

Geology

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Geology published online 6 June 2013;
doi: 10.1130/G34395.1

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Locating South China in Rodinia and Gondwana: A fragment of greater India lithosphere?

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ABSTRACT

From the formation of Rodinia at the end of the Mesoproterozoic to the commencement of Pangea breakup at the end of the Paleozoic, the South China craton first formed and then occupied a position adjacent to Western Australia and northern India. Early Neoproterozoic suprasubduction zone magmatic arc-backarc assemblages in the craton range in age from ca. 1000 Ma to 820 Ma and display a sequential northwest decrease in age. These relations suggest formation and closure of arc systems through southeast-directed subduction, resulting in progressive northward accretion onto the periphery of an already assembled Rodinia. Siliclastic units within an early Paleozoic succession that transgresses across the craton were derived from the southeast and include detritus from beyond the current limits of the craton. Detrital zircon age spectra require an East Gondwana source and are very similar to the Tethyan Himalaya and younger Paleozoic successions from Western Australia, suggesting derivation from a common source and by inference accumulation in linked basins along the northern margin of Gondwana, a situation that continued until rifting and breakup of the craton in the late Paleozoic.

INTRODUCTION

The configurations of the supercontinents of Gondwana and Pangea are relatively well constrained (Veevers, 2004), whereas those of older supercontinents are debated; competing models have been proposed (e.g., Li et al., 2008; Zhang et al., 2012; Zhao et al., 2002). This is particularly the case with the end-Mesoproterozoic supercontinent of Rodinia, the configuration of which remains controversial (e.g., Evans, 2009; Li et al., 2008). At the heart of the controversy is the position of South China craton in Rodinia; the consensus model proposes that it occupied an intracratonic position between Laurentia and Australia (Li et al., 2008, and references therein), whereas other models argue that it was either on the margin of Rodinia near Australia (Zhao and Cawood, 1999; Zhou et al., 2002) or occupied a position external to the supercontinent (Yang et al., 2004). The consensus model assumes that the pre-850 Ma rocks in the South China craton formed in a collisional orogen (termed the Sibao or Jiangnan orogen), coincident with the assembly of the Rodinia. Younger 830–750 Ma igneous rocks in South China are considered the products of anorogenic magmatism in intracontinental rift basins related to mantle plume activity during the breakup of Rodinia. In contrast, other models argued that early to middle Neoproterozoic igneous rock assemblages exposed along the margins of the craton developed in arc systems (Zhao et

al., 2011; Zhou et al., 2002). Uncertainties in paleogeographic reconstructions such as those proposed for South China in Rodinia reflect the incomplete nature of available data sets, resulting in significant gaps in the geologic record and allowing for multiple nonunique interpretations. Thus, limiting the position of even one block with respect to another in supercontinent reconstructions is significant, because changes in the history of one segment must be accommodated in the arrangement of others, and will ultimately limit possible interrelationships between all other blocks. In this paper we summarize geological, geochronological, geochemical, and detrital zircon isotopic data for the Neoproterozoic and Paleozoic rock units from the South China craton. We show that throughout this time frame it was first assembled on, and then was adjacent to, the Western Australia and northern India margins of both Rodinia and Gondwana, prior to rifting off Pangea and finally colliding with Asia to achieve its current position.

SETTING OF SOUTH CHINA

The South China craton consists of the Yangtze block to the northwest and the Cathaysia block to the southeast (Fig. 1; Zhao and Cawood, 2012). The Yangtze block consists of Archean–Paleoproterozoic crystalline basement surrounded by late Mesoproterozoic to early Neoproterozoic folded belts, which are locally unconformably overlain by weakly

metamorphosed Neoproterozoic strata and unmetamorphosed Sinian cover (Fig. 1; Zhao and Cawood, 2012). The Cathaysia block is composed predominantly of Neoproterozoic metamorphic rocks, with minor Paleoproterozoic and Mesoproterozoic lithologies. Archean basement is poorly exposed and largely inferred from the presence of minor inherited and/or xenocrystic zircons in younger rocks (Fig. 1; Zhao and Cawood, 2012). One marked difference between the Cathaysia and Yangtze blocks is that the former underwent a tectonothermal event in the early Paleozoic (460–420 Ma), which resulted in an angular unconformity between post-Silurian cover and metamorphosed pre-Devonian strata with granites emplaced in Cathaysia and adjacent areas in the Yangtze block (Huang, 1977; Wang et al., 2013a). This led some researchers to regard the Cathaysia block as an early Paleozoic folded belt bordering the southeastern margin of the Yangtze block (Huang, 1977), although most researchers favor models that regard Cathaysia as a discrete continental block that amalgamated with the Yangtze block in the early Neoproterozoic (see Zhao and Cawood, 2012, and references therein). In addition, some of the Precambrian to early Paleozoic rocks in the Cathaysia block were strongly reworked by a Late Permian–Early Triassic event, but its tectonic nature remains unknown or controversial (Zhao and Cawood, 2012).

Yangtze-Cathaysia Boundary and Relation to Rodinia

Establishing the nature and age of the boundary between the constituent Yangtze and Cathaysia blocks, generally considered to be delineated by the Sibao (or Jiangnan) orogen (Fig. 1; e.g., Li et al., 2008; Zhao and Cawood, 1999), is critical to understanding the setting of the South China craton. Recent work has shown that rather than a single boundary, the eastern portion of the craton can be subdivided into a series of structural blocks: eastern Cathaysia, western Cathaysia, and eastern Yangtze, which are bounded on their western sides by the Zhenghe-Dapu-Gaoyao-Huilai fault system, the Jiangshan-Shaoxing fault system, and the

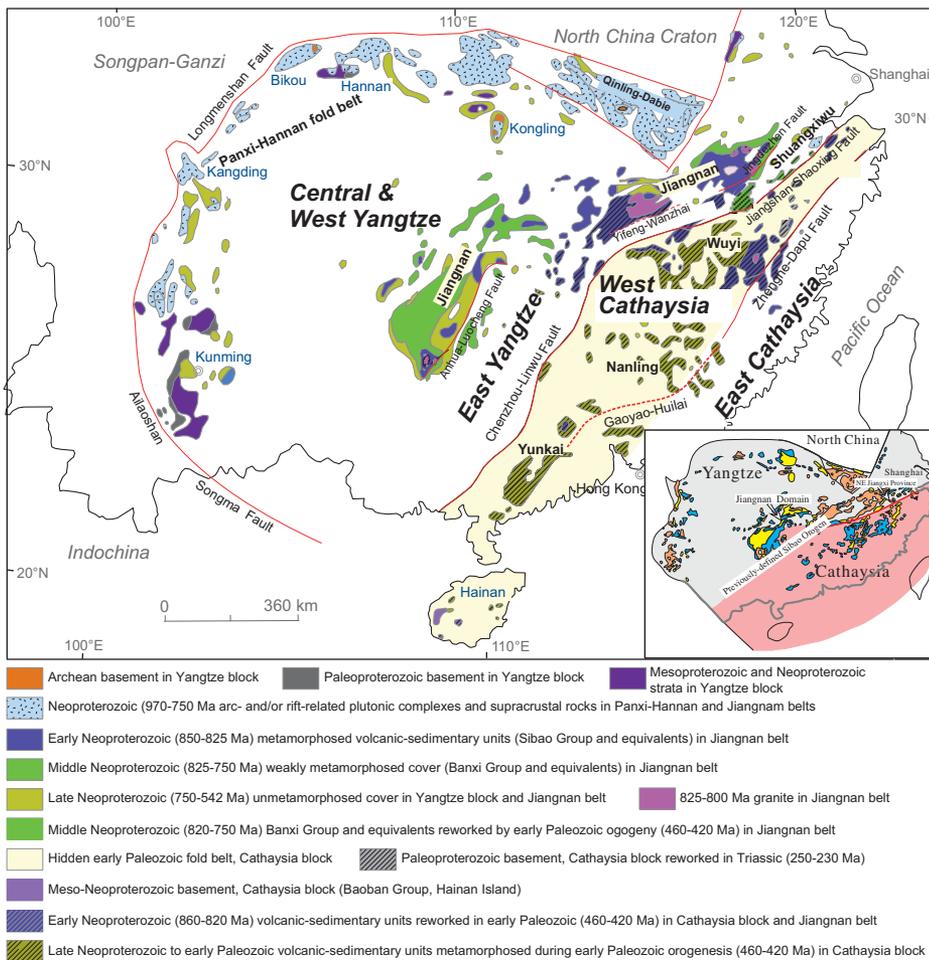


Figure 1. Map of south China (after Zhao and Cawood, 2012) with inset showing Sibao orogen (after Li et al., 2002).

Jingdezhen-Yifeng-Wanzhai-Anhua-Luocheng fault system, respectively (Fig. 1; Wang et al., 2013a, 2013b; Xu et al., 2007). Immediately west of each of these faults is a series of disrupted Proterozoic metamorphic domains, from east to west the Wuyi-Yunkai, Shuangxiwu, and Jiangnan domains (Fig. 1).

The Proterozoic domains consist of mainly mafic-ultramafic rocks with localized occurrences of felsic igneous rock, notably in the Jiangnan domain, and metamorphosed volcanoclastic sedimentary rocks (Shu, 2006). These rock sequences were considered to be Paleoproterozoic and end Mesoproterozoic to earliest Neoproterozoic in age. However, all available geochronological dating has shown that Mesoproterozoic rocks are essentially absent and the units are dominantly early Neoproterozoic (Wang et al., 2013a, 2013b, and references therein). Elemental compositions and isotopic systematics of igneous rocks within all three domains suggest input from a depleted mantle source modified by subduction-derived melts and fluids in a series of arc-backarc systems (a complete list of analytical data used to construct geochemical and geochronological plots and

sources of the data is provided in the GSA Data Repository¹ (Fig. 2; Shu, 2006; Wang et al., 2013b, and references therein). Mafic rocks with mid-oceanic-ridge basalt geochemical affinities from the Wuyi-Yunkai, Shuangxiwu, and Jiangnan domains have $\epsilon_{Nd(t)}$ of 3.5–7.0, 3.2–8.7, and 3.6–9.4, respectively, indicating input from a juvenile source and consistent with an accretionary orogen setting. The age range of igneous activity within the domains, in particular the age of termination of arc magmatism, displays an overall decrease from southeast to northwest. The Wuyi-Yunkai arc system ranges from ca. 1000 Ma to 900 Ma with the end of arc magmatism marked by emplacement of peraluminous (S-type) granites (our data). The Shuangxiwu and Jiangnan domains range from ca. 970–880 Ma and 870–820 Ma, respectively (Li et al., 2009; Wang et al., 2008; Wang et al., 2013b). Formation and closure of these arc-backarc

¹GSA Data Repository item 2013248, a list of data and data sources, is available online at www.geosociety.org/pubs/ft2013.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

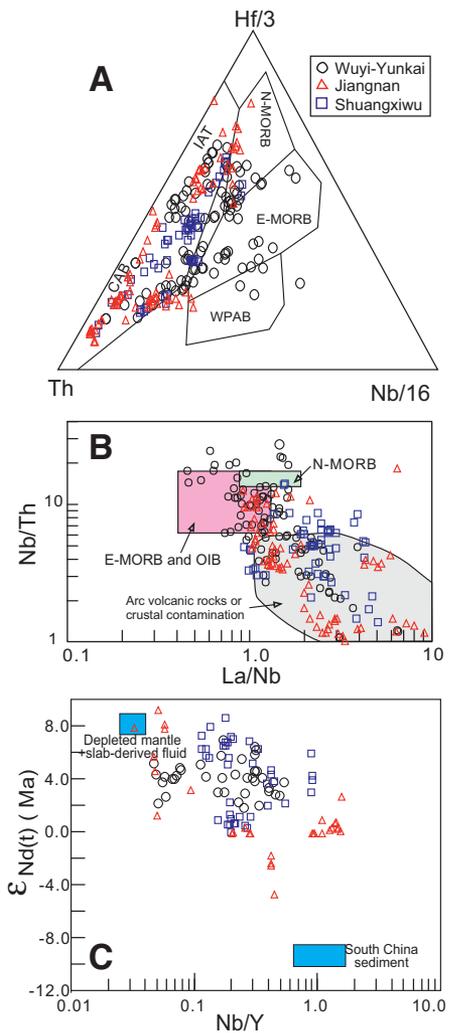


Figure 2. Geochemical plots for mafic rocks along Wuyi-Yunkai, Shuangxiwu, and Jiangnan domains in eastern South China craton. **A:** Hf/3–Th–Nb/16. **B:** Nb/Th versus La/Nb. **C:** $\epsilon_{Nd(t)}$ versus Nb/Y. (Complete list of data and data sources is given in the Data Repository; see footnote 1.) IAT— island-arc tholeiite; CAB— island-arc calc-alkaline basalt; N-MORB— normal mid-oceanic-ridge basalt; E-MORB— enriched mid-oceanic-ridge basalt; WPAB— within-plate alkali basalt; OIB— ocean island basalt.

systems resulted in progressive northwestward amalgamation of the various pieces of Yangtze and Cathaysia to create the South China craton. Furthermore, their Neoproterozoic age and convergent plate margin setting indicate that the craton could not have occupied an intracratonic position during the end Mesoproterozoic collisional assembly of Rodinia, but rather must have been on the periphery of the supercontinent. Synchronous with this phase of assembly of the craton, subduction-related magmatism developed along the western and northern margins of the Yangtze block, along the Panxi-Hannan fold belt that was active from 1000 to 750 Ma (Dong et al., 2012), although Li et al.

(2002, 2008) proposed that the 830–750 Ma magmatism along these margins resulted from a mantle plume that led to the breakup of Rodinia.

Provenance of Paleozoic Strata and Relation to Gondwana

Early Paleozoic strata extend across the South China craton (Fig. 1). Facies relations for Cambrian and Ordovician strata range from siliciclastic-dominated, shallow-marine successions in the Cathaysia block to time-equivalent carbonate-dominated successions in the central Yangtze block, with a deeper water, mixed siliciclastic-carbonate succession in the intervening eastern Yangtze block. Silurian siliciclastic strata overlie the carbonate succession in the central Yangtze block (Wang et al., 2010).

U-Pb analyses of detrital zircon grains from the early Paleozoic siliciclastic strata indicate a range in age from ca. 3350 Ma to 460 Ma; one grain yielded a Hadean age of ca. 4100 Ma (Fig. 3; Wang et al., 2010; our data). All samples contain end Mesoproterozoic and Neoproterozoic detrital zircon ages, a characteristic feature of detritus derived from a Gondwana source (e.g., Cawood and Nemchin, 2000; Myrow et al., 2010). Paleocurrent data indicate derivation of siliciclastic strata from the southeast, and the detrital zircon age signature includes

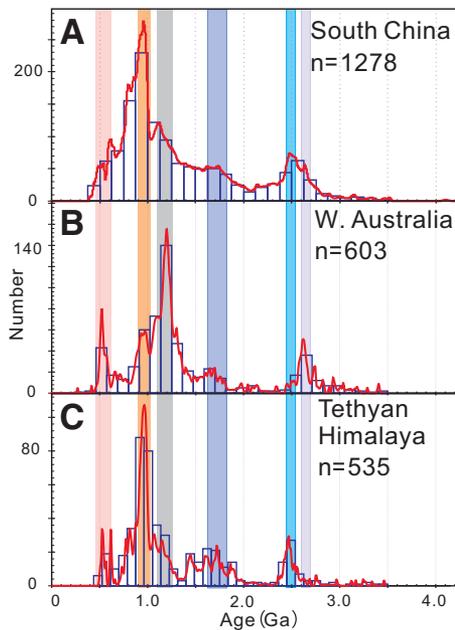


Figure 3. Detrital zircon age distributions for sedimentary rocks from south China, Western (W.) Australia, and Tethyan Himalaya. (Complete list of data and data sources is given in the Data Repository; see footnote 1.) Age peaks important in comparing data sets between three regions are highlighted in color bands; n—total number of analyses. All data based on analyses with <10% discordance. Ages older than 1000 Ma were calculated using $^{207}\text{Pb}/^{206}\text{Pb}$ ratios, and ages younger than 1000 Ma were calculated using $^{206}\text{Pb}/^{238}\text{U}$ ratios.

components derived from beyond the current limits of the craton (Wang et al., 2010). The end Mesoproterozoic to earliest Neoproterozoic age peak that dominates the sandstone samples, along with Hf isotope data from grains of this age, matches source regions in the Wilkes-Albany-Fraser belt between southwest Australia and Antarctica and the Rayner–Eastern Ghats belt between India and Antarctica (our data). Zircon grains with ages (ca. 490 Ma) close to the depositional age of the samples were present in the Ordovician and Silurian successions with source regions ascribed to igneous activity in the North India and Terra Australis orogens (Wang et al., 2010). Furthermore, the overall age spectrum is very similar to those of time-equivalent material from the Tethyan Himalayan and to a lesser extent younger Paleozoic successions from Western Australia, suggesting derivation from a common source and by inference accumulation in linked basins (Fig. 3). These proposed East Gondwana orogenic source regions along with their bounding cratons also provide a likely source for Hadean, Neoproterozoic, and Neoproterozoic detritus within the early Paleozoic sandstones. Thus, in the early Paleozoic the South China craton was likely located at the nexus between India, Antarctica, and Australia, along the northern margin of East Gondwana.

Paleomagnetic records for Neoproterozoic and early Paleozoic strata from the South China craton suggest, on the basis of comparison with data from Gondwana, that the craton occupied a location adjacent to the west coast of Australia (Macouin et al., 2004; Yang et al., 2004). These paleomagnetic constraints, although limited, are consistent with faunal data that suggest a close link in the early to middle Paleozoic, including the affinity of Early Devonian freshwater fish in south China, Vietnam, and the Canning Basin of Western Australia (Burrett et al., 1990).

Geologic, paleomagnetic, and faunal data suggest that South China rifted from Gondwana in the Late Devonian to early Carboniferous before drifting across the Tethys Ocean, and was finally accreted to Asia (north China) along the Qinling-Dabie suture in Permian–Triassic time (Metcalf, 2011).

CONCLUSIONS

A self-consistent set of geologic, geochemical, geochronological, paleomagnetic, and faunal data indicates that the South China craton was assembled and then maintained a position off Western Australia and northeast India from the beginning of the Neoproterozoic to the end of the Paleozoic, along the periphery of both the Rodinian and Gondwanan supercontinents (Fig. 4). Neoproterozoic igneous rocks adjacent to a series of sutures that transgress the craton formed in a succession of suprasubduction zone arc-backarc systems over ~180 m.y.

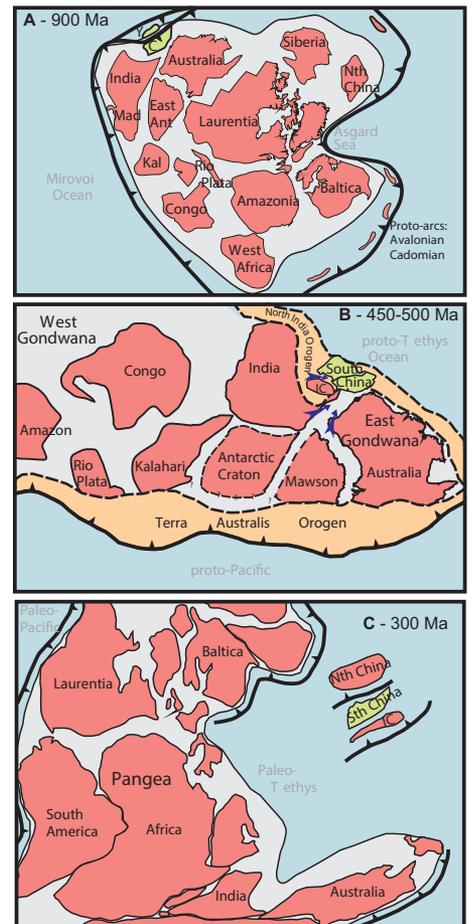


Figure 4. Series of schematic paleogeographic reconstructions showing position of South (Sth; Nth—North) China craton. **A:** Rodinia ca. 900 Ma. Mad—Madagascar; Kal—Kalahari; Ant—Antarctica; C—Cathaysia. **B:** Gondwana ca. 500–450 Ma. IC—Indochina. **C:** Pangea ca. 300 Ma. Gondwana reconstruction is adapted from Cawood and Buchan (2007), and Pangea reconstruction is adapted from Metcalfe (2011). Y—Yangtze.

from 1000 to 820 Ma. Their Neoproterozoic age and convergent plate margin setting argue against the craton occupying an intracratonic setting between Australia and Laurentia during collisional assembly of Rodinia at the end of the Mesoproterozoic. Subduction on the margin of an already assembled Rodinia, as represented by the South China craton arc systems, may have developed in response to the loss of convergent plate margins following collisional suturing of the constituent blocks of Rodinia (Cawood and Buchan, 2007). Furthermore, the presence of multiple arc systems indicates that the Cathaysia and Yangtze blocks of the South China craton did not constitute two preformed, separate entities that subsequently assembled along a single suture zone (Sibao or Jiangnan orogen), but rather represent a series of discrete lithotectonic units (terrane) accreted onto the margin of an already formed Rodinia (Fig. 4A). The

termination of convergent plate margin activity in the South China craton in the mid-Neoproterozoic corresponds with a change to regional extension (e.g., Nanhua rift) and the breakup of Rodinia, perhaps reflecting a global adjustment to plate kinematics. Siliciclastic units within an early Paleozoic succession that transgresses across the craton were derived from the southeast and include detritus from beyond the current limits of the craton. Detrital zircon age spectra from sandstone units indicate an East Gondwana source that included Western Australia–Antarctica and northeastern Indian rock units (Fig. 4B). The link to Gondwana argues against any models invoking the South China craton as occupying a separate plate that rifted off the supercontinent or formed part of Laurentia. The inferred location of South China at the nexus between Western Australia and northern India means that it was along strike from, and could thus represent a preserved fragment of, greater India lithosphere, which elsewhere has been lost due to India–Asia collision. Its preservation reflects separation from Pangea in the late Paleozoic and drifting across the Tethys Ocean prior to accretion onto the North China craton and establishment near its current location within Asia (Fig. 4C).

ACKNOWLEDGMENTS

We thank the Natural Environment Research Council (grant NE/J021822/1) and the National Natural Science Foundation of China (grants 40825009, 41190070, 41190073, and 41272120) for funding support. Reviews by Paul Hoffman, Brendan Murphy, and an anonymous reviewer are gratefully acknowledged.

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Manuscript received 16 January 2013

Revised manuscript received 3 April 2013

Manuscript accepted 4 April 2013

Printed in USA