TECTONICS OF THE SOUTH CHINA BLOCK

INTERPRETING THE ROCK RECORD

Zheng-Xiang Li
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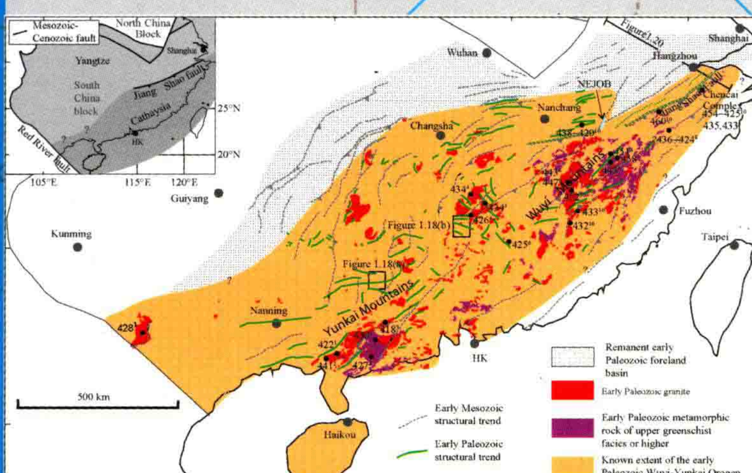

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Brief information

South China experienced an unusually complex tectonic history, and featurs a series of globally significant, and well-preserved geological records. These include records of the assembly and breakup of the Neoproterozoic supercontinent Rodinia, Rodinia- and Pangea-age mantle plume events, Neoproterozoic glacial events, early complex life, large intraplate orogenic and magmatic events, extinction events around the P-T boundary, continental subduction and exhumation, and record of the transition from an Andean-type active margin to the present-day Western Pacific-type active margin. These features make South China one of the few natural laboratories for studying fundamental geoscience problems and testing various theories and hypotheses.

Professor Zheng-Xiang Li and his multinational collaborative team have been working on the tectonic evolution of the South China Block for over 25 years. Their work challenged some traditional views, yet some of their new interpretations remain controversial amongst contemporary researchers. This book provides readers a summary of their views on the tectonic evolution of South China, and evidence that their interpretations were based on. It also provides a well illustrated eight-day field program in which the authors attempt to unravel the tectonic history of eastern South China through the examination of a series of carefully selected field traverses and outcrops. This latter part of the book can also serve as materials for field workshops or short courses on tectonic analysis using multidisciplinary field observations and analytical results.

The book is designed for researchers of all levels and senior geoscience students.

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Preface

South China is the cradle of Chinese geology, where almost a century ago scientists both from within China and the west started ground breaking geological mapping, leading to the first understanding of the geological history of the region. Systematic 1:200,000 geological mapping was completed almost half a century later. The quality of that monumental work is such that those maps still serve as the solid foundation for geological research and resource exploration in the region today.

South China experienced an unusually complex tectonic history, featuring repeated orogenic and magmatic reworking since Neoproterozoic time. Partly due to this complex history, tectonic interpretations for the region have remained controversial. Nonetheless, some unique features found in the geological record of South China have brought the region to the global geoscience community's attention for the past decades, which in-turn enhanced the geoscience research in the region, and led to significant advances in fundamental geoscientific knowledge. These features include a possible record of supercontinent assembly and breakup events (timing, configuration, and mechanisms), repeated mantle plume events (possible superplume events, supercontinent-superplume coupling and plume generation — geodynamics), Neoproterozoic glacial record (the Snowball Earth hypothesis), a superb record of early complex life, large intraplate orogenic and magmatic events (far-field effects of continental collision, flat-subduction and foundering), P-T boundary and extinction events, and continental subduction and exhumation. These features thus make South China one of the few natural laboratories for the study of a range of fundamental geoscience problems and a testing ground for a range of globally-significant theories.

This book is designed to serve as a starting point for people wanting to better understand the tectonic evolution of South China, with a particular emphasis on eastern South China. It starts with a tectonic overview (Part 1, mainly authored by Zheng-Xiang Li) that summarizes some of the recent advances in tectonic research in the region, from its basement composition, to its assembly in the late Precambrian, and major tectonic events in the Phanerozoic. Local to regional observations are interpreted in the context of the broader-scale tectonic background.

Part 2 of the book, contributed by all authors, is an attempt to examine some of the tectonic theories and hypotheses, as summarized in Part 1, through an eight-day traverse in eastern South China, including information about selected outcrops and related analytical results. Readers can refer back to Part 1 for tectonic interpretations and key references for alternative tectonic models. This part is also designed that it can serve as a guide book for either organized field workshops or self-guided geological tours. Daily exercises at the back of each day's program are designed for training research students to construct time-space diagrams and use them for terrane and regional tectonic analyses. A Chinese version of Part 2 is provided as an appendix.

We are grateful to everyone who collaborated with us over the past decades on South China research, or assisted with fieldtrips and data analyses. In particular, we wish to thank Professors Wuxian Li, Jian Wang, Shihong Zhang, Yigang Xu, and Mr Chaomin Bao for their support and cooperation, and Dr Nick Timms for proof-reading the manuscript.

Authors
17 October, 2013

Contents

PART 1

A TECTONIC OVERVIEW OF THE SOUTH CHINA BLOCK

The South China Block (SCB) is bounded by the Qinling-Dabie-Sulu orogenic belt to the north, the Longmenshan Fault to the northwest, the Red River Fault to the southwest, and the continental slope of the East and the South China seas to the southeast, with a possible extension to the Korean Peninsula (Figure 1.1). The northwestern portion of the SCB is widely

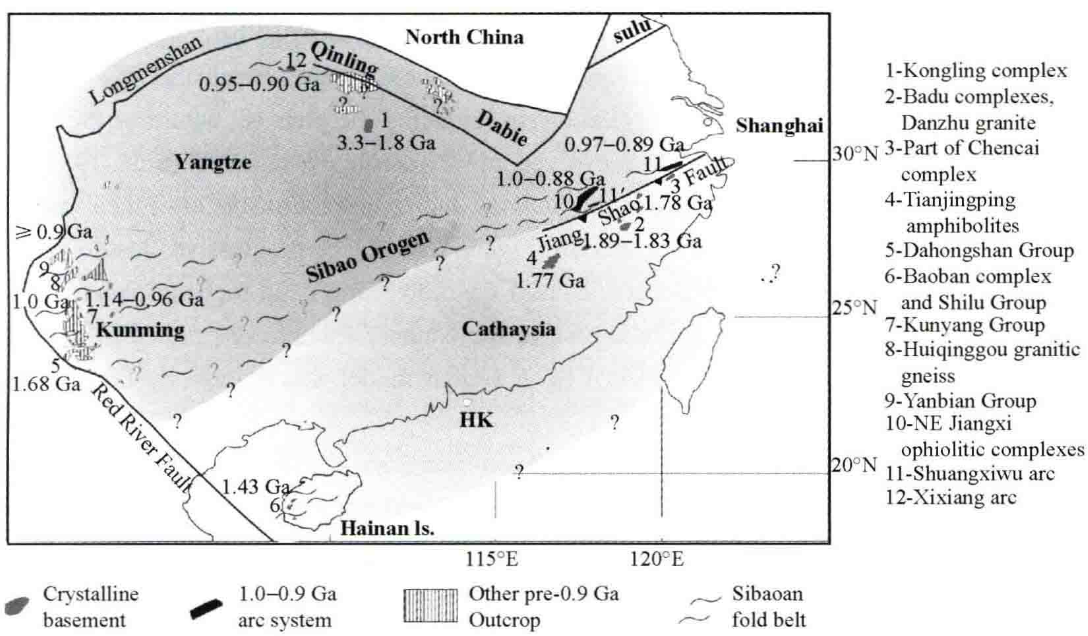

Figure 1.1 Tectonic framework of the South China Block, emphasizing pre-0.9 Ga (900 Ma) records (modified after Li Z X et al., 2007)

Sources for precisely dated rocks are: ① the Kongling Complex (Jiao et al., 2009; Qiu et al., 2000; Zhang et al., 2006; Gao et al., 2011), ② Badu magmatic and metamorphic complexes (Li and Li, 2007; Xiang et al., 2008; Yu et al., 2009), ③ central Chencai Complex (Li Z X et al., 2010), ④ the Tianjingping amphibolites (Li, 1997), ⑤ the Dahongshan Group (Hu et al., 1991; Greentree and Li, 2008), ⑥ the Baoban Complex and the Shilu Group (Li Z X et al., 2008a), ⑦ the Kunyang Group (Greentree et al., 2006), ⑧ the Huiqinggou granitic gneiss (Li Z X et al., 2002), ⑨ the Yanbian Group (Li et al., 2006b), though Sun W H et al. (2009) suggested a slightly younger age, ⑩ the NE Jiangxi ophiolitic complexes (Chen et al., 1991; Li et al., 1994; Li and Li, 2003; Li W X et al., 2008a), ⑪ the Shuangxiwu arc (Ye et al., 2007; Chen et al., 2009; Li et al., 2009), and its southwest extension, the Tianli Schists (Li et al., 2007), ⑫ the Xixiang arc (Ling et al., 2003) accepted as a coherent Yangtze Block/Craton with some Archean basement. However, controversy still remains regarding the timing of collision between the Yangtze and the Cathaysia blocks, and the composition of the Cathaysia Block.

➢1.1 A brief reappraisal of tectonic models for southeastern SCB developed before the 1990s

The dominant tectonic model before the 1980s suggests that southeastern South China Block was an early Paleozoic fold belt developed over a miogeosyncline (now a disused term), recognizing the strong imprint of the Ordovician-Silurian orogenesis on thick volcanic-sedimentary successions in the region (Huang et al., 1980; Ren, 1991). The reason for proposing a miogeosyncline was that no early Paleozoic ophiolite complex had been documented in the region (this remains the case today).

An alternative model, first proposed by Grabau (1924) and attracted renewed interests since the 1980s (Shui, 1987), recognizes the existence of Precambrian basement in various parts of southeastern South China and the continental shelf, and calls the coastal region the Cathaysia paleocontinent, or more commonly known as the Cathaysia Block.

These two concepts are not mutually exclusive regarding the physical nature of the basement of the coastal region. These models evolved into a remnant ocean model (Shui, 1987), in which a remnant ocean existed between the Yangtze and Cathaysia blocks after their eastern ends first touched during the late Precambrian (Figure 1.2(a)). The progressive closure of this remnant ocean during the early Paleozoic caused the deformation and metamorphism in the region (Figure 1.2(b), (c)), commonly known in the Chinese literature as the "Caledonian" orogeny (see an updated view in Section 1.6). A similar model was adapted by Liu and Xü (1994).

Other, more radical models have also been developed since the late 1970s. These include arc/terrane accretion models which suggest that the southeastern half of the SCB was formed through successive accretion of arcs and continental terranes younging toward the coast, from the Mesoproterozoic to as young as the Mesozoic (Qiao and Geng, 1981; Guo et al., 1986; Li, 1992).

Hsü and his Chinese colleagues (Hsü et al., 1988; Hsü et al., 1990), recognizing the widespread Mesozoic thrusting in southeastern South China, proposed a two-plate Alps-style tectonic model involving the closure of a Mesozoic ocean between the Yangtze Block and a coastal terrane they called the Huanan Block (Figure 1.2(d), (e)). This model triggered one of the most heated debates on the tectonic history of south China. Although Hsü (1994) subsequently conceded that the key "Mesozoic Banxi mélange", upon which their two-plate model was based, is likely to be of late Precambrian age, he still insisted on the existence of a Mesozoic ocean-closure between the two plates.

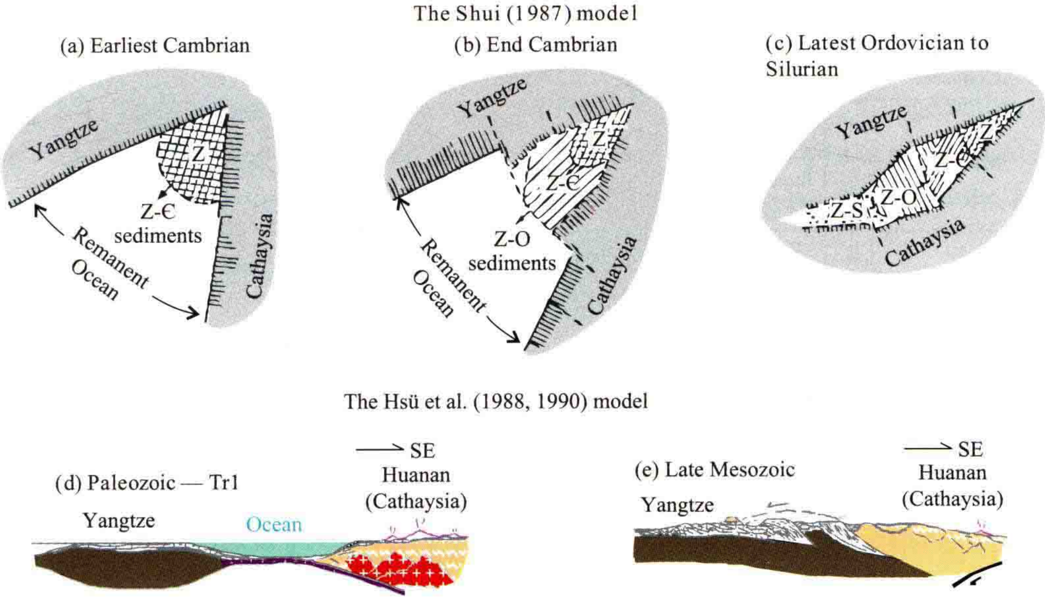

Figure 1.2 Schematic diagrams showing two early tectonic models for South China, modified from the original work by the proponents of each model

A common issue for many of the proposed models is that no reliable geological record exists for active margins in the continental interior since at least the end of the Precambrian. In addition, the distribution of sedimentary facies in South China (Liu and Xü, 1994) exhibits coherent patterns across the proposed Mesozoic sutures since at least the Devonian (Li, 1998).

A resurgence of investigations since the 1990s has seen a rapid accumulation of more systematic and reliable geochronology, geochemistry, and basin analysis results, and revision of the tectonic models in regional or global contexts. Some of these models will be explored/documented in the following sections.

➢1.2 A cartoon time-space diagram summarising major events that shaped the SCB

Figure 1.3 illustrates that distinct pre-Neoproterozoic tectonic histories were recorded by the Yangtze and Cathaysia blocks, and the two blocks started to share a common tectonomagmatic and basin record from the Neoproterozoic.

Major events include :

(1) Late Mesoproterozoic to early Neoproterozoic Sibao/Jiangnan Orogeny (1300–1200 Ma to 880 Ma) leading to the formation of the united SCB;

(2) Mid-Neoproterozoic (850–720 Ma) continental rifting and magmatism (Nanhua, Kangdian and Bikou-Hannan rift basin development), with a failed continental rift basin (the Nanhua Basin) remaining at the end of the Neoproterozoic;

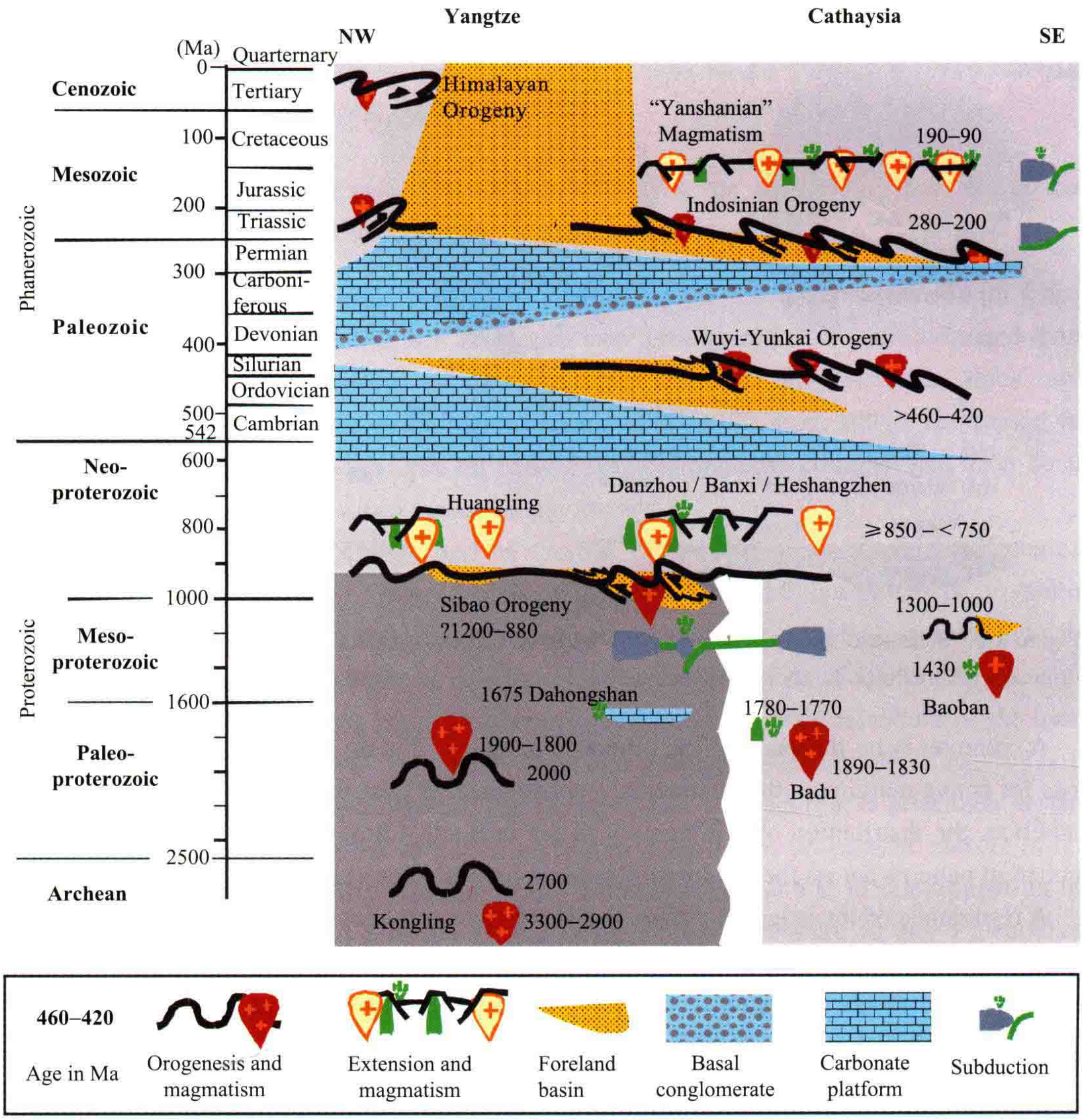

Figure 1.3 A schematic diagram illustrating the timing of major tectonic events in South China

(3) Early Paleozoic Wuyi-Yunkai Orogeny that started from the Cathaysia Block and advanced toward the Yangtze Block, accompanied by widespread, mostly late orogenic magmatism;

(4) Late Paleozoic development of platform cover sequence across the SCB, featuring a marine transgression started from the western side of the continent;

(5) Permo-Triassic Indosinian Orogeny, syn- to late-orogenic sag basin development, and post-orogenic ("Yanshanian") extension and magmatism;

(6) Development of the Sichuan Basin as a three-sided foreland basin since the Mesozoic;

(7) Impact of the Himalaya Orogeny and the opening of the South China Sea in the Cenozoic.

Multiple models exist to explain the cause of most of these events. Even the age ranges of some of the events are controversial. In the following sections, we will give our preferred account of some of the major events based on both field observations and analytical results, and will only briefly touch on some of the alternative interpretations. Please refer to original papers for more complete discussions of the various models.

➤1.3 Pre-1 Ga basement compositions

Outcrops of pre-Neoproterozoic crystalline basement are scarce in South China, with the oldest being the Kongling Complex in the Yangtze Block ("1" in Figure 1.1), which has ca. 3.3–3.2 Ga and 2.95–2.90 Ga igneous (including trondhjemitic) rocks that experienced ca. 2.75 Ga high-grade metamorphism, and 1.9–1.8 Ga granitic intrusions (Qiu et al., 2000; Zhang et al., 2006; Jiao et al., 2009; Gao et al., 2011). Paleoproterozoic rocks were thought to exist along the western margin of the Yangtze Block (e.g., the Kangding Complex), but recent dating indicate that they are either metamorphosed ca. 1000 Ma sediments (Li Z X et al., 2002), or ca. 800–745 Ma intrusions (Zhou et al., 2002b; Li Z X et al., 2003a). The 1.68 Ga Dahongshan Group metavolcanic-sedimentary succession is found in the southwestern corner of the Yangtze Block only ("5" in Figure 1.1; Greentree and Li, 2008; Hu et al., 1991), and more 1.7–1.5 Ga rocks have recently been reported in nearby regions (Sun W H et al., 2009; Zhao et al., 2010; Fan et al., 2013). Sedimentary protolith of the Tianli Schists, with an deposition age no older than its youngest detrital zircon population of 1530 Ma, is also thought to have formed on the southern margin of the Yangtze Block during late Mesoproterozoic ("11" in Figure 1.1; Li Z X et al., 2007).

There have been documented differences in the isotopic signatures between the Yangtze and the Cathaysia blocks (e.g., Chen and Jahn, 1998, Figure 1.4). However, the exact boundary between the two, particularly over the western half of the SCB, remains unclear. In eastern SCB, the early Neoproterozoic Shuangxiwu arc and its extension to the Tianli Schists ("11" and "11′" in Figure 1.1 Li Z X et al., 2007; Ye et al., 2007; Li et al., 2009b) likely mark the southern margin of the Yangtze Block.

Although Archean detrital zircon grains have been reported from Cathaysian rocks in numerous studies (Li, 1997; Wan et al., 2007; Xu et al., 2007; Yu et al., 2009; Li Z X et al., 2010), no Archean rock has been identified so far. The oldest known crystalline rocks are the ca. 1.9–1.8 Ga granitic rocks and basalts (metamorphosed to amphibolite facies) in western Zhejiang ("2" and "3" in Figure 1.1) and northwestern Fujian ("4" in Figure 1.1). On the Hainan Island, granites and metavolcaniclastic rocks are dated at ca. 1.43 Ga ("**6**" in Figure 1.1; Ma et al., 1998; Li Z X et al., 2002; Li Z X et al., 2008a). There are other widespread, mostly high-grade metamorphic rocks in northeastern Cathaysia (regions between "3" and "4" in Figure 1.1) that were thought to be part of the Precambrian crystalline basement of Cathaysia, but recent SHRIMP work indicate that they are Neoproterozoic rift successions metamorphosed during the Phanerozoic (Wan et al., 2007; Li Z X et al., 2010).

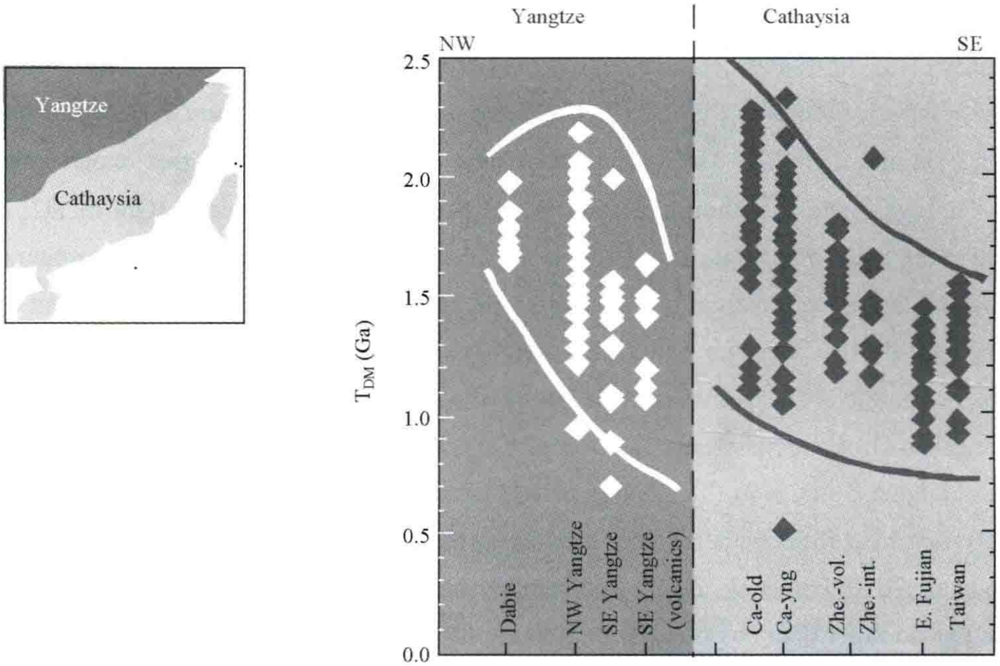

Figure 1.4 Nd model age (T_{DM}) of igneous rocks in South China (after Chen and Jahn, 1998)

Ca – Cathaysia; Zhe. – Zhejiang

➢1.4 Mesoproterozoic to earliest Neoproterozoic Sibao Orogeny: Part of Rodinia assembly?

Most researchers now accept that the Yangtze and Cathaysia blocks joined together by Late Neoproterozoic time, but models differ regarding the timing of this amalgamation and how it occurred. One group suggests that the amalgamation occurred diachronously, first at the SW-ends of the two continental blocks at ca. 1140 Ma (Greentree et al., 2006; Li Z X et al., 2002), and eventually at the NE-ends of the two blocks by 900–880 Ma (Li Z X et al., 2007; Li W X et al., 2008a; Li et al., 2009). In the western Sibao Orogen (also known as the Jiangnan Orogen), the first evidence of sedimentary provenance linkage between the two blocks is the appearance of detrital zircons of possible Cathaysia origin in part of the traditionally defined Kunyang Group (the Laowushan Formation, deposition age 1142 ± 16 Ma, "7" in Figure 1.1; Greentree et al., 2006). Siliciclastic rocks with likely Cathaysia contributions were also found in ca. 1000 Ma sediments in southern Sichuan ("8" in Figure 1.1), where a 1007 ± 14 Ma granitic gneiss was also found (Li Z X et al., 2002). A post-orogenic granodiorite dated at 857 ± 13 Ma (Li X H et al., 2003b) provides the younger age limit for the orogenic events there. On the Cathaysia side, ca. 1300–1000 Ma amphibolite-facies metamorphism occurred in the Hainan Island ("6" in Figure 1.1; Li Z X et al., 2002), but whether the region was part of the Sibao Orogen is still unclear.

In eastern Sibao Orogen, plutonic and volcanic rocks in the Shuangxiwu arc ("11" in Figure 1.1) have been dated at between ca. 970 Ma and 890 Ma (Chen et al., 2009; Li et al., 2009; Ye et al., 2007). The deformed arc was intruded by 849 ± 7 Ma post-orogenic Shenwu dolerite dykes (Li X H et al., 2008), and unconformably overlain by the ca. 800 Ma Luojiamen Group that is interpreted to represent Neoproterozoic rifting (Wang and Li, 2003). The Tianli Schists, a possible SW-extension of the Shangxiwu arc ("11" in Figure 1.1), recorded metamorphism and structural reactivations between ca. 1040 Ma and 940 Ma (Li Z X et al., 2007), and is unconformably overlain by 827 ± 14 Ma bimodal rift magmatism (Li W X et al., 2008b). The NE Jiangxi ophiolitic complexes ("10" in Figure 1.1; Zhou, 1989) started to form at ca. 1000–970 Ma (Chen et al., 1991; Li et al., 1994; Li and Li, 2003) and were obducted at ca. 880 Ma (Li W X et al., 2008a). Sibaoan arc complexes (⩾900 Ma) also exist along the northern margin of the Yangtze Block ("12" in Figure 1.1; Ling et al., 2003).

Meso- to Neoproterozoic orogenic events in South China thus appear to have an age range of 1300–880 Ma, with much of the suturing between the Yangtze and Cathaysia blocks occurred after ca. 1000 Ma (Figure 1.5). Worldwide orogenic events of this time interval, which are often referred to as "Grenvillian" orogenic events but in places lasted longer than the classic Grenville Orogeny in Laurentia (Davidson, 1995; Rivers, 1997), are believed to be responsible for the assembly of the Neoproterozoic supercontinent Rodinia (Dalziel, 1991; Hoffman, 1991; Moores, 1991; Li Z X et al., 2008b).

Recognising the similarity of the Cathaysia crustal provinces with that of southern Laurentia, and the requirement for a western source region similar to Cathaysia for upper Belt Basin deposits (Ross et al., 1992), Z. X. Li and co-workers (Li Z X et al., 1995b, 2002, 2008a, 2008b) suggested that the Cathaysia Block was part of southwestern Laurentia (Figure 1.6), and that the Sibao Orogeny led to the suturing between Laurentia-Cathaysia and the Yangtze Block (Figure 1.5) during the final assembly of Rodinia (Figure 1.7(a), (b)). Such a configuration is consistent with comparable Neoproterozoic rift histories and plume activities between Australia, South China and western Laurentia (see next section). It also provides an answer for geological mismatches in the classic SWEAT configuration for Rodinia (Borg and DePaolo, 1994), because it has Sibaoan sutures between Australia-East Antarctica and Laurentia. The reconstructions as in Figure 1.7(a), (b) are consistent with currently available paleomagnetic results (see reviews in Li Z X et al., 2008b).

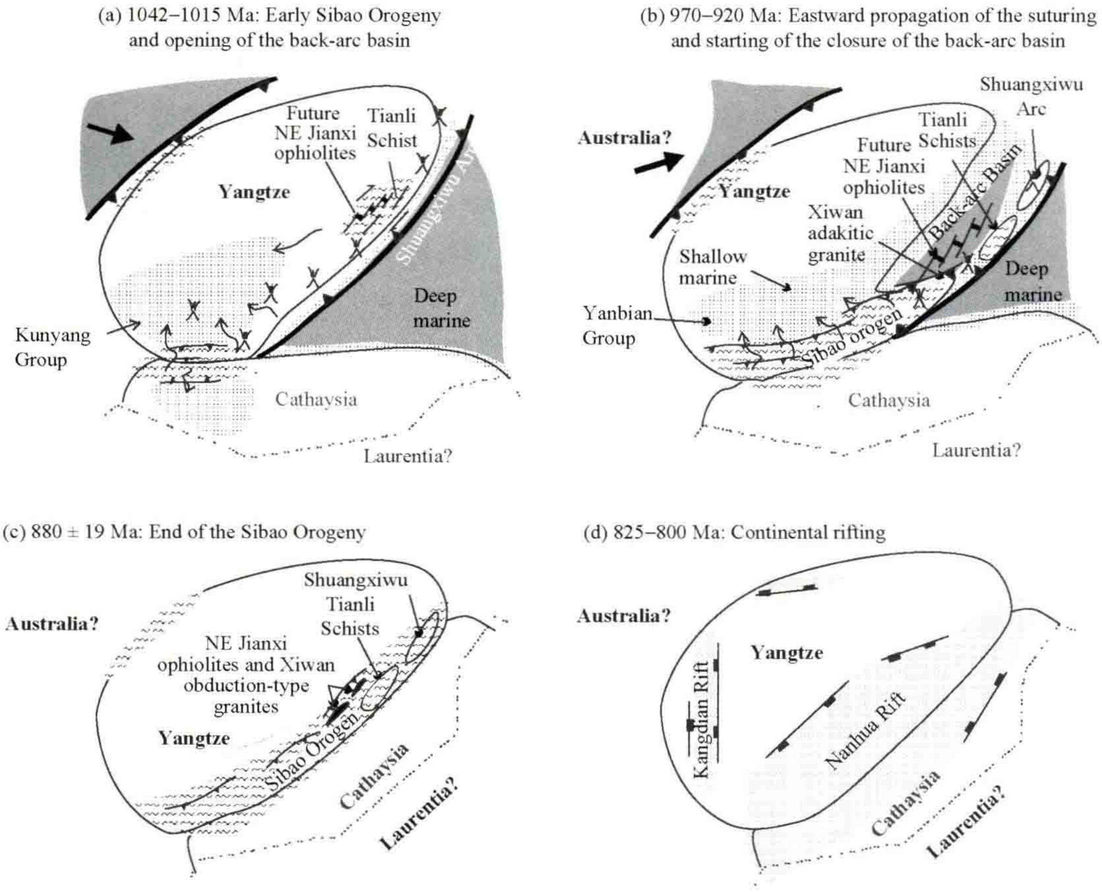

Figure 1.5 A schematic diagram illustrating a possible process of amalgamation between the Yangtze and Cathaysia blocks and the change of tectonic regime into an extensional environment by ca. 850 Ma (Li Z X et al., 2007; Li et al., 2009)

There are also other current tectonic models that imply a ca. 820–800 Ma age for the amalgamation between the Yangtze and Cathaysia blocks (Li, 1999; Zhao and Cawood, 1999; Wang et al., 2006; Wu et al., 2006) or even younger (Zhou et al., 2002b). However, all these models suffer from the lack of post-890 Ma typical arc magmatism, the lack of post-880 Ma metamorphic event related to such a convergent event, and the wide occurrence of ≤850 Ma continental rifting and plume magmatism (see next section).

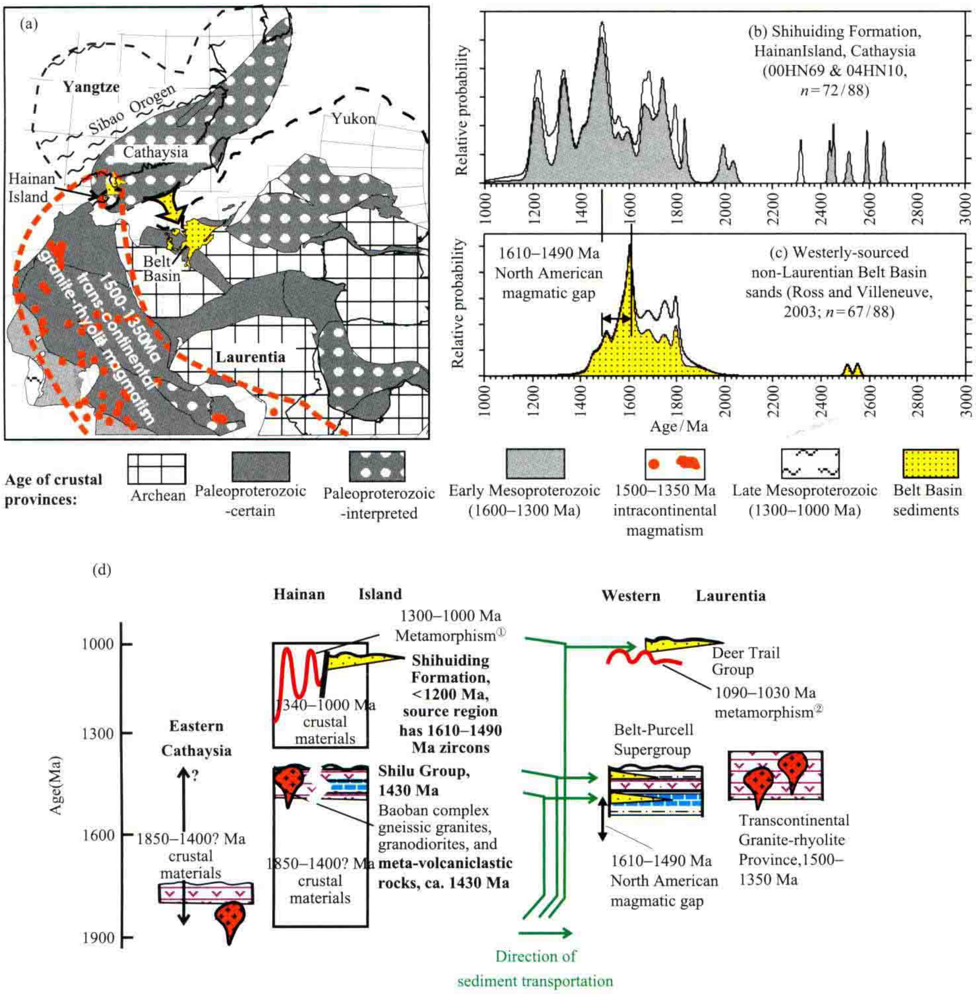

Figure 1.6 (a) Correlations of crustal provinces between Laurentia and Cathaysia (Li Z X et al., 2008a). Rotated present-day coordinates are shown in 5° intervals (thin doted lines); (b), (c) show the correlation of detrital provenance data between Hainan Island of Cathaysia and the westerly-sourced non-Laurentian sands in the Belt Basin of western Laurentia (south-west North America); (d) A schematic diagram illustrating sedimentary provenance linkages and tectonostratigraphic correlations between Mesoproterozoic Hainan Island and south-western Laurentia. The Cathaysia Block is interpreted as a source of sediments for westerly-derived sand wedges in western Laurentia

Data sources: ① Li Z X et al. (2002); ② Anderson and Davis (1995)

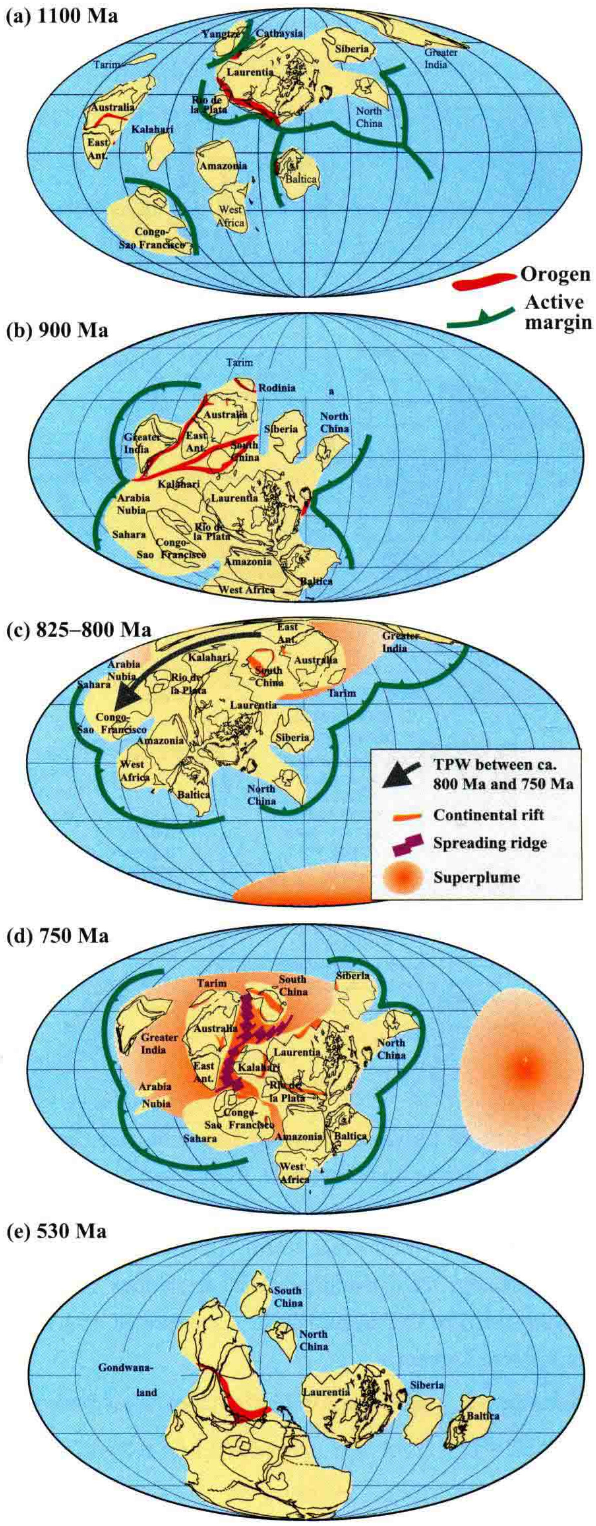

Figure 1.7 The formation and breakup of Rodinia during late Precambrian, and the formation of Gondwanaland by the Early Cambrian (Li Z X et al., 2008b)