text{Hf}}(t)$ values (Fig. 4a, b), coincident with remarkable reworking of ancient lithosphere induced by the ~2.0 Ga convergence. In contrast, no evident Columbia-assembly rock imprint has been reported yet in the SYB. Only two stages of metamorphic events at ~2.0 Ga and ~1.83 Ga are found in some zircon grains in local areas (Wang et al., 2016b; Cui et al., 2020). In addition, ~1.83 Ga magmatism may have been prevailed in the SYB, as indicated by the large proportion of ~1.83 Ga detrital zircon in the pre-Neoproterozoic strata (Fig. 3a). However,

the ~2.0 Ga magmatism seems to be weaker within the SYB as revealed by the minor ~2.0 Ga zircon proportion in the area (Fig. 3a). Furthermore, the SYB ~1.83 Ga detrital zircon predominantly have negative $\epsilon_{\text{Hf}}(t)$ values (Fig. 4d), hinting asynchronous reworking events of ancient lithosphere in the SYB (at ~1.83 Ga) from the NYB (at ~2.0 Ga).

After NYB's stabilization during the Columbia-assembly-related events, it remained stable, without extensive magmatic and craton-lithosphere reworking events until mid-Neoproterozoic (Zhang et al., 2008). The NYB was hence less involved in the extensional processes during the rifting of Columbia supercontinent. In contrast, the SYB preserved at least three episodes of transient continental rift-related magmatism (i.e., ~1.7 Ga, ~1.5 Ga and ~1.05 Ga) (Supplementary Information, Fig. S2). Late Paleoproterozoic to Mesoproterozoic multi-stage extension in the SYB drove continuous basin subsidence and gave rise to the thick (>10,000 m) sediments accommodation and extensive faults (Figs. S2 and S3). These sedimentary rocks present tight spatiotemporal relations with the rift-related igneous rocks, consistent with their deposition in rift-related setting. Therefore, from both magmatic and sedimentary perspectives, the SYB should be remarkably involved in the Columbia-breakup extension process.

In summary, the two parts of the Yangtze Block (NYB and SYB) played different roles during the assembly and breakup of the Columbia supercontinent. The NYB and SYB participated into Columbia-assembly tectonics in different major episode (~2.0 and ~1.83 Ga respectively), and then the NYB kept stable and quiet, while the SYB was significantly affected by continuous extension (failed rift?) associated with Columbia-breakup.

4. Zoned pre-Neoproterozoic basement structure of the Yangtze Block and its nearby regions

Besides the different tectonic evolution during the Paleoproterozoic

to Mesoproterozoic, the NYB and SYB were probably geographically separated during the late Mesoproterozoic as evidenced by: (1) there are large differences in terms of pre-Neoproterozoic rock configurations (including the distinct ~ 2.3 Ga magmatism in the SYB; Fig. 4c) and evolution histories linked with Columbia supercontinent; (2) The detritus of Archean basement is abundant in the NYB but lack in the SYB at late Mesoproterozoic (Fig. 3a, b); and (3) the late Mesoproterozoic strata around the NYB show obviously distinct provenance feature from the synchronous strata within SYB (Fig. 3). Nevertheless, the two parts together (or the whole Yangtze Block) were involved into nearly identical tectonic-magmatic events during the mid-Neoproterozoic era (~ 860 – 750 Ma) (Zhao et al., 2011; Zhao and Cawood, 2012). The ~ 860 Ma volcanic-sedimentary strata (i.e. the Yanbian Group) in the SYB received abundant ~ 2.0 Ga detrital zircon (Sun et al., 2009) which are featured in the NYB. Therefore, we suggest that the SYB and NYB assembled to form the whole Yangtze Block before ~ 860 Ma, and the early Neoproterozoic may be a critical period witnessing the assembly of the SYB and NYB. Above clues motivate us to (1) investigate the timing for the convergence of the whole Yangtze Block and (2) depict the outlines of pre-Neoproterozoic NYB and SYB and seek possible suture zones between them.

Ophiolite suites represent oceanic lithosphere fragment and can indicate fossil suture zones (Stern et al., 2012; Dilek and Furnes, 2014). They can be formed in forearc, backarc or MOR (mid-ocean-ridge) settings, with the former one being the easiest for tectonic emplacement (Stern et al., 2012). Both ophiolite and island arc rocks can be indicators of oceanic lithosphere occurrence and plate margin. According to available studies, at least seven suites of 1.38–0.95 Ga ophiolites and five suites of 1.0–0.93 Ga island arc rocks can be identified with relations to the assembly of the Yangtze Block (Fig. 1b; Supplementary Information). This is consistent with the significant juvenile material input and minor ancient crust reworking during the period 1.0–0.9 Ga as revealed by detrital zircon from the mid-Neoproterozoic strata in southeastern Yangtze Block (e.g., Wang et al., 2014). Some areas (southwestern margin of present Yangtze Block) of the SYB witnessed 1.05–1.02 Ga continental rift magmatism (Chen et al., 2014, 2018; Zhu et al., 2016), precluding an extensive convergence (if possible) in the whole Yangtze Block before ~ 1.02 Ga. In addition, the occurrences of 1.38–0.95 Ga ophiolites, which mostly show SSZ (supra-subduction zone)-type geochemical features, cannot necessarily prove the 1.38–0.95 Ga plate subduction because: (1) ophiolite suites originally formed in subduction-related and subduction-unrelated settings could show similar lithological assemblage and geochemistry, although sometimes the subduction-related ophiolite has larger variability in geochemistry due to the contribution of subducted slab material (Dilek and Furnes, 2014); (2) subduction-unrelated ophiolite suites could be affected by later subduction process during its tectonic emplacement and hence exhibits SSZ-type geochemistry (Wang et al., 2016c); and (3) one suite of ophiolite could contain two successive sequences with tightly evolutionary relationship, such as early-stage MOR-ophiolite derived by seafloor spreading and late-stage forearc-ophiolite derived by slab subduction (Stern et al., 2012). We hence suggest that the widespread convergent processes within or around the Yangtze Block may have initiated at early Neoproterozoic. The initiation timing and duration of subduction could be variable in different areas. Subduction may occur locally, but was not extensively before 1.0 Ga.

The tectonic emplacement of the 1.1–0.95 Ga ophiolites, irrespective of their formation settings, was tightly associated with the subsequent early Neoproterozoic intra-oceanic subduction (Deng et al., 2017; Sun et al., 2018; Wu et al., 2019), with some of them (i.e., Shimian and Miaowan ophiolites) even being intruded by 1.0–0.93 Ga arc rocks (Deng et al., 2017; Hu et al., 2017). We suggest the discontinuously distributed 1.1–0.93 Ga ophiolite suites and island-arc rocks could roughly depict the continental margin of the NYB. Recent studies on the Sulu Orogen (Fig. 1b) identified Yangtze-affinity Eoarchean (~ 3.7 Ga) crustal remnant (Zhou et al., 2020). This finding may hint the NYB could

extend to the northeastern part of the Sulu Orogen. Juxtaposition of 1.1–0.93 Ga ophiolites and island arcs edged the NYB hints accretion of continental fragments and potential circum-NYB intra-oceanic accretionary orogenesis. The NYB was once (partly) surrounded by late Mesoproterozoic to early Neoproterozoic oceanic crust. The Mesoproterozoic strata (i.e., Shennongjia, Macaoyuan and Dagushi Groups) with stable passive continental margin features (Wang et al., 2013; Li et al., 2016b) developed along the continental margin of the NYB, and they received abundant ~ 2.0 Ga and 2.7–2.6 Ga detrital zircons which are featured in the NYB (Fig. 3b, c). In this regard, the continental fragments surrounding the intra-oceanic subduction zones, including the SYB, western Cathaysia Block, the south Qinling Orogenic Belt, in part or in whole, could serve as accretionary terranes. Of them, the western Cathaysia Block and south Qinling Orogenic Belt have rare pre-Neoproterozoic basement outcrops. The western Cathaysia Block documented 1.89–1.88 Ga metamorphism and 1.89–1.77 Ga magmatism on its northeastern part, and ~ 1.43 Ga rift event and 1.1–1.0 Ga igneous-sedimentary rocks on its southern part (Yu et al., 2012; Li et al., 2014b; Yao et al., 2017; Zhang et al., 2018). The 1.1–1.0 Ga strata in the western Cathaysia Block may share provenance with the ~ 1.1 – 1.0 Ga strata within the SYB (Yao et al., 2017), indicating a tight paleogeographic relationship (geographically separated from NYB) during the late Mesoproterozoic. Assembly between the western Cathaysia and Yangtze blocks was thought to date from ~ 1.0 Ga (Li et al., 2007, 2014b) to ca. 820 Ma (Wang et al., 2007, 2014). The Qinling Orogenic Belt witnessed Neoproterozoic amalgamation history on the northern margin of the Yangtze Block (Dong et al., 2008), and can be divided into several tectonic units. Even through there are many uncertainties on its pre-Neoproterozoic basement constitution and evolution, some parts of the Qinling Orogenic Belt (especially for its south part) were generally thought to be involved in southward subduction (Wu et al., 2019) and accretion to the Yangtze Block during the Neoproterozoic (Dong and Santosh, 2016), as recorded by the early Neoproterozoic subduction-related rocks and metamorphism. The aforementioned information indicate that the accretionary terranes are distinct from the NYB in terms of pre-Neoproterozoic rock configuration and tectonic-magmatic processes. In general, based on the spatiotemporal relationships of pre-Neoproterozoic units and extensive intra-oceanic subduction-accretion around the NYB, we propose a zoned pre-Neoproterozoic basement model for the Yangtze Block and its nearby regions as illustrated in Fig. 5. In this model, four main pre-Neoproterozoic units can be defined. We suggest the NYB served as the center of convergence during the early Neoproterozoic and it was surrounded, from innermost to outmost, by circum-NYB continental margin, suture belt and accretionary terranes. The sedimentary rocks on the circum-NYB continental margins received much more detritus from the NYB relative to those in circum-NYB accretionary belt. And the circum-NYB suture belt is marked by early Neoproterozoic intra-oceanic subduction zone along the periphery of the NYB.

5. Continent growth of the Yangtze Block

It has been suggested that the breakup of Columbia supercontinent started as early as ~ 1.8 Ga (Senshu et al., 2009). It was marked by long-term and large-scale continental rift magmatism (Ernst and Buchan, 2001; Ernst et al., 2008). Remarkable rifting process and associated mantle-derived melt input during this period promoted extensive continental breakup, increased the amount of passive continental margins, lessened lithospheric rigidity, and caused continental expansion (Roberts, 2013; Hawkesworth et al., 2016). Continental rifts generally have two possible fates. If they fail to separate the continent, thick volcanic-sedimentary sequences and extensive faults associated with the rifting tectono-magmatic process will be left within the continent (Stein et al., 2018). Alternatively, if the rifts successfully lead to seafloor spreading and the formation of passive continental margins, rifting-related sedimentary-volcanic rocks will be developed along the newly generated

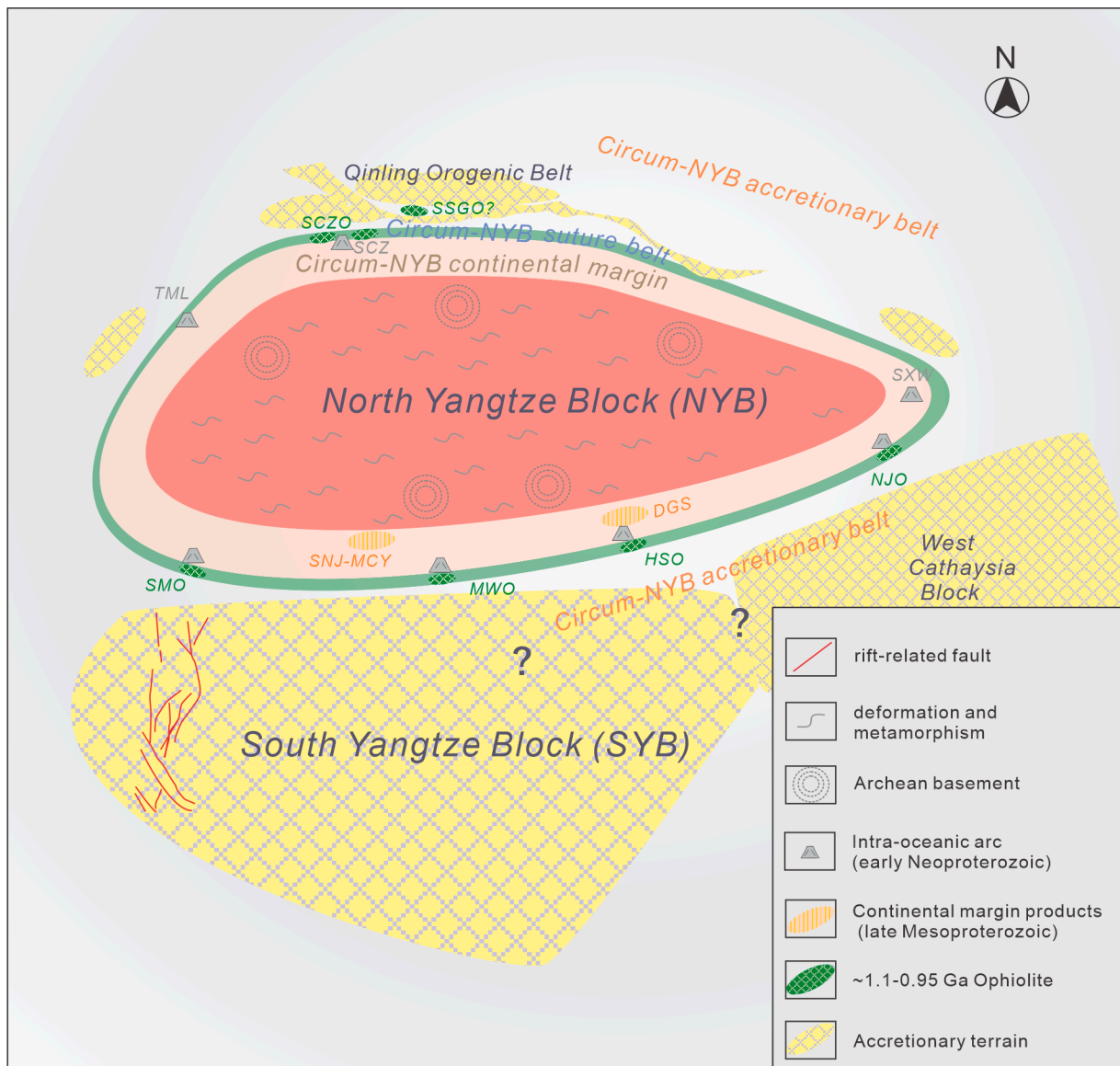


Fig. 5. Cartoon illustrating hypothetical zoned basement structure of the Yangtze Block and its nearby regions during the early Neoproterozoic. SMO– Shimian Ophiolite; MWO– Miaowan Ophiolite; HSO–Huashan Ophiolite; NJO– Northeast Jiangxi Ophiolite; SXV– Shuangxiwu volcanic rocks; TML– Tongmuliang volcanic rocks; SCZO– Sanchazi Ophiolite; SCZ– Sanchazi island arc rocks; SSGO– Songshugou Ophiolite; SNJ-MCY– Shennongjia-Macaoyuan Group; DGS– Dagushi Group.

continental margins, which are featured by thinned continental lithosphere (Stein et al., 2018). Along with continuous seafloor spreading, oceanic lithosphere keeps expanding, which could easily stimulate initial subduction once localized weakening zone of oceanic lithosphere forms (Escartín et al., 2001; Korenaga, 2007). Initial subduction of oceanic lithosphere will not only motivate addition of mantle-derived melts into forearc crust (Stern and Gerya, 2018), but also result in subsequent accretionary orogenesis (Cawood et al., 2009). The former process contributes to juvenile crust growth, while the later process plays a vital role in reshaping the continent by integrating island arcs, dismembered ophiolite suites, oceanic plateaus and allochthonous continental fragments to the edge of pre-existing continents (Cawood et al., 2009).

Columbia-breakup and subsequent Rodinia-assembly had profound effects on the Yangtze Block and its nearby regions. Episodes of rifting-related magmatism (~1.7 Ga, ~1.5 Ga, ~1.4 Ga, and ~1.05 Ga) were well documented within the terranes and rock units around the NYB (Fig. 6). The pre-1.5 Ga rifting probably failed to split the continent, but they brought about crustal thinning and subsidence and inland

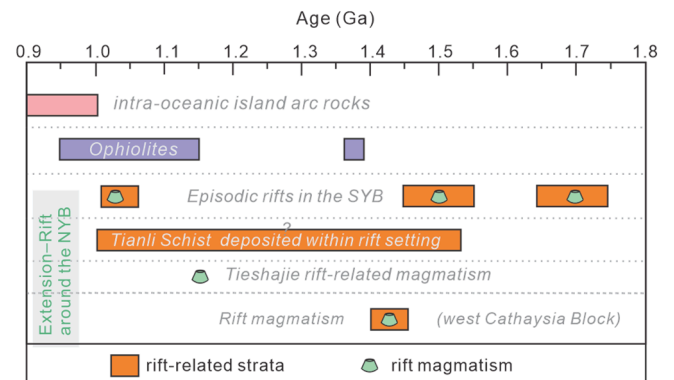


Fig. 6. Time range plot demonstrating extension-rift to intra-oceanic subduction processes around the NYB during 1.8 to 0.9 Ga.

accumulation of thick volcanic-sedimentary rocks within the SYB. In addition, the underplating of hot basaltic magma may heat and weaken the continental lithosphere (Bialas et al., 2010) during extension, paving the way for continental breakup. The post-1.5 Ga rifting activities accumulated voluminous passive-margin strata around the NYB, including the Tianli schist (1.50–1.05 Ga; Wang et al., 2018b), the upper Dongchuan Group (~1.50 Ga; Wang and Zhou, 2014), the Kunyang and Huili Group (~1.1–1.0 Ga; Sun et al., 2009), and the Dagushi and Shennongjia Group (~1.2–1.0 Ga; Wang et al., 2013; Li et al., 2016b). Combined with the occurrence of 1.38–1.0 Ga relic oceanic lithosphere, the post-1.5 Ga rifts were prone to successfully evolve to ridge spreading. The continuous Mesoproterozoic rifting process promoted the increase of passive continental margins and continental fragments (Fig. 7a). Since ~1.0 Ga, widespread slab subduction proceeded around the NYB, producing forearc ophiolite suites and intra-oceanic arcs (Fig. 7b). The continuous convergence finally resulted in the assembly of rift-related terranes and rock units, intra-oceanic arcs, oceanic plateaus and dismembered ophiolite suites to the NYB (Fig. 7c). The Yangtze Block and its nearby regions may document the progressive interconnected networks: (1) early-stage rifting weakened the continental lithosphere; (2) late-stage rifting split the continents and promoted oceanic lithosphere expanding; and (3) subsequent convergent process

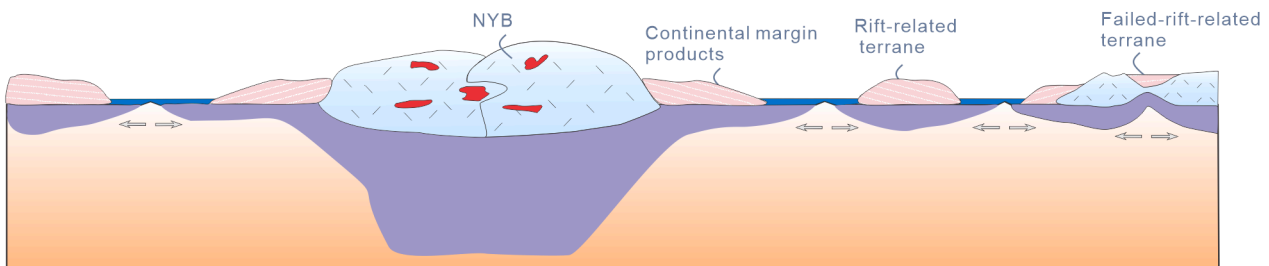
integrated continental fragments to the edge of the NYB. These processes were associated with successive accretion of juvenile crust and constituted a zoned pre-Neoproterozoic basement structure (Fig. 5) (i.e., the Archean-affinity core was bounded with Paleoproterozoic–Mesoproterozoic terranes by Neoproterozoic orogens). The continental subduction-accretion and growth pattern provided by the Yangtze Block could also help us understand why nearly every continent consists of diachronous tectonic units across the supercontinent cycles, as juxtaposition of Archean craton and Paleoproterozoic – Mesoproterozoic terranes have been observed in many continental fragments (Cawood and Korsch, 2008; Pisarevsky et al., 2008; Eglinton et al., 2013; Hoffman, 2014).

6. Yangtze Block in Rodinia supercontinent

The position of the Yangtze Block in Rodinia jigsaw-puzzle is debated with two main viewpoints proposed: (1) it was encompassed by east Antarctica, north and south Australian cratons, western Laurentia and Tasmania (Li et al., 2008; Yao et al., 2017); and (2) it was located on the northwestern margin of Rodinia and geographically close to northern India and western Australia (Yu et al., 2008; Cawood et al., 2013, 2018). Since we have divided pre-Neoproterozoic Yangtze Block into the NYB

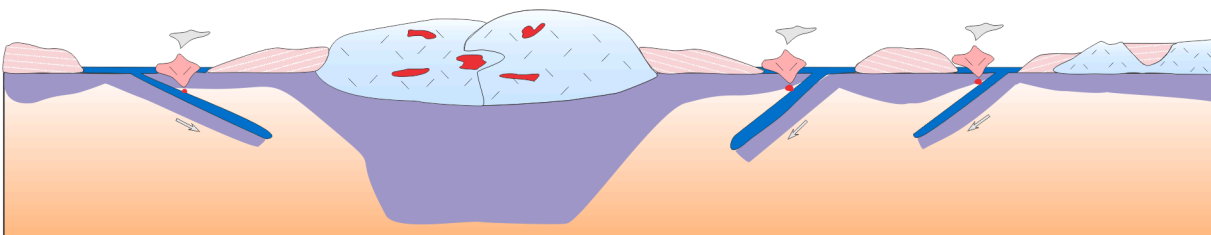
a) Late Paleoproterozoic to Mesoproterozoic:

extension–rift tectonics around NYB (possibly local subduction)



b) Early Neoproterozoic:

widespread intra-oceanic subduction



c) Early Neoproterozoic:

terrane accretion, island arcs+ophiolites emplacement

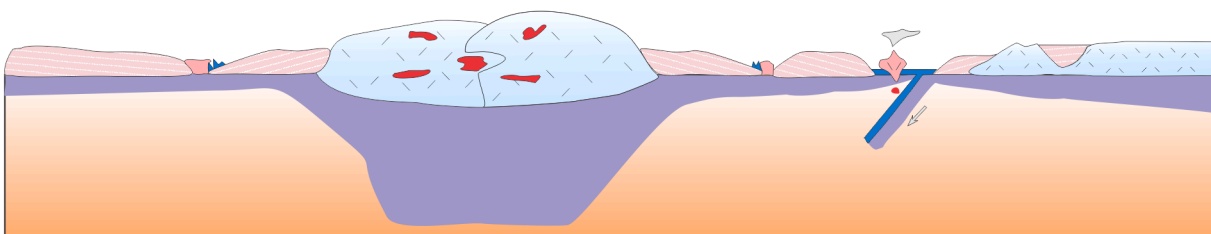


Fig. 7. A cartoon model illustrating the pre-Neoproterozoic growth and reshaping of the Yangtze Block (not to scale). This cartoon illustrated Paleoproterozoic to Mesoproterozoic extension – rift and early Neoproterozoic accretion-subduction processes mainly occurred around the NYB. The NYB had thick and stable lithosphere and was surrounded by accretionary terranes (including the SYB) during late Mesoproterozoic to early Neoproterozoic.

and SYB in this study, this issue deserves to be revisited.

In this study, we suggest the Yangtze Block and its nearby regions were widely involved in Rodinia-assembly tectonics since ~1.0 Ga. During 1.8–1.0 Ga, the SYB suffered at least three stages of extension–rift tectonics while the NYB mainly kept stable and quiet. That means neither the NYB nor the SYB had been involved in the evident 1.8–1.0 Ga convergent orogenesis as seen other places of the Rodinia supercontinent: (1) the junction area of Amazonia, Baltica and South-eastern Laurentia (Johansson, 2009), (2) interior Australia (Cawood and Korsch, 2008), and (3) the Central Indian Tectonic Zone within India (Bhowmik et al., 2012) (Fig. 8). These 1.8–1.0 Ga tectonism zones might be largely distributed in the interior of the Rodinia supercontinent and should be far from the NYB and SYB. Combined with geological, geochemical, geochronological, paleomagnetic evidence as suggested by Cawood et al. (2013,2018), we prefer a marginal position for the Yangtze Block and its nearby regions in Rodinia, close to western Australia and northeast India. At ~1.0 Ga, circum-NYB continental margins turned to be active (Fig. 8), and the SYB, as well as other continental fragments that were located at Rodinia margins and around the NYB, started to accrete onto the NYB. The northern and western margins of the NYB, kept active till at least the mid-Neoproterozoic, producing the Panxi-Hannan arc belt (Zhao et al., 2011, 2018).

7. Additional information

In this study, we didn't use zircon xenocrysts to trace Archean

basement and didn't take geophysical data to assist our division. Zircon xenocrysts captured by younger igneous rocks cannot be directly linked to the existence of Archean basement because they could be contaminated from (meta-)sedimentary wall rocks that have experienced multiple recycling with provenance from inland or extraneous continents. Therefore, tracing Archean crust by identifying Archean zircon xenocryst has large uncertainty if the source is loosely constrained. Similarly, geophysical data for present continents cannot give accurate constraints on ancient plate boundaries and tectonic events except for some certain circumstances. The investigated Yangtze Block underwent multi-stage tectonic overlapping since Archean era and thus it is difficult to place constraints on the ~1.0 Ga boundary between NYB and SYB by geophysical data. As far as we know, the available geophysical observations on the Yangtze Block do not conflict with our division. For example, the crystalline basement beneath the Sichuan basin was divided into western and eastern parts along the Huayin–Chongqing line (Fig. S5) according to their diversity of the middle-lower crustal gravity and aeromagnetic anomalies (Xiong et al., 2015, 2016). Peculiarly, a new deep seismic reflection profile conducted in the eastern Sichuan fold belt identified a frozen subduction zone within the Sichuan basin, which was suspected to be associated to arc-continent collision during Paleoproterozoic (Xiong et al., 2016). Another geophysical work identified an abrupt Moho step along western Hubei provinces (Fig. S5; Huang et al., 2014), which was suggested to be ~2.0 Ga fossil boundary between eastern and western parts of Yangtze Block (Li et al., 2016a). The above two geophysical studies both advocated a possible

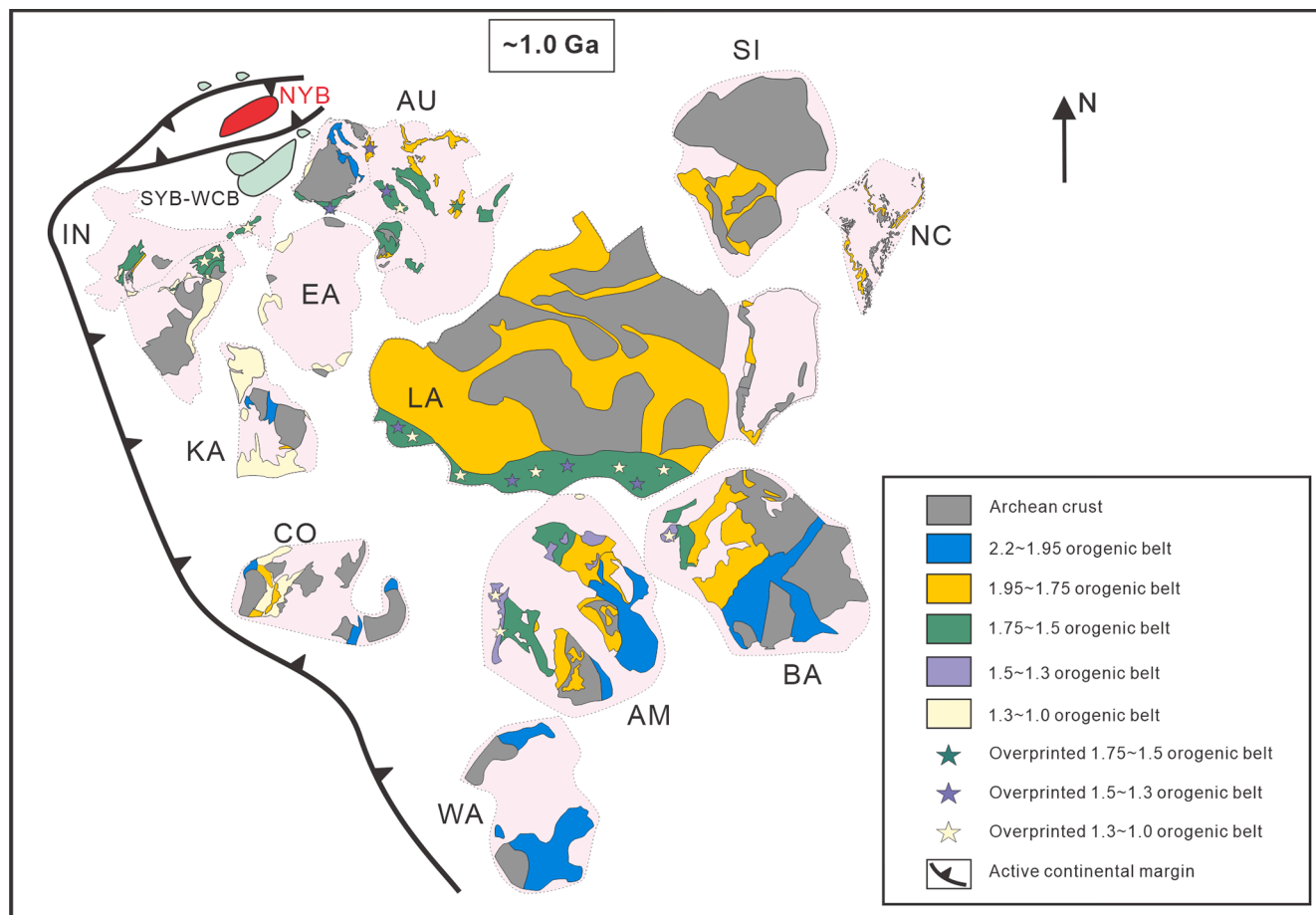


Fig. 8. Schematic paleo-geographic reconstructions showing the position of the NYB and SYB in Rodinia supercontinent reconstruction (adapted from Cawood et al., 2013, 2018). Also marked on the main continent fragments are: earlier (2.2–1.95 Ga) and later (1.95–1.75) orogenic belts related to the assembly of Columbia; 1.75–1.50 and 1.5–1.3 Ga orogenic belts during the Columbia breakup stage; 1.3–1.0 Ga orogenic belts related to the assembly of Rodinia. LA – Laurentia, BA – Baltica, AM – Amazonia, WA – West Africa, SI – Siberia, CO – Congo, NC – North China, KA – Kalahari, AU – Australia, IN – India, AU – Australia, EA – East Antarctica, and WCB – Western Cathaysia Block.

Paleoproterozoic (2.0–1.9 Ga) tectonic boundary. Geophysical data in Dong et al. (2015) revealed there were large-scale and thick old sequences with folded and thrust-imblicated seismic reflectors beneath southeastern Yangtze Block, which led them believe that these sequences represent buried Paleoproterozoic (2.0–1.9 Ga) orogenic terrane (Fig. S5; Dong et al., 2015). However, there is another possibility that the seismic reflectors represent the early Neoproterozoic arc terranes like the Shuangxiwu terrane in the Jiangnan orogen plus some Paleoproterozoic to Mesoproterozoic volcanic-sedimentary rocks as in SW Yangtze Block. Therefore, the thrust-imblicated structure could be induced by Neoproterozoic convergence.

8. Conclusions

Pre-Neoproterozoic Yangtze Block was not a unified block and could be divided into north (NYB) and south (SYB) parts according to their distinct pre-Neoproterozoic rock configuration and evolution histories. The NYB and SYB were geographically separated at late Mesoproterozoic, during which the NYB had thick and stable Archean lithosphere while the SYB didn't have. Terranes and rock units around the NYB were involved into Columbia-breakup extension. Subsequent circum-NYB intra-oceanic accretionary orogenesis during the early Neoproterozoic led to the successive assembly on the margins of the NYB and have contributed to the reshaping and growth of the Yangtze Block.

CRedit authorship contribution statement

Jun-Yong Li: Writing - original draft, Data curation, Methodology, Visualization. **Xiao-Lei Wang:** Supervision, Writing - review & editing, Funding acquisition, Project administration. **Di Wang:** Investigation. **De-Hong Du:** Investigation. **Jin-Hai Yu:** Resources. **Zhi-Dong Gu:** Resources. **Yu Huang:** Investigation. **Lin-Sen Li:** Investigation.

Declaration of Competing Interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.precamres.2020.106081>.

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