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FROM RODINIA TO GONDWANALAND: A TALE OF DETRITAL ZIRCON PROVENANCE ANALYSES FROM THE SOUTHERN NANHUA BASIN, SOUTH CHINA

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ABSTRACT. The paleogeographic positions of the South China Block (SCB) during the Neoproterozoic and early Paleozoic are important for understanding the transition from the break-up of the supercontinent Rodinia to the formation of Gondwanaland. Integrated *in situ* U-Pb ages and Hf-O isotope analyses of detrital zircons from Cambrian sedimentary rocks in the southwestern SCB reveal major age populations at 2500 Ma, 1100 to 900 Ma, 850 to 750 Ma and 650 to 500 Ma, with a predominant group at ~980 Ma that counts for ~50 percent of all analyses. Zircon Hf-O isotopic results suggest three Precambrian episodes of juvenile crustal growth for the source area(s) (3.0 Ga, 2.5 Ga and 1.0 Ga), with major crustal reworking at 580 to 500 Ma. The source provenance as defined by the U-Pb and Hf analyses is distinctly different from the known tectonomagmatic record of the SCB, or that of western Australia or western Laurentia, but matches well with that of the Ediacaran (latest Neoproterozoic)–Cambrian clastic sedimentary rocks and granitic intrusions in the NW Indian Himalaya. The SCB–NW India provenance linkage appears to have started from the Ediacaran. We propose that after breaking away from central Rodinia, the SCB collided with NW India during the Ediacaran–Ordovician time, causing the "Pan-African" Kurgiakh/ Bhimphedian orogeny at the northern margin of India as well as the intraplate Wuyi-Yunkai orogeny (>460 Ma – 415 Ma) in South China. The Ediacaran–lower Paleozoic clastic sedimentary rocks in the Nanhua Basin are therefore interpreted to be foreland deposits formed during the collision of the SCB with Gondwanaland.

Key words: Detrital zircon, Cambrian, Cathaysia Block, South China, North India, Rodinia, Gondwanaland

INTRODUCTION

The South China Block (SCB; fig. 1A inset) has featured prominently in studies of Earth history during the Precambrian-Cambrian transition, including the Neoproterozoic extreme global paleoclimate (for example, Jiang and others, 2003), the rapid explosion of complex life (for example, Zhu and others, 2007), and the closely linked issue of global paleogeography between the break-up of the Neoproterozoic supercontinent Rodinia and the formation of Gondwanaland (for example, Hoffman, 1991; Z. X. Li and others, 1996; Zhou and others, 2002). It has been suggested that the Cathaysia Block of the SCB was once connected to western Laurentia during the Mesoproterozoic, and joined with the Yangtze Block and Australia by *ca.* 900 Ma to become a central part of the early Neoproterozoic supercontinent Rodinia (Z. X. Li and others, 2008a). The coherent SCB broke away during the break-up of Rodinia in the mid- to late-Neoproterozoic (750-650 Ma), and then drifted toward the margin of eastern Gondwanaland by the Cambrian (Z. X. Li and others, 1996; Z. X. Li and Powell, 2001). Alternatively, it has been suggested that the SCB started its western

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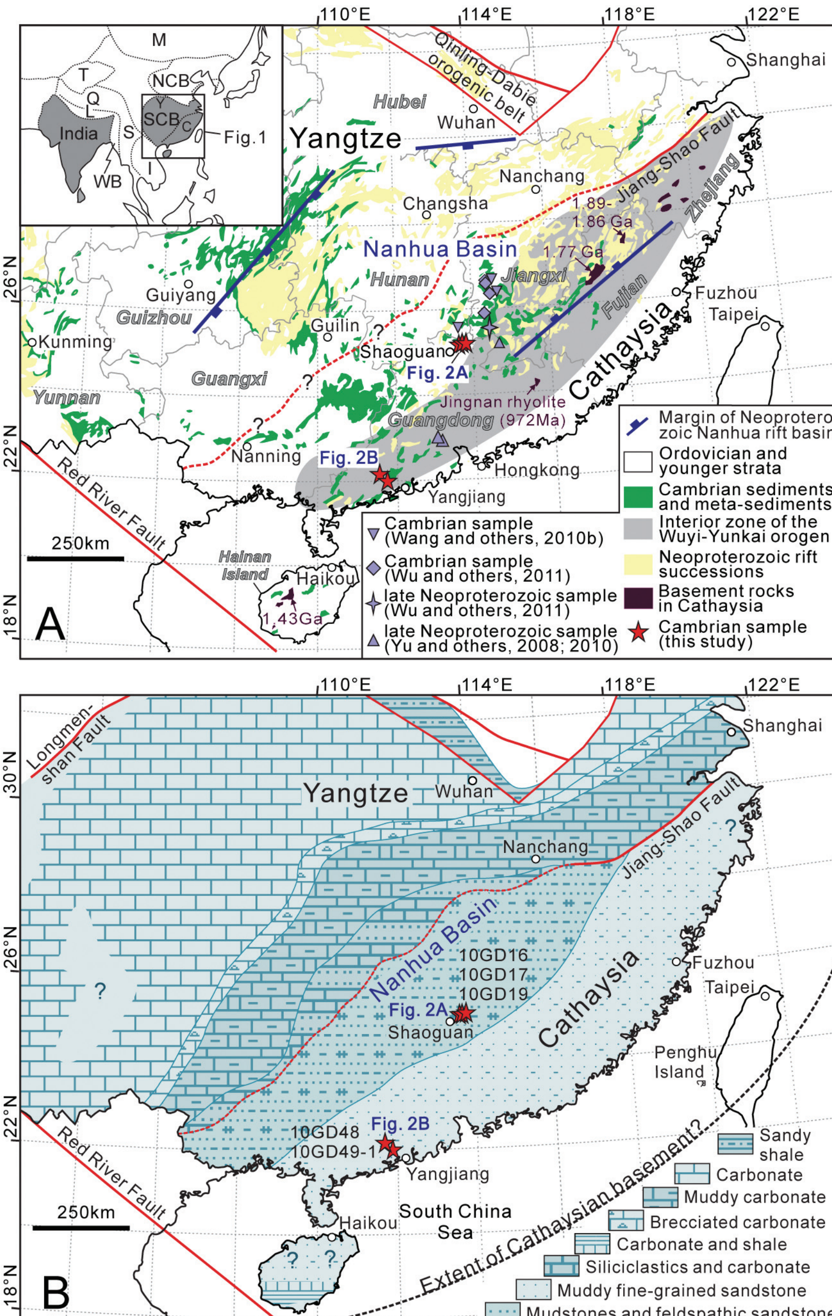

Fig. 1. (A) Distribution of Precambrian and Cambrian rocks in the South China Block (SCB) and sample locations for both this study and previous studies. Inset figure in figure 1A shows the current geographic sketch of major continental blocks/terranes in the Southeast Asia. In which: NCB—North China Block, SCB—South China Block, Y—Yangtze, C—Cathaysia, M—Mongolian terrane, T—Tarim, L—Lhasa, S—Subumasu (including the Qiangtang terrane, shown as "Q"), I—Indochina, WB—West Burma. (B) Mid- to late-Cambrian paleogeographic map of the SCB (revised after Wang, 1985 and Liu and Xu, 2004) with sample locations for this study. Some facies boundaries are truncated by younger thrust faults (red lines).

Australia-northern India connection since Rodinia time or earlier (Zhang and Piper, 1997; Jiang and others, 2003; Yang and others, 2004; Yu and others, 2008; Cawood and others, 2013), or was on the margin of northwestern Australia at that time (Zhou and others, 2002, 2006; Wang and others, 2004). The main reason for the existence of such diverse views is the current poor knowledge of the Precambrian evolution of the Cathaysia Block and that of the SCB in general, due to its extensive Phanerozoic reworking and poor outcrops of basement rocks (for example, Gan and others, 1995; X. H. Li, 1997; Chen and Jahn, 1998; Wan and others, 2007; Xu and others, 2007; Yu and others, 2010).

Detrital zircons from siliciclastic sedimentary rocks have proven to provide a good record of geological information about their source regions (for example, Barth and others, 2000; Neves, 2003). U-Pb age spectra of such detrital zircons can indicate provenance characteristics, including possible magmatic events that the source region experienced and affinity with other terranes/blocks (for example, Condie and others, 2009; Zhu and others, 2011). *In situ* Hf-O isotopic results for detrital zircons can further reveal tectonothermal events involving either mantle input to existing continental crust and/or reworking of pre-existing crustal materials (for example, Griffin and others, 2004; Hawkesworth and Kemp, 2006; Kemp and others, 2006; Belousva and others, 2010). Integrated detrital zircon U-Pb ages and Hf-O isotopic analyses have therefore become a powerful tool for deciphering the evolution of continental crust (for example, Zhang and others, 2006; Condie and others, 2009), for reconstructing continental block/terrane assemblages (for example, Stewart and others, 2001; Zhu and others, 2011)—particularly for terranes like the Cathaysia Block where basement bedrock is poorly exposed, and for analyzing transportation processes and provenance mixing (Zhang and others, 2012).

In this study, we report detrital zircon U-Pb ages and Hf-O isotopes for Cambrian marine sandstones/metasandstones that were deposited in Guangdong Province, western Cathaysia (fig. 1). Together with published detrital zircon U-Pb/Hf data of latest Neoproterozoic (Ediacaran)–Cambrian clastic sedimentary rocks from nearby regions, these data offer new insights on the late Precambrian to early Paleozoic tectonic evolution of the SCB and shed light on its interactions with other continents from the break-up of Rodinia to the assembly of Gondwanaland.

Geological Background and Sampling

The SCB, consisting of the Yangtze Block in the northwest and the Cathaysia Block in the southeast, is bounded by the Mesozoic Qinling-Dabie-Sulu orogenic belt to the north, the Mesozoic-Cenozoic Longmenshan orogenic belt to the northwest, the Cenozoic Red River Fault to the southwest, and the Cenozoic continental slope of the East and South China seas to the southeast (fig. 1). The present boundary between the Yangtze and Cathaysia blocks in eastern South China is approximately the northeasterly trending Jiang-Shao Fault (fig. 1A). However, the southwestern extension of this boundary is unclear due to poor exposure and tectonic modifications (Ren, 1991; Z. X. Li and others, 2010).

The Yangtze and Cathaysia blocks exhibit different pre-Neoproterozoic crustal growth histories with contrasting crystalline basement rocks. The Yangtze basement consists predominantly of Proterozoic rocks with minor outcrops of Archean rocks found in the Kongling Complex in northern Yangtze (locally known as the Kongling "Group," dated at *ca.* 3.3 to 3.2 Ga and *ca.* 2.95 to 2.90 Ga; Qiu and others, 2000; Zheng and others, 2006; Jiao and others, 2009; Gao and others, 2011). Along the southeastern Yangtze margin, scattered outcrops of Mesoproterozoic metasedimentary rocks ($\leq$1.53 Ga) that experienced 1.04 to 0.94 Ga metamorphism/reworking (Z. X. Li and others, 2007), and some 1.16 to 0.88 Ga magmatic rocks (Ye and others, 2007; W. X. Li and others, 2008; X. H. Li and others, 2009; L. Li and others, 2013), are present. More widespread outcrops of *ca.* 1.7 to 0.9 Ga volcanic and sedimentary rocks, or their metamorphosed equivalents, are found along the southwestern Yangtze margin (Z. X. Li and others, 2002; Greentree and others, 2006; Greentree and Z. X. Li, 2008; Sun and others, 2009; Zhao and others, 2010). Widespread mid- to late-Neoproterozoic igneous rocks (860-750 Ma) and volcaniclastic successions are well developed in rift basins along the Yangtze margins (for example, Zhou and others, 2002, 2006; Z. X. Li and others, 2003; X. H. Li and others, 2003; Wang and others, 2006; W. X. Li and others, 2010).

The Cathaysia Block has even less Precambrian basement exposed, with most regions covered by Phanerozoic (particularly Mesozoic) sedimentary and/or volcanic rocks. Although Archean zircons have been reported from either Cathaysian sedimentary rocks (for example, X. H. Li, 1997; Wan and others, 2007; Xu and others, 2007; Yu and others, 2009; Z. X. Li and others, 2010; Yao and others, 2011) or as xenocrysts in volcanic rocks (Zheng and others, 2011), no Archean rocks have been identified so far. The oldest known crystalline basement rocks are the *ca.* 1.89 to 1.77 Ga granites and amphibolite facies metamorphic rocks in western Zhejiang and northwestern Fujian provinces in the northeast part of Cathaysia (X. H. Li, 1997; Z. X. Li and X. H. Li, 2007; Xiang and others, 2008; Zeng and others, 2008; Yu and others, 2011). On Hainan Island in southwestern Cathaysia (fig. 1A), known Precambrian basement rocks include the *ca.* 1.43 Ga Baoban Complex gneissic granitoids, adjacent coeval Shilu Group metavolcaniclastic succession and the overlying *ca.* 1.0 Ga Shihuiding Formation metasedimentary rocks (Ma and others, 1998; Z. X. Li and others, 2002, 2008a). Mid- to late-Neoproterozoic (860-750 Ma) bimodal magmatic rocks and volcaniclastic successions (for example, W. X. Li and others, 2005; Shu and others, 2011) are also widely exposed on the Cathaysian side of the mid-Neoproterozoic Nanhua rift basin (fig. 1A).

Rifting in the mid- to late-Neoproterozoic Nanhua Basin ceased at *ca.* 700 Ma (Wang and Li, 2003), with the failed rift continuing to receive the uppermost Neoproterozoic (Ediacaran) to early Paleozoic (Cambrian) sedimentary successions (fig. 1B; BGMRJX, 1984; BGMRGX, 1985; BGMRGD, 1988; BGMRGZ, 1988; BGMRHN, 1988; Ren, 1991; Ren and others, 1997; Yu and others, 2009). However, the sedimentation patterns of the Yangtze and Cathaysia blocks during the Ediacaran–Cambrian were quite different (Liu and Xu, 1994). The Yangtze Block was dominated by the precipitation of carbonate, argillaceous carbonate/dolomite, and arenaceous carbonate, with siliciclastic intercalations found in the lower Cambrian strata in western Yangtze (BGMRGX, 1985; BGMRGZ, 1988; BGMRHN, 1988). It indicates that for much of the Ediacaran–Cambrian time the Yangtze Block was covered by shallow seas with no major elevated land areas to provide significant terrestrial detritus. In contrast, the Cathaysia Block received massive siliciclastic sedimentation (BGMRJX, 1984; BGMRGX, 1985; BGMRGD, 1988; BGMRHN, 1988), consisting of shale, siltstone, arkosic sandstone, quartz sandstone and minor pebbly sandstone (fig. 1B).

The Cambrian strata in Guangdong Province of western Cathaysia are generally referred to as the Bacun Group (BGMRGD, 1988), exhibiting marine clastic sedimentation. Its lower boundary is defined by a conformably underlying cherty unit at the top of the Ediacaran succession; this cherty unit is well developed and regionally correlatable through much of the Nanhua Basin (Liu and Xu, 1994). The upper boundary of the Cambrian strata is defined by conformably overlying Ordovician strata that contain early-Ordovician graptolites (BGMRGD, 1988; Zhang and He, 1993, and references therein). The Bacun Group in the northern Guangdong Province has been divided into three formations (Zhang and He, 1993). The bottom one is the Xiazhai Formation, consisting of quartz sandstone interlayered with carbonaceous shale and a few “stone coal” (carbon-rich rocks that can be mined as fuels) units, and exhibiting characteristics of turbiditic marine facies. No Cambrian fossil has been found from this formation. The middle Bacun Group is called the Oujiadong Formation, featuring a series of transgression sequences. This formation hosts inarticulate brachiopod fossils *Acrothele* sp., *Homotreta* cf. *venia* (Walcott) and *Obolus* sp., and sponge fossil *Protospongia* sp. (Zhang and He, 1993, and references therein). The upper Bacun Group is called the Laoshuzhai Formation, consisting dominantly arkosic sandstone with muddy shale interlayers. It contains inarticulate brachiopod fossils *Lingulella* cf. *liui* Sun, *Homotreta* cf. *venia, Obolus* sp. and *Palaeobolus* cf. *rotulus* Wang, and the sponge fossil *Protospongia* sp. (Zhang and He, 1993). The three formations have therefore been given the ages of lower-, mid- and upper-Cambrian, respectively (BGMRGD, 1988; Zhang and He, 1993).

The Cambrian strata are best preserved in northern Guangdong Province, where the clastic successions are generally non-metamorphosed, but are complexly deformed and fault-interrupted with no single succession preserving the complete Cambrian strata. Here we examined and sampled the Oujiadong succession near Shaoguan, which is the type section for the Oujiadong and Laoshuzhai formations (figs. 2A and 2C; for location see fig. 1). The lower Cambrian Xiazhai Formation is missing from this succession as the Oujiadong Formation is in fault contact with either Neoproterozoic or Devonian strata (fig. 2A) (Zhang and He, 1993). The succession is exposed along a small mountain track in a densely vegetated area. The lower part of the Oujiadong Formation consists of thick siltstone, fine-grained feldspathic quartz sandstone, and thin gray and purple mudstone. Horizontal laminations are present in muddy sedimentary rocks (fig. 2D), indicating that transport energy was not high. The middle part of the Oujiadong Formation consists of packages of fine- to medium-grained thick quartz sandstone and thin shale units, with local low-angle cross-laminations observed in sandy units (fig. 2E). Local thin cherty units (fig. 2F) are present in the upper part of the Laoshuzhai Formation, which shares similar lithological associations with the underlying Oujiadong Formation. Three sandstone samples were collected from this stratigraphic section for detrital zircon provenance analysis, with samples 10GD16 and 10GD17 from the lower and upper parts of the Oujiadong Formation, respectively. Sample 10GD19 was taken from the upper part of the Laoshuzhai Formaiton according to Zhang and He (1993).

The Bacun Group in the southwestern Guangdong Province (fig. 2B) has generally been metamorphosed to greenschist facies. Although regional lithological correlations and fossils found in the metasedimentary rocks (for example, *Lingulella* cf. *Liui, Homotreta* cf. *venia, H.* cf. *shantungenesis, Acrothele* sp., *Acrothele* cf. *asiatica,* and *Protospongia* sp.) point to a Cambrian age for the metasedimentary rocks, unequivocal stratigraphic subdivision has not been possible (RGMRGD, 1964; BGMRGD, 1988). Here we collected two meta-sandstone samples for detrital zircon provenance analysis because of the approximation of the locality to the basin margin (fig. 1B): sample 10GD48 was from a locality ~50 km northwest of Yangjiang city, and sample 10GD49-1 was from a locality ~20 km west of Yangjiang (fig. 2B).

ANALYTICAL METHODS

Sample Preparation

Mineral separation of the five samples was conducted at the Institute of Hebei Regional Geology and Mineral Survey in Langfang, China. The crushed samples were washed with water and then with alcohol to extract the denser components. Magnetic and heavy liquid separation techniques were adopted for concentrating heavy minerals. Zircon grains were hand-picked under a binocular microscope, and then mounted in epoxy resin with zircon U-Pb standards 91500 and Plešovice, and zircon oxygen standard Penglai. The mounts were polished to expose the internal structure of the

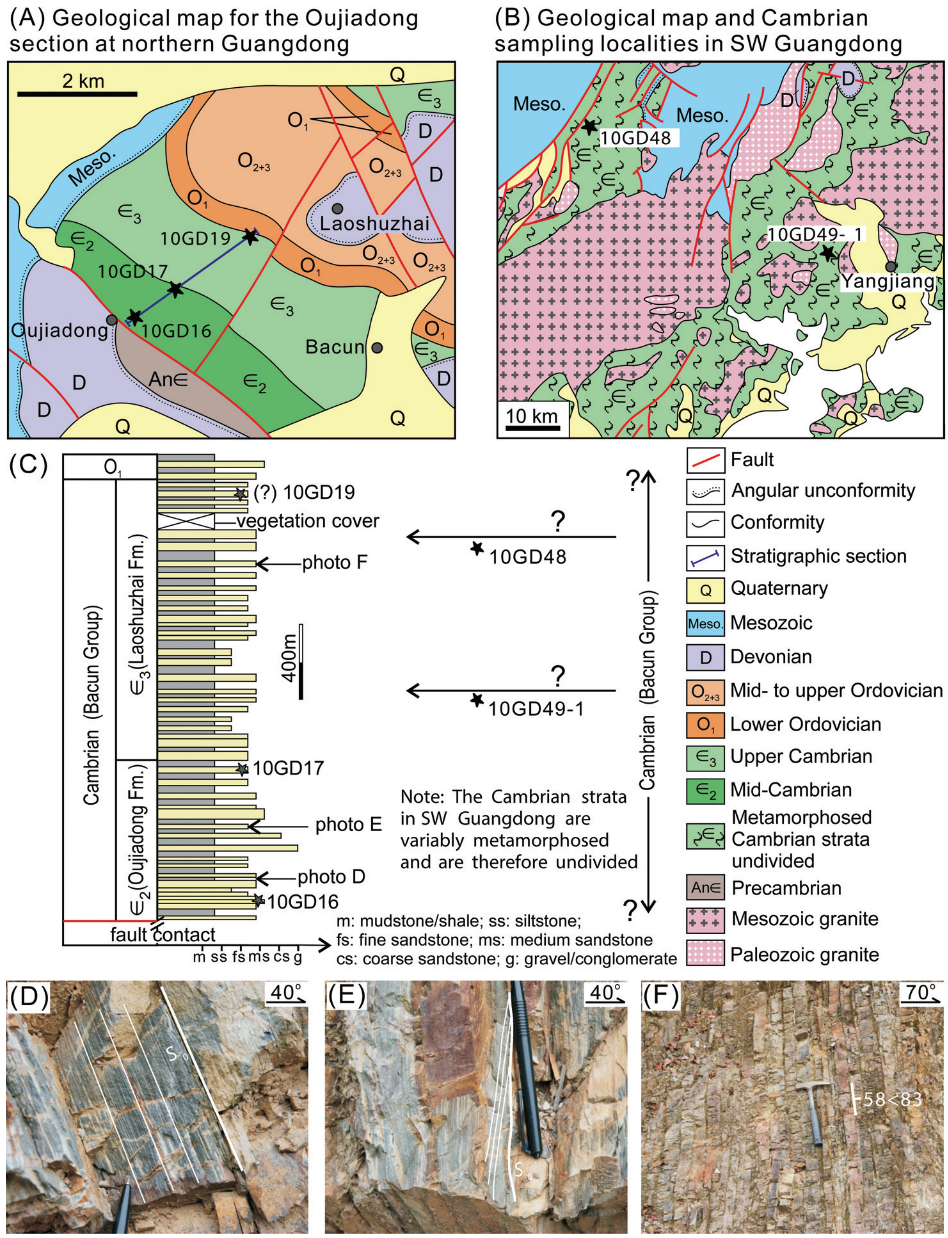

Fig. 2. (A) Regional geological map and sampling localities along the Oujiadong section near Shaoguan, northern Guangdong Province (after Zhang and He, 1993). (B) Regional geological map and sampling localities in the southwestern Guangdong Province (after RGMRGD, 1964). See figure 1 for map locations of both (A) and (B). (C) Stratigraphy of the Oujiadong section [see location in (A)] with sampling positions. Note that the stratigraphic positions of the two metasedimentary samples from southwestern Guangdong can not be precisely located. (D) Horizontal laminations in gray-black muddy shale. (E) Low-angle cross-laminations (marked as "S_1") in siltstone layers. (F) Cherty layers with high dip angles. The hammer is 28 cm in length, and the pencil is 15 cm in length, for scale.

zircon grains. We analyzed at least 100 grains for each sample. All analyzed zircon grains were imaged in transmitted and reflected light, as well as by cathodoluminescence (CL) to reveal their internal structures. For those grains with rim-core structures, we analyzed their rims only, since these ages record the most recent tectonothermal events.

Zircon U-Pb Geochronology

LA-ICP-MS U-Pb dating.—Detrital zircon analyses for samples 10GD48 and 10GD49-1 were conducted at the Institute of Geology and Geophysics (IGG), Chinese Academy of Sciences (CAS) in Beijing, using an Agilent 7500a multicollector-inductively coupled plasma-mass spectrometer (MC-ICP-MS). Each analysis included a ~30s background measurement with laser off and a ~60s measurement at peak intensity. The ablation pits were generally ~45 μm in diameter and 30 to 40 μm in depth. External zircon standards 91500 with a $^{207}U/^{206}Pb$ age of 1065.4 ± 0.6 Ma (Wiedenbeck and others, 1995, 2004) and GJ-1 with a $^{206}U/^{238}Pb$ age of 608.5 ± 0.4 Ma (Jackson and others, 2004) were employed to correct for mass bias affecting U-Th-Pb ratios of the unknown zircon grains. NIST 610 glass was used for concentration information and the U/Th ratio determination. Detailed analytical procedures follow that of Xie and others (2008). Detrital zircon U-Pb analyses of samples 10GD16, 10GD17 and 10GD19 were conducted using the LA-ICP-MS facility at the Geological Laboratory Center, China University of Geosciences (Beijing), following the analytical procedure of Song and others (2010). Calibration of U-Th-Pb concentrations was carried out using zircon 91500 (Wiedenbeck and others, 1995) as an external standard. Zircon standards TEMORA (Black and others, 2003) and Plešovice (Sláma and others, 2008) were also used as additional monitors for ratio measurements and age calculations. Fractionation correction and age results were calculated using the GLITTER v. 4.0 (Van Achterbergh and others, 2001) and ISOPLOT/Ex v. 2.49 (Ludwig, 2001a) software packages. Common lead was corrected following the methods described by Anderson (2002). The analytical LA-ICP-MS U-Pb data are presented in Appendix table 1 [http://earth.geology.yale.edu/~ajs/SupplementaryData/2014/05Yao.doc]. The U-Pb ages are based on $^{206}Pb/^{238}U$ for ages younger than 1000 Ma and $^{207}Pb/^{206}Pb$ for ages older than 1000 Ma, with uncertainties for both at the 1σ level.

SHRIMP U-Pb dating.—Additional zircon U-Pb analyses on samples 10GD48 and 10GD49-1 were carried out at Curtin University, Australia, using the Sensitive High Resolution Ion Micro Probe (SHRIMP) facility. Standard operation conditions of 2 nA O_2^- primary beam and spot size of ~25 μm in diameter and ~20 μm in depth were followed and each U-Th-Pb measurement consisted of six cycles. U abundances were calibrated using zircon 91500 (Wiedenbeck and others, 1995), and $^{206}Pb/^{238}U$ ratios were constrained by zircon Plešovice (Sláma and others, 2008). The detailed analytical procedure follows that of Williams (1998). Data reduction was carried out using the SQUID v. 2.50 (Ludwig, 2001b) and ISOPLOT/Ex v. 2.49 (Ludwig, 2001a) packages. The interpreted U-Pb ages are based on $^{206}Pb/^{238}U$ for ages younger than 1000 Ma and $^{207}Pb/^{206}Pb$ for ages older than 1000 Ma, with uncertainties at the 1σ level, whereas the weighted mean ages are quoted at the 95 percent confidence interval (2σ). The SHRIMP U-Pb data are presented in Appendix table 2 (http://earth.geology.yale.edu/~ajs/SupplementaryData/2014/05Yao.doc).

Zircon Oxygen Isotopic Analyses

Zircon oxygen isotopic analyses were conducted on the Cameca IMS 1280 large radius SIMS facility at IGG-CAS. The Cs^+ primary ion beam was accelerated to 10 kV with an intensity of 2 nA. The analytical spots were the same as the U-Pb sites, with U-Pb analyses conducted after the oxygen isotope measurements. Zircon standard Penglai with $\delta^{18}O$ = 5.31 ± 0.10‰ (2σ) (X. H. Li and others, 2010a) was adopted for monitoring and correcting oxygen isotope measurements on unknown zircon grains. The detailed analytical procedure follows that described by X. H. Li and others (2010b). The zircon oxygen isotopic data for the samples from southwest Guangdong are given in Appendix table 3 (http://earth.geology.yale.edu/~ajs/SupplementaryData/2014/05Yao.doc).

Zircon Lu-Hf Isotopic Analyses

Zircon Lu-Hf isotopic analyses were carried out at IGG-CAS, using a Neptune MC-ICP-MS equipped with a 193 nm excimer ArF laser-ablation system. Zircon standards 91500 and GJ-1 were used as reference standards, with a recommended ^{176}Hf/^{177}Hf ratio of 0.282307 ± 0.000031 (2σ) (for example, Wu and others, 2006) and 0.282000 ± 0.000005 (2σ) (Morel and others, 2008), respectively. Laser ablation Hf analytical spots were placed as closely as possible on the previously analyzed U-Pb sites guided by their zircon CL images, with spots of 60 μm in diameter and 45 μm in depth. Details of the analytical and calculation procedures follow that of Wu and others (2006). Lu-Hf isotope data for all samples are given in Appendix table 3.

Sandstone Modal Compositions

Modal compositions of sandstone samples were analyzed using the following procedure. Sandstone thin-sections were made from hand samples, and mounted with epoxy resin. Six hundred grains were counted per thin-section using the Gazzi-Dickinson method (Gazzi, 1966; Dickinson, 1970; Ingersoll and others, 1984; Dickinson, 1985). The mineral types were identified and tabulated following the methods of Ingersoll and others (1984) and Dickinson (1985). Only quartz (Q), feldspar (F) and lithic fragments (L) were counted in our analyses to determine the first-order trend of sand composition.

ANALYTICAL RESULTS

Zircon U-Pb Geochronology

A total of 655 zircon grains from five Cambrian clastic sedimentary samples was analyzed in this study. Apart from 25 measurements that gave Th/U <0.10, all the remaining 630 zircon grains have Th/U ratios ranging from 0.10 to 3.01. Except for a few Archean grains which are rounded in shape with no clear internal structures, most detrital zircons have subhedral shapes and show oscillatory zoning in CL images (fig. 3). These features suggest that most detrital zircons are of magmatic origin (for example, Corfu and others, 2003). For the following provenance analyses, we filtered the U-Pb results using a discordance cut-off <10 percent at the 1σ level.

Sample 10GD16, northern Guangdong.—Sample 10GD16 was collected from the lower Oujiadong Formation in northern Guangdong (figs. 1 and 2). We analyzed 100 U-Pb spots on 100 zircon grains, all of which are concordant within uncertainties (that is, the 1σ ellipses overlap the concordia line). The measured ^{206}Pb/^{238}U (<1000 Ma) and ^{207}Pb/^{206}Pb (≥1000 Ma) ages range from 490 Ma to 3480 Ma, but the majority is between 500 and 1080 Ma, with a major peak at ~920 Ma and a minor one at ~520 Ma (fig. 3A). The four youngest grains give a weighted mean ^{206}Pb/^{238}U age of 499 ± 8 Ma (fig. 3A inset), defining the maximum depositional age.

Sample 10GD17, northern Guangdong.—Sample 10GD17 was collected from the top part of the Oujiadong Formation in northern Guangdong (figs. 1 and 2). We analyzed 100 U-Pb spots on 100 zircon grains, and all 100 results are concordant within uncertainties (fig. 3B). The ages of detrital zircons range from 500 Ma to 3310 Ma with two major peaks at ~530 Ma and ~1000 Ma. The three youngest zircon grains give a weighted mean ^{206}Pb/^{238}U age of 502 ± 7 Ma (fig. 3B inset), defining the maximum depositional age of the sample.

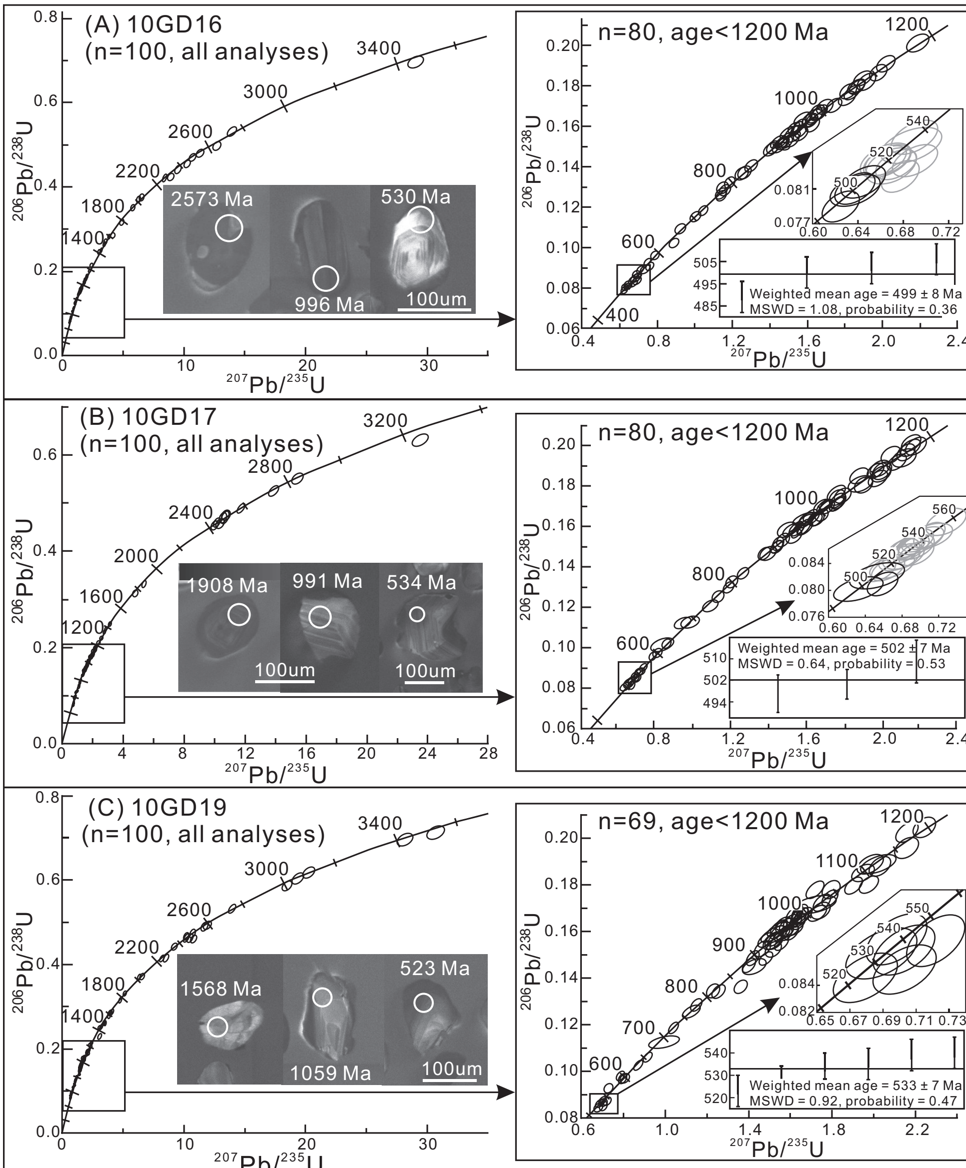

Fig. 3. U-Pb concordia plots of detrital zircons from the five Cambrian sandstone samples in northern and southwestern Guangdong. Representative CL images with analytical spots are also present.

Sample 10GD19, northern Guangdong.—Sample 10GD19 was collected from the upper Laoshuzhai Formation in northern Guangdong (figs. 1 and 2). Of the 100 analyses on 100 zircon grains from this sample, 97 are concordant within uncertainties (fig. 3C). Most analyses define a Neoproterozoic age peak at ~960 Ma. The six youngest grains give a weighted mean $^{206}Pb/^{238}U$ age of 533 ± 7 Ma (fig. 3C inset), defining the maximum depositional age.

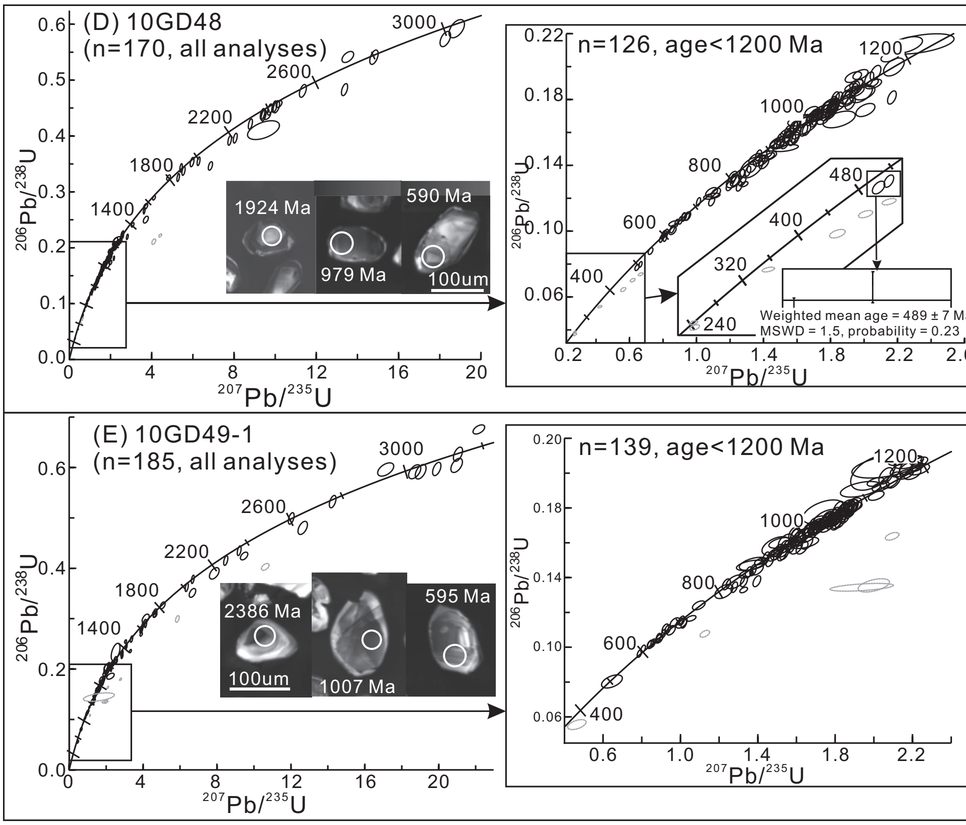

Fig. 3 (continued).

Sample 10GD48, southwestern Guangdong.—Sample 10GD48 was collected from the metamorphosed Cambrian Bacun Group in southwestern Guangdong. We analyzed 170 U-Pb spots (120 LA-ICP-MS analyses and 50 SHRIMP analyses) on 170 zircon grains, and 165 U-Pb results are concordant within uncertainties (Appendix tables 1 and 2; fig. 3D). The largest age population is ~1000 Ma, with minor clusters between 500 and 3000 Ma. There are six analyses with $^{206}Pb/^{238}U$ ages younger than the Cambrian chronostratigraphic age, including three discordant and three concordant ones (236, 244 and 339 Ma) (fig. 3D inset, shown in gray). The six young analyses likely reflect the metamorphic influences of post-Cambrian metamorphic event(s), particularly the Permo-Triassic Indosinian orogeny (for example, Z. X. Li and X. H. Li, 2007). Indeed, this sampling region is within the crystalline interior zones of both the Ordovician-Silurian Wuyi-Yunkai orogen (for example, Charvet and others, 2010; Z. X. Li and others, 2010) (fig. 1A) and the Indosinian orogen, where widespread Paleozoic and Mesozoic metamorphic and magmatic events have been reported (for example, Wang and others, 2007; Wan and others, 2010). Excluding these six results, the two youngest grains in the remaining analyses give a weighted mean $^{206}Pb/^{238}U$ age of 489 ± 7 Ma (fig. 3D inset), defining the maximum depositional age for the protolith of the metasedimentary rock.

Sample 10GD49-1, southwestern Guangdong.—Sample 10GD49-1 was also collected from the Cambrian Bacun Group in the western Cathaysia Block. We analyzed 185

U-Pb spots (120 LA-ICP-MS analyses and 65 SHRIMP analyses) on 185 zircon grains, and 176 U-Pb results are concordant within uncertainties (fig. 3E). There is one zircon with a $^{206}Pb/^{238}U$ age of ~350 Ma (fig. 3E inset), which is again interpreted as being resulted from the Wuyi-Yunkai and/or the Indosinian orogenies (see previous paragraph). The remaining 175 concordant analyses form a major cluster around 1000 Ma, and several minor clusters between 600 and 3100 Ma. The youngest zircon gives a $^{206}Pb/^{238}U$ age of 500 ± 15 Ma, defining the maximum depositional age for the protolith of the metasedimentary rock.

Zircon Oxygen Isotopes

A total of 239 dated detrital zircons from samples 10GD48 and 10GD49-1 was selected for oxygen isotopic analysis. The $\delta^{18}O$ values range from 4.5 permil to 11.9 permil (fig. 4A), and the minimum values for both samples are 4.5 to 5.0 permil, consistent with mantle-derived zircon values (5.3 ± 0.6‰, Valley and others, 1998), whereas the maximum values increase from 7.6 permil in the Archean zircons to 11.9 permil in the Paleozoic zircons, following a trend similar to that documented by Valley and others (2005).

Zircon Lu-Hf Isotopes

In situ Hf isotopic analyses were conducted for a total of 536 detrital zircons with determined U-Pb ages from all five Cambrian samples. The zircon $\varepsilon_{Hf}(t)$ values range from −40 to +14, and the variation changes through time: $\varepsilon_{Hf}(t)$ values of the Archean zircons are dominantly of −11 to +9, whereas those of Neoproterozoic age vary from −40 to +12 (fig. 4B). Apart from two zircons of 2.57 Ga and 1.16 Ga, all others plot below the depleted mantle line. Specifically, the Ediacaran to Cambrian (680−488 Ma) zircons can be divided into two subgroups with different Hf-isotope features. The >580 Ma zircons show either positive or negative $\varepsilon_{Hf}(t)$ values, whereas $\varepsilon_{Hf}(t)$ values of <580 Ma zircons are always negative (fig. 4C).

Sandstone Modal Compositions

Modal composition analyses show that the northern Guangdong samples (10GD16, 10GD17 and 10GD19) plot in the field of dissected arc in the Q-F-L diagram (fig. 5; table 1). Quartz and other detrital grains in the thin sections of these samples show primary sedimentary textures (fig. 5, microphotos 1-3). The southwestern Guangdong metasedimentary samples (10GD48 and 10GD49-1), on the other hand, have lost their primary sedimentary textures, with quartz grains show secondary interlocking grain boundaries rather than their primary detrital grain boundaries (fig. 5, microphotos 4 and 5). Although these two samples plot in the field of "continental block" with abundant quartz but few lithic fragments (fig. 5), the Q-F-L plot is unlikely to give a valid interpretation on the tectonic environment of the source region(s) because of the metamorphic modification.

INTERPRETATION AND DISCUSSION

Results of Statistical Analysis to Determine Cambrian Provenance Variation within Cathaysia

Here we summarize all published detrital U-Pb zircon age data of Cambrian clastic sedimentary rocks in the western Cathaysia Block (Wang and others, 2010b; Wu and others, 2010) and compare them with our new results (see table 2 for sample locations, and fig. 1 for sample localities). All our analyzed samples have similar age spectra, with a large population of zircons falling in the 1100 to 900 Ma age range (fig. 6), suggesting that they may have been derived from similar sources. To further determine the degree of similarity in the detrital sources between these samples, we ran the two-sample Kolmogorov-Smirnov (K-S) test (Kolmogorov, 1933; Smirnov, 1944). In the K-S test,

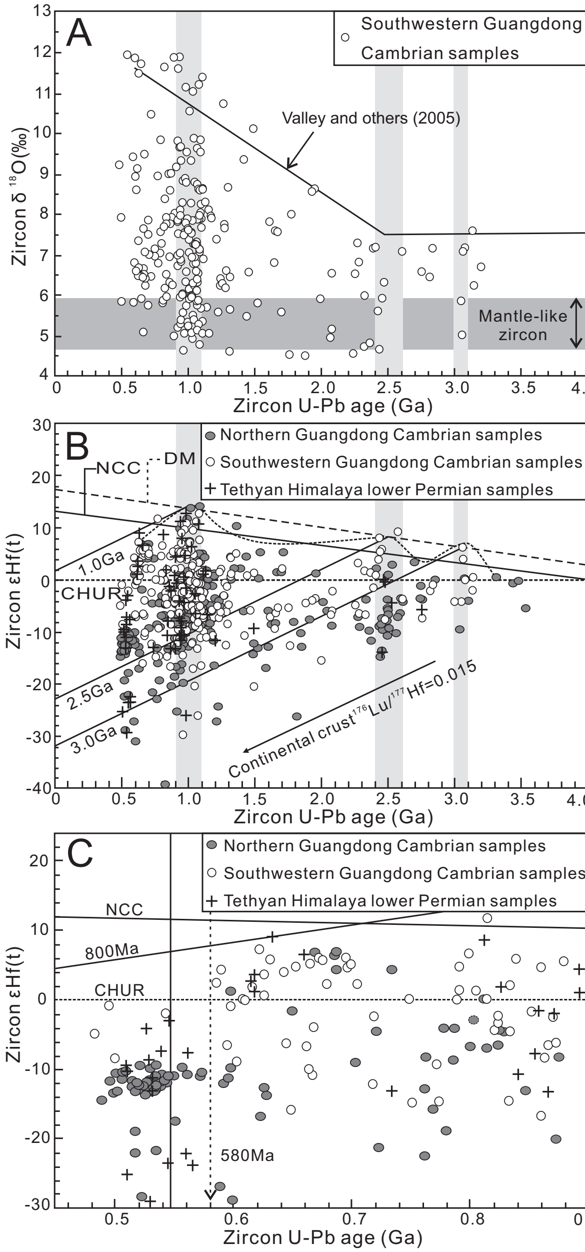

Fig. 4. (A) Plot of detrital zircon $\delta^{18}O$ values versus U-Pb ages for Cambrian samples in southwestern Guangdong. The highlighted dark grey band represents the mantle-like zircon $\delta^{18}O$ value range (4.7-5.9‰, 2σ; Valley and others, 1998). (B) Plot of zircon $\varepsilon_{Hf}(t)$ values versus U-Pb ages for Cambrian samples from Cathaysia and Permian samples from the Tethyan Himalaya. (C) Enlarged plot of zircon $\varepsilon_{Hf}(t)$ values versus U-Pb ages as in (B) for the 900–400 Ma range, where the dashed arrow indicates more negative $\varepsilon_{Hf}(t)$ values after *ca.* 580 Ma. The depleted mantle (DM) and new continental crust (NCC) evolution lines were extrapolated after Griffin and others (2000) and Dhuime and others (2011), respectively. Light gray bands in (A)–(B) highlight potential episodes of new continental crustal growth. Potential crustal evolution lines at 3.0 Ga, 2.5 Ga and 1.0 Ga were calculated for the mean continental crust of $^{176}Lu/^{177}Hf$ value of 0.015 after Griffin and others (2000).

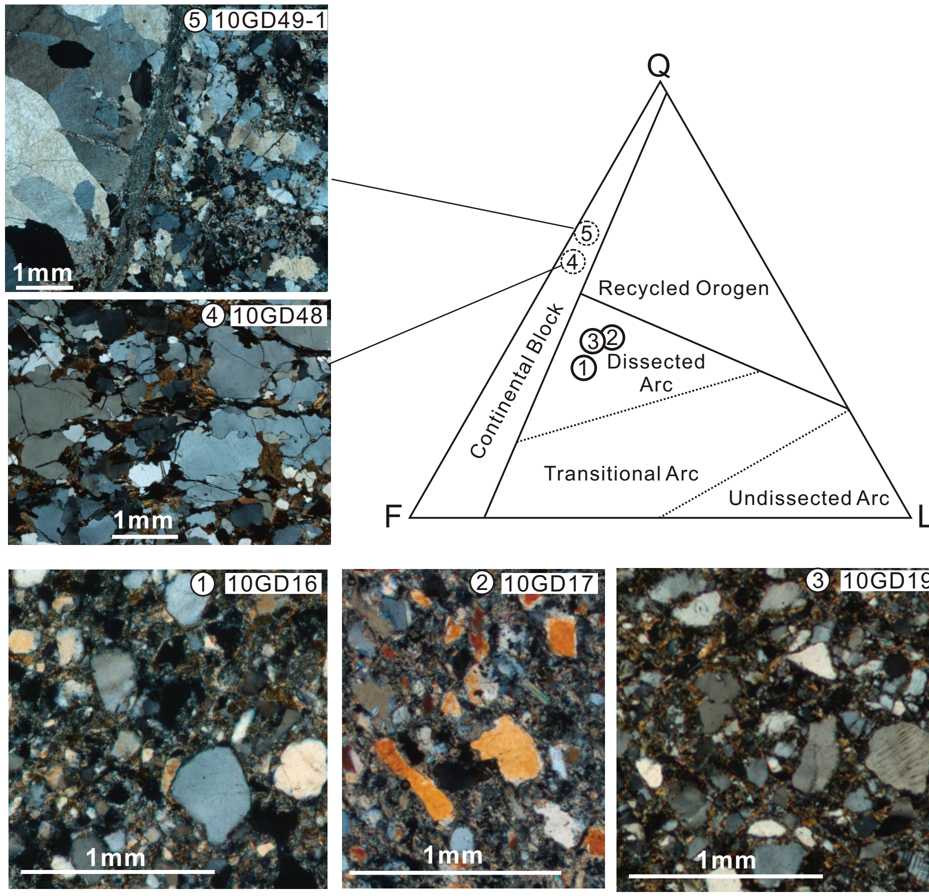

Fig. 5. Q-F-L diagram (parameters after Dickinson, 1970, 1985; Dickinson and others, 1983) of Cambrian sandstone/metasandstone samples from Guangdong, western Cathaysia, with a photomicrograph of each of the sample. Sample (1) 10GD16, (2) 10GD17 and (3) 10GD19 are from sandstone samples from the Oujiadong section of the northern Guangdong Province, whereas samples (4) 10GD48 and (5) 10DG49-1 are from meta-sandstone samples from southwestern Guangdong Province (see fig. 1 for sample locations).

the largest vertical difference between the cumulative probabilities of two tested samples is defined as the D value, and a critical D value for a test with 95 percent confidence ($P_0 = 0.05$) is given by $D_{critical} = 1.36\ ([M+N]/[MN])^{1/2}$ where M and N are the numbers of dated zircons with concordant ages from the two compared samples. If D value > $D_{critical}$ ($P_0 = 0.05$), the null hypothesis (H_0) that the two samples were derived from the same population can be rejected at a 95 percent confidence level. Otherwise, it would suggest that the two tested samples could have shared the same source. Alternatively, the probability level (P) at which the null hypothesis can be rejected is calculated following Schervish (1996). If the P value for a pair of samples is larger than 0.05, the null hypothesis cannot be rejected at a 95 percent confidence; in other words, detritus of the two samples have not been shown to have difference provenances.

The zircon number for each tested Cambrian sample is given in table 2, and their calculated P and D ($D_{critical}$) values are given in table 3. The samples can be divided

Table 1

Modal composition of Cambrian sandstone samples

Sample name	Component counts			Total	Component percentage (%)		
	Q	F	L		Q	F	L
10GD16	206	289	105	600	34.3	48.2	17.5
10GD17	243	247	110	600	40.5	40.2	18.3
10GD19	244	254	102	600	40.7	42.3	17.0
10GD48	353	234	13	600	58.8	39.0	2.2
10GD49-1	398	200	2	600	66.3	33.3	0.4

Note: Q = Quartz, F = Feldspar, L = Lithic fragment.

into three groups according to their paired P values. The northern Guangdong samples (10GD16, 10GD17 and 10GD19) have P values > 0.05 when compared between them, implying that these three samples likely shared the same provenance. The southwestern Guangdong samples (10GD48 and 10GD49-1) have a P value of

Table 2

Summary of all Cambrian sample names and locations

Sample name	Location	Latitude (°N)	Longitude (°E)	Zircons numbers (concordant)	Data source
Northern Guangdong, Western Cathaysia Block					
10GD16	Renhua, Guangdong	25°01′19.9″	113°47′55.5″	100	This study
10GD17	Renhua, Guangdong	25°01′27.6″	113°48′12.1″	100	This study
10GD19	Renhua, Guangdong	25°01′45.6″	113°48′45.2″	97	This study
Southwestern Guangdong, Western Cathaysia Block					
10GD48	Yangjiang, Guangdong	22°04′28.2″	111°26′44.9″	162*	This study
10GD49-1	Yangjiang, Guangdong	21°52′53.0″	111°49′35.1″	175*	This study
Western Jiangxi, Western Cathaysia Block					
J186	Jinggangshan, Jiangxi	26°49′36.6″	114°37′16.4″	117	Wu and others (2010)
J188	Jinggangshan, Jiangxi	26°48′50.0″	114°26′16.4″	116	Wu and others (2010)
J192	Suichuan, Jiangxi	26°27′15.6″	114°12′49.0″	125	Wu and others (2010)
J200	Chongyi, Jiangxi	25°24′27.1″	114°18′36.4″	107	Wu and others (2010)
JX12	Jinggangshan, Jiangxi	26°25′14.6″	114°13′48.4″	40	Wang and others (2010b)
JX16	Suichuan, Jiangxi	26°21′43.0″	114°27′09.2″	41	Wang and others (2010b)
HU37	Rucheng, Hunan	25°32′47.5″	113°51′50.2″	40	Wang and others (2010b)

* Number of zircons with concordant ages, excluding zircons showing lead loss (see “analytical results”).

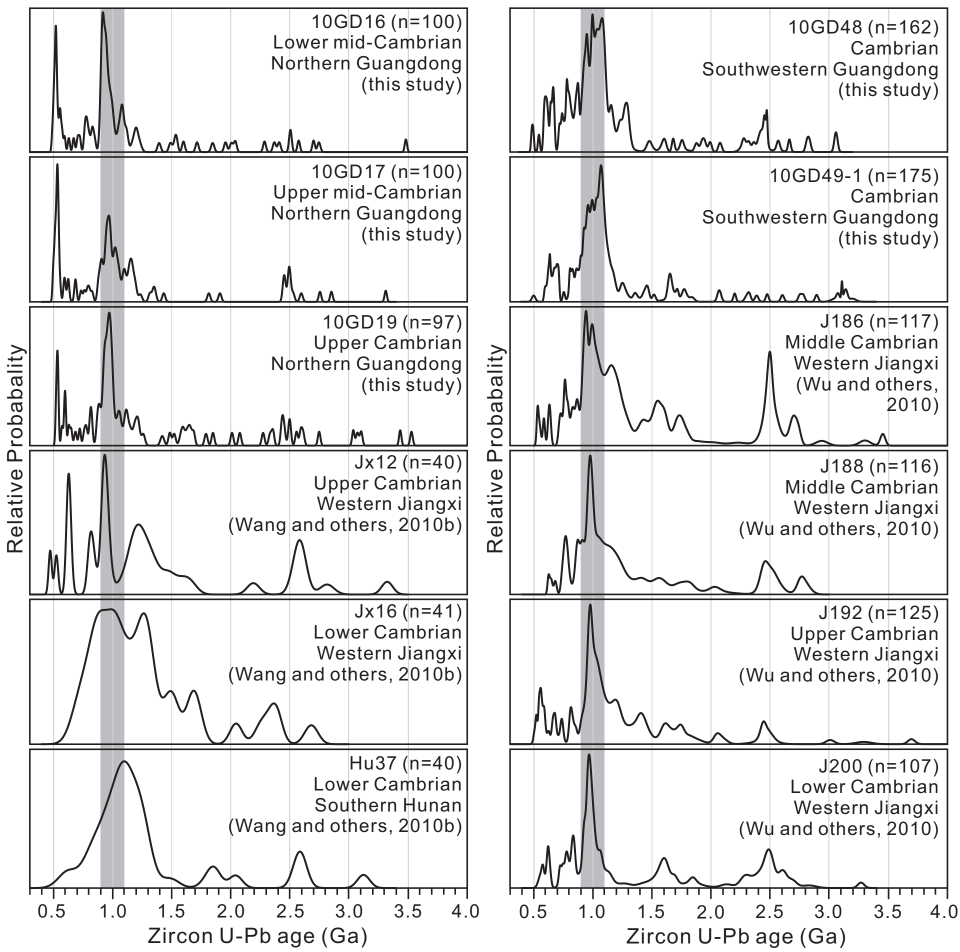

Fig. 6. Detrital zircon age spectra of Cambrian sandstone samples in different localities in the western Cathaysia Block (see text for details). n = total number of concordant analyses. All zircon U-Pb ages are within 90% concordance.

0.739 (> 0.05), also suggesting a common source. Of these two groups of samples, 10GD19 is statistically indistinguishable from 10GD48 (P = 0.314) and 10GD49-1 (P = 0.309). Therefore, the Cambrian samples from northern and southwestern Guangdong Province can be regarded as being derived from the same provenance.

The western Jiangxi samples (J186, J188, J192, J200, JX12, JX16 and HU37—note that sample HU37 is located in the easternmost Hunan Province near Jiangxi, and is here treated as part of the western Jiangxi sample group) have P values >0.05 when any two of them are compared, and P values mostly >0.05 when compare any one of them with Guangdong samples 10GD19, 10GD48, and 10GD49-1 (table 3). This indicates that the western Jiangxi samples likely share a similar provenance with these Guangdong samples. However, when comparing any one of the western Jiangxi samples with Guangdong samples 10GD16 and 10GD17, the P values are <0.05 (table 3), indicating a difference between them.

We observe that all three northern Guangdong samples (10GD16, 10GD17 and 10GD19) contain large zircon population with peaks between 535 and 520 Ma (~13%

Table 3

P and D values of two-sample Kolmogorov-Smirnov (K-S) Tests

	10GD16	10GD17	10GD19	10GD48	10GD49-1	J186	J188	J192	J200	JX12	JX16	HU37
10GD16	–	0.106 *(0.192)*	0.184 *(0.194)*	0.209 *(0.173)*	0.262 *(0.170)*	0.337 *(0.185)*	0.310 *(0.186)*	0.298 *(0.182)*	0.245 *(0.189)*	0.306 *(0.254)*	0.310 *(0.252)*	0.343 *(0.254)*
10GD17	**0.622**	–	0.159 *(0.194)*	0.171 *(0.173)*	0.196 *(0.170)*	0.283 *(0.185)*	0.225 *(0.186)*	0.196 *(0.182)*	0.262 *(0.189)*	0.292 *(0.254)*	0.274 *(0.252)*	0.270 *(0.254)*
10GD19	**0.070**	**0.167**	–	0.123 *(0.175)*	0.122 *(0.172)*	0.203 *(0.187)*	0.145 *(0.187)*	0.132 *(0.184)*	0.111 *(0.191)*	0.164 (0.256)	0.182 (0.253)	0.211 (0.256)
10GD48	0.009	**0.054**	**0.314**	–	0.074 (0.148)	0.242 (0.165)	0.173 (0.165)	0.132 (0.162)	0.228 (0.169)	0.239 (0.240)	0.225 (0.238)	0.193 (0.240)
10GD49-1	0.000	0.015	**0.309**	**0.739**	–	0.254 (0.162)	0.186 (0.163)	0.149 (0.159)	0.225 (0.167)	0.259 (0.238)	0.240 (0.236)	0.195 (0.238)
J186	0.000	0.000	0.025	0.001	0.000	–	0.068 (0.178)	0.132 (0.175)	0.137 (0.182)	0.130 (0.249)	0.155 (0.247)	0.183 (0.249)
J188	0.000	0.009	**0.218**	0.034	0.016	**0.948**	–	0.096 (0.175)	0.109 (0.182)	0.129 (0.249)	0.109 (0.247)	0.119 (0.249)
J192	0.000	0.028	**0.296**	**0.174**	**0.078**	**0.243**	**0.632**	–	0.174 (0.179)	0.129 (0.247)	0.093 (0.245)	0.093 (0.247)
J200	0.004	0.002	**0.557**	0.002	0.002	**0.245**	**0.522**	**0.060**	–	0.131 (0.252)	0.168 (0.250)	0.210 (0.252)
JX12	0.010	0.015	**0.434**	**0.051**	0.025	**0.694**	**0.708**	**0.690**	**0.701**	–	0.146 (0.302)	0.132 (0.304)
JX16	0.008	0.026	**0.297**	**0.074**	**0.044**	**0.461**	**0.862**	**0.953**	**0.374**	**0.781**	–	0.111 (0.302)
HU37	0.002	0.031	**0.159**	**0.182**	**0.169**	**0.268**	**0.796**	**0.957**	**0.150**	**0.876**	**0.964**	–

P value

D value ($D_{critical\ value}$)

Note: The software (K-S test 1.0.xls) used in this study is from the University of Arizona, USA.

of all analyses), which are not as prominent in the other samples (fig. 6). This dissimilarity can be caused by a number of reasons. One is that three of the previously reported samples from western Jiangxi (samples JX12, JX16 and HU37) only have about 40 concordant analyses each, and there is therefore a high probability that the datasets are missing some zircon populations. The other is that as the ages of the sampled rocks spread from lower to upper Cambrian, they may thus contain different peaks related to syn-depositional magmatic activity. Excluding analyses younger than 540 Ma from all samples, a re-run of the K-S test revealed that the majority of the samples from the werstern Jiangxi and the northern Guangdong samples can no longer be distinguished from each other. Therefore, we conclude that the Guangdong samples and the western Jiangxi samples probably contained detritus from the same source(s).

Transport Processes Affecting Age Distribution of Detrital Zircons

Sediments carrying zircon grains are considered to be eroded from topographic highs, being washed and selected by stream action in drainage systems, and finally deposited in sedimentary basins (Reading, 1996; Nichols, 2009). Therefore, processes like recycling, dilution and temporal variation of drainage geometry are all important factors contributing to the age distribution of detrital zircons in a sedimentary rock (for example, Stewart and others, 2001; Gehrels and others, 2011). For modern sedimentation, it is possible to reconstruct the drainage system and transport processes (for example, Zhang and others, 2012). However, it is often difficult to do so for ancient sedimentary rocks due to the loss of paleotopography and the fragmented record of paleo-drainages (for example, Veevers and others, 2005; Myrow and others, 2010). Indirect information such as paleocurrents (indicating stream directions in paleo-drainage; for example, Myrow and others, 2006a, 2006b; Wang and others, 2010b), and sandstone compositions (suggesting transport distance away from source areas; for example, Ingersoll and others, 1984) can then be utilized for determining ancient transport processes affecting the sediments.

Based on systematic regional data compilation and facies analyses, it has been established that the Cathaysia Block was a NW-deepening (in present coordinates) continental shelf/slope that received marine clastic deposition in Cambrian time (for example, Wang, 1985; Liu and Xu, 1994; Chen and others, 1995, 1997) (fig. 1B). As the grain sizes of clastic sediments increase to the southeast (BGMRJX, 1984; BGMRFJ, 1985; BGMRGD, 1988; BGMRHN, 1988; Chen and others, 1997), this may suggest a potential source region to the southeast. However, with almost the entire region beneath the sea during the Cambrian, we speculate that the sediments might have been transported from their source region(s) and deposited first as major deltaic systems (like the Cenozoic Bengal delta system, for example), and then carried by shore-parallel currents, with little local addition. This is similar to the case suggested for Cambrian–Triassic eastern Australia where the sediments were considered to have been mainly derived from neighboring East Antarctica within Gondwanaland (Veevers and others, 2006).

To analyze the effect of recycling from underlying sedimentary successions on the age distribution of detrital zircons in the Cambrian samples, we compared the age spectra of detrital zircons with those of Ediacaran (Yu and others, 2008, 2010; Wu and others, 2010) and Cryogenian (Wang and others, 2010a, 2012a) sedimentary rocks in the Nanhua Basin (figs. 7A-7C). The Cambrian and Ediacaran sedimentary rocks, both from the Cathaysia side of the Nanhua Basin, share similar age spectra, with a common age peak at ~980 Ma (K-S test P = 0.101, greater than 0.05), but they differ significantly from the Cryogenian rifting-related sedimentary rocks (peaking at ~800 Ma; K-S test P = 0.00 for both tests, smaller than 0.05). Furthermore, the Ediacaran sedimentary facies are similar to those of the Cambrian sedimentary rocks in the

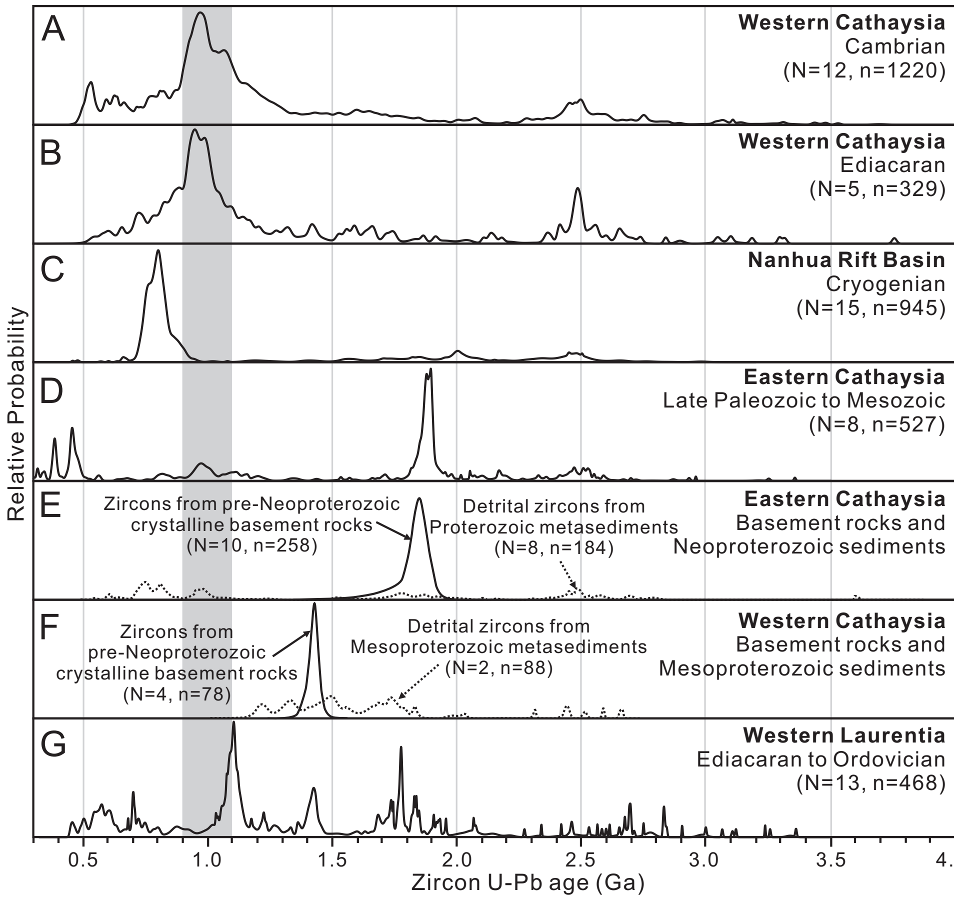

Fig. 7. Summary provenance plots of U-Pb zircon age spectra of sedimentary rocks in Cathaysia, and comparisons with both the basement age spectra and provenance data for western Laurentia. (A) Western Cathaysia Cambrian strata (this study; Wang and others, 2010b; Wu and others, 2010); (B) Western Cathaysia Ediacaran strata (Yu and others, 2008, 2010; Wu and others, 2010); (C) Mid-Neoproterozoic Nanhua Rift Basin (Wang and others, 2010a; Wang and others, 2012a); (D) Eastern Cathaysia late Paleozoic to Mesozoic strata (X. H. Li and others, 2012; Yao and others, 2012); (E) Eastern Cathaysia Neoproterozoic metasediments and Precambrian crystalline basement rocks (X. H. Li, 1997; Z. X. Li and X. H Li, 2007; Wan and others, 2007; Liu and others, 2009; Yu and others, 2009; Z. X. Li and others, 2010); (F) Western Cathaysia Mesoproterozoic metasediments and Precambrian crystalline basement rocks (Z. X. Li and others, 2002, 2008a); (G) Western Laurentia (Smith and Gehrels, 1994; Stewart and others, 2001; Vega-Granillo and others, 2008). N = number of samples, n = total number of concordant analyses. All zircon U-Pb ages are within 90% concordance.

Cathaysia Block (Liu and Xu, 1994). These observations indicate that the Cathaysia Block received continuous turbiditic to shallow marine siliciclastic sedimentation throughout Ediacaran–Cambrian time, which is in stark contrast to the dominantly carbonate platform deposition over the Yangtze Block (fig. 1B). The Ediacaran–Cambrian clastic sedimentary rocks exhibit a common provenance (fig. 7A-B) that is different from the underlying Cryogenian sedimentary rocks (fig. 7C). This suggests that recycling of pre-existing local sedimentary rocks contributed little to the provenance of the Ediacaran–Cambrian sedimentary rocks. Furthermore, the almost complete water coverage of the region for the entire Ediacaran–Cambrian period (Wang, 1985; Liu and Xu, 1994; fig. 1B for mid-Cambrian time) means that no known local pre-existing sedimentary rocks were exposed or eroded into the Nanhua Basin at that time.

Crustal History of the Source Region for the Cambrian Sandstones

The overall age spectra of all available Cambrian sandstone samples in the western Cathaysia Block show a dominant population of 1100 to 900 Ma, peaking at ~980 Ma, and minor age populations of *ca.* 2500, 850 to 750 and 650 to 500 Ma (fig. 7A). The data suggest that the source region(s) possibly experienced four broad episodes of tectono-magmatic events. Specifically, Archean-Paleoproterozoic zircons account for 9 percent of all analyzed zircon grains, with a peak at ~2.5 Ga. Most zircons of this age group are round in shape and show signs of abrasion, suggesting multiple episodes of sedimentary recycling. These zircons have relatively low $\delta^{18}O$ values of 4.6 to 7.3 permil (fig. 4A) and variable $\varepsilon_{Hf}(t)$ values of −14.8 to +9.2 (fig. 4B), indicating that both mantle-derived melts and remelted old crustal components were involved. Grenvillian (1100-900 Ma) zircons make up 50 percent of the population with a pronounced peak at ~980 Ma (fig. 7A). Variable $\delta^{18}O$ values (4.6-11.8‰) and $\varepsilon_{Hf}(t)$ values (−30 to +14) (figs. 4A-4B) suggest contributions from both juvenile and reworked crustal materials. Zircons form a subordinate population at 850 to 750 Ma (7% of all analyses) with $\delta^{18}O$ values of 5.7 to 11.6 permil and $\varepsilon_{Hf}(t)$ values of −40 to +11 (figs. 4A-4B), suggesting crystallization from reworked older crust, with minor new mantle input. The age of this population coincides with widespread continental rifting events related to the break-up of the Rodinia supercontinent (for example, Hoffman, 1991; Z. X. Li and others, 2008b). Zircons with ages of 650 to 500 Ma (~15% of all analyses) have $\delta^{18}O$ values mostly falling outside the range for mantle-like zircons (fig. 4A) and negative $\varepsilon_{Hf}(t)$ values (fig. 4C), suggesting that these zircons were mainly derived from remelting and recycling of ancient crustal materials. Within this population, there is a dramatic shift in zircon Hf isotopes at ~580 Ma (fig. 4C). A large number of pre-580 Ma zircons have positive $\varepsilon_{Hf}(t)$ values, whereas post-580 Ma zircons exclusively record negative $\varepsilon_{Hf}(t)$ values, hinting at a possible change of tectonic environment in the source region(s).

In summary, zircon Hf isotopic data indicate that the source region(s) of the Cambrian sandstones probably experienced three Precambrian episodes of juvenile crustal growth, at 3.0 Ga, 2.5 Ga and 1.0 Ga, and two possible minor events at 1.35 Ga and 850 to 580 Ma (fig. 4B), which is consistent with the mantle-like $\delta^{18}O$ values (fig. 4A). Zircon Hf-O isotope results also suggest that the source region(s) underwent extensive crustal remelting and reworking without new crustal addition at 580 to 500 Ma.

Provenance of the Cambrian Sedimentary Rocks in the Cathaysia Block

Not sourced from the Cathaysia or the Yangtze blocks.—Some previous work typically viewed the lower Paleozoic clastic rocks along the Cathaysian margin as sourced from the Cathaysia Block itself, and suggested that these rocks can reflect the crustal history of Cathaysia (for example, Yao and others, 2011). However, a closer examination of the available data suggests that the provenance interpretation of these clastic rocks may not be that straightforward. If we ignore the post-540 Ma grains in the Cambrian samples, the age spectra of detrital zircons from the Cambrian and Ediacaran clastic samples in western Cathaysia are consistent (figs. 7A-7B), suggesting common sources for the continuous sedimentation on the Cathaysian side of the Nanhua Basin during Ediacaran to Cambrian time (fig. 1B). The *ca.* 540 to 490 Ma grains in the Cambrian samples are interpreted as input from newly formed magmatic rocks in the source region(s).

We have already ruled out recycling of local underlying sedimentary rocks as a source for the Ediacaran–Cambrian sedimentation in Cathaysia. Known basement rocks from Cathaysia are also unlikely to have contributed to the sedimentation for two reasons. First, most of the known Cathaysian pre-Neoproterozoic bedrock areas were covered by sea water and marine deposits during much of Ediacaran to Cambrian time (fig. 1B; Wang, 1985; Liu and Xu, 1994), and thus could not have served as a source of detritus for the Ediacaran–Cambrian sedimentary rocks. Second, the age spectra of the sedimentary rocks are different from that of the basement. We show in figures 7E-7F age spectra of known Cathaysian basement rocks, and in figure 7D younger provenance data from eastern Cathaysia that mimics the basement data. Eastern Cathaysia has a dominant 1.89 to 1.86 Ga age peak in its crystalline basement (figs. 1A and 7E), which is reflected in the age spectra of the late Paleozoic to Mesozoic sandstones found in the region (fig. 7D). Western Cathaysia, on the other hand, has a prominent *ca.* 1.43 Ga age peak in the basement that crops out in Hainan Island (figs. 1A and 7F). Clearly neither peak from the basement rocks is clearly shown in the provenance data for the Ediacaran–Cambrian strata (figs. 7A-7B). Rare Grenville-age magmatic rocks have been reported within Cathaysia (for example, the ~972 Ma Jingnan rhyolites in eastern Guangdong by Shu and others, 2008; fig. 1A) that fit the prominent 980 Ma peak of the Ediacaran–Cambrian deposits (figs. 7A-7B), but, as stated above, the extensive sedimentary and sea-water coverage of the entire region rule out such rocks as a potential detritus source.

The neighboring Yangtze Block is another potential source for the clastic sedimentary rocks. There are some 1100 to 900 Ma magmatic rocks along the margins of the Yangtze Block (Z. X. Li and others, 2002; Ling and others, 2003; Greentree and others, 2006; Ye and others, 2007; X. H. Li and others, 2009), which are the same age as the prominent peak in the Cambrian samples (fig. 7A). However, the large-scale carbonate deposition over the Yangtze Block (fig. 1B) makes it an unlikely source region for the vast amount of clastic sediments on the Cathaysia side of the Nanhua Basin. In addition, no *ca.* 600 to 500 Ma magmatism has been reported from the Yangtze Block.

Consequently, the prominent Grenvillian zircon population would have to be from an area outboard of the known Cathaysian basement, either in the concealed part of the South China continental crust along the South China Sea margin (fig. 1B), or an exotic terrane once connected to the Cathaysia Block during Ediacaran–Cambrian time but subsequently drifted away. In the former scenario, the concealed source area along the current continental margin would have been an elevated region striking NE-SW along the present-day continental margin (fig. 1B). The dominant 1100 to 900 Ma zircon population and subordinate 850 to 750 Ma and 650 to 500 Ma populations in the Ediacaran–Cambrian sedimentary rocks demand the concealed source area to be part of a Grenville-aged orogenic belt that not only experienced 850 to 750 Ma continental rifting similar to the Nanhua Basin (for example, Z. X. Li and others, 2003; Wang and Li, 2003), but also underwent prominent 580–500 Ma crustal melting. However, there is no such outcrop of basement rocks in the speculated offshore region. A study of xenoliths from Cenozoic basalts in Penghu Island (fig. 1B) reported sulphide T_{RD} age peaks of 1.9 Ga, 1.7 to 1.6 Ga, 1.4 to 1.3 Ga and 0.9 to 0.8 Ga, which were interpreted to represent the timing of melt extraction and/or metasomatic events in the sub-continental lithospheric mantle beneath the region (Wang and others, 2009). Such inferred events correlate well with tectonothermal events in the exposed Cathaysia Block, including the 1.9 to 1.8 Ga event in eastern Cathaysia and the 1.4 Ga event on Hainan Island. It is thus likely that known basement components in mainland Cathaysia extend to the Taiwan region (at least to Penghu Island). On the other hand, almost no record of magmatic events at 1100 to 900 Ma or 580 to 500 Ma, as demanded by the Ediacaran–Cambrian clastic sedimentary provenance data (figs. 7A-7B), has been reported from either the coastal area of the Cathaysia Block or its offshore extension (except for some *ca.* 1.3-1.0 Ga metamorphic ages from Hainan Island; Z. X. Li and others, 2002, 2008a). Therefore, although the possibility of the concealed offshore extension area being the source region cannot be totally ruled out, it appears unlikely.

Possible Exotic Sources from the East African Orogen and the Northern Indian Margin

To test the possibility of exotic sources for the detritus, we compared the zircon age spectra of the Ediacaran–Cambrian samples from western Cathaysia with those from several potential continental blocks that were suggested to be adjacent to the SCB during that time interval (for example, Zhang and Piper, 1997; Z. X. Li and Powell, 2001; Zhou and others, 2002; Jiang and others, 2003; Yang and others, 2004; Z. X. Li and others, 2008b; Yu and others, 2008, 2009; Cook and Torsvik, 2013). Most of the detrital zircons were derived from siliciclastic successions coeval with the studied rocks in the Cathaysia Block. The prominent age peaks at 1.1 Ga, 1.4 Ga and 1.8 Ga in Ediacaran–Ordovician sedimentary rocks from western Laurentia (fig. 7G) (Smith and Gehrels, 1994; Stewart and others, 2001; Vega-Granillo and others, 2008) bear no similarity to those of the western Cathaysia samples (figs. 7A-7B). Likewise, the distinct 1.2 Ga age peak from western Australian Ordovician and Permian sedimentary rocks (fig. 8H) (Cawood and Nemchin, 2000; Veevers and others, 2005) has no counterpart in the Cathaysian provenance data (fig. 8A). These differences indicate that during the Ediacaran–Cambrian time interval, the Cathaysia Block was unlikely to have a direct connection with either western Australia or western Laurentia, both of which were previously suggested to be connected to the southeast margin of the Cathaysia Block sometime during the Proterozoic (for example, Yang and others (2004) for a Cathaysia-western Australia connection, and Z. X. Li and others (2008a) for a Cathaysia-western Laurentia connection) and/or the lower Paleozoic (for example, Zhang and Piper (1997) and Yang and others (2004) for a Cathaysia-western Australia connection).

To examine a possible SCB–northern India connection, as previously speculated based on (1) their comparative Ediacaran–Cambrian tectonostratigraphic records (Kumar, 1984; Jiang and others, 2003), (2) their Cambrian faunal affinities (for example, Jell and Hughes, 1997; Peng and others, 2009), (3) paleomagnetism (Z. X. Li and others, 2004; Zhang, 2004), and (4) similarities in their Ediacaran detrital zircon provenance data and tectonomagmatic records (Yu and others, 2008), we first look at the tectonic framework and provenance data for northern India.

The Paleozoic northern Indian margin (that is, the Himalaya region; fig. 8) includes three modern tectonic units from north to south: the Tethyan Himalaya (TH), the Greater Himalaya (GH) and the Lesser Himalaya (LH) (for example, Le Fort, 1975). Although there are models arguing for an exotic origin for some of the tectonic units (for example, Liu and others, 2012), here we follow the view that these tectonic units are all part of the northern margin of the Indian craton that were dismembered and reworked during the India-Asia collision. This is because they: (1) exhibit coherent continental shelf–slope litho-facies, tectonostratigraphy and paleoenvironment in the late Precambrian–Paleozoic (for example, Brookfield, 1993; Pogue and others, 1999; Myrow and others, 2003); (2) share a similar bioprovince (Peng and others, 2009); and (3) have similar detrital zircon age distribution patterns (for example, Myrow and others, 2003, 2010).

Precambrian crystalline basement rocks are poorly exposed along the northern margin of India, with the oldest being 1.8 to 1.6 Ga igneous rocks reported in the eastern Himalaya (Cottle and others, 2009; Yin and others, 2010a) and around the Shillong Plateau (Ameen and others, 2007; Yin and others, 2010b), 1.9 to 1.8 Ga magmatic rocks in the central Himalaya (Nepal) (Kohn and others, 2010), and 2.0 to 1.84 Ga granites and 1.8 Ga mafic igneous rocks in the western Himalaya (Miller and others, 2000; Singh and others, 2006). In addition, *ca.* 1.1 to 1.0 Ga, 880 to 820 Ma, and 550 to 470 Ma tectono-magmatic events have been reported from the region (for example, Schärer and others, 1986; Brookfield, 1993; Miller and others, 2001; Singh

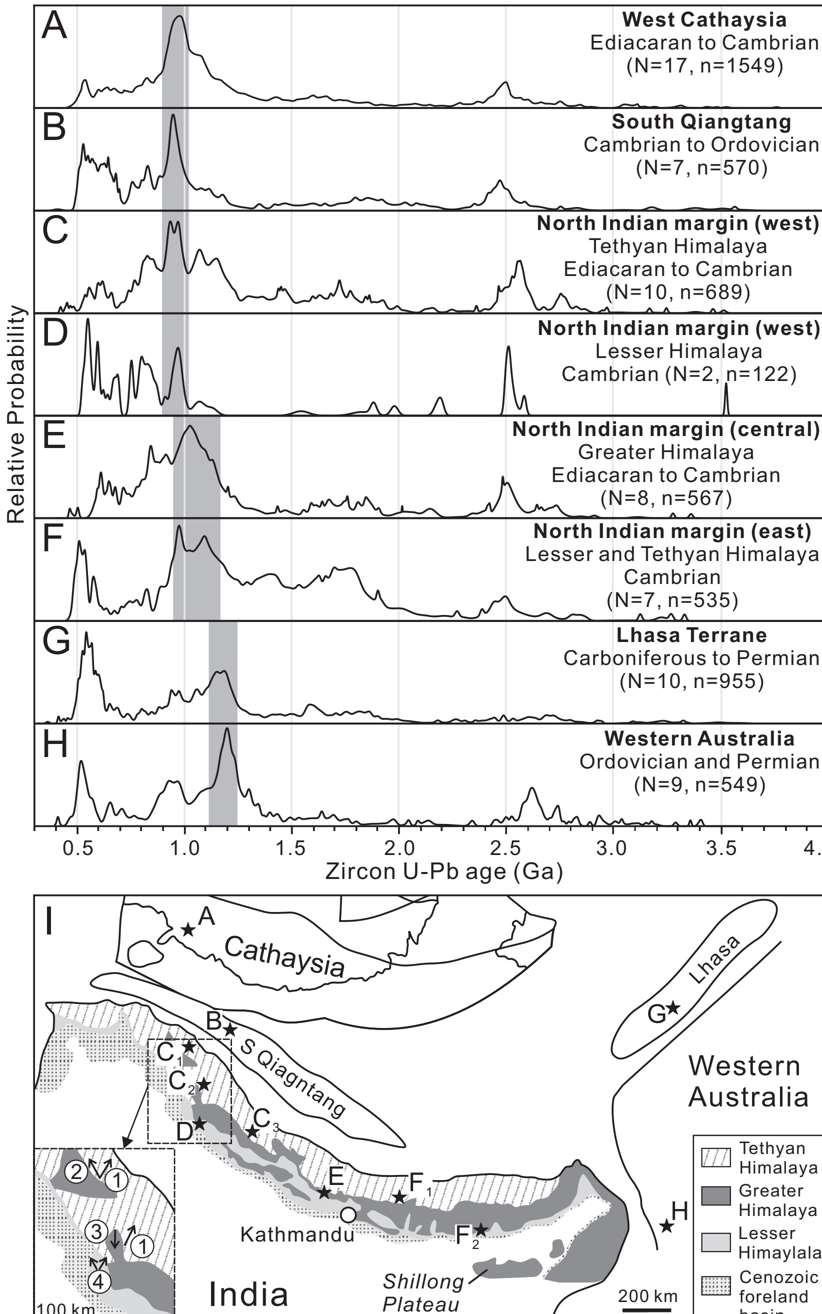

Fig. 8. Provenance variations of Ediacaran–Cambrian sedimentary rocks along the northern margin of India, and comparisons with provenance results from possible adjacent continents/terranes in Gondwanaland, Age spectra in (A)–(H) correspond to data points A–H in the location cartoon (I), where data points C_1–C_3 and D represent western North Indian margin, data points E represent central North Indian margin, and data points F_1 and F_2 represent eastern North Indian margin. Sources of detrital zircon age spectra: A—this study, Yu and others (2008, 2010), Wang and others (2010b) and Wu and others (2010); B—Dong and others (2011), Pullen and others (2011) and Zhu and others (2011); C_1—Myrow and others (2010); C_2—Myrow and others (2010) and Webb and others (2011); C_3—Myrow and others (2010); D—Myrow and

and others, 2002; Cawood and others, 2007; Liu and others, 2007; Cottle and others, 2009; Yin and others, 2010a, 2010b).

Figure 8 shows that the age spectra of the Cathaysia detrital zircons match well with similar-aged clastic sedimentary rocks from the northern margin of India. In particular, the Cathaysia age spectra with a distinct age peak of 980 Ma (fig. 8A) match well with similar-aged sedimentary rocks from the western part of the northern Indian margin (Myrow and others, 2003, 2009, 2010; Webb and others, 2011) (figs. 8C-8D). Similar age spectra persisted in the central and eastern segment of the northern Indian margin, although *ca.* 1.2 to 1.1 Ga age populations in general become more prominent in this region (figs. 8E-8F) (Gehrels and others, 2003, 2006a, 2006b; Martin and others, 2005; McQuarrie and others, 2008; Myrow and others, 2010; Hughes and others, 2011). These correlations indicate that the Cathaysia Block possibly shared a similar provenance with the northern Indian margin during the Ediacaran–Cambrian time. The comparable zircon Hf isotopic characteristics between the Cathaysian Cambrian sedimentary rocks (this study) and the Tethyan Himalayan Permian sedimentary rocks (Zhu and others, 2011) that share a similar age spectrum to the Ediacaran–Cambrian samples, including the common lack of any zircon with a positive $\varepsilon_{Hf}(t)$ value after 580 Ma, also support such a speculation (figs. 4B-4C).

Figure 8 further illustrates that the similarities between the age spectra of the Cathaysian sedimentary rocks and those from the Indo-Australian Gondwana margin gradually decrease toward Australia, with a prominent Grenvillian age peak shifting from *ca.* 980 Ma for Cathaysia (fig. 8A), Qiangtang (fig. 8B) and western Himalaya (figs. 8C-8D), to *ca.* 1100 Ma for much of central–eastern Himalaya (figs. 8E-8F, with F still showing a prominent *ca.* 980 Ma peak), and finally to nearly *ca.* 1200 Ma for the Lhasa terrane and western Australia (figs. 8G-8H). It thus indicates that western Cathaysia (SCB) likely shared the same detritus provenance as the northwestern Indian Himalaya, and the provenance connection appears to gradually weaken toward western Australia.

The South China Block (SCB): from Central Rodinia in the Early Neoproterozoic to Northeastern Gondwanan Margin in the Cambrian?

As discussed in the introduction section, the paleo-position of the SCB in the Neoproterozoic supercontinent Rodinia and its subsequent connection with Gondwanaland in the early Paleozoic has been a subject of ongoing debate. Although current paleomagnetic results permit the SCB to be on either side of the Australian continent in Rodinia (for example, Z. X. Li and others, 2004; Yang and others, 2004; Z. X. Li and Evans, 2011), some previous studies prefer the SCB to be adjacent to either western Australia or northern India in Rodinia (Zhang and Piper, 1997; Jiang and others, 2003; Yang and others, 2004; Yu and others, 2008). Z. X. Li and others (2008b), on the other hand, preferred the so-called "missing-link" model, where the SCB is placed between Australia and western Laurentia in Rodinia because such a configuration: (1) explains the close similarities in both basement geology and possible late Mesoproterozoic

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others (2010); E—Martin and others (2005) and Gehrels and others (2011); F_1—Myrow and others (2010) and Gehrels and others (2011); F_2—McQuarrie and others (2008), Myrow and others (2010) and Hughes and others (2011); G—Leier and others (2007), Gehrels and others (2011) and Zhu and others (2011); H—Cawood and Nemchin (2000) and Veevers and others (2005). Inset in (I) shows paleocurrent directions, with data sources being as follows: (1) Tethyan Himalaya, lower–middle Cambrian rocks in the Spiti and Zanskar valleys (Myrow and others, 2006a, 2006b; Bagati and others, 1991); (2) Tethyan Himalaya, lower and upper Cambrian rocks in the Zanskar Valley (Garzanti and others, 1986); (3) Greater Himalaya, lower Cambrian rocks at Keylong (Draganits, ms, 2000); (4) Lesser Himalaya, Ediacaran rocks at Simla (Valdiya, 1970). The positions of South Qiangtang and Lhasa terranes relative to Indo-Australia in Gondwanaland, as shown in (I), follow that of Zhu and others (2011).

provenance connections between southern Cathaysia and southern Laurentia (Z. X. Li and others, 2008a); (2) allows the SCB to be above a Neoproterozoic plume-center as indicated by dike swarms in both Australia and western Laurentia and corresponding plume-centers in the SCB (Z. X. Li and others, 2003); (3) explains the Grenvillian metamorphic/magmatic events in both eastern Australia and western Laurentia (Z. X. Li and others, 2008b and references therein; Nesheim and others, 2012); and (4) provides a solution for geological mismatch between Laurentia and Australia-East Antarctica during Rodinian time and fills the gap between them as required by the paleomagnetic results (Z. X. Li and others, 2008b; Z. X. Li and Evans, 2011). Following this scenario, the SCB was considered to have drifted adjacent to the northwestern margin of Gondwanaland by the Cambrian (Z. X. Li and others, 1996; Metcalfe, 1996; Z. X. Li and Powell, 2001). In addition, as we will discuss in the following paragraphs, the "missing-link" model and the following scenario (fig. 9) is not only consistent with our provenance analyses, but it also permits the northern margin of India to develop an active margin during Ediacaran to Cambrian time (for example, DeCelles and others, 2000; Cawood and others, 2007), and provides a driving mechanism for the early Paleozoic Wuyi-Yunkai orogeny in the SCB (for example, Charvet and others, 2010; Z. X. Li and others, 2010).

Wang and others (2010a, 2012a) documented the provenance of middle Neoproterozoic successions in the central Nanhua Basin (the region between Shaoguan and Guilin in fig. 1B), and revealed a dominant early Neoproterozoic zircon age population with a peak at *ca.* 800 Ma, and a small number of older grains between 2.5 and 1.5 Ga (fig. 7C). A similar detrital provenance is identified in metasedimentary rift successions (protolith ages of 840-720 Ma) in eastern Cathaysia (fig. 7E, Wan and others, 2007; Z. X. Li and others, 2010). Such age patterns can be explained by local sources inside the SCB without invoking exotic sources, as one would expect of rift basin deposits sourced predominantly from elevated rift shoulders and syn-rifting volcanic rocks (Z. X. Li and others, 2003; Wang and Li, 2003).

The provenance of the clastic sediments on the Cathaysia side of the Nanhua Basin changed dramatically during the Ediacaran, as shown by the lack of a 2.1 to 1.8 Ga zircon population and the dominance of a 1.1 to 0.9 Ga zircon population (fig. 7B). A similar provenance continued to at least the Cambrian, but with the addition of 540 to 500 Ma magmatic zircons (fig. 7A). This potential exotic provenance matches well with that of northwestern Indian Himalaya (see discussion in the previous sections; figs. 8A, 8C-8D). We thus suggest that the SCB drifted north of Australia (current configuration) to approach northern India during the Ediacaran (figs. 9B-9C), which is consistent with available 650 to 580 Ma paleomagnetic constraints (Z. X. Li and others, 2013). The older end of the 588 $\pm$ 33 to 423 $\pm$ 7 Ma monazite $^{208}Pb^{*}/^{232}Th$ metamorphic age spectrum reported from schists in the northwestern Indian section of the western Himalaya (Webb and others, 2011) may thus reflect the onset of the SCB-India collision. In such a paleogeographic configuration (fig. 9C), western Cathaysia and the northwestern margin of the Indian continent started to receive dominantly siliciclastic deposits from that time, probably from a common source such as the giant East African orogen (for example, Myrow and others, 2010; McQuarrie and others, 2013).

The SCB possibly rotated clockwise relative to Gondwanaland during Cambro-Ordovician time (fig. 9D), leading to the closure of the V-shaped ocean during the Ordovician (*ca.* 470 Ma). Apart from their strong sedimentary provenance and bioprovenance connections as discussed above, and paleomagnetic evidence for the SCB to join Gondwanaland adjacent to northern India during the Cambrian (Zhang and others, 2013), such a collisional event is also consistent with a number of other observations across India and the SCB. First, the model can accommodate the

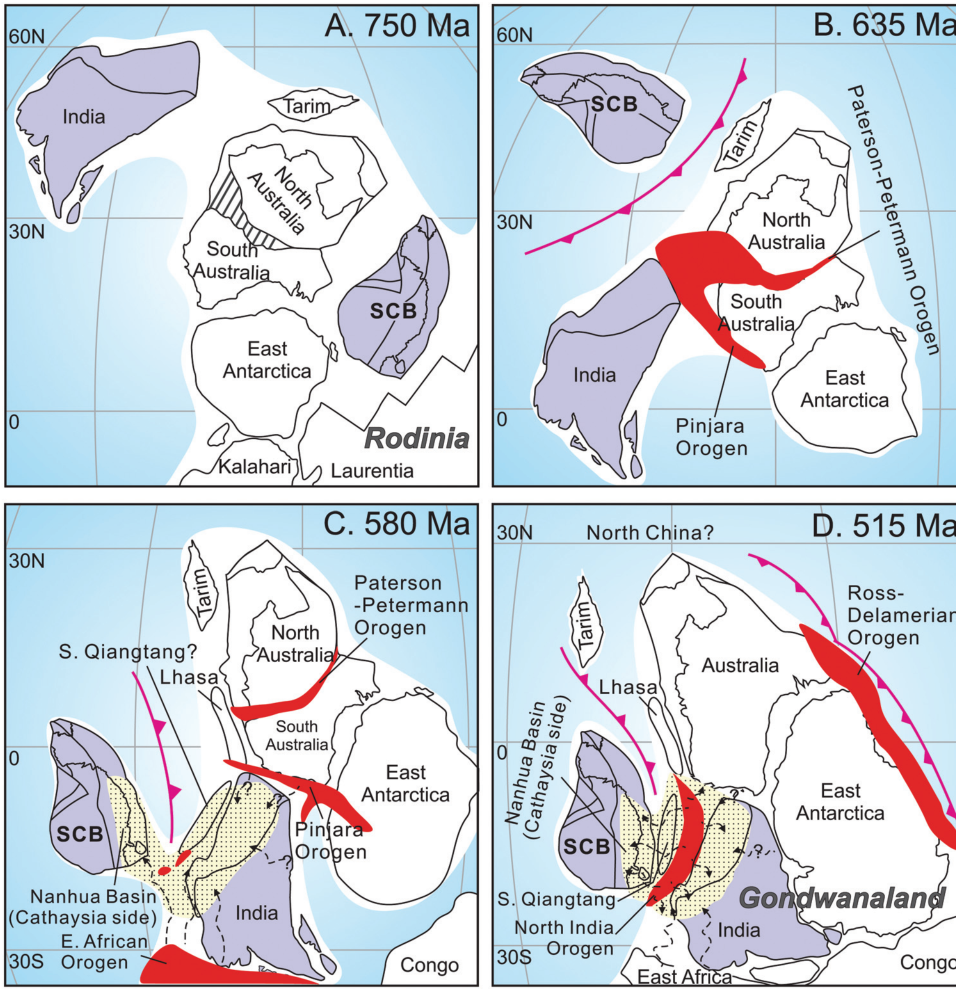

Fig. 9. Paleogeographic reconstructions showing paleoposition of the SCB (A) before the break-up of Rodinia in the mid-Neoproterozoic (750 Ma), (B) after Rodinia broke up, but prior to its collision with India during the assembly of Gondwanaland (635 Ma), (C) beginning of collision with NW India at *ca.* 580 Ma during the assembly of Gondwanaland, and (D) colliding with India to become part of Gondwanaland (515 Ma). Active orogens, and speculated drainage directions for Ediacaran–Cambrian time, are shown (see text for detailed discussion). Paleogeographic reconstructions follow that of Zhu and others (2012) for relative positions of the Lhasa and Qiangtang terranes, and Z. X. Li and others (2013) for the rest. The cartoon paleo-drainage patterns are modified after Myrow and others (2010). North China is notional shown close to northern Australia in the Cambrian because of some bioprovince and detrital zircon provenance similarities (for example, McKenzie and others, 2011), but there is no evidence to suggest that it was a coherent part of Gondwanaland at that time (for example, Z. X. Li and Powell, 2001; Cocks and Torsvik, 2013).

development of an Andean-type active plate margin during the Cambrian, resulting in the formation of a trans-Himalaya granitic belt between *ca.* 550 Ma and *ca.* 470 Ma (for example, DeCelles and others, 2000; Miller and others, 2001; Gehrels and others, 2003; Cawood and others, 2007; Yin and others, 2010b; Webb and others, 2011; Wang and others, 2012b). The granites of this belt are commonly reported to be the result of continental crustal melts, with the Cambrian ones possibly forming in a back-arc environment associated with slab roll-back, whereas the younger, Cambro-Ordovician ones are associated with terrane accretion/collision after the ocean closure (for example, Cawood and others, 2007; Yin and others, 2010b; Wang and others, 2012b). Here we interpret that "accreted" terrane to be the SCB which completely accreted/collided with northern India by *ca.* 470 Ma. Second, the *ca.* 580(?)–420 Ma metamorphic ages reported from the northwestern Indian Himalaya (Webb and others, 2011), and the 500 to 450 Ma metamorphism and deformation prior to 490 to 470 Ma granitic intrusions in the central Himalaya (Gehrels and others, 2003), are consistent with a diachronous collision with the SCB. Third, a Cambro-Ordovician hiatus has been recognized across the Himalaya range between the more deformed and metamorphosed Ediacaran to mid-Cambrian sedimentary strata [with some Cambro-Ordovician(?) granites intruding the strata being exposed and eroded], and a widespread overlying Cambrian(?)–Ordovician conglomerate unit (for example, Gehrels and others, 2003; McQuarrie and others, 2013 and references therein), noting that the overlying conglomerate unit could be as young as mid- to late-Ordovician (Torsvik and others, 2009). This tectonism has been interpreted as indicating a trans-Himalaya Cambro-Ordovician mountain-building event (the Kurgiakh orogeny, Srikantia, 1977, as quoted in Bhargava and others, 2011; also known as the Bhimphedian orogeny, with the orogen called the North India orogen, Cawood and others, 2007) featuring south-verging thrusting. We speculate here that the orogenic event possibly started at the northwestern margin of the Indian craton when it collided with the SCB (fig. 9D), with a fold-and-thrust belt propagating to the south during the Ordovician (Gehrels and others, 2003; McQuarrie and others, 2013). Fourth, the model can account for the presence of both north-directed and south-directed paleo-flow directions observed in the Ediacaran to Ordovician clastic strata in the Himalaya range (Valdiya, 1970; Garzanti and others, 1986; Bagati and others, 1991; Draganits, ms, 2000; Myrow and others, 2006a, 2006b; McQuarrie and others, 2013) (see fig. 8I inset for western Himalaya dataset), driven by paleo-topography away from northern India, and the emerging North India orogen (figs. 9C-9D). Fifth, continuing convergence between the SCB and India (as part of Gondwanaland) after the ocean closure by *ca.* 470 Ma can explain the driving force for the intraplate orogenic event in South China—the >460 to 415 Ma Wuyi-Yunkai orogeny (Z. X. Li and others, 2010) in a similar way as the Cenozoic India-Eurasia collision causing the intraplate orogeny along the Tianshan (Yin and others, 1998).

Models that have South China connected to western Australia-northern India since Rodinia time (Zhang and Piper, 1997; Jiang and others, 2003; Yang and others, 2004; Yu and others, 2008; Cawood and others, 2013), on the other hand, would have difficulties in accounting for a number of geotectonic observations and events: the development of a "Pan-African" continental margin in northern India and possibly northwestern Australia (for example, DeCelles and others, 2000; Cawood and others, 2007; Yin and others, 2010b; Zhu and others, 2011, 2012; Wang and others, 2012b); the notably closer provenance connection between Cathaysia and northwestern India rather than with northeastern India or Lhasa–western Australia (fig. 8); paleomagnetic evidence that South China was in different positions with respect to India and Australia before it joined Gondwanaland in the Cambro-Ordovician (Zhang and others, 2013); the development of the intraplate Wuyi-Yunkai orogeny in southeastern South China during the early Paleozoic; and the lack of any early Paleozoic active margin along the northwestern and northern SCB continental margin as would be expected had the SCB been a coherent part of northern India or western Australia before that time.

In our preferred model, the Cathaysia side of the Nanhua Basin (fig. 1B) probably largely received sediments from a similar source to the northern margin of India during the early stage of the SCB-India suturing/collision (fig. 9C), when the entire northern margin of the Indian craton was under water and receiving similar sediments (for example, Myrow and others, 2010). However, as the proposed diachronous collision progressed, part of the Indian margin would have been uplifted and eroded, and could have therefore provided both recycled Ediacaran–Cambrian sediments and detritus from exposed Cambro-Ordovician granites, that typically intruded the Ediacaran–Cambrian strata, to foreland basins on both sides of the new orogen (fig. 9D). In both cases, the source regions (that is, the East African orogen, and/or the new North India orogen) appear to satisfy the characteristics of the Ediacaran–Cambrian Cathaysian sediments as being derived from dissected arc(s) and including post-580 Ma magmatism sourced from an old continental crust [see low $\varepsilon_{Hf}(t)$ values of zircons in fig. 4C and sandstone model compositions in fig. 5].

In addition, our model of having the SCB joining Gondwanaland during a Cambro-Ordovician collisional event is consistent with the paleomagnetic argument that the SCB started to share a common apparent polar wander path with Gondwanaland from Cambro-Ordovician time until the Early Devonian (Zhang, 2004; Zhang and others, 2013). It can also account for the lack of clastic deposition on the Yangtze side of the SCB during much of the Cambrian (fig. 1B), as it was separated by the Nanhua foreland basin from the Ediacaran–Ordovician orogens. The propagation of the Wuyi-Yunkai orogeny from the Cathaysia Block toward the Yangtze Block eventually pushed the remnant Nanhua foreland basin to the Yangtze side by the Silurian (Liu and Xu, 1994; Z. X. Li, 1998). The foreland basin ceased to develop by the Early Devonian, when the entire SCB started to develop a platformal marine transgression leading to the formation of an upper Paleozoic platform cover sequence (Liu and Xu, 1994).

CONCLUSIONS

Integrated U-Pb and Hf-O isotopic analyses of zircons from Cambrian sandstones/metasandstones from the western Cathaysia Block of South China reveal an exotic source region(s) that experienced three Precambrian episodes of juvenile crustal growth at 3.0, 2.5 and 1.0 Ga, and underwent extensive crustal remelting and reworking at 580 to 500 Ma. This provenance shows remarkable similarities to that of the NW Indian Himalaya during Ediacaran–Cambrian time. The two regions also share similarities in terms of Ediacaran–Cambrian tectonostratigraphy and Cambrian bioprovinces. We consider that the SCB (including Cathaysia) drifted away from central Rodinia during supercontinent break-up after *ca.* 750 Ma. Its collision with the NW Indian Himalaya between the late Ediacaran (*ca.* 580 Ma) and the Ordovician as part of Gondwana assembly, led to the formation of a "Pan-African" orogenic belt along the Himalaya at the northern Indian margin. The Cathaysia side of the Nanhua Basin possibly received sediments similar to northern India, dominantly shed from the East African orogen, during late Ediacaran. As the collision progressed, the Nanhua Basin was transformed into a fully-developed foreland basin, probably receiving both recycled sediments and eroded detritus from 550 to 470 Ma granites in the Cambro-Orodvician trans-Himalaya North India orogen. Far-field tectonic stress of the SCB-India collision eventually caused the Ordovician–Silurian intraplate Wuyi-Yunkai orogeny (>460-415 Ma) in southeastern South China that resulted in closure of the Nanhua Basin.

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Appendix tables

http://earth.geology.yale.edu/~ajs/SupplementaryData/2014/05Yao.doc

References

Ameen, S. M. M., Wilde, S. A., Kabir, Z., Akon, E., Chowdhury, K. R., and Khan, S. H., 2007, Paleoproterozoic granitoids in the basement of Bangladesh: A piece of the Indian shield or an exotic fragment of the Gondwana jigsaw?: Gondwana Research, v. 12, n. 4, p. 380–387, http://dx.doi.org/10.1016/j.gr.2007.02.001

Anderson, T., 2002, Correction of common lead in U-Pb analyses that do not report ^{204}Pb: Chemical Geology, v. 192, n. 1–2, p. 59–79, http://dx.doi.org/10.1016/S0009-2541(02)00195-X

Bagati, T. N., Kumar, R., and Ghosh, S. K., 1991, Regressive-transgressive sedimentation in the Ordovician sequence of the Spiti (Tethys) basin, Himachal Pradesh, India: Sedimentary Geology, v. 73, n. 1–2, p. 171–184, http://dx.doi.org/10.1016/0037-0738(91)90029-D

Barth, A. P., Wooden, J. L., Coleman, D. S., and Fanning, C. M., 2000, Geochronology of the Proterozoic basement of southwesternmost North America, and the origin and evolution of the Mojave crustal province: Tectonics, v. 19, n. 4, p. 616–629, http://dx.doi.org/10.1029/1999TC001145

Belousova, E. A., Kostitsyn, Y. A., Griffin, W. L., Begg, G. C., O'Reilly, S. Y., and Pearson, N. J., 2010, The growth of the continental crust: constraints from zircon Hf-isotope data: Lithos, v. 119, n. 3–4, p. 457–466, http://dx.doi.org/10.1016/j.lithos.2010.07.024

BGMRFJ (Bureau of Geology and Mineral Resources of Fujian Province), 1985, Regional Geology of the Fujian Province: Beijing, Geological Publishing House, 671 p. (in Chinese with English abstract).

BGMRGD (Bureau of Geology and Mineral Resources of Guangdong Province), 1988, Regional Geology of the Guangdong Province: Beijing, Geological Publishing House, 971 p. (in Chinese with English abstract).

BGMRGX (Bureau of Geology and Mineral Resources of Guangxi Province), 1985, Regional Geology of the Guangxi Province: Beijing, Geological Publishing House, 853 p. (in Chinese with English abstract).

BGMRGZ (Bureau of Geology and Mineral Resources of Guizhou Province), 1988, Regional Geology of the Guizhou Province: Beijing, Geological Publishing House, 698 p. (in Chinese with English abstract).

BGMRHN (Bureau of Geology and Mineral Resources of Hunan Province), 1988, Regional Geology of the Hunan Province: Beijing, Geological Publishing House, 719 p. (in Chinese with English abstract).

BGMRJX (Bureau of Geology and Mineral Resources of Jiangxi Province), 1984, Regional Geology of the Jiangxi Province: Beijing, Geological Publishing House, 921 p. (in Chinese with English abstract).

Bhargava, O. N., Frank, W., and Bertle, R., 2011, Late Cambrian deformation in the Lesser Himalaya: Journal of Asian Earth Sciences, v. 40, n. 1–4, p. 201–212, http://dx.doi.org/10.1016/j.jseaes.2010.07.015

Black L. P., Kamo, S. L., Allen, C. M., Aleinikoff, J. N., Davis, D. W., Korsch, R. J., and Foudoulis, C., 2003, TEMORA1: a new zircon standard for Phanerozoic U-Pb geochronology: Chemical Geology, v. 200, n. 1–2, p. 155–170, http://dx.doi.org/10.1016/S0009-2541(03)00165-7

Brookfield, M. E., 1993, The Himalayan passive margin from Precambrian to Cretaceous times: Sedimentary Geology, v. 84, n. 1–4, p. 1–35, http://dx.doi.org/10.1016/0037-0738(93)90042-4

Cawood, P. A., and Nemchin, A. A., 2000, Provenance record of a rift basin: U/Pb ages of detrital zircons from the Perth Basin, Western Australia: Sedimentary Geology, v. 134, n. 3–4, p. 209–234, http://dx.doi.org/10.1016/S0037-0738(00)00044-0

Cawood, P. A., Johnson, M. R. W., and Nemchin, A. A., 2007, Early Palaeozoic orogenesis along the Indian margin of Gondwana: Tectonic response to Gondwana assembly: Earth and Planetary Science Letters, v. 255, n. 1–2, p. 70–84, http://dx.doi.org/10.1016/j.epsl.2006.12.006

Cawood, P. A., Wang, Y. J., Xu, Y. J., and Zhao, G. C., 2013, Locating South China in Rodinia and Gondwana: A fragment of greater India lithosphere?: Geology, v. 41, n. 8, p. 903–906, http://dx.doi.org/10.1130/G34395.1

Charvet, J., Shu, L., Faure, M., Choulet, F., Wang, B., Lu, H., and Le Breton, N., 2010, Structural development of the Lower Paleozoic belt of South China: Genesis of an intracontinental orogen: Journal of Asian Earth Sciences, v. 39, n. 4, p. 309–330, http://dx.doi.org/10.1016/j.jseaes.2010.03.006

Chen, J., and Jahn, B. M., 1998, Crustal evolution of southeastern China: Nd and Sr isotopic evidence: Tectonophysics, v. 284, n. 1–2, p. 101–133, http://dx.doi.org/10.1016/S0040-1951(97)00186-8

Chen, X., Rong, J., Rowley, D. B., Zhang, J., Zhang, Y. D., and Zhan, R. B., 1995, Is the early Paleozoic Banxi Ocean in South China necessary?: Geological Review, v. 41, p. 389–400 (in Chinese with English abstract).

Chen, X., Rowley, D. B., Rong, J., Zhang, J., Zhang, Y. D., and Zhan, R. B., 1997, Late Precambrian through Early Paleozoic stratigraphic and tectonic evolution of the Nanling region, Hunan Province, South

China: International Geology Review, v. 39, n. 5, p. 469–478, http://dx.doi.org/10.1080/00206819709465285

Cocks, L. R. M., and Torsvik, T. H., 2013, The dynamic evolution of the Palaeozoic geography of eastern Asia: Earth-Science Reviews, v. 117, p. 40–79, http://dx.doi.org/10.1016/j.earscirev.2012.12.001

Condie, K. C., Belousova, E., Griffin, W. L., and Sircombe, K. N., 2009, Granitoid events in space and time: Constraints from igneous and detrital zircon age spectra: Gondwana Research, v. 15, n. 3–4, p. 228–242, http://dx.doi.org/10.1016/j.gr.2008.06.001

Corfu, F., Hanchar, J. M., Hoskin, P. W. O., and Kinny, P., 2003, Altas of zircon textures: Reviews in Mineralogy and Geochemistry, v. 53, n. 1, p. 469–500, http://dx.doi.org/10.2113/0530469

Cottle, J. M., Jessup, M. J., Newell, D. L., Horstwood, M. S. A., Noble, S. R., Parrish, R. R., Waters, D. J., and Searle, M. P., 2009, Geochronology of granulitized eclogite from the Ama Drime Massif: Implications for the tectonic evolution of the South Tibetan Himalaya: Tectonics, v. 28, n. 1, http://dx.doi.org/10.1029/2008TC002256

DeCelles, P. G., Gehrels, G. E., Quade, J., LaReau, B., and Spurlin, M., 2000, Tectonic implications of U–Pb zircon ages of the Himalayan orogenic belt in Nepal: Science, v. 288, n. 5465, p. 497–499, http://dx.doi.org/10.1126/science.288.5465.497

Dhuime, B., Hawkesworth, C., and Cawood, P., 2011, When continents formed: Science, v. 331, n. 6014, p. 154–155, http://dx.doi.org/10.1126/science.1201245

Dickinson, W. R., 1970, Interpreting detrital modes of graywacke and arkose: Journal of Sedimentary Research, v. 40, n. 2, p. 695–707, http://dx.doi.org/10.1306/74D72018-2B21-11D7-8648000102C1865D

——— 1985, Interpreting provenance relations from detrital modes of sandstones, *in* Zuffa, G. G., editor, Provenance of Arenites: NATO ASI series C, v. 148: Dordrecht/Boston/Lancaster, D. Reidel Publishing Company, p. 333–361.

Dickinson, W. R., Beard, L. S., Brakenridge, G. R., Erjavec, J. L., Ferguson, R. C., Inman, K. F., Knepp, R. A., Lindberg, F. A., and Ryberg, P. T., 1983, Provenance of North American Phanerozoic sandstones in relation to tectonic setting: Geological Society of America Bulletin, v. 94, n. 2, p. 222–235, http://dx.doi.org/10.1130/0016-7606(1983)94⟨222:PONAPS⟩2.0.CO;2

Dong, C. Y., Li, C., Wan, Y. S., Wang, W., Wu, Y. W., Xie, H. Q., and Liu, D. Y., 2011, Detrital zircon age model of Ordovician Wenquan quartzite south of Lungmuco-Shuanghu suture in the Qiangtang area, Tibet: Constraint on tectonic affinity and source regions: Science China, Earth Sciences, v. 54, n. 7, p. 1034–1042, http://dx.doi.org/10.1007/s11430-010-4166-x

Draganits, E., ms, 2000, The Muth Formation in the Pin Valley (Spiti, N-India): Depositional environment and Ichnofauna of a Lower Devonian barrier island system: Vienna, Austria, University of Vienna, Ph. D. thesis, 144 p.

Gan, X. C., Li, H. M., and Sun, D. Z., 1995, A geochronological study on early Proterozoic granitic rocks, Southwestern Zhejiang: Acta Petrologica et Mineralogica, v. 14, p. 1–8 (in Chinese with English abstract).

Gao, S., Yang, J., Zhou, L., Li, M., Hu, Z., Guo, J., Yuan, H., Gong, H., Xiao, G., and Wei, J., 2011, Age and growth of the Archean Kongling terrain, South China, with emphasis on 3.3 Ga granitoid gneisses: American Journal of Science, v. 311, n. 2, p. 153–182, http://dx.doi.org/10.2475/02.2011.03

Garzanti, E., Casnedi, R., and Jadoul, F., 1986, Sedimentary evidence of a Cambro-Ordovician orogenic event in the northwestern Himalaya: Sedimentary Geology, v. 48, n. 3–4, p. 237–265, http://dx.doi.org/10.1016/0037-0738(86)90032-1

Gazzi, P., 1966, Le arenarie del flysch sopracretaceo dell'Appennino modenese; correlazioni con il flysch di Monghidoro: Acta Mineralogica-Peteographica, v. 12, p. 69–97.

Gehrels, G. E., DeCelles, P. G., Martin, A., Ojha, T. P., and Pinhassi, G., 2003, Initiation of the Himalayan orogen as an early Paleozoic thin-skinned thrust belt: GSA today, v. 13, n. 9, p. 4–9, http://dx.doi.org/10.1130/1052-5173(2003)13⟨4:IOTHOA⟩2.0.CO;2

Gehrels, G. E., DeCelles, P. G., Ojha, T. P., and Upreti, B. N., 2006a, Geologic and U-Th-Pb geochronologic evidence for early Paleozoic tectonism in the Kathmandu thrust sheet, central Nepal Himalaya: Geological Society of America Bulletin, v. 118, n. 1–2, p. 185–198, http://dx.doi.org/10.1130/B25753.1

——— 2006b, Geologic and U-Pb geochronologic evidence for early Paleozoic tectonism in the Dadeldhura thrust sheet, far-west Nepal Himalaya: Journal of Asian Earth Sciences, v. 28, n. 4–6, p. 386–408, http://dx.doi.org/10.1016/j.jseaes.2005.09.012

Gehrels, G. E., Kapp, P., DeCelles, P., Pullen, A., Blakey, R., Weislogel, A., Ding, L., Guynn, J., Martin, A., McQuarrie, N., and Yin, A., 2011, Detrital zircon geochronology of pre-Tertiary strata in the Tibetan-Himalayan orogen: Tectonics, v. 30, n. 5, p. 1–27, http://dx.doi.org/10.1029/2011TC002868

Greentree, M. R., and Li, Z. X., 2008, The oldest known rocks in south-western China: SHRIMP U-Pb magmatic crystallisation age and detrital provenance analysis of the Paleoproterozoic Dahongshan Group: Journal of Asian Earth Sciences, v. 33, n. 5–6, p. 289–302, http://dx.doi.org/10.1016/j.jseaes.2008.01.001

Greentree, M. R., Li, Z. X., Li, X. H., and Wu, H. C., 2006, Late Mesoproterozoic to earliest Neoproterozoic basin record of the Sibao orogenesis in western South China and relationship to the assembly of Rodinia: Precambrian Research, v. 151, n. 1–2, p. 79–100, http://dx.doi.org/10.1016/j.precamres.2006.08.002

Griffin, W. L., Pearson, N. J., Belousova, E., Jackson, S. E., van Achterbergh, E., O'Reilly, S. Y., and Shee, S. R., 2000, The Hf isotope composition of cratonic mantle: LAM-MC-ICPMS analysis of zircon megacrysts in kimberlites: Geochimica et Cosmochimica Acta, v. 64, n. 1, p. 133–147, http://dx.doi.org/10.1016/S0016-7037(99)00343-9

Griffin, W. L., Belousova, E. A., Shee, S. R., Pearson, N. J., and O'Reilly, S. Y., 2004, Archean crustal evolution

in the northern Yilgarn Craton: U-Pb and Hf-isotope evidence from detrital zircons: Precambrian Research, v. 131, p. 231–282, http://dx.doi.org/10.1016/j.precamres.2003.12.011
Hawkesworth, C. J., and Kemp, A. I. S., 2006, Using hafnium and oxygen isotopes in zircons to unravel the record of crustal evolution: Chemical Geology, v. 226, n. 3–4, p. 144–162, http://dx.doi.org/10.1016/j.chemgeo.2005.09.018
Hoffman, P. F., 1991, Did the breakout of Laurentia turn Gondwanaland inside-out? Science, v. 252, n. 5011, p. 1409–1412, http://dx.doi.org/10.1126/science.252.5011.1409
Hughes, N. C., Myrow, P. M., Mckenzie, N. R., Harper, D. A. T., Bhargava, O. N., Tangri, S. K., Ghalley, K. S., and Fanning, C. M., 2011, Cambrian rocks and faunas of the Wachi La, Black Mountains, Bhutan: Geological Magazine, v. 148, n. 3, p. 351–379, http://dx.doi.org/10.1017/S0016756810000750
Ingersoll, R. V., Bullard, T. P., Ford, R. L., Grimm, J. P., Pickle, J. D., and Sares, S. W., 1984, The effect of grain size on detrital modes: A test of the Gazzi-Dickinson point-counting method: Sedimentary Petrology, v. 54, p. 103–116, http://dx.doi.org/doi:10.1306/212F83B9-2B24-11D7-8648000102C1865D
Jackson, S. E., Pearson, N. J., Griffin, W. L., and Belousova, E. A., 2004, The application of laser ablation-inductively coupled plasma-mass spectrometry to *in situ* U-Pb zircon geochronology: Chemical Geology, v. 211, n. 1–2, p. 47–69, http://dx.doi.org/10.1016/j.chemgeo.2004.06.017
Jell, P. A., and Hughes, N. C., 1997, Himalayan Cambrian trilobites: Special Papers in Palaeontology, v. 58, p. 1–113.
Jiang, G., Sohl, L. E., and Christie-Blick, N., 2003, Neoproterozoic stratigraphic comparison of the Lesser Himalaya (India) and Yangtze block (south China): Paleogeographic implications: Geology, v. 31, n. 10, p. 917–920, http://dx.doi.org/10.1130/G19790.1
Jiao, W. F., Wu, Y. B., Yang, S. H., Peng, M., and Yang, J., 2009, The oldest basement rock in the Yangtze Craton revealed by zircon U-Pb age and Hf isotope composition: Science in China Series D: Earth Sciences, v. 52, n. 9, p. 1393–1399, http://dx.doi.org/10.1007/s11430-009-0135-7
Kemp, A. I. S., Hawkesworth, C. J., Paterson, B. A., and Kinny, P. D., 2006, Episodic growth of the Gondwana supercontinent from hafnium and oxygen isotopes in zircon: Nature, v. 439, p. 580–583, http://dx.doi.org/10.1038/nature04505
Kohn, M. J., Paul, S. K., and Corrie, S. L., 2010, The lower Lesser Himalayan sequence: A Paleoproterozoic arc on the northern margin of the Indian plate: Geological Society of America Bulletin, v. 122, n. 3–4, p. 323–335, http://dx.doi.org/10.1130/B26587.1
Kolmogorov, A. N., 1933, Sulla determinazione empirica di una legge di distribuzione: Giornale dell'Istituto Italiano degli Attuari, v. 4, p. 83–91.
Kumar, G., 1984, The Precambrian-Cambrian boundary beds, northwest Himalaya, India, and boundary problems, *in* Proceedings of the Fifth Indian Geophytological Conference, Lucknow, November 1983: Palaeobotanical Society of India, Special Publications, Lucknow, p. 98–111.
Le Fort, P., 1975, Himalayas: collided range. Present knowledge of continental arc: American Journal of Science, v. 275-A, p. 1–44.
Leier, A. L., Kapp, P., Gehrels, G. E., and DeCelles, P. G., 2007, Detrital zircon geochronology of Carboniferous-Cretaceous strata in the Lhasa terrane, Southern Tibet: Basin Research, v. 19, n. 3, p. 361–378, http://dx.doi.org/10.1111/j.1365-2117.2007.00330.x
Li, L., Lin, S., Xing, G., Davis, D. W., Davis, W. J., Xiao, W., and Yin, C., 2013, Geochemistry and tectonic implications of late Mesoproterozoic alkaline bimodal volcanic rocks from the Tieshajie Group in the southeastern Yangtze Block, South China: Precambrian Research, v. 230, p. 179–192, http://dx.doi.org/10.1016/j.precamres.2013.02.004
Li, W. X., Li, X. H., and Li, Z. X., 2005, Neoproterozoic bimodal magmatism in the Cathaysia Block of South China and its tectonic significance: Precambrian Research, v. 136, n. 1, p. 51–66, http://dx.doi.org/10.1016/j.precamres.2004.09.008
——— 2010, *Ca.* 850 Ma bimodal volcanic rocks in northeastern Jiangxi Province, South China: Initial extension during the breakup of Rodinia?: American Journal of Science, v. 310, n. 9, p. 951–980, http://dx.doi.org/10.2475/09.2010.08
Li, W. X., Li, X. H., Li, Z. X., and Lou, F. S., 2008, Obduction-type granites within the NE Jiangxi Ophiolite: Implications for the final amalgamation between the Yangtze and Cathaysia Blocks: Gondwana Research, v. 13, n. 3, p. 288–301, http://dx.doi.org/10.1016/j.gr.2007.12.010
Li, X. H., 1997, Timing of the Cathaysia block formation: constraints from SHRIMP U-Pb zircon geochronology: Episodes, v. 20, n. 3, p. 188–192.
Li, X. H., Li, Z. X., Ge, W. C., Zhou, H. W., Li, W. X., Liu, Y., and Wingate, M. T. D., 2003, Neoproterozoic granitoids in South China: crustal melting above a mantle plume at *ca.* 825 Ma?: Precambrian Research, v. 122, n. 1–2, p. 45–83, http://dx.doi.org/10.1016/S0301-9268(02)00207-3
Li, X. H., Li, W. X., Li, Z. X., Lo, C. H., Wang, J., Ye, M. F., and Yang, Y. H., 2009, Amalgamation between the Yangtze and Cathaysia blocks in South China: Constraints from SHRIMP U-Pb zircon ages, geochemistry and Nd-Hf isotopes of the Shuangxiwu volcanic rocks: Precambrian Research, v. 174, n. 1–2, p. 117–128, http://dx.doi.org/10.1016/j.precamres.2009.07.004
Li, X. H., Long, W. G., Li, Q. L., Liu, Y., Zheng, Y. F., Yang, Y. H., Chamberlain, K. R., Wan, D. F., Guo, C. H., Wang, X. C., and Tao, H., 2010a, Penglai zircon megacrysts: A potential new working reference material for microbeam determination of Hf-O isotopes and U-Pb age: Geostandards and Geoanalytical Research, v. 34, n. 2, p. 117–134, http://dx.doi.org/10.1111/j.1751-908X.2010.00036.x
Li, X. H., Li, W. X., Li, Q. L., Wang, X. C., Liu, Y., and Yang, Y. H., 2010b, Petrogenesis and tectonic significance of the ~ 850 Ma Gangbian alkaline complex in South China: Evidence from *in situ* zircon U-Pb dating, Hf-O isotopes and whole rock geochemistry: Lithos, v. 114, n. 1–2, p. 1–15, http://dx.doi.org/10.1016/j.lithos.2009.07.011
Li, X. H., Li, Z. X., He, B., Li, W. X., Li, Q. L., Gao, Y. Y., and Wang, X. C., 2012, The Early Permian active continental margin and crustal growth of the Cathaysia Block: *In situ* U-Pb, Lu-Hf and O isotope analyses

of detrital zircons: Chemical Geology, v. 328, p. 195–207, http://dx.doi.org/10.1016/j.chemgeo.2011.10.027

Li, Z. X., 1998, Tectonic history of the major East Asian lithospheric blocks since the mid-Proterozoic-a synthesis, *in* Flower, M. F. J., Chung, S. L., Lo, C. H., and Lee, T. Y., editors, Mantle dynamics and plate interactions in East Asia: Washington, D.C., United States, American Geophysical Union, p. 221–243, http://dx.doi.org/10.1029/GD027p0221

Li, Z. X., and Evans, D. A. D., 2011, Late Neoproterozoic 40° intraplate rotation within Australia allows for a tighter-fitting and longer-lasting Rodinia: Geology, v. 39, n. 1, p. 39–42, http://dx.doi.org/10.1130/G31461.1

Li, Z. X., and Li, X. H., 2007, Formation of the 1300 km-wide intracontinental orogen and postorogenic magmatic province in Mesozoic South China: A flat-slab subduction model: Geology, v. 35, n. 2, p. 179–182, http://dx.doi.org/10.1130/G23193A.1

Li, Z. X., and Powell, C. McA., 2001, An outline of the Palaeogeographic evolution of the Australasian region since the beginning of the Neoproterozoic: Earth-Science Reviews, v. 53, n. 3–4, p. 237–277, http://dx.doi.org/10.1016/S0012-8252(00)00021-0

Li, Z. X., Zhang, L. H., and Powell, C. McA., 1996, Positions of the East Asian cratons in the Neoproterozoic supercontinent Rodinia: Australian Journal of Earth Sciences, v. 43, n. 6, p. 593–604, http://dx.doi.org/10.1080/08120099608728281

Li, Z. X., Li, X. H., Zhou, H. W., and Kinny, P. D., 2002, Grenvillian continental collision in south China: New SHRIMP U-Pb zircon results and implications for the configuration of Rodinia: Geology, v. 30, n. 2, p. 163–166, http://dx.doi.org/10.1130/0091-7613(2002)030⟨0163:GCCISC⟩2.0.CO;2

Li, Z. X., Li, X. H., Kinny, P. D., Wang, J., Zhang, S., and Zhou, H. W., 2003, Geochronology of Neoproterozoic syn-rift magmatism in the Yangtze Craton, South China and correlations with other continents: evidence for a mantle superplume that broke up Rodinia: Precambrian Research, v. 122, n. 1–4, p. 85–109, http://dx.doi.org/10.1016/S0301-9268(02)00208-5

Li, Z. X., Evans, D. A. D., and Zhang, S. H., 2004, A 90° Spin on Rodinia: Possible causal links between the Neoproterozoic supercontinent, superplume, true polar wander and low-latitude glaciation: Earth and Planetary Science Letters, v. 220, n. 3–4, p. 409–421, http://dx.doi.org/10.1016/S0012-821X(04)00064-0

Li, Z. X., Wartho, J. A., Occhipinti, S., Zhang, C. L., Li, X. H., Wang, J., and Bao, C. M., 2007, Early history of the eastern Sibao Orogen (South China) during the assembly of Rodinia: New mica $^{40}Ar/^{39}Ar$ dating and SHRIMP U-Pb detrital zircon provenance constraints: Precambrian Research, v. 159, n. 1–2, p. 79–94, http://dx.doi.org/10.1016/j.precamres.2007.05.003

Li, Z. X., Li, X. H., Li, W. X., and Ding, S., 2008a, Was Cathaysia part of Proterozoic Larentia?—new data from Hainan Island, south China: Terra Nova, v. 20, n. 2, p. 154–164, http://dx.doi.org/10.1111/j.1365-3121.2008.00802.x

Li, Z. X., Bogdanova, S. V., Collins, A. S., Davidson, A., De Waele, B., Ernst, R. E., Fitzsimons, I. C. W., Fuck, R. A., Gladkochub, D. P., Jacobs, J., Karlstrom, K. E., Lu, S., Natapov, L. M., Pease, V., Pisarevsky, S. A., Thrane, K., and Vernikosky, V., 2008b, Assembly, configuration, and break-up history of Rodinia: A synthesis: Precambrian Research, v. 160, n. 1–2, p. 179–210, http://dx.doi.org/10.1016/j.precamres.2007.04.021

Li, Z. X., Li, X. H., Wartho, J. A., Clark, C., Li, W. X., Zhang, C. L., and Bao, C. M., 2010, Magmatic and metamorphic events during the early Paleozoic Wuyi-Yunkai orogeny, southeastern South China: New age constraints and pressure-temperature conditions: Geological Society of America Bulletin, v. 122, n. 5–6, p. 772–793, http://dx.doi.org/10.1130/B30021.1

Li, Z. X., Evans, D. A. D., and Halverson, G. P., 2013, Neoproterozoic glaciations in a revised global paleogeography from the breakup of Rodinia to the assembly of Gondwanaland: Sedimentary Geology, v. 294, p. 219–232, http://dx.doi.org/10.1016/j.sedgeo.2013.05.016

Ling, W., Gao, S., Zhang, B., Li, H., Liu, Y., and Cheng, J., 2003, Neoproterozoic tectonic evolution of Yangtze craton, South China: implications for amalgamation and break-up of the Rodinia Supercontinent: Precambrian Research, v. 122, n. 1–4, p. 111–140, http://dx.doi.org/10.1016/S0301-9268(02)00222-X

Liu, B., and Xu, X., 1994, Atlas of Lithofacies and Paleogeography of South China: Beijing, Science Press, 188 p.

Liu, R., Zhou, H. W., Zhang, L., Zhong, Z. Q., Zeng, W., Xiang, H., Jin, S., Lu, X. Q., and Li, C. Z., 2009, Paleoproterozoic reworking of ancient crust in the Cathaysia Block, South China: Evidence from zircon trace elements, U-Pb and Lu-Hf isotopes: Chinese Science Bulletin, v. 54, n. 9, p. 1543–1554, http://dx.doi.org/10.1007/s11434-009-0096-4

Liu, X., Hsu, K. J., Ju, Y., Li, G., Liu, X., Wei, L., Zhou, X., and Zhang, X., 2012, New interpretation of tectonic model in south Tibet: Journal of Asian Earth Sciences, v. 56, p. 147–159, http://dx.doi.org/10.1016/j.jseaes.2012.05.005

Liu, Y., Siebel, W., Massonne, H., and Xiao, X., 2007, Geochronological and petrological constraints for tectonic evolution of the central Greater Himalayan sequence in the Kharta area, southern Tibet: The Journal of Geology, v. 115, n. 2, p. 215–230, http://dx.doi.org/10.1086/510806

Ludwig, K. R., 2001a, ISOPLOT/EX version 2.49—A geochronological toolkit for Microsoft excel: Berkley Geochronological Centre Special Publication No. 1, 56 p.

——— 2001b, SQUID version 1.02—A geochronological toolkit for Microsoft excel: Berkley Geochronological Centre Special Publication No. 2, 19 p.

Ma, D., Huang, X., Xiao, Z., Chen, Z., Zhang, W., and Zhong, S., 1998, The crystalline basement of the Hainan Island—stratigraphy and geochronology of the Baoban group: Wuhan, China University of Geosciences Press, 60 p. (In Chinese).

Martin, A. J., DeCelles, P. G., Gehrels, G. E., Patchett, P. J., and Isachsen, C., 2005, Isotopic and structural constraints on the location of the main Central thrust in the Annapurna Range, central Nepal Himalaya:

Geological Society of America Bulletin, v. 117, n. 7–8, p. 926–944, http://dx.doi.org/10.1130/B25646.1
McKenzie, N. R., Hughes, N. C., Myrow, P. M., Choi, D. K., and Park, T.-y., 2011, Trilobites and zircons link north China with the eastern Himalaya during the Cambrian: Geology, v. 39, n. 6, p. 591–594, http://dx.doi.org/10.1130/G31838.1
McQuarrie, N., Robinson, D., Long, S., Tobgay, T., Grujic, D., Gehrels, G., and Duce, M., 2008, Preliminary stratigraphic and structural architecture of Bhutan: Implications for the along strike architecture of the Himalayan system: Earth and Planetary Science Letters, v. 272, n. 1–2, p. 105–117, http://dx.doi.org/10.1016/j.epsl.2008.04.030
McQuarrie, N., Long, S. P., Tobgay, T., Nesbit, J. N., Gehrels, G., and Ducea, M. N., 2013, Documenting basin scale, geometry and provenance through detrital geochemical data: Lessons from the Neoproterozoic to Ordovician Lesser, Greater, and Tethyan Himalayan strata of Bhutan: Gondwana Research, v. 23, n. 4, p. 1491–1510, http://dx.doi.org/10.1016/j.gr.2012.09.002
Metcalfe, I., 1996, Gondwanaland dispersion, Asian accretion and evolution of eastern Tethys: Australian Journal of Earth Sciences, v. 43, n. 6, p. 605–623, http://dx.doi.org/10.1080/08120099608728282
Miller, C., Klötzli, U., Frank, W., Thoni, M., and Grasemann, B., 2000, Proterozoic crustal evolution in the NW Himalaya (India) as recorded by circa 1.80 Ga mafic and 1.84 Ga granitic magmatism: Precambrian Research, v. 103, n. 3–4, p. 191–206, http://dx.doi.org/10.1016/S0301-9268(00)00091-7
Miller, C., Thoni, M., Frank, W., Grasemann, B., Klotzli, U., Guntli, P., and Draganits, E., 2001, The early Palaeozoic magmatic event in the Northwest Himalaya, India: source, tectonic setting and age of emplacement: Geological Magazine, v. 138, n. 3, p. 237–251, http://dx.doi.org/10.1017/S0016756801005283
Morel, M. L. A., Nebel, O., Nebel-Jacobsen, Y. J., Miller, J. S., and Vroon, P. Z., 2008, Hafnium isotope characterization of the GJ-1 zircon reference material by solution and laser ablation MC-ICPMS: Chemical Geology, v. 255, p. 231–235, http://dx.doi.org/10.1016/j.chemgeo.2008.06.040
Myrow, P. M., Hughes, N. C., Paulsen, T. S., Williams, I. S., Parcha, S. K., Thompson, K. R., Bowring, S. A., Peng, S. C., and Ahluwalia, A. D., 2003, Intergrated tectonostratigraphic analysis of the Himalaya and implications for its tectonic reconstruction: Earth and Planetary Science Letters, v. 212, n. 3–4, p. 433–441, http://dx.doi.org/10.1016/S0012-821X(03)00280-2
Myrow, P. M., Snell, K. E., Hughes, N. C., Paulsen, T. S., Heim, N. A., and Parcha, S. K., 2006a, Cambrian depositional history of the Zanskar Valley region of the Indian Himalaya: tectonic implications: Journal of Sedimentary Research, v. 76, n. 2, p. 364–381, http://dx.doi.org/10.2110/jsr.2006.020
Myrow, P. M., Thompson, K. R., Hughes, N. C., Paulsen, T. S., Sell, B. K., and Parcha, S. K., 2006b, Cambrian stratigraphy and depositional history of the northern Indian Himalaya, Spiti Valley, north-central India: Geological Society of America Bulletin, v. 118, n. 3–4, p. 491–510, http://dx.doi.org/10.1130/B25828.1
Myrow, P. M., Hughes, N. C., Searle, M. P., Fanning, C. M., Peng, S. C., and Parcha, S. K., 2009, Stratigraphic correlation of Cambrian-Ordovician deposits along the Himalaya: Implications for the age and nature of rocks in the Mount Everest region: Geological Society of America Bulletin, v. 121, n. 3–4, p. 323–332, http://dx.doi.org/10.1130/B26384.1
Myrow, P. M., Hughes, N. C., Goodge, J. W., Fanning, C. M., Williams, I. S., Peng, S. C., Bhargava, O. N., Parcha, S. K., and Pogue, K. R., 2010, Extraordinary transport and mixing of sediment across Himalayan central Gondwana during the Cambrian-Ordovician: Geological Society of America Bulletin, v. 122, n. 9–10, p. 1660–1670, http://dx.doi.org/10.1130/B30123.1
Nesheim, T. O., Vervoort, J. D., McClelland, W. C., Gilotti, J. A., and Lang, H. M., 2012, Mesoproterozoic syntectonic garnet within Belt Supergroup metamorphic tectonites: Evidence of Grenville-age metamorphism and deformation along northwest Laurentia: Lithos, v. 134–135, p. 91–107, http://dx.doi.org/10.1016/j.lithos.2011.12.008
Neves, S. P., 2003, Proterozoic history of the Borborema province (NE Brazil): Correlations with neighboring cratons and Pan-African belts and implications for the evolution of western Gondwana: Tectonics, v. 22, n. 4, p. 1031–1044, http://dx.doi.org/10.1029/2001TC001352
Nichols, G., 2009, Sedimentology and Stratigraphy (second edition): London, Blackwell Science Publishing, 419 p.
Peng, S., Hughes, N. C., Heim, N. A., Sell, B. K., Zhu, X. J, Myrow, P. M., and Parcha, S. K., 2009, Cambrian trilobites from the Parahio and Zanskar Valleys, Indian Himalaya: Paleontological Society Memoirs (Journal of Paleontology Supplement), v. 71, p. 1–95.
Pogue, K. R., Hylland, M. D., Yeats, R. S., Khattak, W. U., and Hussain, A., 1999, Stratigraphic and structural framework of Himalayan foothills, northern Pakistan, *in* Macfarlane, A., Sorkhabi, R. B., and Quade, J., editors, Himalaya and Tibet: Mountain Roots to Mountain Tops: Geological Society of America Special Papers, v. 328, p. 257–274, http://dx.doi.org/10.1130/0-8137-2328-0.257
Pullen, A., Kapp, P., Gehrels, G. E., Ding, L., and Zhang, Q., 2011, Metamorphic rocks in central Tibet: Lateral variations and implications for crustal structure: Geological Society of America Bulletin, v. 123, n. 3–4, p. 585–600, http://dx.doi.org/10.1130/B30154.1
Qiu, Y. M., Gao, S., McNaughton, N. J., Groves, D. I., and Ling, W., 2000, First evidence of >3.2 Ga continental crust in the Yangtze craton of south China and its implications for Archean crustal evolution and Phanerozoic tectonics: Geology, v. 28, n. 1, p. 11–14, http://dx.doi.org/10.1130/0091-7613(2000)028⟨0011:FEOGCC⟩2.0.CO;2
Reading, H. G., 1996, Sedimentary Environments: Processes, Facies and Stratigraphy: London, Blackwell Science Publishing, 687 p.
Ren, J., 1991, On the geotectonics of southern China: Acta Geologica Sinica, v. 4, p. 111–130.
Ren, J., Wang, Z., Chen, B., Jiang, C., and Niu, B., 1997, Tectonic map of China and adjacent regions: Beijing, Geological Publishing House, scale 1:5,000,000.

RGMRGD, 1964, Regional Geological Mapping and Report of Guangdong Province–Yangjiang Sheet: Beijing, Institute of Geoscience, Ministry of Geology (in Chinese), scale 1:200,000.
Schärer, U., Xu, R. H., and Allègre, C. J., 1986, U-(Th)-Pb systematics and ages of Himalayan leucogranites, South Tibet: Earth and Planetary Science Letters, v. 77, n. 1, p. 35–48, http://dx.doi.org/10.1016/0012-821X(86)90130-5
Schervish, M. J., 1996, P values: what they are and what they are not: The American Statistician, v. 50, n. 3, p. 203–206.
Shu, L. S., Deng, P., Yu, J. H., Wang, Y. B., and Jiang, S. Y., 2008, The age and tectonic environment of the rhyolitic rocks on the western side of Wuyi Mountain, South China: Science in China, Series D: Earth Sciences, v. 51, n. 8, p. 1053–1063, http://dx.doi.org/10.1007/s11430-008-0078-4
Shu, L. S., Faure, M., Yu, J. H., and Jahn, B. M., 2011, Geochronological and geochemical features of the Cathaysia block (South China): New evidence for the Neoproterozoic breakup of Rodinia: Precambrian Research, v. 187, n. 3–4, p. 263–276, http://dx.doi.org/10.1016/j.precamres.2011.03.003
Singh, S., Barley, M. E., Brown, S. J., Jain, A. K., and Manickavasagam, R. M., 2002, SHRIMP U-Pb in zircon geochronology of the Chor granitoid: evidence for Neoproterozoic magmatism in the Lesser Himalayan granite belt of NW India: Precambrian Research, v. 118, n. 3–4, p. 285–292, http://dx.doi.org/10.1016/S0301-9268(02)00107-9
Singh, S., Claesson, S., Jain, A. K., Gee, D. G., Andreasson, P. G., and Manickavasagam, R. M., 2006, 2.0 Ga granite of the lower package of the Higher Himalayan crystallines, Maglad Khad, Sutlej Valley, Himachal Pradesh: Journal of the Geological Society of India, v. 67, n. 3, p. 295–300.
Sláma, J., Kosler, J., Condon, D. J., Crowley, J. L., Gerdes, A., Hanchar, J. M., Horstwood, M. S. A., Morris, G. A., Nasdala, L., Norberg, N., Schaltegger U., Schoene, B., Tubrett, M. N., and Whitehouse, M. J., 2008, Plesovice zircon: a new natural reference material for U-Pb and Hf isotopic microanalysis: Chemical Geology, v. 249, n. 1–2, p. 1–35, http://dx.doi.org/10.1016/j.chemgeo.2007.11.005
Smirnov, N. V., 1944, Approximate laws of distribution of random variables from empirical data: Uspekhi Matematicheskikh Nauk, v. 10, p. 179–206 (In Russian).
Smith, M., and Gehrels, G., 1994, Detrital zircon geochronology and the provenance of the Harmony and Valmy Formations, Roberts Mountains allochthon, Nevada: Geological Society of America Bulletin, v. 106, n. 7, p. 968–979, http://dx.doi.org/10.1130/0016-7606(1994)106⟨0968:DZGATP⟩2.3.CO;2
Song, S., Niu, Y., Wei, C., Ji, J., and Su, L., 2010, Metamorphism, anatexis, zircon ages and tectonic evolution of the Gongshan block in the northern Indochina continent—An eastern extension of the Lhasa Block: Lithos, v. 120, n. 3–4, p. 327–346, http://dx.doi.org/10.1016/j.lithos.2010.08.021
Srikantia, S. V., 1977, Sedimentary cycles in the Himalaya and their significance on the Orogenic evolution of the mountain belt: International Colloquium Centre National de la Recherche Scientiques, v. 268, p. 395–407.
Stewart, J. H., Gehrels, G. E., Barth, A. P., Link, P. K., Christie-Blick, N., and Wrucke, C. T., 2001, Detrital zircon provenance of Mesoproterozoic to Cambrian arenites in the western United States and northwestern Mexico: Geological Society of America Bulletin, v. 113, n. 10, p. 1343–1356, http://dx.doi.org/10.1130/0016-7606(2001)113⟨1343:DZPOMT⟩2.0.CO;2
Sun, W. H., Zhou, M. F., Gao, J. F., Yang, Y. H., Zhao, X. F., and Zhao, J. H., 2009, Detrital zircon U-Pb geochronological and Lu-Hf isotopic constraints on the Precambrian magmatic and crustal evolution of the western Yangtze Block, SW China: Precambrian Research, v. 172, n. 1–2, p. 99–126, http://dx.doi.org/10.1016/j.precamres.2009.03.010
Torsvik, T. H., Paulsen, T. S., Hughes, N. C., Myrow, P. M., and Ganerod, M., 2009, The Tethyan Himalaya: palaeogeographical and tectonic constraints from Ordovician palaeomagnetic data: Journal of the Geological Society, v. 166, n. 4, p. 679–687, http://dx.doi.org/10.1144/0016-76492008-123
Valdiya, K. S., 1970, Simla Slates: The Precambrian flysch of the Lesser Himalaya, its turbidites, sedimentary structures and paleocurrents: Geological Society of America Bulletin, v. 81, n. 2, p. 451–468, http://dx.doi.org/10.1130/0016-7606(1970)81[451:SSTPFO]2.0.CO;2
Valley, J. W., Kinny, P. D., Schulze, D. J., and Spicuzza, M. J., 1998, Zircon megacrysts from kimberlite: oxygen isotope variability among mantle melts: Contributions to Mineralogy and Petrology, v. 133, n. 1–2, p. 1–11, http://dx.doi.org/10.1007/s004100050432
Valley, J. W., Lackey, J. S., Cavosie, A. J., Clechenko, C. C., Spicuzza, M. J., Basei, M. A. S., Bindeman, I. N., Ferreira, V. P., Sial, A. N., King, E. M., Peck, W. H., Sinha, A. K., and Wei, C. S., 2005, 4.4 billion years of crustal maturation: oxygen isotope ratios of magmatic zircon: Contributions to Mineralogy and Petrology, v. 150, n. 6, p. 561–580, http://dx.doi.org/10.1007/s00410-005-0025-8
Van Achterbergh, E., Ryan, C. G., Jackson, S. E., and Griffin, W. L., 2001, Data reduction software for LA-ICP-MS: appendix, *in* Sylvester, P. J., editor, Laser Ablation-ICP-Mass Spectrometry in the Earth Sciences: Principles and Applications: Ottawa, Canada, Mineralogist Association Canada (MAC) Short Course Series, v. 29, p. 239–243.
Veevers, J. J., Saeed, A., Belousova, E. A., and Griffin, W. L., 2005, U-Pb ages and source composition by Hf-isotope and trace–element analysis of detrital zircons in Permian sandstone and modern sand from southwestern Australia and a review of the paleogeographical and denudational history of the Yilgarn Craton: Earth-Science Reviews, v. 68, n. 3–4, p. 245–279, http://dx.doi.org/10.1016/j.earscirev.2004.05.005
Veevers, J. J., Belousova, E. A., Saeed, A., Sircombe, K., Cooper, A. F., and Read, S. E., 2006, Pan-Gondwanaland detrital zircons from Australia analysed for Hf-isotopes and trace elements reflect an ice-covered Antarctic provenance of 700–500 Ma age, T_{DM} of 2.0–1.0 Ga, and alkaline affinity: Earth-Science Reviews, v. 76, n. 3–4, p. 135–174, http://dx.doi.org/10.1016/j.earscirev.2005.11.001
Vega-Granillo, R., Salgado-Souto, S., Herrera-Urbina, S., Valencia, V., Ruiz, J., Meza-Figueroa, D., and Talavera-Mendoza, O., 2008, U-Pb detrital zircon data of the Rio Fuerte Formation (NW Mexico): Its

peri-Gondwanan provenance and exotic nature in relation to southwestern North America: Journal of South American Earth Sciences, v. 26, n. 4, p. 343–354, http://dx.doi.org/10.1016/j.jsames.2008.08.011
Wan, Y., Liu, D., Xu, M., Zhuang, J., Song, B., Shi, Y., and Du, L., 2007, SHRIMP U-Pb zircon geochronology and geochemistry of metavolcanic and metasedimentary rocks in Northwestern Fujian, Cathaysia block, China: Tectonic implications and the need to redefine lithostratigraphic units: Gondwana Research, v. 12, n. 1–2, p. 166–183, http://dx.doi.org/10.1016/j.gr.2006.10.016
Wan, Y., Liu, D., Wilde, S. A., Cao, J., Chen, B., Dong, C., Song, B., and Du, L., 2010, Evolution of the Yunkai Terrane, South China: Evidence from SHRIMP zircon U–Pb dating, geochemistry and Nd isotope: Journal of Asian Earth Sciences, v. 37, n. 2, p. 140–153, http://dx.doi.org/10.1016/j.jseaes.2009.08.002
Wang, H. (Chief Compiler), 1985, Atlas of the Palaeogeography of China: Beijing, China, Cartographic Publishing House, 281 p.
Wang, J., and Li, Z. X., 2003, History of Neoproterozoic rift basins in South China: implications for Rodinia break-up: Precambrian Research, v. 122, n. 1–4, p. 141–158, http://dx.doi.org/10.1016/S0301-9268(02)00209-7
Wang, K. L., O'Reilly, S. Y., Griffin, W. L., Pearson, N. J., and Zhang, M., 2009, Sulfides in mantle peridotites from Penghu Islands, Taiwan: Melt percolation, PGE fractionation, and the lithospheric evolution of the South China block: Geochimica et Cosmochimica Acta, v. 73, n. 15, p. 4531–4557, http://dx.doi.org/10.1016/j.gca.2009.04.030
Wang, L. J., Griffin, W. L., Yu, J. H., and O'Reilly, S. Y., 2010a, Precambrian crustal evolution of the Yangtze Block tracked by detrital zircons from Neoproterozoic sedimentary rocks: Precambrian Research, v. 177, n. 1–2, p. 131–144, http://dx.doi.org/10.1016/j.precamres.2009.11.008
Wang, X., Zhou, J., Qiu, J., and Gao, J., 2004, Geochemistry of the Meso- to Neoproterozoic basic–acid rocks from Hunan Province, South China: implications for the evolution of the western Jiangnan orogen: Precambrian Research, v. 135, n. 1–2, p. 79–103, http://dx.doi.org/10.1016/j.precamres.2004.07.006
Wang, X., Zhang, J., Santosh, M., Liu, J., Yan, S., and Guo, L., 2012b, Andean-type orogeny in the Himalayas of south Tibet: Implications for early Paleozoic tectonics along the Indian margin of Gondwana: Lithos, v. 154, p. 248–262, http://dx.doi.org/10.1016/j.lithos.2012.07.011
Wang, X. C., Li, X. H., Li, Z. X., Li, Q. L., Tang, G. Q., Gao, Y. Y., Zhang, Q. R., and Liu, Y., 2012a, Episodic Precambrian crust growth: Evidence from U-Pb ages and Hf-O isotopes of zircon in the Nanhua Basin, central South China: Precambrian Research, v. 222–223, p. 386–403, http://dx.doi.org/10.1016/j.precamres.2011.06.001
Wang, X. L., Zhou, J. C., Qiu, J. S., Zhang, W. L., Liu, X. M., and Zhang, G. L., 2006, LA-ICP-MS U-Pb zircon geochronology of the Neoproterozoic igneous rocks from Northern Guangxi, South China: Implications for tectonic evolution: Precambrian Research, v. 145, n. 1–2, p. 111–130, http://dx.doi.org/10.1016/j.precamres.2005.11.014
Wang, Y., Fan, W., Zhao, G., Ji, S., and Peng, T., 2007, Zircon U-Pb geochronology of gneissic rocks in the Yunkai massif and its implications on the Caledonian event in the South China Block: Gondwana Research, v. 12, n. 4, p. 404–416, http://dx.doi.org/10.1016/j.gr.2006.10.003
Wang, Y., Zhang, F., Fan, W., Zhang, G., Chen, S., Cawood, P. A., and Zhang, A., 2010b, Tectonic setting of the South China Block in the early Paleozoic: Resolving intracontinental and ocean closure models from detrital zircon U-Pb geochronology: Tectonics, v. 29, n. 6, TC6020, http://dx.doi.org/10.1029/2010TC002750
Webb, A. A. G., Yin, A., Harrison, T. M., Célérier, J., Gehrels, G. E., Manning, C. E., and Grove, M., 2011, Cenozoic tectonic history of the Himachal Himalaya (northwestern India) and its constraints on the formation mechanism of the Himalayan orogen: Geosphere, v. 7, n. 4, p. 1013–1061, http://dx.doi.org/10.1130/GES00627.1
Wiedenbeck, M., Allé, P., Corfu, F., Griffin, W. L., Meier, M., Oberli, F., Von Quadt, A., Roddick, J. C., and Spiegel, W., 1995, Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analyses: Geostandards Newsletter, v. 19, n. 1, p. 1–23 http://dx.doi.org/10.1111/j.1751-908X.1995.tb00147.x
Wiedenbeck, M., Hanchar, J. M., Peck, W. H., Sylvester, P., Valley, J., Whitehouse, M., Kronz, A., Morishita, Y., Nasdala, L., Fiebig, J., Franchi, I., Girard, J. P., Greenwood, R. C., Hinton, R., Kita, N., Mason, P. R. D., Norman, M., Ogasawara, M., Piccoli, P. M., Rhede, D., Satoh, H., Schulz-Dobrick, B., Skar, O., Spicuzza, M. J., Terada, K., Tindle, A., Togashi, S., Vennemann, T., Xie, Q., and Zheng, Y. F., 2004, Further characterization of the 91500 zircon crystal: Geostandards newsletter, v. 28, n. 1, p. 9–39, 10.1111/j.1751-908X.2004.tb01041.x
Williams, I. S., 1998, U-Th-Pb geochronology by ion microprobe, *in* McKibben, M. A., Shanks III, W. C., and Ridley, W. I., editors, Applications of microanalytical techniques to understanding mineralizing processes: Reviews in Economic Geology, Special Publication, v. 7, p. 1–35.
Wu, F. Y., Yang, Y. H., Xie, L. W., Yang, J. H., and Xu, P., 2006, Hf isotopic compositions of the standard zircons and baddeleyites used in U-Pb geochronology: Chemical Geology, v. 234, n. 1–2, p. 105–126, http://dx.doi.org/10.1016/j.chemgeo.2006.05.003
Wu, L., Jia, D., Li, H., Deng, F., and Li, Y., 2010, Provenance of detrital zircons from the late Neoproterozoic to Ordovician sandstones of South China: implications for its continental affinity: Geological Magazine, v. 147, n. 6, p. 974–980, http://dx.doi.org/10.1017/S0016756810000725
Xiang, H., Zhang, L., Zhou, H. W., Zhong, Z. Q., Zeng, W., Liu, R., and Jin, S., 2008, U-Pb zircon geochronology and Hf isotope study of metamorphosed basic-ultrabasic rocks from metamorphic basement in southwestern Zhejiang: The response of the Cathaysia Block to Indosinian orogenic event: Science in China Series D: Earth Sciences, v. 51, n. 6, p. 788–800, http://dx.doi.org/10.1007/s11430-008-0053-0
Xie, L. W., Zhang, Y. B., Zhang, H. H., Sun, J. F., and Wu, F. Y., 2008, *In situ* simultaneous determination of trace elements, U-Pb and Lu-Hf isotopes in zircon and baddeleyite: Chinese Science Bulletin, v. 53, n. 10, p. 1565–1573, http://dx.doi.org/10.1007/s11434-008-0086-y

Xu, X., O'Reilly, S. Y., Griffin, W. L., Wang, X., Pearson, N. J., and He, Z., 2007, The crust of Cathaysia: Age, assembly and reworking of two terranes: Precambrian Research, v. 158, n. 1–2, p. 51–78, http://dx.doi.org/10.1016/j.precamres.2007.04.010

Yang, Z., Sun, Z., Yang, T., and Pei, J., 2004, A long connection (750-380 Ma) between South China and Australia: paleomagnetic constraints: Earth and Planetary Science Letters, v. 220, n. 3–4, p. 423–434, http://dx.doi.org/10.1016/S0012-821X(04)00053-6

Yao, J., Shu, L., and Santosh, M., 2011, Detrital zircon U-Pb geochronology, Hf-isotopes and geochemistry—new clues for the Precambrian crustal evolution of Cathaysia Block, South China: Gondwana Research, v. 20, n. 2–3, p. 553–567, http://dx.doi.org/10.1016/j.gr.2011.01.005

Yao, J., Shu, L., Santosh, M., and Li, J., 2012, Precambrian crustal evolution of the South China Block and its relation to supercontinent history: Constraints from U-Pb ages, Lu-Hf isotopes and REE geochemistry of zircons from sandstones and granodiorite: Precambrian Research, v. 208–211, p. 19–48, http://dx.doi.org/10.1016/j.precamres.2012.03.009

Ye, M. F., Li, X. H., Li, W. X., Liu, Y., and Li, Z. X., 2007, SHRIMP zircon U-Pb geochronological and whole-rock geochemical evidence for an early Neoproterozoic Sibaoan magmatic arc along the southeastern margin of the Yangtze Block: Gondwana Research, v. 12, n. 1–2, p. 144–156, http://dx.doi.org/10.1016/j.gr.2006.09.001

Yin, A., Nie, S., Craig, P., Harrison, T. M., Ryerson, F. J., Qian, X., and Yang, G., 1998, Late Cenozoic tectonic evolution of the southern Chinese Tian Shan: Tectonics, v. 17, n. 1, p. 1–27, http://dx.doi.org/10.1029/97TC03140

Yin, A., Dubey, C. S., Kelty, T. K., Webb, A. A. G., Harrison, T. M., Chou, C. Y., and Célérier, J., 2010a, Geologic correlation of the Himalayan orogen and Indian craton: Part 2. Structural geology, geochronology, and tectonic evolution of the eastern Himalayan: Geological Society of America Bulletin, v. 122, n. 3–4, p. 360–395, http://dx.doi.org/10.1130/B26461.1

Yin, A., Dubey, C. S., Webb, A. A. G., Kelty, T. K., Grove, M., Gehrels, G. E., and Burgess, W. P., 2010b, Geologic correlation of the Himalayan orogen and Indian craton: Part 1, Structural geology, U-Pb zircon geochronology, and tectonic evolution of the Shillong Plateau and its neighboring regions in NE India: Geological Society of America Bulletin, v. 122, p. 336–359, http://dx.doi.org/10.1130/B26460.1

Yu, J. H., O'Reilly, S. Y., Wang, L., Griffin, W. L., Zhang, M., Wang, R., Jiang, S., and Shu, L., 2008, Where was South China in the Rodinia supercontinent?: Evidence from U-Pb geochronology and Hf isotopes of detrital zircons: Precambrian Research, v. 164, n. 1–2, p. 1–15, http://dx.doi.org/10.1016/j.precamres.2008.03.002

Yu, J. H., Wang, L., O'Reilly, S. Y., Griffin, W. L., Zhang, M., Li, C., and Shu, L., 2009, A Paleoproterozoic orogeny recorded in a long-lived cratonic remnant (Wuyishan terrane), eastern Cathaysia Block, China: Precambrian Research, v. 174, n. 3–4, p. 347–363, http://dx.doi.org/10.1016/j.precamres.2009.08.009

Yu, J. H., O'Reilly, S. Y., Wang, L., Griffin, W. L., Zhou, M. F., Zhang, M., and Shu, L., 2010, Components and episodic growth of Precambrian crust in the Cathaysia Block, South China: Evidence from U-Pb ages and Hf isotopes of zircons in Newproterozoic sediments: Precambrian Research, v. 181, n. 1–4, p. 97–114, http://dx.doi.org/10.1016/j.precamres.2010.05.016

Yu, J. H., O'Reilly, S. Y., Zhou, M. F., Griffin, W. L., and Wang, L., 2011, U-Pb geochronology and Hf-Nd isotopic geochemistry of the Badu Complex, Southeastern China: Implications for the Precambrian crustal evolution and paleogeography of the Cathaysia Block: Precambrian Research, v. 222–223, p. 424–449, http://dx.doi.org/10.1016/j.precamres.2011.07.014

Zeng, W., Zhang, L., Zhou, H. W., Zhong, Z. Q., Xiang, H., Liu, R., Jin, S., Lu, X. Q., and Li, C. Z., 2008, Caledonian reworking of Paleoproterozoic basement in the Cathaysia Block: Constraints from zircon U-Pb dating, Hf isotopes and trace elements: Chinese Science Bulletin, v. 53, n. 6, p. 895–904, http://dx.doi.org/10.1007/s11434-008-0076-0

Zhang, J. Y., Yin, A., Liu, W. C., Wu, F. Y., Lin, D., and Grove, M., 2012, Coupled U-Pb dating and Hf isotopic analysis of detrital zircon of modern river sand from the Yalu River (Yalung Tsangpo) drainage system in southern Tibet: Constraints on the transport processes and evolution of Himalayan river: Geological Society of America Bulletin, v. 124, n. 9–10, p. 1449–1473, http://dx.doi.org/10.1130/B30592.1

Zhang, L., and He, Q., 1993, On the revision of Bacun Group and the establishment of Xiazhai, Oujiadong and Laoshuzhai Formations in northern Guangdong Province: Guangdong Geology, v. 8, p. 1–14 (in Chinese with English abstract).

Zhang, Q. R., and Piper, J. D. A., 1997, Palaeomagnetic study of Neoproterozoic glacial rocks of the Yangtzi Block: palaeolatitude and configuration of South China in the late Proterozoic Supercontinent: Precambrian Research, v. 85, p. 173–199, http://dx.doi.org/10.1016/S0301-9268(97)00031-4

Zhang, S., 2004, South China's Gondwana connection in the Paleozoic: Paleomagnetic evidence: Progress in Natural Science, v. 14, p. 85–90, http://dx.doi.org/10.1080/10020070412331343191

Zhang, S., Evans, D. A. D., Li, H., Wu, H., Jiang, G., Dong, J., Zhao, Q., Raub, T. D., and Yang, T., 2013, Paleomagnetism of the late Cryogenian Nantuo Formation and paleogeographic implications for the South China Block: Journal of Asian Earth Sciences, v. 72, p. 164–177, http://dx.doi.org/10.1016/j.jseaes.2012.11.022

Zhang, S. B., Zheng, Y. F., Wu, Y. B., Zhao, Z. F., Gao, S., and Wu, F. Y., 2006, Zircon U-Pb age and Hf-O isotope evidence for Paleoproterozoic metamorphic event in South China: Precambrian Research, v. 151, n. 3–4, p. 265–288, http://dx.doi.org/10.1016/j.precamres.2006.08.009

Zhao, X. F., Zhou, M. F., Li, J. W., Sun, M., Gao, J. F., Sun, W. H., and Yang, J. H., 2010, Late Paleoproterozoic to early Mesoproterozoic Dongchuan Group in Yunnan, SW China: Implications for tectonic evolution of the Yangtze Block: Precambrian Research, v. 182, n. 1–2, p. 57–69, http://dx.doi.org/10.1016/j.precamres.2010.06.021

Zheng, J., Griffin, W. L., O'Reilly, S. Y., Zhang, M., Pearson, N., and Pan, Y., 2006, Widespread Archean basement beneath the Yangtze craton: Geology, v. 34, n. 6, p. 417–420, http://dx.doi.org/10.1130/G22282.1

Zheng, J. P., Griffin, W. L., Li, L. S., O'Reilly, S. Y., Pearson, N. J., Tang, H. Y., Liu, G. L., Zhao, J. H., Yu, C. M., and Su, Y. P., 2011, Highly evolved Archean basement beneath the western Cathaysia Block, South China: Geochimica et Cosmochimica Acta, v. 75, n. 1, p. 242–255, http://dx.doi.org/10.1016/j.gca.2010.09.035

Zhou, M. F., Yan, D. P., Kennedy, A. K., Li, Y., and Ding, J., 2002, SHRIMP U-Pb zircon geochronological and geochemical evidence for Neoproterozoic arc-magmatism along the western margin of the Yangtze Block, South China: Earth and Planetary Science Letters, v. 196, n. 1–2, p. 51–67, http://dx.doi.org/10.1016/S0012-821X(01)00595-7

Zhou, M. F., Ma, Y., Yan, D. P., Xia, X., Zhao, J. H., and Sun, M., 2006, The Yanbian Terrane (Southern Sichuan Province, SW China): A Neoproterozoic arc assemblage in the western margin of the Yangtze Block: Precambrian Research, v. 144, n. 1–2, p. 19–38, http://dx.doi.org/10.1016/j.precamres.2005.11.002

Zhu, D. C., Zhao, Z. D., Niu, Y., Dilek, Y., and Mo, X. X., 2011, Lhasa terrane in southern Tibet came from Australia: Geology, v. 39, n. 9, p. 727–730, http://dx.doi.org/10.1130/G31895.1

Zhu, D. C., Zhao, Z. D., Niu, Y., Dilek, Y., Wang, Q., Ji, W. H., Dong, G. C., Sui, Q. L., Liu, Y. S., Yuan, H. L., and Mo, X. X., 2012, Cambrian bimodal volcanism in the Lhasa Terrane, southern Tibet: Record of an early Paleozoic Andean-type magmatic arc in the Australian proto-Tethyan margin: Chemical Geology, v. 328, p. 290–308, http://dx.doi.org/10.1016/j.chemgeo.2011.12.024

Zhu, M., Strauss, H., and Shields, G. A., 2007, From snowball earth to the Cambrian bioradiation: Calibration of Ediacaran–Cambrian earth history in South China: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 254, n. 1–2, p. 1–6, http://dx.doi.org/10.1016/j.palaeo.2007.03.026