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**RAPID COMMUNICATION**

# Provenance of detrital zircons from the late Neoproterozoic to Ordovician sandstones of South China: implications for its continental affinity

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**Abstract**

The U–Pb geochronology of 687 detrital zircons from the voluminous Upper Neoproterozoic–Ordovician succession in the Wuyishan Fold Belt of South China reveals a common dominant *c.* 1200–950 Ma group, indicative of an outboard provenance terrane with a Grenville-age province to the southeast during the late Neoproterozoic–Early Palaeozoic. Compared with coeval samples from the Gondwanan and eastern Laurentian margins, our data show a scarcity of distinctive Gondwanan provenances (*c.* 650–500 Ma) and reveal some Laurentian signatures. These results argue against the peri-Gondwanan setting for South China during the late Neoproterozoic–Ordovician, instead implying a Laurentian affinity.

Keywords: South China, detrital zircon, Grenville-age province, continental affinity, Laurentia

## 1. Introduction

The Neoproterozoic–Early Palaeozoic palaeoposition of South China is uncertain and controversial (Li, Zhang & Powell, 1995; Li *et al.* 2002, 2008; Evans *et al.* 2000; Yang *et al.* 2004; Yu *et al.* 2008). This is partially due to the sparsity of high quality palaeomagnetic data; only three high-quality palaeomagnetic poles for the Neoproterozoic (748 Ma), Middle Cambrian and Middle Silurian have been obtained from South China owing to late widespread remagnetization (Evans *et al.* 2000; Yang *et al.* 2004). Using detrital zircon from late Neoproterozoic paragneisses and migmatites, Yu *et al.* (2008) proposed a northern Gondwana palaeoposition for South China in the Neoproterozoic, which conflicts with the 'missing link' model in which South China was between Laurentia and Australia based on geochronological, stratigraphic and tectonothermal correlations (Li, Zhang & Powell, 1995; Li *et al.* 2002, 2008). In most early Palaeozoic palaeobiogeographic models, South China is an isolated continental block that had varied faunal links but seems close to peri-Gondwana (Fortey & Cocks, 2003; Rong *et al.* 2003). However, Arenigian brachiopods and acritarchs of South China show a high degree of endemism and strong faunal differences compared with those of the peri-Gondwanan province (Xu & Liu, 1984; Playford, Ribecai & Tongiorgi, 1995).

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A provenance study of the voluminous late Neoproterozoic (Sinian)–Ordovician deepwater terrigeneous siliciclastic rocks in the Wuyishan Fold Belt is crucial to understanding the sedimentary and tectonic history of South China. In this paper, we report the detrital zircon U–Pb ages of six samples from five sedimentary units in this succession obtained by LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry). We compare our results with published data from time-equivalent strata of the Gondwanan and eastern Laurentian margins to provide a new perspective on the continental affinity of South China.

## 2. Geological setting

South China is divided into two parts by the Jiangshao Fault Zone: the Yangtze craton to the northwest and the Wuyishan Fold Belt to the southeast (Fig. 1a). In the Yangtze craton, the Precambrian basement rocks record extensive rift-related magmatism (*c.* 850–720 Ma) in the development of the Neoproterozoic continental rifts of South China, which has been interpreted as episodic events during the break-up of the Rodinia supercontinent (e.g. Li *et al.* 2008). These basement rocks are largely overlain by late Neoproterozoic–Ordovician shallow-marine platform strata with abundant evaporites (mainly carbonates) in the Yangtze craton as well as some siliciclastic input on the southeastern margin (Fig. 2a; e.g. Liu & Xu, 1994). The facies assemblages of the cover strata developed in the Yangtze depositional domain represent a typical passive margin setting in the late Neoproterozoic–Ordovician (Fig. 2a; BGMRJX, 1984; Liu & Xu, 1994).

Southeast of the Jiangshao Fault Zone, the Wuyishan Fold Belt (also known as the South China Caledonian-period orogenic belt) has been identified as an early Palaeozoic (*c.* 460–400 Ma) orogenic belt with a regional unconformity between the Early Palaeozoic sequences and the Middle–Upper Devonian coarse clastic sediments (Fig. 1b, c; Huang, 1945; BGMRJX, 1984; BGMRGD, 1988; Guo *et al.* 1989; Shu, 2006; Li *et al.* 2010). In contrast to the late Neoproterozoic–Ordovician strata on the Yangtze craton, coeval sedimentary rocks in the Wuyishan Fold Belt were intensely deformed during the early Palaeozoic orogenic event, with widespread tight to isoclinal folding, greenschist- to amphibolite-facies metamorphism, intrusions of granites and the formation of migmatites at *c.* 460–400 Ma (e.g. Guo *et al.* 1989; Shu, 2006; Li *et al.* 2010). This early Palaeozoic orogenic belt, which covers the southeastern half of South China (Fig. 1a), overlaps with the regional extent of the late Neoproterozoic–early Palaeozoic basin, which started as a

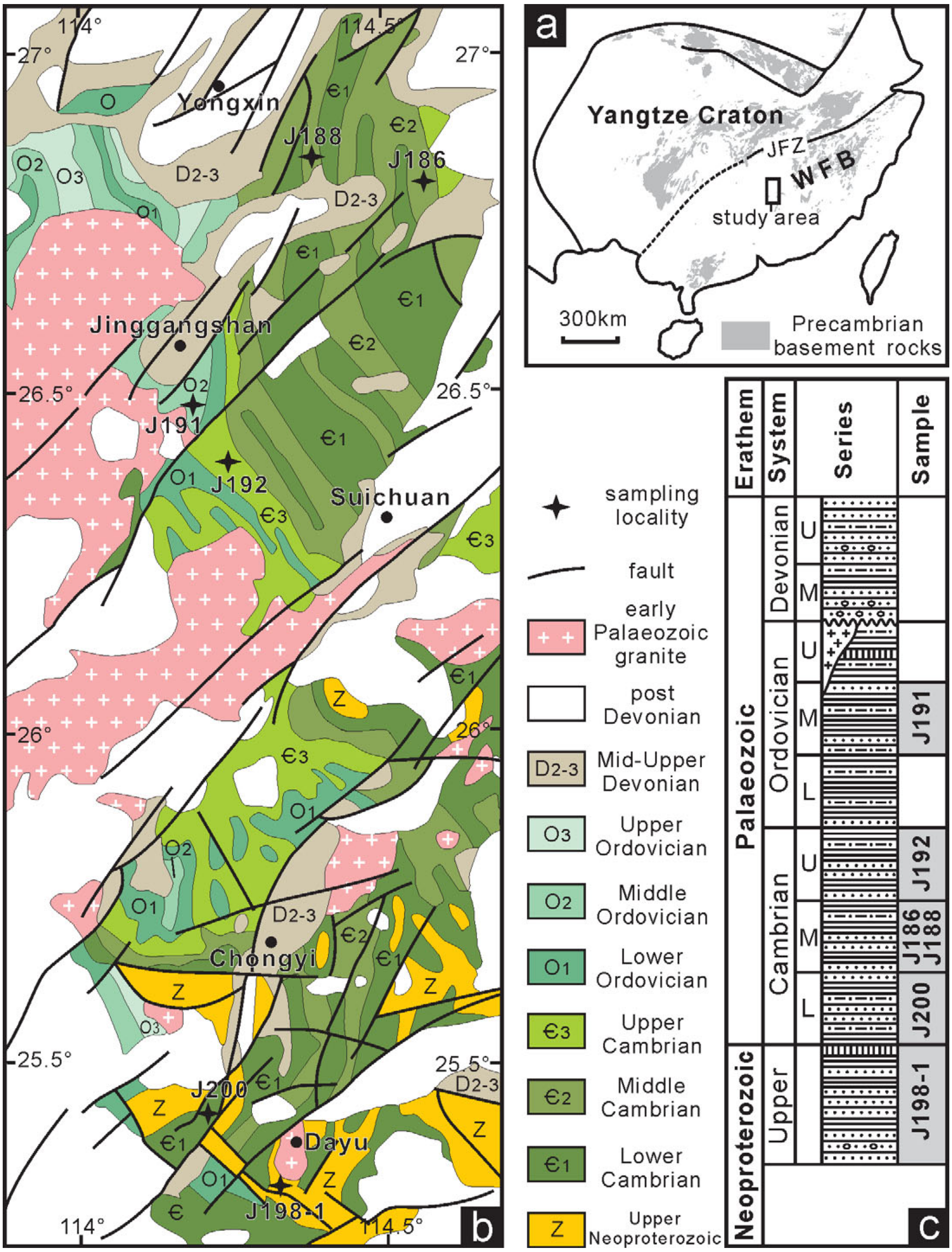


Figure 1. (a) Main tectonic elements of South China. JFZ – Jiangshao Fault Zone, WFB – Wuyishan Fold Belt. (b) Geological map of study area in the Wuyishan Fold Belt, showing sampling localities. (c) Stratigraphic column of the sampling area with marked sample positions.

failed continental rift and was subject to thick sedimentation (Li *et al.* 2010), here termed the Southeast Basin (Fig. 2a, b). The late Neoproterozoic–Ordovician strata deposited in the Southeast Basin are mainly composed of extensive $\sim$ 10 km thick deepwater terrigenous clastic turbidites; the clastic rocks of this succession coarsen southeastward/coastward and reveal a general palaeocurrent direction towards the northwest (Fig. 2a, b; BGMRGD, 1988; Liu & Xu, 1994).

## 3. Methods and results

Six fine- to medium-grained meta-sandstone samples were collected from the Upper Neoproterozoic (J198–1), Lower Cambrian (J200), Middle Cambrian (J186, J188), Upper Cambrian (J192) and Middle Ordovician (J191) strata in the Chongyi district of the southern Jiangxi Province within the Wuyishan Fold Belt (Fig. 1b). The upper Neoproterozoic–Ordovician strata are successive and have undergone greenschist-facies metamorphism (BGMRJX, 1984). These samples were processed by standard methods to separate zircons, and backscattered electron (BSE) imaging was conducted to spot target detrital zircons for U–Pb geochronology analysis. The BSE imaging and LA-ICP-MS U–Pb geochronology were carried out in the State Key Laboratory for Mineral Deposits Research, Nanjing University. Isotopic ratios were calculated using GLITTER

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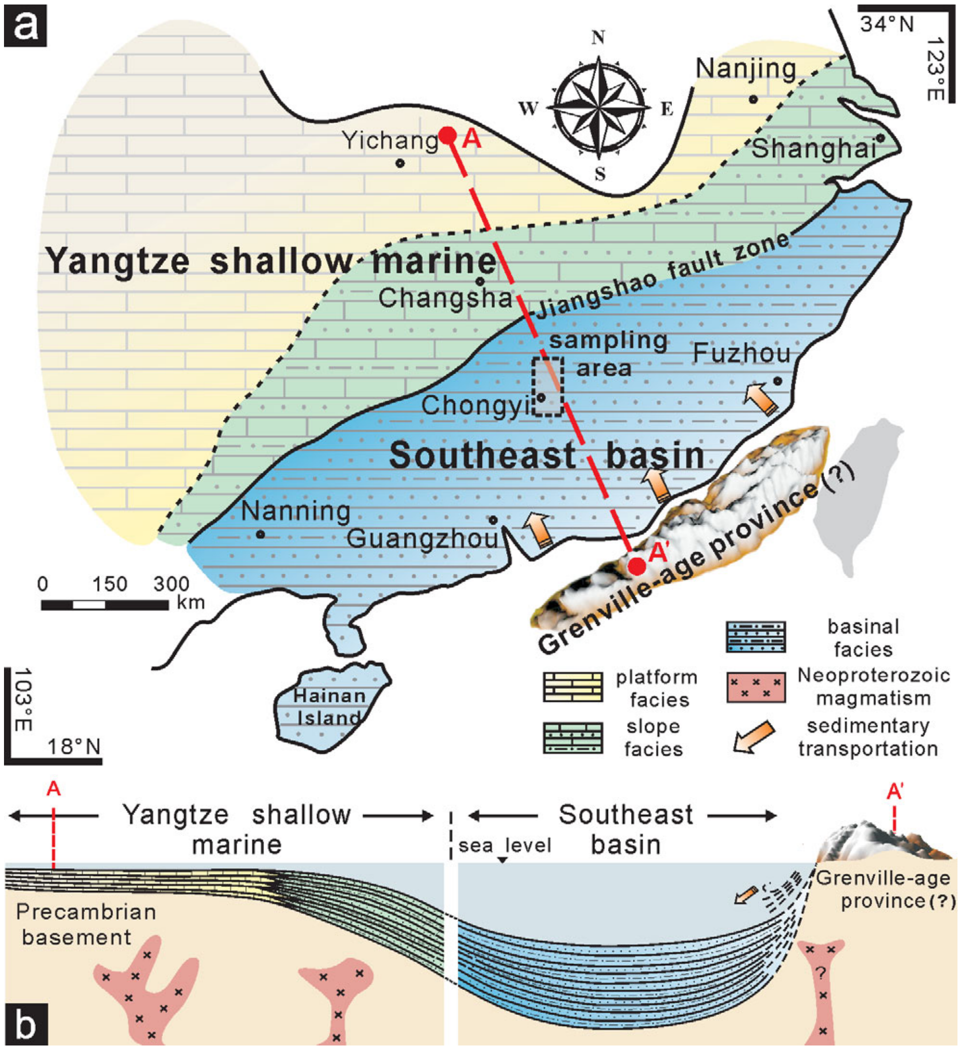


Figure 2. (a) Schematic lithofacies palaeogeographic map of South China during the early Palaeozoic, showing two principal stratigraphic regions, the sampling area, and a proposed source terrane with a Grenville-age province in a highly uncertain location. (b) Interpretation of cross-section A–A′. Location of section is indicated in (a).

(ver. 4.4) All zircon ages described here exclude analyses with > 10 % discordance or > 10 % reverse discordance. Details of the sample descriptions and preparation, analysis procedure, full tables of results, and exact sampling localities are shown in Appendix 1, available online at http://journals.cambridge.org/geo.

Five age histograms of the six samples are presented in Figure 3a. Of the detrital zircon ages, 687 range from 3447 ± 36 to 506 ± 8 Ma. All samples yield primary age peaks at *c.* 1200–950 Ma, and present a series of detrital age peaks in the Palaeo- to Mesoproterozoic (2050–1550 Ma). Peaks at *c.* 1400 Ma are noticeable in J198–1, J186, J188, J192 and J191. Five Phanerozoic samples show a cluster ranging from 2700–2400 Ma, mainly early Palaeoproterozoic (*c.* 2470 Ma). Minor grains from 900–500 Ma are also observed. Rare analysed grains (ten) yield concordant ages older than 3000 Ma. Detrital zircons of all samples exhibit large compositional variations of Th and U, and most zircons (∼ 84 %) have Th/U > 0.3; only 30 grains (∼ 4 %) are below 0.1 (online Appendix 1). The Th/U ratio analysis and BSE images suggest that most detrital zircons of these samples are magmatic (with high Th and U contents and Th/U ratio), but they crystallized from complex compositions under different conditions. A remarkably uniform age signature of the detritus is revealed for different stratigraphic levels of the thick succession, indicating a common sediment source throughout the duration of deposition (*c.* 150 Ma, from late Neoproterozoic to Ordovician).

## 4. Discussion

### 4.a. An outboard source terrane with a Grenville-age province

All samples share a common dominant (∼ 37 %) age population ranging from 1200 to 950 Ma (Fig. 3a). These dominant concordant ages are consistent with the Grenville-age provinces formed during the period 1300–900 Ma, owing to the convergence of the Rodinia supercontinent (Hoffman, 1991). Based on Sm–Nd dating using whole-rock samples, feldspar and pyroxene from a gabbro unit in an ophiolite suite in NE Jiangxi Province (with a internal isochron age of 1.034 ± 0.024 Ga; Chen *et al.* 1991), a Grenville-age orogen has been suggested along the southeastern edge of the Yangtze craton as a result of the continental collision during amalgamation of South China (Li, Zhang & Powell, 1995; Li *et al.* 2002). However, Yu *et al.* (2008) argued that granitoids or high-grade metamorphic rocks with Grenville ages that could denote a continental-collision setting were absent in that region. Therefore, using the fact that the rocks with precise Grenvillian U–Pb ages were not reported within the southeastern half of South China, Yu *et al.*

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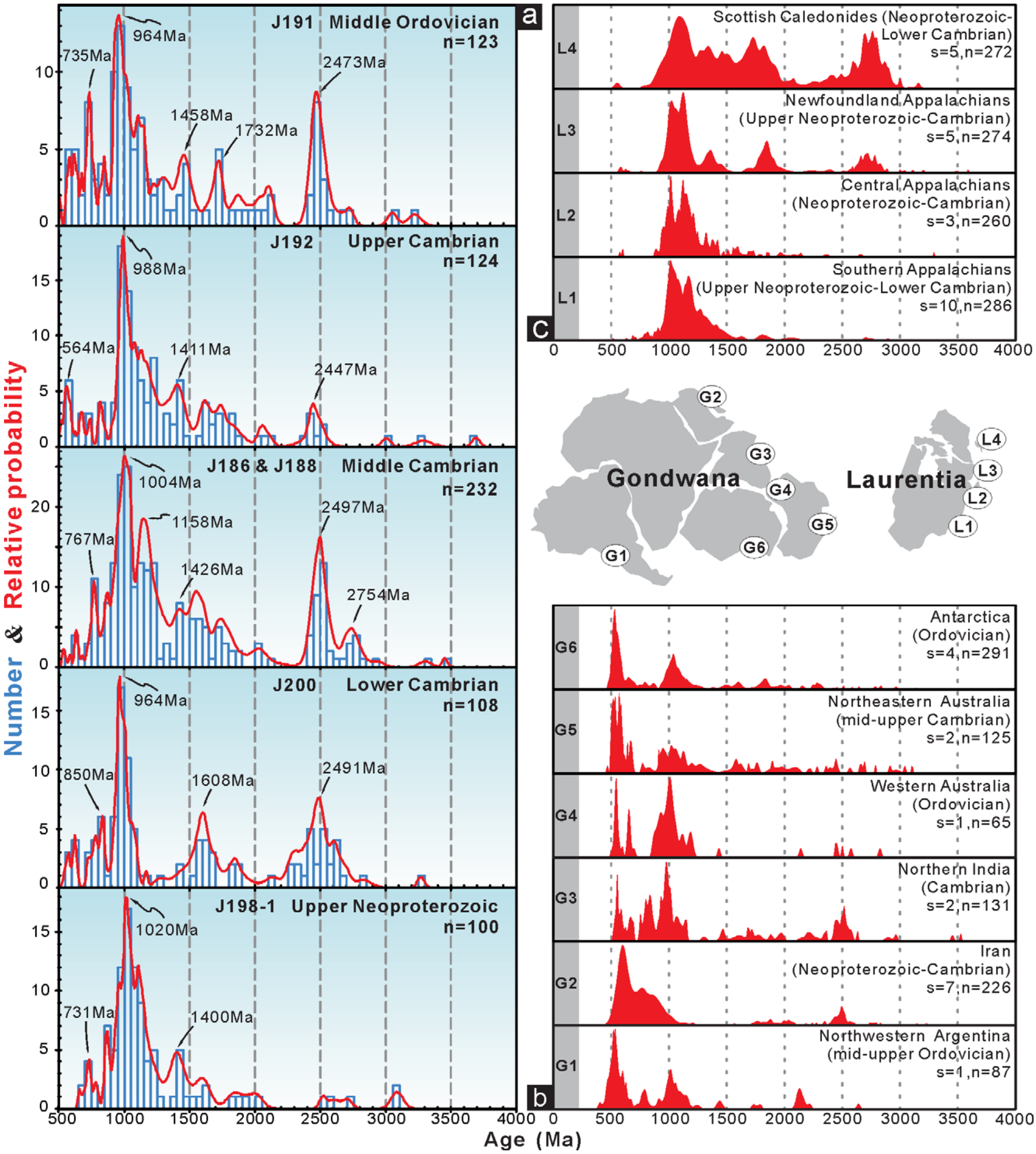


Figure 3. Histograms displaying U–Pb detrital zircon age distributions of Neoproterozoic to early Palaeozoic sedimentary samples. (a) Six samples from the Wuyishan Fold Belt in the present study. (b) Samples from the Gondwanan margin. Source of data: G1 (Copalayo Formation) – DeCelles, Carrapa & Gehrels (2007); G2 (Kahar, Bayandor, Barut, Lalun, Mila formations) – Horton *et al.* (2008); G3 (Tethyan and Lesser Himalayan sample) – Myrow *et al.* (2003); G4 (Tumblagooda Sandstone) – Cawood & Nemchin (2000); G5 (Argentine Metamorphics, Wynyard Metamorphics) – Fergusson *et al.* (2001, 2007); G6 (Douglas Conglomerate, Starshot, Douglas, Dick formations) – Goodge, Williams & Myrow (2004). (c) Samples from the eastern Laurentian margin. Source of data: L1 (central Blue Ridge, Dahlonega gold belt, eastern Blue Ridge and Sauratown Mountains window) – Bream *et al.* (2004); L2 (Unicoi, Erwin, Hardystron formations) – Eriksson *et al.* (2004); L3 (South Brook, Summerside, Blow-Me-Down, Bradore, Hawke Bay formations) – Cawood & Nemchin (2001); L4 (Argyll Group, Southern Highland Group) – Cawood *et al.* (2003). s – number of samples; n – number of analyses.

(2008) suggested a southern derivation of the numerous euhedral Grenville-age detrital zircons obtained from the late Neoproterozoic paragneisses and migmatites in the Wuyishan Fold Belt. In this regard, our study reveals a similar scenario to Yu *et al.* (2008). Moreover, in the present study, the late Neoproterozoic–Ordovician lithofacies palaeogeography of South China provides palaeogeographic constraints on the source direction from which these thick siliciclastic sediments in the Southeast basin were mainly derived: the southeast (Fig. 2a; Liu & Xu, 1994). This

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northwestward sedimentary transport is also supported by several palaeocurrent indicators preserved in the strata (BGMRJX, 1984; BGMRGD, 1988; Liu & Xu, 1994). Thus, our results indicate the existence of a terrane with a Grenville-age province to the southeast of South China, which acted as a sustained (*c.* 150 Ma) source terrane for the voluminous siliciclastic succession of Upper Neoproterozoic to Ordovician (Fig. 2a, b), although the exact distance and extension direction of the Grenville-age province have not been identified.

### 4.b. Gondwanan affinity of South China

The Grenville-age provinces were mainly seated in Gondwana and eastern Laurentia in the early Palaeozoic when the two continents were largely isolated (e.g. Hoffman, 1991; Li *et al.* 2008), so we compare our results with published data from coeval strata of the Gondwanan and eastern Laurentian margins to evaluate the continental affinity of South China (Fig. 3). Our comparison reveals that the distinctive 650–500 Ma age component that is well represented in the Gondwanan margin samples (DeCelles, Carrapa & Gehrels, 2007; Horton *et al.* 2008; Myrow *et al.* 2003; Cawood & Nemchin, 2000; Fergusson *et al.* 2001, 2007; Goodge, Williams & Myrow, 2004) is poorly represented in our samples as well as eastern Laurentian margin samples (Bream *et al.* 2004; Eriksson *et al.* 2004; Cawood & Nemchin, 2001; Cawood *et al.* 2003, 2007) (Fig. 3). This remarkable difference can be attributed to the Pan-Gondwanaland event representing the assembly of Gondwana and the subsequent orogenic belts along the Gondwanan margin (e.g. Pampean, Ross-Delamerian; Goodge, Williams & Myrow, 2004; Horton *et al.* 2008). Moreover, Gondwanaland is also characterized by widespread intrusions of 650–500 Ma alkaline rocks and carbonatites (Veevers, 2007). However, none of the structural deformations or igneous activities of these 650–500 Ma thermo-tectonic events, which are extensive in much of Gondwana, have been identified in South China, which experienced continuous sedimentation in the late Neoproterozoic–Ordovician and witnessed the subsequent formation of the Wuyishan Fold Belt at *c.* 460–400 Ma (BGMRJX, 1984; BGMRGD, 1988; Guo *et al.* 1989; Shu, 2006; Li *et al.* 2010). Thus, the geological and geochronological evidence presented in our study is difficult to reconcile with those Gondwanan affinity models for South China. For instance, the late Neoproterozoic northern Gondwanan palaeoposition model (Yu *et al.* 2008), which is based on isotopic analysis and comparisons between detrital zircon ages of late Neoproterozoic metamorphic rocks in the Wuyishan Fold Belt and the pre-Ordovician passive margin strata in northern Gondwana (e.g. G3 in Fig. 3b; Myrow *et al.* 2003), failed due to the recognition of the early Palaeozoic North India Orogen (*c.* 530–470 Ma, see Cawood, Johnson & Nemchin, 2007) along northern Gondwana.

### 4.c. Laurentian affinity of South China

A noticeable peak at *c.* 1400 Ma in our five samples coincides with the age of the trans-Laurentian granite–rhyolite province as well as the granodiorites (1436 ± 7 Ma) exposed in Hainan Island of South China, which have been proposed as important pieces of evidence for connecting South China and Laurentia (Li *et al.* 2002, 2008). In addition, the detrital zircon signatures of the analysed samples, particularly the presence of a series of detrital age peaks in the Palaeo- to Mesoproterozoic (2050–1550 Ma), the paucity of mid-Mesoproterozoic detritus (1400–1250 Ma) and the evidence for a Grenvillian (*c.* 1200–950 Ma) tectonothermal event, show several similarities to coeval strata preserved in the eastern Laurentian margin (Fig. 3c; Bream *et al.* 2004; Eriksson *et al.* 2004; Cawood & Nemchin, 2001; Cawood *et al.* 2003, 2007). These correlation and age signatures suggest that Laurentia could be regarded as the potential source terrane.

The Neoarchaean–Early Palaeoproterozoic (2700–2400 Ma) age cluster in the Phanerozoic samples has a peak at around 2470 Ma. These old grains record the *c.* 2.5 Ga global tectonics environmental change and submarine–subaerial magmatism (e.g. Bleeker, 2003; Barley, Bekker & Krapez, 2005). The same detrital age group revealed in late Neoproterozoic metamorphic rocks from the Wuyishan Fold Belt had been regarded as another correlation with India and East Antarctica (Yu *et al.* 2008). However, the magmatism at *c.* 2.5 Ga was suggested to be global in nature (Heaman, 1997). Large igneous provinces at 2500–2450 Ma also occur in the Superior and Wyoming cratons (Barley, Bekker & Krapez, 2005). Therefore, the presence of several Neoarchaean (*c.* 2.5 Ga) rocks documented in Laurentia (e.g. Friend & Kinny, 1995; Heaman, 1997; Schultz *et al.* 2007) increases the possibility that the 2700–2400 Ma detritus originated from Laurentia.

The mid-Neoproterozoic (*c.* 850–720 Ma) detritus is presented in this study with the exact positions of the individual peaks varying between samples (Fig. 3a). Detritus of this age is contemporaneous with extensive Neoproterozoic rift-related magmatism documented in the Yangtze craton (e.g. Li *et al.* 2008), suggesting that the Neoproterozoic rift-related magmatism may have also occurred on the proposed source terrane (Fig. 2b). However, this result provides only weak constraints on the continental affinity of South China owing to the widespread Neoproterozoic continental rifting records across the globe during the break-up of Rodinia (Li *et al.* 2008). Nevertheless, these continental rifting intrusions in the Laurentian margin (e.g. Dalziel & Soper, 2001; Heaman, LeCheminant & Rainbird, 1992), Neoproterozoic grains in sedimentary rocks (e.g. Bream *et al.* 2004; Cawood *et al.* 2007) and the comparable Neoproterozoic rifting history make the Laurentian affinity of South China possible.

In addition, the remarkably uniform age signature of the detritus within these strata (Fig. 3a), which have depositional ages spanning up to 150 Ma, suggests extensive reworking and homogenization of detritus before deposition and/or a uniform age character of rock units within the source terrane so that changes in specific source areas with time had little effect on the age distribution. We note that the geology of Laurentia is consistent with the latter point, and the Laurentian affinity of South China meets several requirements of significant tectonic events and provenance characteristics as follows: (1) the distribution of Grenville-age province at *c.* 1.2–1.0 Ga, the transcontinental magmatic belt at *c.* 1.4 Ga, and Archaean rocks at *c.* 2.5–2.7 Ga in Laurentia; (2) the Neoproterozoic rift events in both South China and Laurentia; (3) the relative quiescence with continuous sedimentation during the late Neoproterozoic–Ordovician; and (4) the subsequent orogenic event at *c.* 460–400 Ma (e.g. Wuyishan Fold Belt, Caledonides). If this correlation is correct, then the implication is that South China was a continental block that did not drift away from Laurentia during the formation of the Southeast Basin during the ongoing fragmentation of Rodinia, received thick sediments in the late Neoproterozoic–Ordovician (Fig. 2a, b), and collided with Laurentia to form the Wuyishan Fold Belt in late Ordovician–Silurian time. These hypotheses can be tested by further systematic structural, metamorphic, stratigraphic, geochronological and geodynamic investigations focused on the orogenic mechanism of Wuyishan Fold Belt, and more

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evidence is needed to establish the exact palaeogeographic reconstruction of these two continents during this time.

## 5. Conclusions

South China experienced continuous sedimentation during the late Neoproterozoic–Ordovician prior to the development of the Wuyishan Fold Belt (*c.* 460–400 Ma). In this paper, U–Pb detrital zircon ages were obtained from the voluminous Upper Neoproterozoic–Ordovician siliciclastic strata within the Wuyishan Fold Belt, and we draw the following conclusions:

(1) Coupled with lithofacies palaeogeography and palaeocurrent evidence for South China, the predominant *c.* 1200–950 Ma ages in our samples indicate the existence of an outboard provenance terrane with a Grenville-age province to the southeast.

(2) South China lacks both geochronological and field evidence for a Pan-Gondwanaland (*c.* 650–500 Ma) event in a comparison between our samples and coeval Gondwanan margin samples, arguing strongly against the previously suggested peri-Gondwanan setting of South China.

(3) Similarities between our new geochronological results and existing data from Laurentian margin samples, together with the integrated provenance and tectonic analyses of the two continents, suggest that Laurentia could be regarded as the potential source terrane for the Southeast Basin of South China during late Neoproterozoic–Early Palaeozoic times.

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## References

Barley, M. E., Bekker, A. & Krapez, B. 2005. Late Archean to Early Paleoproterozoic global tectonics, environmental change and the rise of atmospheric oxygen. *Earth and Planetary Science Letters* **238**, 156–71.

BGMRGD (Bureau of Geology and Mineral Resources of Guangdong Province). 1988. *Regional Geology of Guangdong Province*, pp. 10–52. Beijing: Geological Publishing House (in Chinese with English abstract).

BGMRJX (Bureau of Geology and Mineral Resources of Jiangxi Province). 1984. *Regional Geology of Jiangxi Province*, pp. 6–151. Beijing: Geological Publishing House (in Chinese with English abstract).

Bleeker, W. 2003. The late Archean record: a puzzle in c. 35 pieces. *Lithos* **71**, 99–134.

Bream, B. R., Hatcher, J. R. D., Miller, C. F. & Fullagar, P. D. 2004. Detrital zircon ages and Nd isotopic data from the southern Appalachian crystalline core, Georgia, Southern Carolina, North Carolina, and Tennessee: new provenance constraints for part of the Laurentian margin. In *Proterozoic Tectonic Evolution of the Grenville Orogen in North America* (eds R. P. Tollo, L. Corriveau, J. McLelland & M. J. Bartholomew), pp. 459–75. Geological Society of America, Memoir no. 197.

Cawood, P. A., Johnson, M. R. W. & Nemchin, A. A. 2007. Early Palaeozoic orogenesis along the Indian margin of Gondwana: tectonic response to Gondwana assembly. *Earth and Planetary Science Letters* **255**, 70–84.

Cawood, P. A. & Nemchin, A. A. 2000. Provenance record of a rift basin: U/Pb ages of detrital zircons from the Perth Basin, Western Australia. *Sedimentary Geology* **134**, 209–34.

Cawood, P. A. & Nemchin, A. A. 2001. Source regions for Laurentian margin sediments: constraints from U/Pb dating of detrital zircon in the Newfoundland Appalachians. *Geological Society of America Bulletin* **113**, 1234–46.

Cawood, P. A., Nemchin, A. A., Smith, M. & Loewy, S. 2003. Source of the Dalradian Supergroup constrained by U/Pb dating of detrital zircon and implications for the East Laurentian margin. *Journal of the Geological Society, London* **160**, 231–46.

Cawood, P. A., Nemchin, A. A., Strachan, R. A., Prave, T. & Krabbendam, M. 2007. Sedimentary basin and detrital zircon record along East Laurentia and Baltica during assembly and breakup of Rodinia. *Journal of the Geological Society, London* **164**, 257–75.

Chen, J., Foland, K. A., Xing, F., Xu, X. & Zhou, T. 1991. Magmatism along the southeast margin of the Yangtze block: Precambrian collision of the Yangtze and Cathysia blocks of China. *Geology* **19**, 815–18.

Dalziel, I. W. D. & Soper, N. J. 2001. Neoproterozoic extension on the Scottish Promontory of Laurentia; paleogeographic and tectonic implications. *Journal of Geology* **109**, 299–317.

DeCelles, P. G., Carrapa, B. & Gehrels, G. E. 2007. Detrital zircon U–Pb ages provide provenance and chronostratigraphic information from Eocene synorogenic deposits in northwestern Argentina. *Geology* **119**, 275–88.

Eriksson, K. A., Campbell, I. H., Palin, J. M., Allen, C. M. & Bock, B. 2004. Evidence for multiple recycling in Neoproterozoic through Pennsylvanian sedimentary rocks of the Central Appalachian Basin. *Journal of Geology* **112**, 261–76.

Evans, D. A. D., Li, Z. X., Kirchvink, J. L. & Wingate, M. T. D. 2000. A high-quality mid-Neoproterozoic paleomagnetic pole from South China, with implications for ice ages and the breakup configuration of Rodinia. *Precambrian Research* **100**, 313–34.

Fergusson, C. L., Carr, P. F., Fanning, C. M. & Green, T. J. 2001. Proterozoic–Cambrian detrital zircon and monazite ages from the Anakie Inlier, central Queensland: Grenville and Pacific-Gondwana signatures. *Australian Journal of Earth Sciences* **48**, 857–66.

Fergusson, C. L., Henderson, R. A., Fanning, C. M. & Withnall, I. W. 2007. Detrital zircon ages in Neoproterozoic to Ordovician siliciclastic rocks, northeastern Australia: implications for the tectonic history of the East Gondwana continental margin. *Journal of the Geological Society, London* **164**, 215–25.

Fortey, R. A. & Cocks, L. R. M. 2003. Palaeontological evidence bearing on global Ordovician–Silurian continental reconstructions. *Earth-Science Reviews* **61**, 245–307.

Friend, C. R. L. & Kinny, P. D. 1995. New evidence for protolith ages of Lewisian granulites, northwest Scotland. *Geology* **23**, 1027–30.

Goodge, J. W., Williams, I. S. & Myrow, P. M. 2004. Provenance of Neoproterozoic and lower Paleozoic siliciclastic rocks of the central Ross orogen, Antarctica: detrital record of rift-, passive-, and active-margin sedimentation. *Geological Society of America Bulletin* **116**, 1253–79.

Guo, L. Z., Shi, Y. S., Lu, H. F., Ma, R. S., Dong, H. G. & Yang, S. F. 1989. The pre-Devonian tectonic patterns and evolution of South China. *Journal of SE Asian Earth Sciences* **3**, 87–93.

Heaman, L. M. 1997. Global mafic magmatism at 2.45 Ga: remnants of an ancient large igneous province? *Geology* **25**, 299–302.

Heaman, L. M., LeCheminant, A. N. & Rainbird, R. H. 1992. Nature and timing of Franklin igneous events Canada; implications for a late Proterozoic mantle plume and the break-up of Laurentia. *Earth and Planetary Science Letters* **109**, 117–31.

Hoffman, P. F. 1991. Did the breakout of Laurentia turn Gondwanaland inside-out? *Science* **252**, 1409–12.

Horton, B. K., Hassanzadeh, J., Stockli, D. F., Axen, G. J., Gillis, R. J., Guest, B., Amini, A., Fakhari, M. D., Zamanzadeh, S. M. & Grove, M. 2008. Detrital zircon provenance of Neoproterozoic to Cenozoic deposits in Iran: implications for chronostratigraphy and collisional tectonics. *Tectonophysics* **451**, 97–122.

Huang, T. K. 1945. *On major tectonic forms of China*. Geological Memoirs of the Geological Survey of China, Series A, no. 20. Chungking: National Geological Survey of China, 165 (in Chinese with English abstract).

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., Pisarevski, S. A., Trane, K. & Vernikovski, V. 2008. Assembly, configuration, and break-up history of Rodinia: a synthesis. *Precambrian Research* **160**, 179–210.

Li, Z. X., Li, X. H., Wartho, J., Clark, C., Li, W. X., Zhang, C. L. & Bao, C. 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* **122**, 772–93.

Li, Z. X., Li, X. H., Zhou, H. & Kinny, P. D. 2002. Grenvillian continental collision in south China: new SHRIMP U–Pb zircon results and implications for the configuration of Rodinia. *Geology* **30**, 163–6.

Li, Z. X., Zhang, L. & Powell, C. M. 1995. South China in Rodinia: part of the missing link between Australia–East Antarctica and Laurentia? *Geology* **23**, 407–10.

Liu, B. & Xu, X. 1994. *Atlas of the Lithofacies and Paleogeography of South China (Sinian to Triassic)*, pp. 30–67. Beijing: Science Press.

Myrow, P. M., Hughes, N. C., Paulsen, T. S., Williams, I. S., Parcha, S. K., Thompson, K. R., Bowring, S. A., Peng, S. C. & Ahluwalia, A. D. 2003. Integrated tectonostratigraphic analysis of the Himalaya and implications for its tectonic reconstruction. *Earth and Planetary Science Letters* **212**, 433–41.

Playford, G., Ribecai, C. & Tongiorgi, M. 1995. Ordovician acritarch genera Peteinosphaeridium, Liliosphaeridium and Cycloposphaeridium: morphology, taxonomy, biostratigraphy and paleogeographic significance. *Bollettino della Societa Paleontologica Italiana* **34**, 3–54.

Rong, J. Y., Chen, X., Su, Y. Z., Ni, Y. N., Zhan, R. B., Chen, T. E., Fu, L. P., Li, R. Y. & Fan, J. X. 2003. Silurian paleogeography of China. In *Silurian Lands and Seas: Paleogeography outside of Laurentia* (eds E. Landing & M. Johnson), pp. 243–98. New York State Museum Bulletin no. 493.

Schultz, M. E. J., Chacko, T., Heaman, L. M., Sandeman, H. A., Simonetti, A. & Creaser, R. A. 2007. Queen Maud block: a newly recognized Paleoproterozoic (2.4–2.5 Ga) terrane in northwest Laurentia. *Geology* **35**, 707–10.

Shu, L. 2006. Pre-Devonian tectonic evolution of South China: from Cathaysian block to Caledonian period folded orogenic belt. *Geological Journal of China Universities* **12**, 418–31.

Veevers, J. J. 2007. Pan-Gondwanaland post-collisional extension marked by 650–500 Ma alkaline rocks and carbonatites and related detrital zircons: a review. *Earth-Science Reviews* **83**, 1–47.

Xu, H. K. & Liu, D. Y. 1984. Late Early Ordovician brachiopods of southwestern China: Bulletin of Nanjing Institute of Geology and Paleontology. *Academia Sinica* **8**, 147–236.

Yang, Z., Sun, Z., Yang, T. & Pei, J. 2004. A long connection (750–380 Ma) between South China and Australia: paleomagnetic constraints. *Earth and Planetary Science Letters* **220**, 423–34.

Yu, J. H., O'Reilly, S. Y., Wang, L., Griffin, W. L., Zhang, M., Wang, R., Jiang, S. & Shu, L. 2008. Where was South China in the Rodinia supercontinent? Evidence from U–Pb geochronology and Hf isotopes of detrital zircons. *Precambrian Research* **164**, 1–15.

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