Revisiting Neoproterozoic tectono-magmatic evolution of the northern margin of the Yangtze Block, South China

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Abstract

The Neoproterozoic tectonics of South China is crucial for understanding its evolution history throughout the assembly and disintegration of Rodinia. Herein, we employ integrally tectono-magmatic records over the period of ~1.0-0.6 Ga from the northern Yangtze block, combining with available geochemical and geological data, to investigate the secular tectonic evolution of the craton. Early Neoproterozoic intra-oceanic subduction may have initiated at ~1.0-0.9 Ga after a long-period of late Mesoproterozoic passive margin. A flare-up of magmatism at ~900 Ma attributed to continental arc magmatism that led to increased crustal reworking during episodes of arc compression and lithospheric thickening, and subsequently enhanced juvenile mantle input during the transition to extensional back-arc rift modes. The isotope–time pattern displays cyclic trends shifting towards less radiogenic values and then progression to more radiogenic, near-depleted mantle isotope compositions, indicating alternation regimes of contractional and extensional tectonics due to repeatedly slab advancing and rollback. The occurrence of volumetrically-large radiogenic isotope-depleted calc-alkaline rocks associations, low-$\delta^{18}O$ and bimodal rocks along the Yangtze-block continental margin likely indicates rapid reworking of juvenile crust within a composite tectonic setting involving both arcs and rifts, which may maintain until the end of calc-alkaline arc magmatism at ~730-720 Ma and ultimately evolved into an anorogenic rifted passive margin setting, as revealed by the deposition of massive ~720-620 Ma syn-rift Yaolinghe-group volcanic-sedimentary sequence and intraplate-like magmatism. Collectively, prolonged (~1.0-0.7 Ga) suprasubduction-related magmatism traces accretion to the Yangtze-block margin, and thus likely indicates a paleogeographically peripheral position of South China in Rodinia.

Key words:

Accretionary orogen, Rift magmatism, Tectono-magmatic evolution, Neoproterozoic, Yangtze Block, Rodinia

1. Introduction

The South China Block, one of the largest Precambrian blocks in China, has been considered as a key element in supercontinent Rodinia (Zhao and Cawood, 2012; Zhang and Zheng, 2013a; Cawood et al., 2013). However, the configuration of Rodina remains controversial (e.g., Li et al., 2008; Evans, 2009). Much of the disagreement revolves around the paleogeographic position of South China in Rodinia and whether it occupied an internal or peripheral location within the supercontinent (Cawood et al., 2013; Li et al., 2008), or whether it was even part of Rodinia (Merdith et al., 2017). In reconstruction models favoring an internal location within Rodinia, the South China has been invoked as providing a key link between Laurentia and Australia (Missing-link, Li et al., 1995). The amalgamation of the Cathaysia and Yangtze blocks is envisaged as occurring in an late Mesoproterozoic to early Neoproterozoic Grenvillian collisional orogen (ca. 1000–890 Ma; Li et al., 2007, 2009), and is associated with the overall assembly of Laurentia and East Australia-Antarctica, resulting in an united South China Block occupying an interior position in an assembled Rodinia (Li et al., 2014). Subsequent breakout of South China from this internal location is proposed to have involved pulses of bimodal mantle plume magmatism between ~830–740 Ma and associated rift-related sedimentation (Li et al., 2003a, 2007). In contrast, in models favoring an external location for South China in Rodinia (Zhao and Cawood, 1999), assembly of the Cathaysia and Yangtze blocks occurred in an overall accretionary orogenic setting (e.g., Wang et al., 2004, 2014; Cawood et al., 2013; Yao et al., 2016). Final assembly of the Yangtze and Cathaysia blocks was not complete until around 830–810 Ma and subduction along the western margin of the Yangtze Block is inferred to have continued until at least 730 Ma (Zhou et al., 2002a,b; Zhao et al., 2011).

The two mutually exclusive models for the paleogeographic position of South China in Rodinia have opposite consequences for the Neoproterozoic geological history of South China. The former requires subduction to be completed by 890 Ma (Li et al., 2002; Li et al., 2008) or 860 Ma (Shu and Charvet, 1996) and subsequent magmatism is related to lithospheric extension associated with a mantle superplume, whereas the latter has subduction continuing until as late as 830–810 Ma on the southeastern margin of Yangtze (Wang et al., 2006, 2007b, 2016c) and 730–720 Ma on its northern to western margin (Zhou et al., 2002a,b; Dong et al., 2012). Thereby, the source nature, age, petrogenesis and tectonic setting of the early to mid-Neoproterozoic (ca. 1000–700 Ma) rocks in South China and in particular whether they formed in an accretionary orogenic setting or an anorogeinc setting are the key in constraining the role of South China in the Rodinia cycle (Zhou et al., 2002a,b; Li et al., 2003b,c; Zheng et al., 2007, 2008; Zhao et al., 2011).

In the past few decades, massive data, primarily focusing on geochronology, geochemistry and petrogenesis of the Neoproterozoic igneous and sedimentary rocks in South China, have been published. In recent years, many new data have been available because of the development of in-situ analytical techniques. Despite the numerous studies, the above issues continue to be debated. One of the most important reason is the geochemical ambiguities, and thus allows for multiple non-unique tectonic interpretations. More importantly, a critical evaluation and integration of all available geological information, including paleomagnetism, magmatism, metamorphism, lithostratigraphy and sedimentary provenance, remains inadequate.

The northern Yangtze is a key area that preserves continuous tectono-magmatic records including varying lithotypes with ages spanning ~1000-600 Ma, and thus is ideal for determining and clarifying the secular evolution of South China during Neoproterozoic. Herein, we mainly employ published whole-rock chemistry, magmatic/detrital zircon U-Pb ages and Hf-O isotopes from both the igneous rocks and sedimentary rocks from the northern Yangtze craton, and integrate available regional metamorphism, tectono-stratigraphy and sedimentary provenance information. The aim of this study is to explain the petrogenesis and tectonics of magmatism on a large-scale time period rather than a specific individual pluton, or we may lose the big picture. We finally outlined a revisited tectonic model and highlight four tectonic stages: 1) intra-oceanic arc (~1000-900 Ma), 2) subsequent flare-up of active continental margin arc magmatism and arc accretion (~890-830 Ma), 3) coexisting of continental arc and extensional intra-arc rift setting (~830?-730 Ma), and 4) rifted passive margin (~720-620 Ma). The paleogeographic position of South China in Rodinia was also addressed.

2. Geological characteristics of the northern Yangtze

To fully address the geological characteristics of the Neoproterozoic rocks and geological framework in the northern margin of the craton, we made a compilation of published detrital zircon U-Pb-Lu-Hf isotopes of sedimentary rocks, magmatic zircon U-Pb-Hf-O isotopes, and whole-rock chemistry of igneous rocks (except those from the Dabie orogen where their Neoproterozoic protoliths suffered Triassic high-grade metamorphism). To allow identification, we provide, where given in Supplementary Table S1-S5, original sample number, rock type, geologic unit, and location description. We revalued some samples important to our interpretation; this was done in particular for Chinese language papers, in cases of incomplete presentation (e.g., emphasis on a specific age group), or when we chose to highlight particular aspects of the data that were not the focus of the original publication. In the following, we describe the Neoproterozoic blocks/units/complexes identified in the northern margin of the craton from west to east (Fig. 1), and provide an assessment of their tectono-stratigraphy and magmatic-metamorphic evolution based on the integrated dataset.

2.1 Bikou block and Mian-Lue complex

The oldest crystalline basement (termed Yudongzi complex) exposes on the northeastern edge of the Bikou block (Fig. 1b), consisting of ~2.8-2.5 Ga TTG gneiss, granitic gneiss, amphibolite, chlorite schist, magnetite quartzite and has undergone ~2.48, 1.85 Ga regional metamorphism (Qin et al., 1992; Zhang et al., 2001; Zhang et al., 2010; Zhou et al., 2018a; Zhang et al. 2020; Hui et al., 2017; Hui, 2021). The Bikou block comprises the Bikou and the Hengdan Groups and a series of intrusive rocks. The Bikou Group is a volcano-sedimentary unit dominated by both arc-related and intraplate-like spilite, basalt, basaltic andesite, dacite, and rhyolite (Zhao et al., 1990; Yan et al., 2004a; Wang et al., 2008; Bader et al., 2013; Wu et al., 2019b). Intrusive equivalents comprise a series of gabbro, diorite, granodiorite and quartz monzonite that are linearly distributed along the NE-SW trending fault in the eastern part of the Bikou block as lenses (Lai et al., 2007; Xiao et al., 2007; Ye et al., 2009; Wang et al., 2012a; Gong et al., 2013; Ping et al., 2014; Hui et al., 2021), consistent with the main structural stress direction (e.g., Pei, 1992). The Hengdan Group is a typical suite of bathyal abysmal, pelagic to turbiditic, coarsening-upward (gravity-flow) flysch sequence, consisting mainly of coarse-grained tuffaceous greywacke and sandstone, with a small amount of phyllite and mud slate interbedded. These sequences are generally weakly metamorphosed and still retain primary sedimentary structures. Stratigraphic geochemical characteristics indicate that the Hengdan Group was most likely deposited in a fore-arc basin (e.g., Druschke et al., 2006). New detrital zircon U-Pb data constrain the maximum depositional age of the Hengdan Group was at ca. 720 Ma (Gao et al., 2020; Hui et al., 2020b). The youngest rocks in the Bikou block belong to a mafic dike swarm (~689 Ma; Yan et al., 2004a), which probably formed in a rifted passive margin setting.

The Mian-Lue complex is situated at the northern edge of the Bikou block (Fig. 1b), composed predominantly of nappes with minor outcrops of ophiolitic blocks that consists of low-grade serpentinized harzburgite and minor dunite, amphibolite, gabbro, metabasalt, basaltic andesite, and andesite, which shows multiple strongly ductile shear deformation (Dong et al., 2011b). The ultramafic-mafic blocks, together with marble, phyllite, schist and early Carboniferous radiolarian-bearing chert were termed as the "Mianlue mélange", which has been posited as a potential Phanerozoic suture zone traversing the entire northern margin of the Yangtze craton based on the conjectured existence of a Devonian-Permian "Mian-Lue ocean" (e.g., Meng and Zhang, 1999, 2000; Lai et al., 2008). The primary evidence in support of this hypothesis is the presence of ophiolitic blocks distributed along this suture zone, as well as the occurrence of Middle-Late Paleozoic sediments (Lower Carboniferous, Feng, 1996) in faulted contact with the ophiolites. The Triassic metamorphic (~220-200 Ma) overprint has been interpreted as a consequence of the closure of the

Mianlue ocean. (e.g., Li et al., 1996; Zhang et al., 2002). However, this hypothesis was questionable, given that there are no ophiolites of matching age known along the entirety of the Mian-Lue zone. Most of these metamorphic sedimentary rocks could instead represent strata that record the Middle-Late Paleozoic subsidence of the Yangtze passive margin (e.g., Ratschbacher et al., 2004). Recently zircon U-Pb dating has revealed that these ophiolitic and arc-related rocks were formed during the early Neoproterozoic (~985-800 Ma), rather than the Paleozoic (Fig. 2a-b; Zhang et al., 2005; Yan et al., 2007; Wang et al., 2011; Bader et al., 2013; Lin et al., 2013; Xu et al., 2017; Wu et al., 2019, 2021).

2.2 Micangshan-Hannan massifs

The oldest crystalline basement of the Micangshan-Hannan massifs is Paleoproterozoic Houhe complex (~2.08 Ga; Wu et al., 2012), which comprises mainly migmatites, tonalitic/trondhjemitic gneisses and minor amphibolites. The unconformably overlying Huodiya Group consists mainly of marble dominated Mawozi Formation (~1970 Ma, Li et al., 2021a) and the Shangliang Formation, and was intruded by ~1.76 Ga A-type granites (Deng et al., 2017, 2020; Li et al., 2021a). The Tiechuanshan Formation was thought to belong to the upper sequence of the Huodiya Group, and was dated at ~817 Ma (Ling et al., 2003), consistent with the regionally upper amphibolite-facies metamorphism (~815 Ma, Ling et al., 2006; Berkana et al., 2022). The Neoproterozoic Xixiang-group strata exposed in the Hannan region was originally subdivided into a hypometamorphic unit (the Baimianxia, Sanwan, and Sanhuashi formations) and a epimetamorphic unit (the Sunjiahe, Dashigou, and Sanlangpu formations) (Tao et al., 1982). Convincing geochronological data yielded the formation ages of ~950-890 Ma for the Baimianxia formation (Ling et al., 2002, 2003; Xu et al., 2009a), ~845-833 Ma for the Sunjiahe formation (Zhao et al., 2006; Xu et al., 2009b; Cui et al., 2010, 2013), ~803-776 Ma for the Dashigou formation, and ~760 Ma for the Sanlangpu formation (Xia et al., 2009; Deng et al., 2013a). Alternatively, Ling et al. (2003) proposed that the Xixiang Group could be further subdivided into the lower suite consisting of low-K basalts and basaltic andesites, and the upper suite that composed of calc-alkaline to alkaline basaltic andesites, dacites, and rhyolites. Volcanic and intrusive rocks (mostly granitoids) in the Micangshan-Hannan massifs indicate a seemingly uninterrupted magmatic activity spanning from ~0.96 to 0.72 Ga (Fig. 3b, Zhou et al., 2002a; Ling et al., 2002, 2003, 2006; Zhao et al., 2006; Zhao and Zhou, 2008, 2009a, b; Liu et al., 2009; Xia et al., 2009; Li, 2010; Geng, 2010; Zhao et al., 2010; Dong et al., 2011a, 2012; Cui et al., 2013; Ao 2015; Gan 2015; Wang et al., 2016a; Gan et al., 2017; Duan et al., 2018; Luo et al., 2018; Zhou et al., 2018b; Zhu et al., 2018; Ao et al., 2019; Wei et al., 2019; Hui et al., 2020a; Zhang et al., 2020).

2.3 South Qinling Belt

Minor gneisses and granulites within voluminous Triassic granitoids from the Foping dome record a few ~2.5 and ~1.9 Ga inheritances of the South Qinling (Li et al., 2000); Gneiss and schist of the Douling complex comprise the Neoarchean core (~2.6-2.5 Ga) of the South Qinling (R.G.S. Henan, 1989; Zhang et al. 2004a, b; Zhang et al. 2005; Hu et al., 2013; Wu et al., 2014; Nie et al., 2016). The Douling complex underwent medium-grade regional amphibolite-facies metamorphism at ~820 and ~780 Ma with peak metamorphic P-T conditions of 630-720°C and 8-11 kbar, accompanied with a clockwise P-T path (Zhang et al., 1996; Hu et al., 2013, 2019; Nie et al., 2016; He et al., 2020). Isotope characteristics and age suggest that their protoliths are juvenile arc crust that formed at ~860 Ma (He et al., 2020). The Douling complex was intruded by younger (~760-730 Ma) plutonic rocks (mostly gabbro to granodiorite) (Fig. 2c; Xue et al. 1996; Chen et al. 2006b; Zhang et al. 2018; Bai et al., 2019; Nie et al., 2019)

Early Neoproterozoic igneous rocks (~950-830 Ma; Liu, 2011; Liu et al. 2011, 2018; Yan et al. 2014; Hu et al. 2016; Zhang et al., 2016; Dong et al., 2017; Yang et al., 2020; Cai et al., 2021; Wang et al., 2021; Yang, 2021) only exposed in the northern margin of the South Qinling Belt (Fig. 2a-b). This magmatic belt stretches E-W more than 200 km (Fig. 2b), likely defining the northernmost boundary of the Yangtze craton (e.g., Mattauer et al., 1985). By comparison, the middle to late

Neoproterozoic volcano-sedimentary sequences and their intrusive equivalents are widespread throughout the South Qinling belt (Fig. 2c-d). The volcano-sedimentary sequences, mostly affected by greenschist-facies metamorphism, can be subdivided into the Wudang, Yunxi, Suixian and Yaolinghe Groups.

The Wudang Group (Fig. 1b) comprises mainly of dacitic and rhyolitic tuff with a small amount of basic and intermediate tuffs (Li and Zhu, 1930; R.G.S. Hubei, 1990). The Wudang Group that distributes in the Yunxi area was renamed as the Yunxi Group, which is also referred to those volcano-sedimentary sequences that expose in the Pingli and Niushan areas in southern Shaanxi Province (R.G.S. Shaanxi, 1989). Thus, the Wudang and Yunxi groups are actually synonymous. Geochronology suggests that the age of the Wudang and Yunxi groups span 802-725 Ma (Li et al., 2003a; Cai et al., 2006; Ling et al., 2007; Xia et al., 2008; Zhu et al., 2008; Yan et al., 2010; Liu et al., 2020). The Suixian Group located to the southern side of the Tongbai Mountains (Fig. 1b) consists mainly of schist, sandstone and meta-rhyolite layers (HGB, 1982). Geochronology reveals that the Suixian Group was deposited during ~760-720 Ma (Xue et al., 2011; Yang et al., 2016).

The Yaolinghe Group was originally named after the green-color meta-volcano-sedimentary sequences in the Yaolinghe area of the Shangnan region (Fig. 1b; Yan, 1959), but now it generally refers to those greenschist-facies volcano-sedimentary sequences that occupy a marginal location around the Wudang and Yunxi groups in the Ankang-Piling-Wudangshan domes and contact with the underlying Wudang and Yunxi groups by parallel unconformity and/or by ductile shear zone (e.g., Su et al., 2006; Ling et al., 2007). Recent studies reveals that the so-called Yaolinghe-group sequences exposed in the Zhen'an-Yaolinghe-Shangnan regions consist mainly of early Neoproterozoic (~850 Ma) arc-like tholeiitic basalt and calc-alkaline andesitic to rhyolitic rock associations with minor metasedimentary rocks (Li et al., 2003a; Bader et al., 2013; Zhu et al., 2014; Yang, 2021; Zhao et al., 2022), whereas the late Neoproterozoic Yaolinghe Group (637-641 Ma; Lan et al., 2022) outcropped in the Niushan-Pingli-Wudangshan areas comprises mainly of tholeiitic basalts with a few alkaline rhyolites (Cai et al., 2007; Ling et al., 2007, 2008; Xue, et al., 2011; Zhang et al., 2013; Huang et al., 2021a; Wu et al., 2021b; Zhao et al., 2022). A number of mafic dikes/sills and A-type granitic dikes were thought to be the intrusive equivalents of the late Neoproterozoic within-plate volcanism (Hu et al. 2002; Niu et al. 2006; Wu, et al., 2012; Wang et al., 2013, 2016b, 2017a,b; Guo et al., 2014; Shi and Deng, 2014; Zhu et al., 2015; Deng et al., 2016; Li and Zhao, 2016; Liu and Zhang, 2018; Zhang et al., 2018; Zhao and Asimow, 2018; Liu et al., 2022).

2.4 Kongling Complex and Dahongshan

The Kongling complex, exposed in the Huangling dome of the north interior of the Yangtze Block, comprises volumetrically Archean rocks (Fig. 1b; Zhang et al., 2006; Gao et al., 2011). High-grade metamorphism occurred at ~2.0 Ga (e.g., Wu et al., 2009); post-orogenic granitoids intruded at ~1.85 Ga (e.g., Peng et al., 2012a). The latest phase of magmatism in the Kongling area (termed Huangling pluton) was at ~0.8 Ga (e.g., Zhang et al., 2008).

The late Meso- to early Neoproterozoic Miaowan ophiolite (Fig. 1b) located in the southwestern Huangling dome, comprises amphibolite with pillow-lava relicts and N-MORB tholeiitic chemistry, gabbro, diabase dikes, and ultramafic rocks (dunite, harzburgite, podiform chromite) that formed at ~1.1-1.0 Ga (Peng et al., 2012b; Deng et al., 2012, 2017). Dating of detrital zircons from the sedimentary unit and intruded leucocratic veins of the Miaowan ophiolite constrains its emplacement age of ca. 900-860 Ma (Lu et al., 2020).

In the Dahongshan area, southernmost of the Tongbai Mountain (Fig. 1b), the Neoproterozoic Huashan Group is an angular unconformably overlain on the late Mesoproterozoic Dagusi Group (~1.0 Ga, Huang et al., 2021b). The older (~970-840 Ma) felsic volcanic rocks, gabbros and granitoids display arc-like geochemical affinities (Shi et al., 2007; Liao et al., 2016; Xu et al., 2016; Huang et al., 2023), whilst the younger (~830-790 Ma) volcanic rocks and intrusives are bimodality and show within-plate affinities (Deng et al., 2013c; Hu et al., 2015; Tian et al., 2017; Liu and Zhao, 2019; Li et al., 2020; Liu et al., 2021; Huang et al., 2023). Detrital zircon U-Pb dating places constraints on the maximum depositional ages of ~810-820 Ma for the Huashan Group (Yang et al., 2018; Huang et al., 2021b).

2.5 Tongbai–Hong'an–Dabie

The Tongbai-Hong'an-Dabie orogen, the northeast part of the Yangtze Craton (Fig. 1b), had been significantly reshaped due to the Mesozoic collision between the North China Craton and the South China Block, resulting in multi-stage metamorphic overprinting of the Precambrian rocks and strata. The Huangtuling complex is the oldest crystalline basement of this region. Its protolith likely crystallized at ~2.70-2.75 Ga and the granulite-facies (1.3 GPa, 850°C) overprint was at ~2.0 Ga (Chen et al., 2006a; Wu et al., 2008), which is nearly coeval with the ~2.0 Ga metamorphism in the Kongling complex. Numerous studies on the Triassic metamorphic rocks in the Dabie orogen provid an understanding of their overwhelmingly Neoproterozoic meta-igneous protoliths (Fig. 2); the protolith ages of gneisses cover ~950-582 Ma (median at ~750 Ma, Fig. 3d). Most critically, positive zircon $\varepsilon_{Hf}(t)$ and extensive low-$\delta^{18}O$ values suggest that their protoliths formed through rapid reworking of dominantly juvenile crustal materials that had undergone high-T meteoric-hydrothermal alteration (e.g., Yui et al., 1995; Ames et al., 1996; Rumble and Yui, 1998; Rumble et al., 2002; Zheng et al., 2003, 2004, 2006, 2007; Wu et al., 2007; Fu et al., 2013; He et al., 2016, 2018).

3. Discussion

3.1. Protracted subduction accretion

3.1.1 Early Neoproterozoic intra-oceanic subduction

Rarely exposed Late Mesoproterozoic rocks in South China have traditionally been thought to mark Grenvillian orogens and are widely used for reconstruction of Rodinia (e.g., Li et al., 2008). However, petrological and geochemical investigations on these rocks, such as the ca. 1020 Ma mafic dykes and A-type granitoids in the Tianbaoshan Formation of the Huili Group (Zhu et al., 2016; Wang et al., 2019a,c), the ca. 1140 Ma alkali basalts in the Laowushan Formation on the western margin of the Yangtze craton (Greentree et al., 2006), and the ca. 1159 Ma Tieshajie bimodal volcanic rocks (Li et al., 2013b) on the southeastern margin of the craton, indicate formation in a rifting setting. Additionally, detrital zircon U-Pb-Hf-O isotopes and stratigraphical studies on the late Mesoproterozoic sedimentary sequences on the peripheries of the craton, such as the Kunyang, Huili and Julin Groups in the western margin, and the Shennongjia and Dagushi groups in the northern margin (e.g., Sun et al., 2009; Qiu et al., 2011; Li et al., 2013a; Du et al., 2016), suggest a stable passive continental margin setting, arguing against existence of the so-called Grenvillian collisional orogen in South China.

Nevertheless, stratigraphical and provenance studies on the Huili and Julin sequences also imply a transition from a passive margin to a convergent continental margin setting (e.g., Sun et al., 2022), which is consistent with the observations of fold deformations developed in the late Mesoproterozoic Dagushi Group and the overlying Huashan Group in the Dahongshan area. These fold deformations are interpreted to be attributed to early Neoproterozoic subduction-related tectonic compression events (Huang et al., 2021b). Although how the tectonic switching from the late Mesoproterozoic rifted passive margin to the early Neoproterozoic convergent active continental margin is still controversial, the occurrence of ~1.0-0.9 Ga arc rocks and associated ophiolites within and/or around the craton indicates the remnants of fossil subducted oceanic lithosphere of the circum-Yangtze subduction (e.g., Deng et al., 2012, 2017; Hu et al., 2017). To date, chronology suggests the ages of intra-oceanic arc magmatism range from ~985 to 900 Ma (e.g., Li et al., 2009; Li et al., 2018a; Wu et al., 2019, 2021; Huang et al., 2023), suggesting that the initiation timing and duration of intra-oceanic subduction could be variable in different areas of the Yangtze craton. These island arc magmatic activities may be diachronous- since they have been formed in an identical subduction-related tectono-magmatic setting around the Yangtze craton, but through different time (Li et al., 2021a). The ~1.0-0.9 Ga arc rocks have strongly positive zircon $\varepsilon_{Hf}(t)$ values, mantle-like zircon $\delta^{18}O$ values (Fig. 4) and relatively low concentrations of highly incompatible trace elements compared to the average upper continental crust (Rudnick and Gao, 2003), which are similar to the juvenile arc lavas from the modern IBM island arc, and further suggestive of an intra-oceanic subduction origin (e.g., Li et al., 2009, 2018a; Wu et al., 2019, 2021).

3.1.2 From intra-oceanic subduction to ocean-continent subduction

Published geochronological data coverage shows that <0.9 Ga arc rocks are widespread throughout the northern Yangtze (Fig. 2b), likely indicates a flare-up of continental arc magmatism along the Yangtze-block continental margin. The possible tectonic transition from ocean-ocean subduction to ocean-continent subduction are supported by the following evidences: 1) Rarely exposed 1.0-0.9 Ga island arc rocks suggest only a few were survived from being subducted or accretionary erosion; 2) the 1.0-0.9 Ga arc rocks are geochemically low- to mid-K series (Fig. 5) and have relatively low concentrations of highly incompatible trace elements (Fig. 6), similar to the geochemical affinities of the modern island arc rocks (e.g., Izu-Bonin-Mariana, Saito and Tani, 2017), whilst the post-0.9 Ga arc rocks have pronounced enrichment of LILEs and LREEs (Fig. 6), resembling the composition of the mature continental crust; 3) The 1.0-0.9 Ga arc rocks have little ancient inherited zircons and are isotopically characterized by strongly positive whole-rock ε_{Nd}(t), zircon ε_{Hf}(t) values and mantle-like zircon $\delta^{18}O$ values, while the post-900 Ma arc rocks show stronger continental reworking with less radiogenic isotopes and elevated zircon $\delta^{18}O$ values (Fig. 4); 4) The sharp change of detrital zircon Hf-O isotopes may reflect the tectonic switching, i.e., detritus zircons with ages of ca. 970-900 Ma from the Miaowan fore-arc metasedimentary have mantle-like zircon $\delta^{18}O$ (4.5–6.0‰) and high ε_{Hf}(t) values (up to +14), whereas some 900 Ma detrital zircons low ε_{Hf}(t) values (-6~ -33) and high $\delta^{18}O$ values (6.5-9.2‰), indicating incorporation of recycled supracrustal materials into the sources (Lu et al., 2020). Similarly, detrital zircon Hf isotopes of the Huashan Group in the Dahongshan area also show a sharp decrease at ~900-880 Ma (from +13.5 to -18.5, Huang et al., 2021b), which is interpreted as the tectonic transition from island arc to continental arc; 5) The emplacement of ~890-860 Ma alkaline intrusive rocks aligning with an EW trend paralleled to the fossil subduction zone in the innermost of the Micangshan massif (Gan et al., 2017), which were likely formed in a local extensional setting caused by roll-back of the slab that had subducted underneath the Yangtze continental margin (Zhou et al., 2018b). In summary, an integral geochronological, geochemical and isotopic evidences for igneous rocks and sedimentary provenance herald the tectonic switch from island arc to continental arc at ~900-880 Ma, which manifests enhanced crustal reworking and the change of magma source via incorporation of more continental clastic components into the ocean-continental subduction channel along the Yangtze-block margin.

3.1.3 Periodically extensional and contractional tectonics

Generally, an accretionary orogen can undergo multiple cycles of tectonic mode switching (e.g., Lister et al., 2001; Collins and Richards, 2008; Kemp et al., 2009). However, the prolonged accretionary history of the northern margin of the Yangtze block has not been well understood yet. Here, we address this issue by employing the distinctive archive of oxygen and hafnium isotopes in igneous rock-hosted zircon from the northern Yangtze. Because zircon-hosted isotope tracer information has potential for evaluating relative contributions from mantle and crustal sources (Kemp et al., 2007; Yang et al., 2007), and thus for monitoring tectonic mode alternation during magmatic episodes.

The published zircon Hf-O isotope compositions of Neoproterozoic igneous rocks from the northern Yangtze are illustrated in Supplementary Table S3 and S4. When plotted as a function of crystallization age, the zircon Hf and O isotope data define striking temporal trends. During 0.9-0.8 Ga, the ε_{Hf}–time pattern of magmatism from the northern Yangtze shows an overall at least two abrupt decreases (~870 Ma and ~830 Ma) and then approach depleted mantle-like values (Fig. 4). The zircon $\delta^{18}O$–time patterns change from mantle-like $\delta^{18}O$ values to progressively elevated during ~900-830 Ma, and then downward to mantle-like or sub-mantle values for the post-830 Ma igneous rocks (Fig. 4). The similar $\delta^{18}O$–time pattern and “W-shaped”

ε_{Hf}–time pattern are duplicated in different regions of the northern Yangtze, such as the Mian-Lue–Bikou, Dahonshan, Hannan-Micangshan and the South Qinling, likely indicates consistent tectonic dynamic processes along the northern margin of the craton during the prolonged accretionary orogenesis.

Tectonic mode switching appears capable of reconciling the complex isotope–time patterns defined by the northern Yangtze magmatic rocks. In this scenario, trends towards decreasing $\varepsilon_{Hf}(t)$ values and elevated $\delta^{18}O$ values reflect enhanced crustal reworking attending arc compression and lithospheric thickening. Enhanced crustal input could have occurred by increased sediment subduction, greater subduction erosion and delivering more supracrustal materials to the mantle source, or various contamination with ancient continental basement materials during the magmas passage through the thickened crust. However, the subsequent progression to juvenile isotope signatures manifests enhanced mantle input as switching to an extensional mode induced by the re-initiation of subduction retreat. In particular, the episodically emplaced A-type rocks and associated mafic-ultramafic rocks with intraplate-like geochemical affinities (e.g., Ling et al., 2002; Gan et al., 2017; Luo et al., 2018; Zhou et al., 2018b, 2019; Ao et al., 2019; Wei et al., 2019; Wu et al., 2019b) are evidently controlled by the continental back-arc rifts, which in turn is linked to periodically slab rollback. The transition in geochemistry from arc-like to intraplate-like reflects a diminishing subduction-induced enrichment in the mantle source as switching to extensional episodes. Collectively, the repeated isotope-time enriching and depleting variations of igneous rocks was proposed to correlate with the alternating regimes of contractional and extensional tectonics of a prolonged active continental margin developed along the northern margin of the Yangtze craton, and suggest a long term feedback between tectonic activities and magma source during Neoproterozoic (e.g., Wu et al., 2023).

3.2 Rift-related magmatism revisited

3.2.1 Early Neoproterozoic localized rifting during arc accretion

The origin and tectonic setting of early Neoproterozoic rift-related magmatism are still controversial. Zhou et al. (2019) reported ca. 900 Ma low-$\delta^{18}O$ A-type rhyolite from the Tongbai area of the northern Yangtze, and interpreted that they were formed in a back-arc rift setting in an accretionary orogen. In contrast, Zhou et al. (2018) reported a series of ca. 900-890 Ma mafic intrusions and alkaline complexes with intraplate-like geochemical affinities from the innermost Micangshan area, and proposed that they may mark the onset of continental rifting or the ending of Late Mesoproterozoic to Early Neoproterozoic lithospheric extension. However, another episode of alkaline intrusives (ca. 870-860 Ma; Gan et al., 2017) in the same area, contemporaneous with the ca. 865-860 Ma Wangcang alkaline, tholeiitic and high-Nb volcanism, were considered to be formed in an extensional back-arc setting (Berkana et al., 2022). The ca. 860 Ma arc-like tholeiitic mafic sills in the same Micangshan area were suggested to be generated by partial melting of a metasomatized mantle wedge, which further supports a continental back-arc setting (Hui et al., 2020a). Besides, the occurrence of ca. 850-850 Ma intraplate-like mafic intrusives and high-Mg diorites from the Xiaomoling complex of the South Qinling Belt (Wu et al., 2023) , and ca. 830 Ma low-$\delta^{18}O$ A-type rhyolites from the Dahongshan area of the northern Yangtze (Huang et al., 2023) also support a local back-arc rift origin during the early Neoproterozoic subduction accretionary orogen. Therefore, the temporally continuous but spatially dispersed early Neoproterozoic rift-related (or intraplate-like) magmatic activities (Fig. 7) are most likely indicative of localized back-arc rifting environment induced by periodic subduction retreat in a prolonged accretionary orogen along the northern Yangtze as discussed in section 3.1.

3.2.2 Origin of post-830 Ma rocks: Anorogenic magmatism?

Widespread mid-Neoproterozoic rift magmatism and rifting-basin sequences in South China are traditionally considered the products of anorogenic magmatism in intracontinental rift basins related to mantle plume activity during the breakup of

Rodinia (Li et al., 2008, and references therein), and thus supporting the “internal model” for the position of South China in the configuration of Rodinia (Li et al., 2008 and references therein). Plume-rift model further proposed that continental rift magmatism has initiated since ca. 830 Ma (or even earlier at ca. 860 Ma, Li et al., 2003b). Supporting evidences include: (1) the ca. 830 Ma mafic to ultramafic dykes and sills in South China are identical in age to the Gairdner Dyke Swarm in Australia (Li et al., 1999), (2) the ca. 825 Ma Yiyang komatiitic basalts were considered the products of mantle plume (Wang et al., 2007a), and a few ca. 820-810 Ma basalts with intraplate-like affinities from the Bikou Group and the Tiechuanshan Formation were regarded as the remnants of flood basalt (e.g., Li et al., 2002; Ling et al., 2003; Wang et al., 2008; Wu et al., 2019b); (3) the regionally unconformity between the Banxi Group and Lengjiaxi Group were interpreted as continent-scale doming and unroofing due to underplating of plume head; (4) The stratigraphic characteristics and provenance record of the Neoproterozoic rift basin (Nanhua and Kangdian) have also been used to support internal models for the position of South China (Li et al., 2002, 2003a). Proponents of the internal model suggest extension was associated with a “superplume” that cause the breakup of Rodinia and correlates with contemporaneous rift systems in eastern Australia and western Laurentia (Li et al., 2008). Thus the Nanhua sequences and equivalents (e.g., Kangdian sequences) represent sediment accumulation during lithospheric extension (Wang and Li, 2003).

Authors that argued against the “plume-rift” hypothesis demonstrate that sedimentary detritus supplied to the Nanhua Basin sequences were largely sourced from Neoproterozoic rocks within South China based on U-Pb age patterns and Hf isotopic signatures of detrital zircons from the Danzhou, Xiajiang and Banxi groups (Wang and Zhou, 2012; Wang et al., 2012b). The absence of late Mesoproterozoic aged detritus as well as only minor input from Archean and Paleoproterozoic cratonic sources in the Nanhua sequences is distinct from the detrital age patterns of time-equivalent strata in Laurentia and Australia, but is similar to that of Cryogenian strata in the Lesser Himalaya of northwest India (Hofmann et al., 2011). Specifically, flood basalts related to the inferred ‘super-plume’ are documented in Australia but are not present in the Yangtze Block. Although Li et al. (1999) suggests that the absence of flood basalts in South China may have been attributed to erosion during sedimentation of the Neoproterozoic sedimentary basins, similar to that occurred in the Adelaide Fold Belt in Australia (Barovich and Foden, 2000) However, sedimentary rocks from the Nanhua sequences have trace elemental and Sm-Nd isotopic signatures indicative of sources dominantly composed of granitic to dioritic end-members from the interior of the Yangtze Block (Xu et al., 2007; Wang and Zhou, 2012), arguing against derivation of sedimentary detritus from a flood basalt province. Besides, stratigraphical studies suggest that the Hengdan Group in the Bikou block was deposited in a fore-arc setting at ca. 720 Ma (Druschke et al., 2006; Gao et al., 2020; Hui et al., 2020b), and continuously received clastic materials from the early to mid-Neoproterozoic magmatic detritus.

On the other hand, the occurrence of voluminous mid-Neoproterozoic calc-alkaline rock assemblages characterized by hornblende-rich lithologies (mostly diorite and granitoids) along the northern and northwestern margins of the Yangtze craton (Fig. 7) cannot be reconciled with the anorogenic magmatism induced by a mantle superplume activity. Because it seems highly unlikely that the calc-alkaline rock associations are dominant lithotypes rather than the flood basalts and bimodal volcanics in a typical intracontinental rift, i.e., the Main Ethiopian rift of the East African rift system and the Iceland rift (e.g., Corti, 2009). The typical calc-alkaline rock associations are widespread in the northern to western Yangtze, including the ca. 750-730 Ma Fenghuangshan dioritic-granitic plutons, the ca. 730 Ma Gangou gabbric-granitic plutons in the Douling batholith (e.g., Wang et al., 2019b), the ca. 760 Ma Xixiang hornblende-rich diorite (Zhao et al., 2010) and a series of ca. 810-730 Ma adakitic tonalite-trondhjemite and associated granitic plutons, such as the Erliba-Wudumen plutons in the Hannan batholith and the Xielongbao, Shimian, Yele, Mopanshan, Dajianshan and Datian plutons from the western Yangtze (Zhao and Zhou, 2008; Zhao et al., 2021). Detailed petrological, bulk-rock and mineral geochemical and O–Hf–Nd isotopic studies suggest that these ~800-730 Ma calc-alkaline granitoid associations were most probably generated through partial melting of hydrated basaltic rocks in the arc root, and thus support a continental arc setting (e.g., Zhao et al., 2021).

Despite the two mutually exclusive models (slab-arc vs. plume-rift), a reconciled "plate-rift" model proposed by Zheng et al. (2007, 2008) emphasizes the 830–800 Ma magmatism as the product of the orogenic collapse of an arc-continent collisional orogen rather than a superplume that led to the breakup of Rodinia, and suggests that the whole South China experienced lithospheric extension and intracontinental rifting during ~780–740 Ma due to mantle upwelling and concomitant orogenic collapse that may have triggered supercontinent break-up and associated syn-rift magmatism. However, The plate-rift model is based on a systematic study of zircon U–Pb and Lu–Hf isotopes and whole-rock Sr–Nd isotopes for the Neoproterozoic volcanic rocks and granitoids from the eastern part of the Jiangnan Belt, whether it can applicate for interpreting the tectonic evolution of the northern-Yangtze magmatism needs to be further verified and examined.

3.2.3 Mid-Neoproterozoic magmatism revisited: rifts superposed on continental arc

Thus far, a paucity of exact petrological and geological documentation exists pertaining to plume-related magmatic activity (episodic and short duration, ~1–5 m·yr). Alternatively, an abundance of petrological, geochemical and geological evidences for the slab-arc model (a long-lived active convergent margin) are the most persuasive among other models especially for those igneous rocks from the northern to western Yangtze (e.g., Zhou et al., 2002a,b, 2006a,b; Zhao and Zhou, 2009b; Zhao et al., 2011, 2021; Luo et al., 2018; Wang et al., 2019b; Zhao et al., 2021). Nevertheless, oxygen isotope data coverage (Fig. 4h) reveals that continental-scale rift magmatism appears to have been most active at ca. 780-750 Ma. An abundance of post-800 Ma low-δ^{18}O igneous rocks and associated A-type granitoids and bimodal volcanism were identified in the northern, western and southeastern margin of the Yangtze craton (e.g., Lu et al. 1999; Wang et al., 2009, 2010; Zhang and Zheng, 2013b; Zou et al., 2021), providing compelling support for tectonic interpretations positing that the middle Neoproterozoic rift-related magmatism likely emerged within craton-scale continental rifts, probably coinciding with the breakup of Rodinia. However, the occurrence of voluminous ~800-730 Ma calc-alkaline rock associations consisting of hornblende-rich gabbro, diorite, tonalite, and granodiorite in the northern and western margin of the Yangtze craton indicates unlikely an anorogenic tectonic setting, because typical anorogenic intracontinental rifts produce predominately flood basalts and bimodal volcanic lithologies rather than calc-alkaline rocks associations (e.g., Corti, 2009). Specifically, most of the ~800-730 Ma igneous rocks are characterized by juvenile isotope signatures such as positive whole-rock $\varepsilon_{Nd}(t)$ and zircon $\varepsilon_{Hf}(t)$ values, suggesting rapid reworking of juvenile crustal materials. Collectively, we propose a composite tectonic setting involving both intra-arc rift and continental arc may have existed along the periphery of the Yangtze craton during ~800-730 Ma. Such composite tectonic regime was also observed in the early Mesozoic to Cenozoic Cordillera Orogen, where intra-arc rifts co-exist with the protracted continental arc during the subduction of (proto-) pacific slab (e.g., Lawton and McMillan, 1999; Rapela et al., 2005).

This composite tectonic setting can self-consistently well explains the origin of both voluminous calc-alkaline and bimodal rock associations fingerprinted with ^{18}O-depletion signatures. Since crustal fingerprinting by low $\delta^{18}O$ meteoric/glacial water may be accomplished via tectonically induced water-rock interaction during syngenetic rifting and alteration along normal faults (e.g., Bindeman and Simakin, 2014). Rifting and burial due to extension in turn create additional hydrogeological conditions for hydrothermal fluid circulation. Conditions for remelting may be optimized when the low $\delta^{18}O$ protoliths are brought down closer to the heat source during crustal burial processes. Such crustal burial processes may have enhanced by rapid endogenic recycling process in the intra-continental arc thrust faults (e.g., DeCelles et al., 2009; Sauer et al., 2017; Pearson et al., 2018; Li et al., 2021b). Therefore low-$\delta^{18}O$ protoliths formed through high-temperature hydrothermal alteration in upper-crust rifts or normal faults can potentially and efficiently be transported into the lower crust depth where partial melting taking place and producing massive low-$\delta^{18}O$ magmas (Fig. 2c). According to the estimates of the maximum burial rates of ~4 mm/yr (Sauer et al., 2017), the time scale for supracrustal materials transporting into the ~30 km-depth crustal level is less than ~8 Ma. This time is even shorten for the low-$\delta^{18}O$ protoliths because they could have formed in the deep compared to the supracrustal materials. Thus the time interval is less or in the range of analytical error of SIMS or LA-ICPMS zircon U-Pb dating for the Precambrian rocks. Consequently, it seems that the Neoproterozoic low-$\delta^{18}O$ magmatic rocks were formed through cannibalization or remelting of syn-magmatically altered rocks during syngenetic rift hydrothermal alteration and magma pulse (e.g., He et al., 2018). Taking together, we hence proposed that the ca. 830–730 Ma rocks in South China are most likely formed in a composite tectonic setting rather than a single tectonic environment. This setting likely involved the presence of both continental rifts and continental arcs, though in different regions the things might be different.

3.2.4 Late Neoproterozoic rifted passive margin

The calc-alkaline magmatism ended at approximately 730-720 Ma (Nie et al., 2019; Wang et al., 2019b), likely indicates the end of continental arc setting along the northern to western margin of the Yangtze craton. Chronology reflects that the post-720 Ma magmatism can last until ~620 Ma, with mostly exposed in the South Qinling Belt (Fig. 2d and Fig. 3c), as is representative of the Yaolinghe-group volcanism. This late Neoproterozoic volcanoclastic sequence is of more than 1,200 m in thickness and was considered to have formed in an intracontinental rift basin (e.g., Ling et al., 2008) or a passive continental rifted margin (insert in Fig. 2d; Zhao and Asimow, 2018). New high-precise chronology reveals that the Yaolinghe-group volcanism erupted at 637-641 Ma (CA-ID-IRMS, Lan et al., 2022), 2–6 Myr before the termination of the Marinoan glaciation. An early stage of large magmatic province (~720-717 Ma) prior to the initiation of the Sturtian snowball has also been identified, which is interpreted as relating to the Franklin-aged mantle superplume beneath supercontinent Rodinia (Lu et al., 2022). Besides, there are several small-scale magmatic pules between the ~720-620 Ma, such as the ca. 690-680 Ma and the ca. 660-650 Ma volcanism and equivalent intrusives (e.g., Niu et al., 2006; Ling et al., 2007; Zhu et al., 2008, 2015; Lan et al., 2015a,b; Zhao and Asimov, 2018; Liu et al., 2022; Zhao et al., 2022). Geochemical compositionally, the ~720-620 Ma magmatism that can be attributed more clearly to intraplate-like and bimodal magmatism compared to that of the pre-720 magmatic rocks (Fig. 5 and 6). The tholeiitic basalts and mafic-ultramafic sills range from MORB-type to OIB-type trace element patterns, while the acid end-member (mostly granite and rhyolite) showing clear A-type affinities with strongly enrichment of LILEs and HFSEs and depletion of Sr, Ti and Y contents (Fig. 6). In Th/Yb versus Ta/Yb (Fig. S1) and the Nb versus Y diagrams (Fig. S2), both the A-type rocks and mafic rocks were plotted in the within-plate field. Besides, the generation of low-$\delta^{18}O$ felsic volcanic rocks and intrusive equivalents during this period (e.g., Liu and Zhang, 2013; Yang et al., 2016; Liu and Zhang, 2018) suggests that intracontinental rifts were widely developed along the periphery of the Yangtze craton accompanied with the continuous extensional tectonic setting due to the breakup of Rodinia. Collectively, the ^{18}O-depletion signatures, bimodality and intraplate-like geochemical affinities strongly indicate that the late Neoproterozoic (ca. 720-620 Ma) magmatism in the northern Yangtze were formed in a typical rifted passive margin setting.

4. Implication to South China locating in Rodinia

The paleogeographic location of South China within the supercontinent Rodinia has been hotly debated (e.g., Li et al., 2008; Evans, 2009; Cawood et al., 2013, 2018). Traditionally, South China was considered to situate at low latitudes between Laurentia and Australiathe (Li et al., 1995). However, new reliable paleomagnetic data propose that South China was either completely disconnected from Rodinia or located at its periphery between ~1000 to 720 Ma (Jing et al., 2015, 2019, 2021; Niu et al., 2016; Park et al., 2021; Xian et al., 2020; Chang et al., 2022; Fu et al., 2022). This is consistent with the prolonged subduction accretion in South China during early to middle Neoproterozoic (~1000-730 Ma, Fig. 2a-d), which cannot be reconciled with a position of South China within the interior of a stable supercontinent anytime in the Tonian Period. Besides, synchronous Neoproterozoic low $\delta^{18}O$ magmatism occurred in South China, NW India (Wang et al., 2017), Madagascar (Archibald et al., 2016) and Seychelles (Harris and Ashwal, 2002) suggests a close linkage among these blocks during the Rodinia breakup (e.g., Huang et al., 2019; Wu et al., 2020). This was supported by the similar provenance records of the late Neoproterozoic to Paleozoic passive margin clastic sequences from both the South China and India (Hofmann et al., 2011), implying their proximity along the same passive margin during the break-up of Rodinia. Collectively, an integration of key data sets such as paleomagnetism, geology and tectono-stratigraphy indicates that South China was unlikely to have occupied a central position in Rodinia (Fig. 8).

5. Conclusions

1. The initiation of intra-oceanic subduction along the periphery of Yangtze was diachronous during ca. 1000-900 Ma, followed by the flare-up of active continental margin arc magmatism at ca. 900-880 Ma.

2. Repeatedly variants of isotopic compositions of igneous rocks reveal the alternating regimes of contractional and extensional tectonics during the early Neoproterozoic arc accretion. The episodically occurrence of A-type, intraplate-like and low-$\delta^{18}O$ magmatism during this period marks the transition of tectonic switching to extensional modes due to the retreat of subduction.

4. Massive radiogenic isotope-depleted calc-alkaline rock associations, low-$\delta^{18}O$ and bimodal volcanism exposed along the Yangtze-craton margin may formed in a composite tectonic setting that involves both continental arc and rift settings. The end of arc magmatism was marked by the termination of calc-alkaline magmatism at ~730-720 Ma prior to the onset of the Sturtian glaciation.

5. The ~720-620 Ma magmatism formed in the intra-continental rifts of the volcanic passive margin setting.

6. South China is likely peripheral or disconnected from Rodinia.

Data Availability Statement

All data are available at the following link https://doi.org/XXXX.figshare.XXX

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Figure captions

Fig. 1. Simplified geological map of South China (A), and the northern margin of the Yangtze craton (B) and highlighting the distribution of Neoproterozoic and older rocks units (adapted from Zhao et al., 2022).

Fig. 2. Distribution of Neoproterozoic igneous rocks in the northern margin of the Yangtze craton with reliable zircon U-Pb ages labelled. Insets illustrate schematic tectonics evolution of different stages.

Fig. 3. Histograms of the zircon U-Pb ages of Neoproterozoic igneous rocks (A-E) from different domes of the northern margin of the South China Block. Detrital zircon U-Pb ages of sedimentary rocks from the Bikou, South Qinling and Dahongshan areas are also shown for comparison. See "Supplementary Table S1 and S5" for references.

Fig. 4. (A-D) U-Pb age versus zircon $\varepsilon_{Hf}(t)$, and (E-H) U-Pb age versus zircon O for the igneous rocks from the northern Yangtze. Mantle zircon O values of 5.3 ± 0.6‰ (2s, Valley et al., 1998). In Supplementary Table S3-4 for references.

Fig. 5. Chemical classification diagrams of $Na_2O + K_2O$ versus SiO_2 (Middlemost, 1994), K_2O versus SiO_2 (Rickwood, 1989) and AFM diagram (Irvine and Barragar, 1971). The classification boundary of AFM diagrams are from Kuno (1968). For references of compiled data, please see "Supplementary Table S2".

Fig. 6. Primitive-mantle-normalized trace element patterns of Neoproterozoic rocks from the northern Yangtze Block. Data for normalization are from McDonough and Sun (1995). The compositions of OIB, E-MORB and N-MORB for comparison are from Sun and McDonough (1989). The composition of average Andean and Aleutian arc basalts are from Kelemen et al. (2003). In Supplementary Table S2 for references.

Fig. 7. Time–space plot for various fragments of the northern margin of the South China Block for the period from the end of the Mesoproterozoic to the early Paleozoic. Sources of data for individual columns given in Supplementary Table S1.

Fig. 8. Schematic reconstructions place South China at high latitudes connected to India at the periphery of Rodinia, which satisfies the ca. 755 and 780 Ma paleomagnetic data and allows for an active margin along the northern to western margin of South China at this time. Modified after Park et al. (2021).

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Captions for Supplementary Figures S1 and S2

Figure S1. Diagram of Th/Yb vs. Ta/Yb (Pearce, 2008) for Neoproterozoic mafic igneous rocks from the north(west)ern margin of the Yangtze Block. Values for N-MORB, E-MORB and OIB are from Sun and McDonough (1989). Supplementary Table S2 for references.

Figure S2. Nb vs Y diagram (Pearce et al., 1984) for classification of Neoproterozoic felsic magmatic rocks from the north(western) margin of the Yangtze Block. For references of data, please see Supplementary Table S2.

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Captions for Supplementary Tables S1 to S5

Tables S1. Geochronology of (pre-)Neoproterozoic rocks from the northern Yangtze.

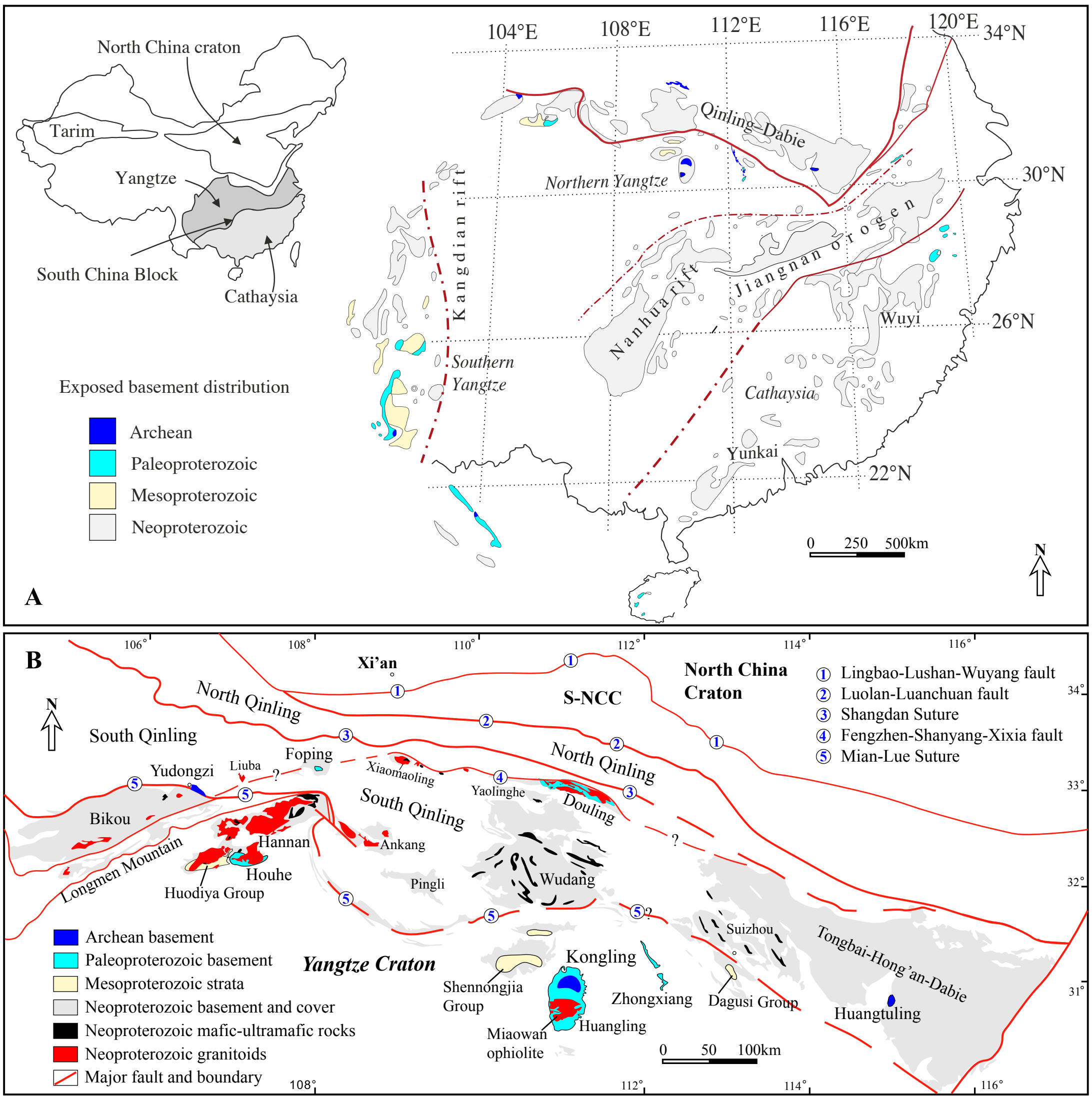
Table S2. Whole-rock major and trace element of Neoproterozoic igneous rocks from the northern Yangtze.

Table S3. Zircon Lu-Hf isotope compositions of Neoproterozoic igneous rocks from the northern Yangtze.

Table S4. Zircon O isotope compositions of Neoproterozoic igneous rocks from the northern Yangtze.

Table S5. Detrital zircon U-Pb ages and partial Hf-O isotope compositions of sedimentary rocks from the northern Yangtze.

Figure 1 to 8.



A
North China craton
Tarim
Yangtze
South China Block
Cathaysia
Exposed basement distribution
Archean
Paleoproterozoic
Mesoproterozoic
Neoproterozoic
104°E
108°E
112°E
116°E
120°E
34°N
30°N
26°N
22°N
Qinling-Dabie
Northern Yangtze
Kangdian rift
Jiangnan orogen
Nanhua rift
Southern Yangtze
Wuyi
Cathaysia
Yunkai
0 250 500km
N
B
North Qinling
South Qinling
Xi'an
S-NCC
North China Craton
Lingbao-Lushan-Wuyang fault
Luolan-Luanchuan fault
Shangdan Suture
Fengzhen-Shanyang-Xiaxia fault
Mian-Lue Suture
Yudongzi
Liuba
Foping
Xiaomaoling
Yaolinghe
Douling
Bikou
Hannan
Ankang
Longmen Mountain
Houhe
Huodiya Group
Pingli
Wudang
Suizhou
Tongbai-Hong'an-Dabie
Archean basement
Paleoproterozoic basement
Mesoproterozoic strata
Neoproterozoic basement and cover
Neoproterozoic mafic-ultramafic rocks
Neoproterozoic granitoids
Major fault and boundary
Yangtze Craton
Kongling
Shennongjia Group
Zhongxiang
Dagusi Group
Huangtuling
Miaowan ophiolite
Huangling
0 50 100km
106°
108°
110°
112°
114°
116°
34°
33°
32°
31°

Fig. 1

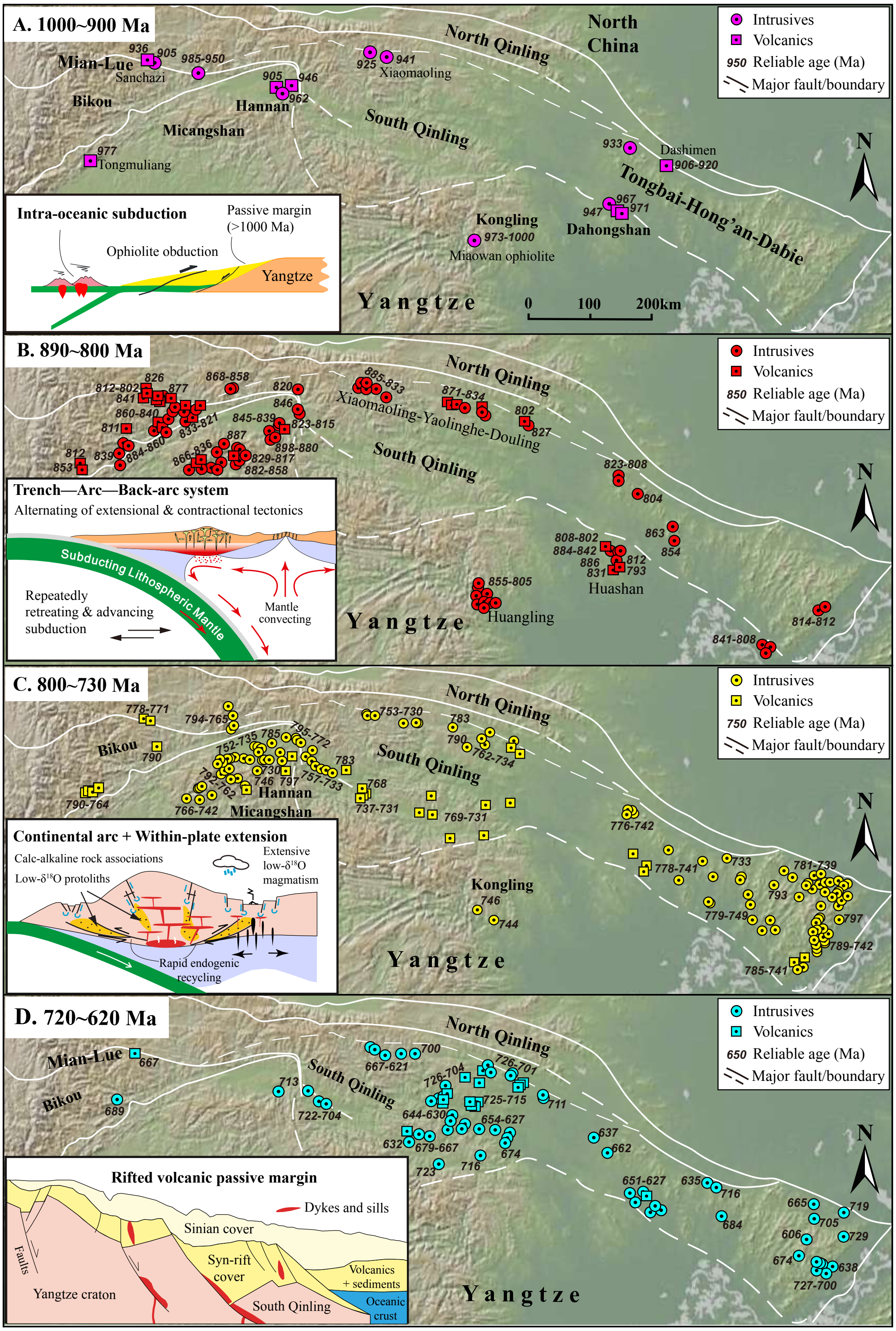

A. 1000~900 Ma
Intrusives
Volcanics
950 Reliable age (Ma)
Major fault/boundary
North China
North Qinling
South Qinling
Mian-Lue
Sanchazi
Bikou
Hannan
Micangshan
Tongmuliang
Xiaomaoling
Dashimen
Tongbai-Hong'an-Dabie
Dahongshan
Kongling
Miaowan ophiolite
Yangtze
0 100 200km
Intra-oceanic subduction
Passive margin (>1000 Ma)
Ophiolite obduction
B. 890~800 Ma
850 Reliable age (Ma)
Xiaomaoling-Yaolinghe-Douling
Huashan
Huangling
Trench—Arc—Back-arc system
Alternating of extensional & contractional tectonics
Subducting Lithospheric Mantle
Repeatedly retreating & advancing subduction
Mantle convecting
C. 800~730 Ma
750 Reliable age (Ma)
Continental arc + Within-plate extension
Calc-alkaline rock associations
Low-δ18O protoliths
Extensive low-δ18O magmatism
Rapid endogenic recycling
D. 720~620 Ma
650 Reliable age (Ma)
Rifted volcanic passive margin
Dykes and sills
Sinian cover
Syn-rift cover
Volcanics + sediments
Faults
Yangtze craton
South Qinling
Oceanic crust

Fig. 2

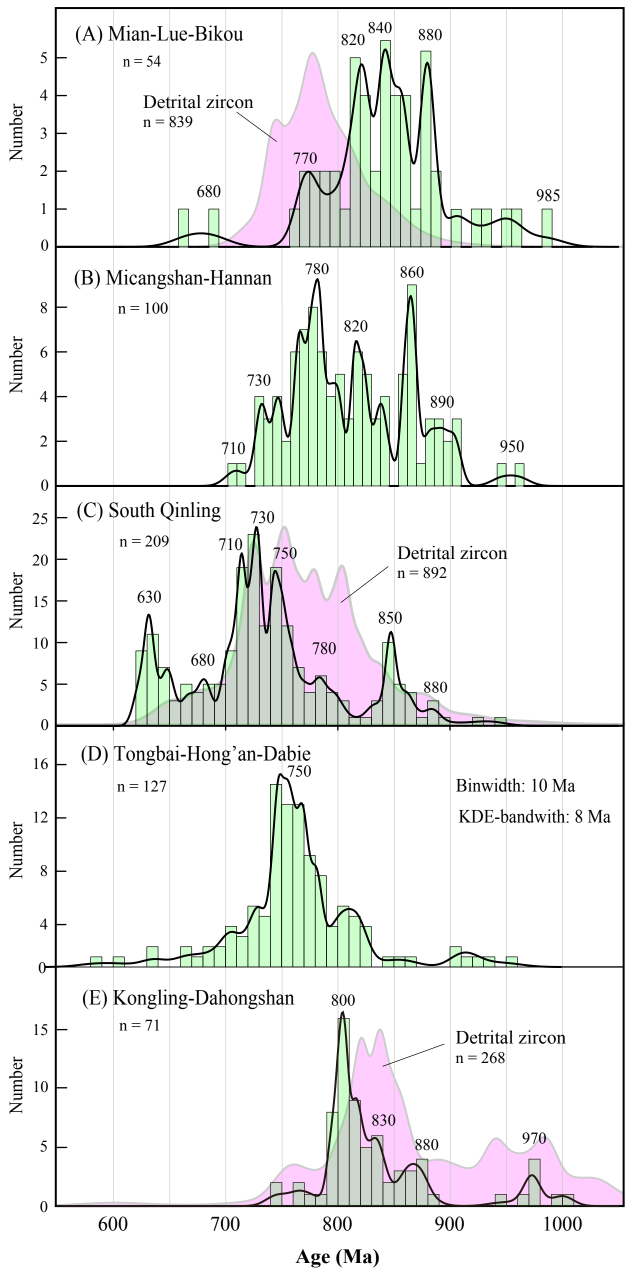
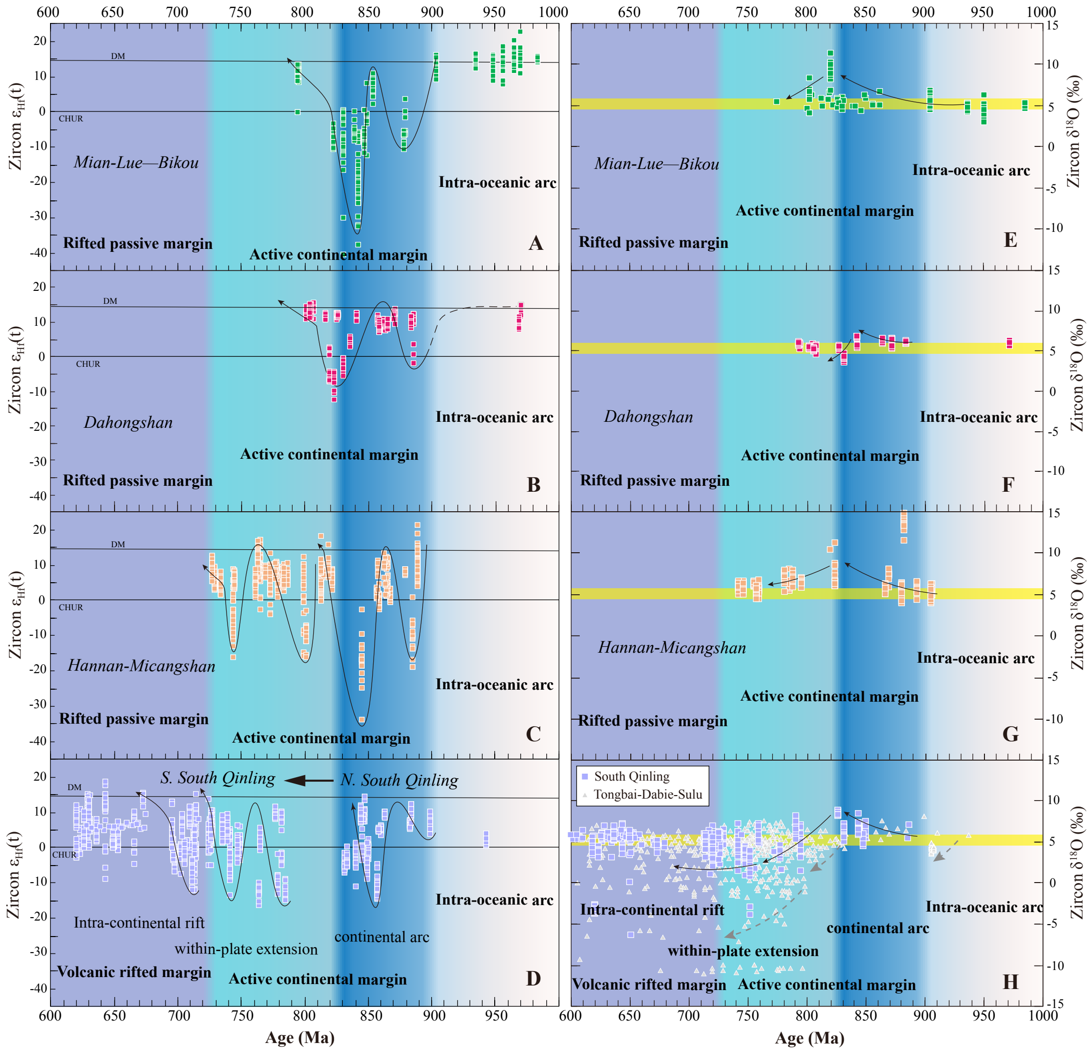

(A) Mian-Lue-Bikou
n = 54
Detrital zircon
n = 839
680
770
820
840
880
985
(B) Micangshan-Hannan
n = 100
710
730
780
820
860
890
950
(C) South Qinling
n = 209
630
680
710
730
750
780
850
880
Detrital zircon
n = 892
(D) Tongbai-Hong'an-Dabie
n = 127
750
Binwidth: 10 Ma
KDE-bandwith: 8 Ma
(E) Kongling-Dahongshan
n = 71
800
830
880
970
Detrital zircon
n = 268
Number
Age (Ma)
600
700
800
900
1000

Fig. 3



Zircon εHf(t)
Zircon δ18O (‰)
Age (Ma)
DM
CHUR
Mian-Lue—Bikou
Dahongshan
Hannan-Micangshan
S. South Qinling
N. South Qinling
Rifted passive margin
Active continental margin
Intra-oceanic arc
Intra-continental rift
within-plate extension
continental arc
Volcanic rifted margin
South Qinling
Tongbai-Dabie-Sulu
A
B
C
D
E
F
G
H

Fig. 4

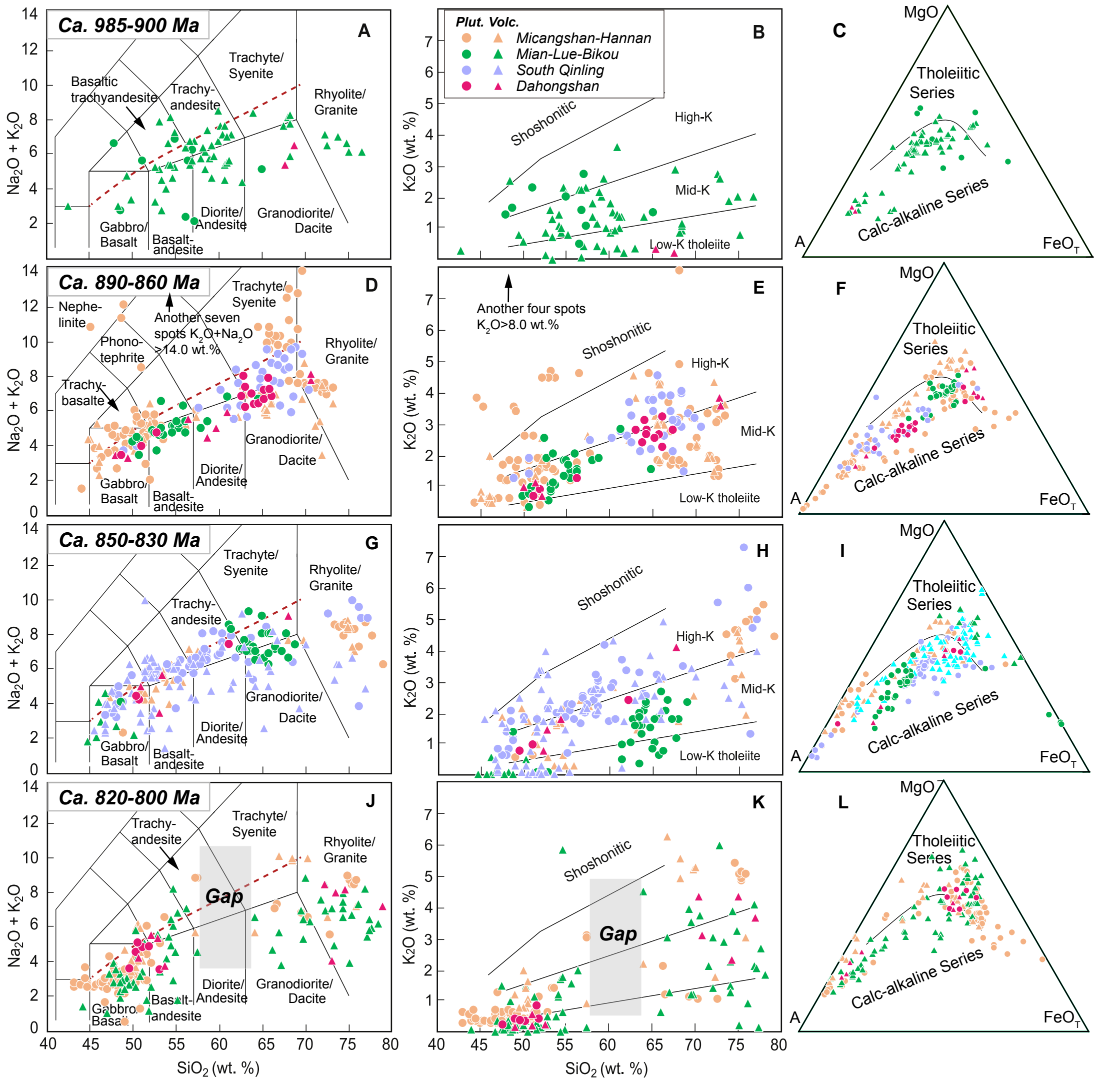


Fig. 5. (Continued)

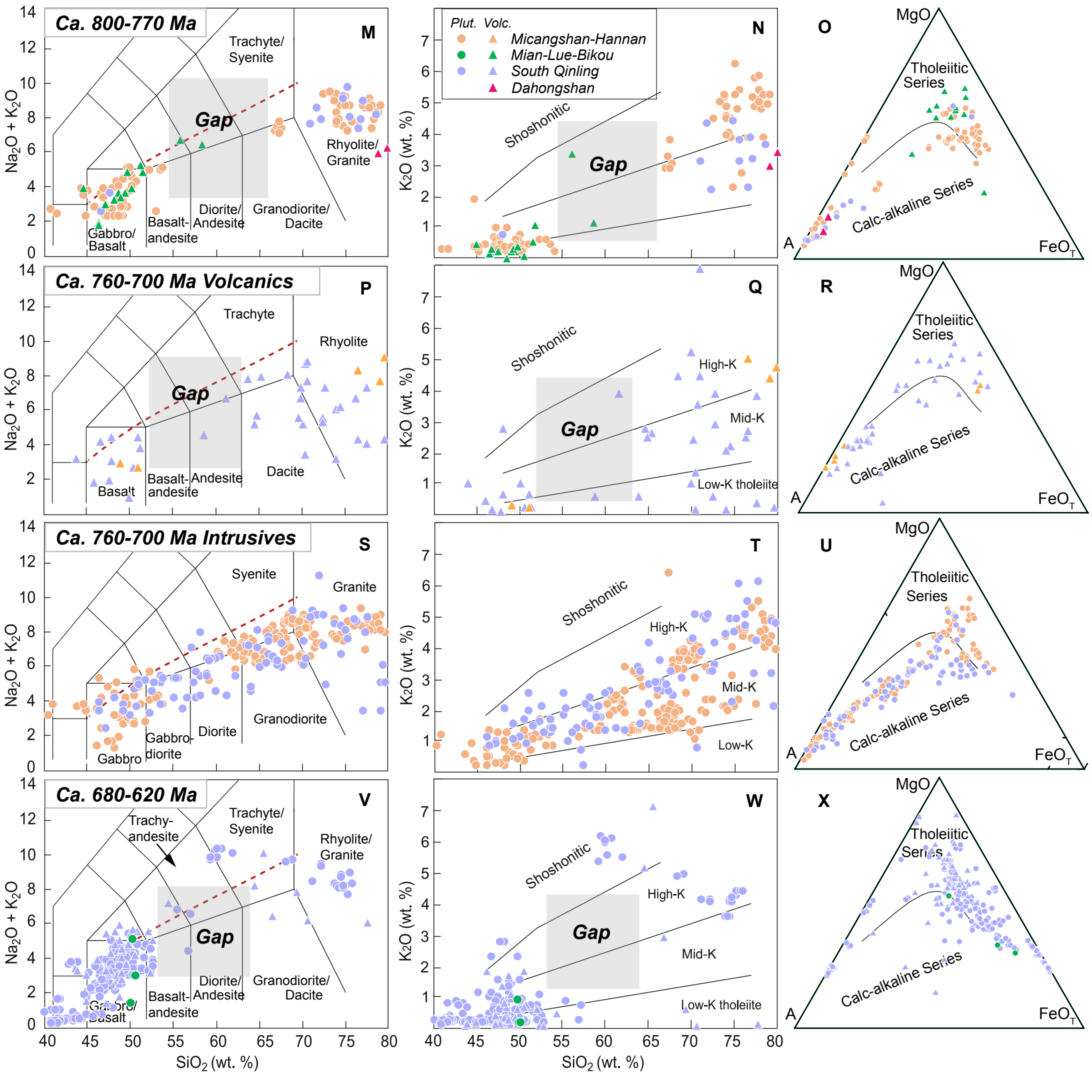

Ca. 800-770 Ma
M
N
O
Plut. Volc.
Micangshan-Hannan
Mian-Lue-Bikou
South Qinling
Dahongshan
Gap
Trachyte/ Syenite
Rhyolite/ Granite
Diorite/ Andesite
Granodiorite/ Dacite
Gabbro/ Basalt
Basalt-andesite
Shoshonitic
MgO
Tholeiitic Series
Calc-alkaline Series
A
FeO_T
Ca. 760-700 Ma Volcanics
P
Q
R
Trachyte
Rhyolite
Dacite
Basalt
High-K
Mid-K
Low-K tholeiite
Ca. 760-700 Ma Intrusives
S
T
U
Syenite
Granite
Granodiorite
Diorite
Gabbro-diorite
Gabbro
Low-K
Ca. 680-620 Ma
V
W
X
Trachy-andesite
Na2O + K2O
K2O (wt. %)
SiO2 (wt. %)

Fig. 5.

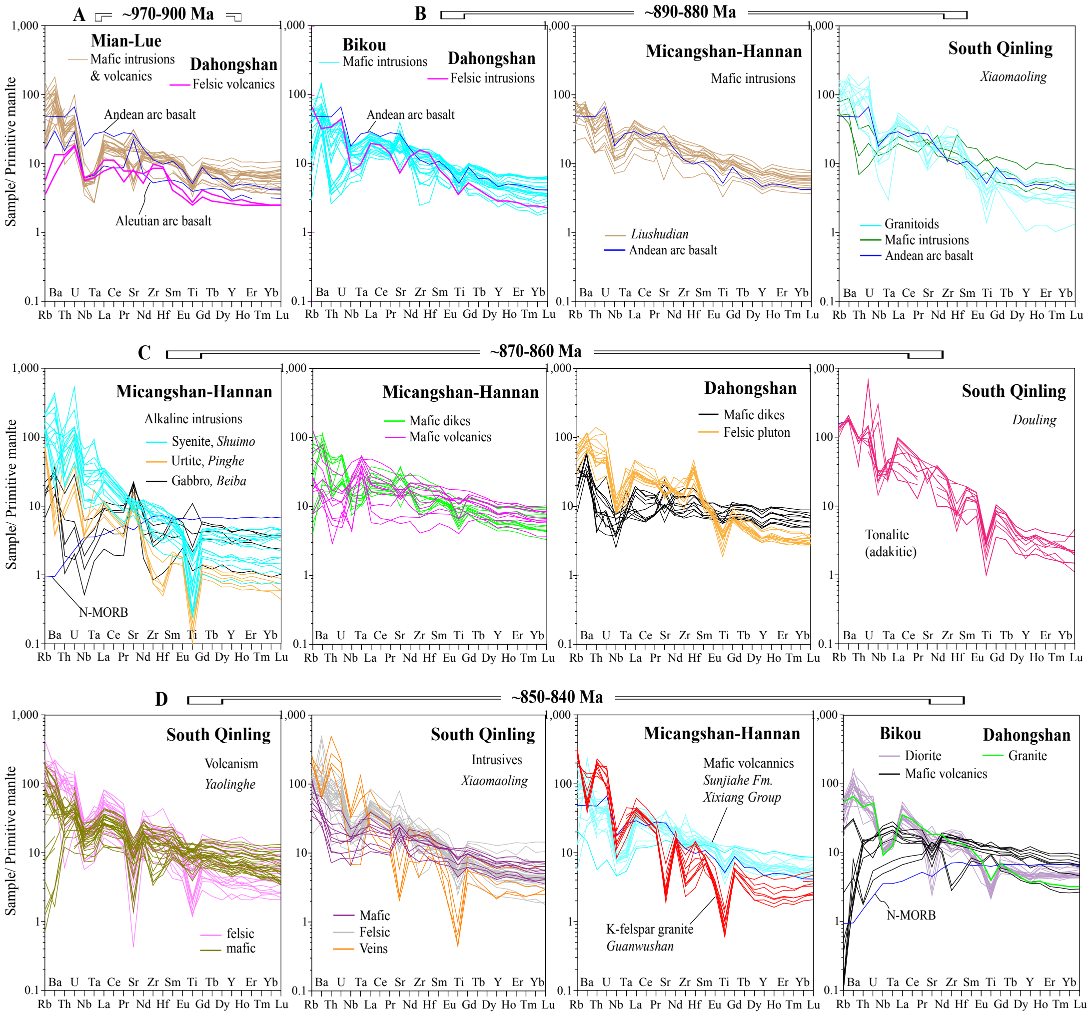


Fig. 6. (Continued)

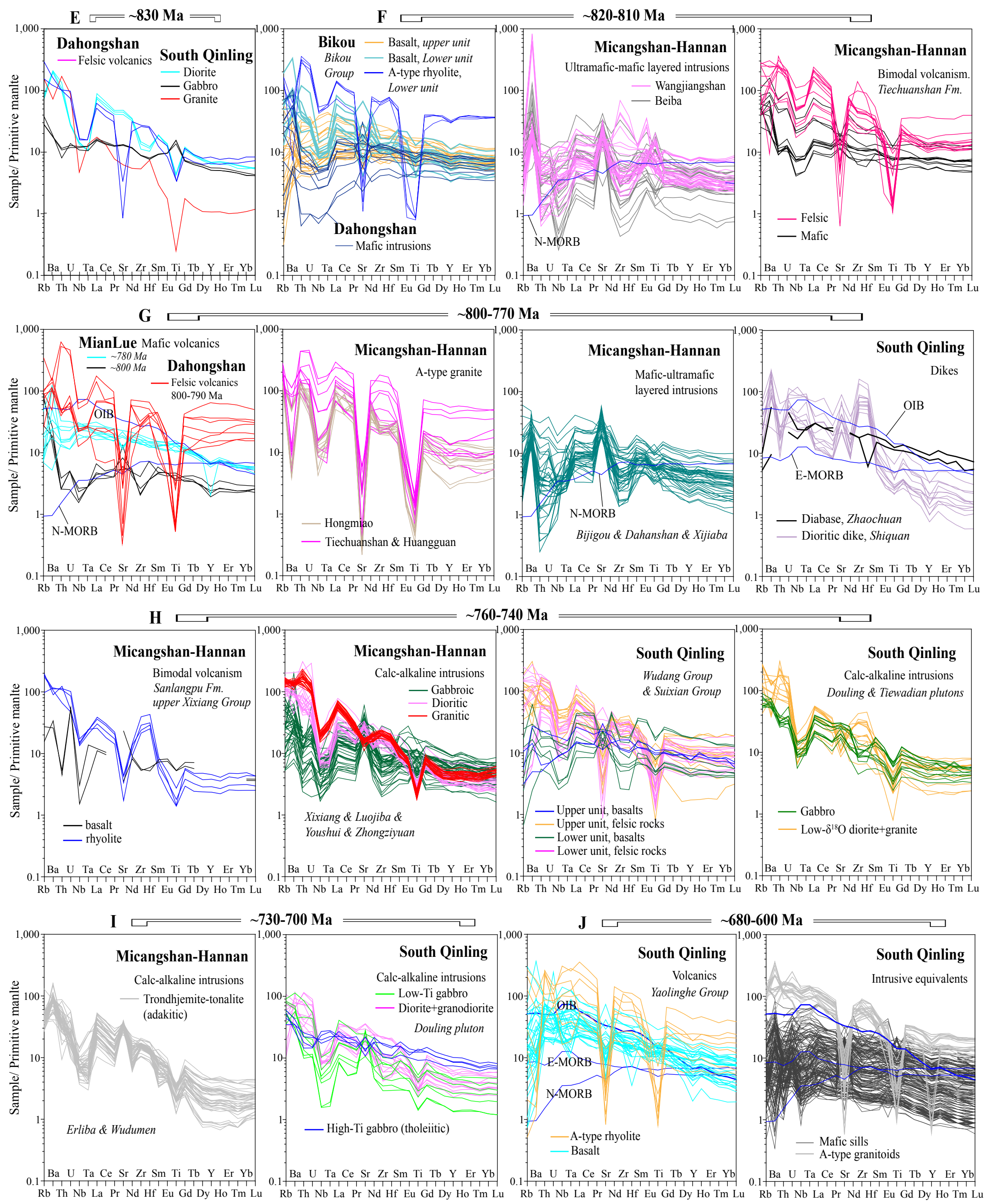
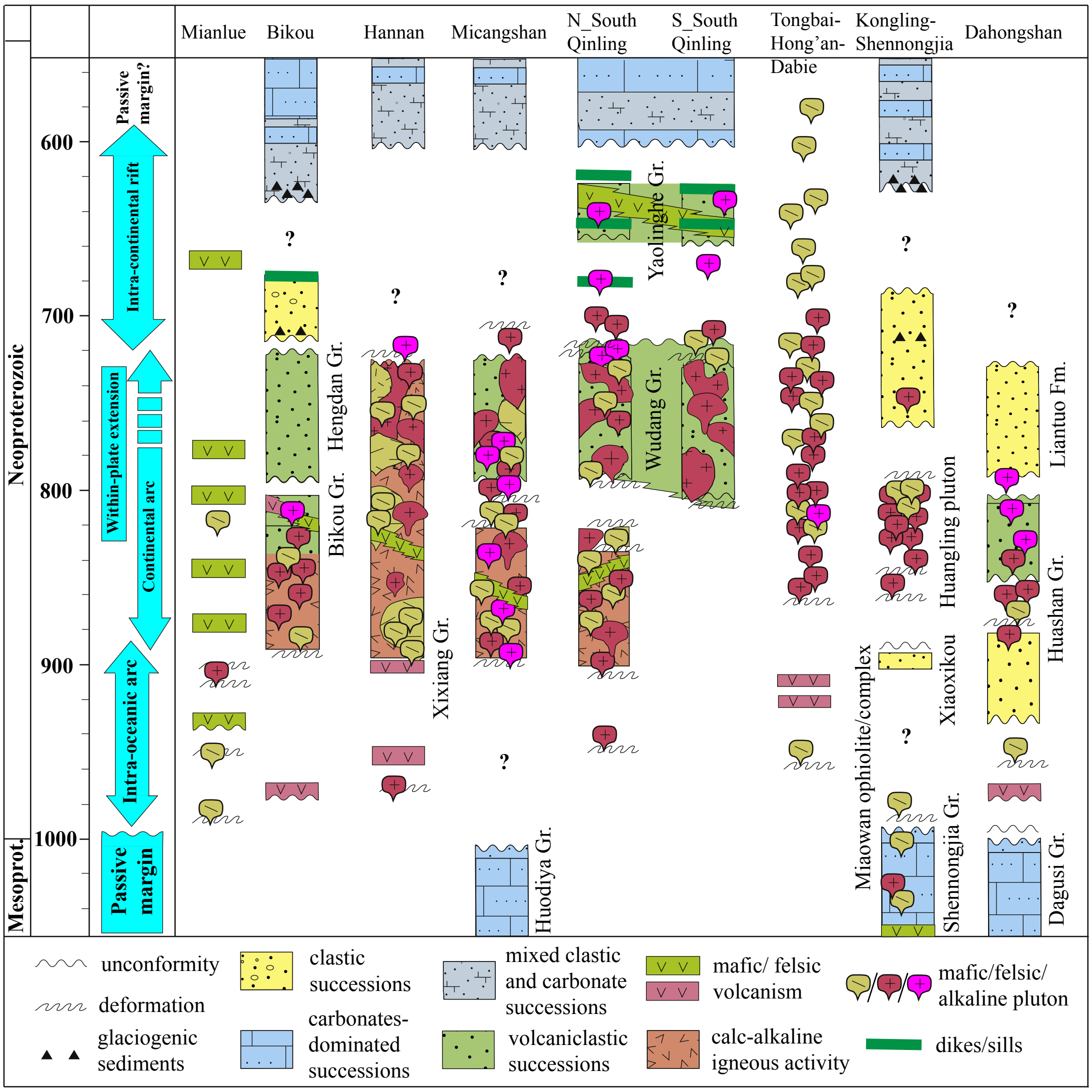


Fig. 6.



Mianlue
Bikou
Hannan
Micangshan
N_South Qinling
S_South Qinling
Tongbai-Hong'an-Dabie
Kongling-Shennongjia
Dahongshan
Neoproterozoic
Mesoprot.
600
700
800
900
1000
Passive margin?
Intra-continental rift
Within-plate extension
Continental arc
Intra-oceanic arc
Passive margin
Hengdan Gr.
Bikou Gr.
Xixiang Gr.
Huodiya Gr.
Yaolinghe Gr.
Wudang Gr.
Miaowan ophiolite/complex
Huangling pluton
Xiaoxikou
Shennongjia Gr.
Liantuo Fm.
Huashan Gr.
Dagusi Gr.
unconformity
deformation
glaciogenic sediments
clastic successions
carbonates-dominated successions
mixed clastic and carbonate successions
volcaniclastic successions
mafic/ felsic volcanism
calc-alkaline igneous activity
mafic/felsic/ alkaline pluton
dikes/sills

Fig. 7.

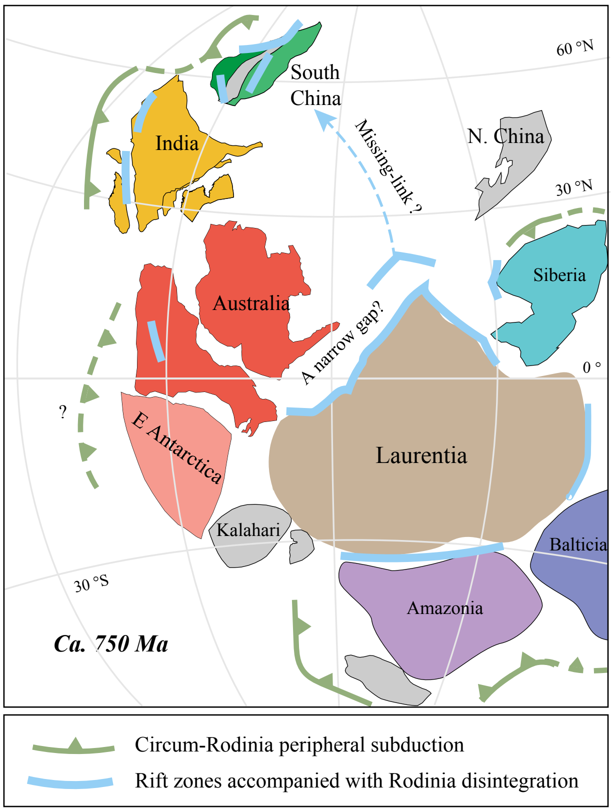

60 °N
South
China
India
N. China
Missing-link ?
30 °N
Siberia
Australia
A narrow gap?
0 °
?
E Antarctica
Laurentia
Kalahari
Baltica
30 °S
Amazonia
Ca. 750 Ma
Circum-Rodinia peripheral subduction
Rift zones accompanied with Rodinia disintegration

Fig. 8