

Detrital record of mountain building: Provenance of Jurassic foreland basin to the Dabie Mountains

Jianhai Yang,^{1,2} Peter A. Cawood,^{3,4} and Yuansheng Du^{1,2}

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[1] The Huangshi foreland basin developed on the southern margin of the Dabie Mountains as a result of tectonic loading during Triassic collisional suturing between the North China and South China cratons. Modal and detrital zircon data for Jurassic samples within the basin suggest a multicomponent source with input from both the South China Craton and Dabie Orogen. Samples are predominantly quartz arenites derived, on the basis of framework compositions, from a recycled orogen source. Detrital zircons range in age from Archean to Triassic with a dominant component in the late Paleoproterozoic between 1.9–1.7 Ga and subsidiary components at 2.6–2.2 Ga, 0.8–0.7 Ga, 0.5–0.4 Ga, and 0.33–0.2 Ga. Age data integrated with cathodoluminescence and trace element data for the zircons indicate that the Archean and Proterozoic detritus was derived from igneous and metamorphic sources that overlap with time-equivalent pulses of such activity within the South China Craton. Phanerozoic zircon ages overlap the times of the Ordovician, Carboniferous and Triassic high-pressure metamorphism in the Dabie Mountains. The provenance record, integrated with paleocurrent and regional relations, enables a paleogeographic reconstruction in which the Huangshi Basin was fed by a major axial flowing trunk river system carrying detritus from eastern and southern sources within the South China Craton and was also fed by short south flowing tributaries supplying some detritus from the evolving Dabie Orogen. The dominance of cratonic-derived detritus within the provenance record of the Huangshi Basin contrasts with that of the Hefei foreland basin that lies to the north of the Dabie Mountains, which is dominated by Neoproterozoic – Mesozoic detritus derived directly from the Dabie Mountains and lacks any significant

older Paleoproterozoic or Archean components. Easterly extensions of the Dabie-Sulu collisional suture and of the resultant Huangshi Basin occur in Korea and Japan over an along strike length of some 2000 km. **Citation:** Yang, J., P. A. Cawood, and Y. Du (2010), Detrital record of mountain building: Provenance of Jurassic foreland basin to the Dabie Mountains, *Tectonics*, 29, TC4011, doi:10.1029/2009TC002600.

1. Introduction

[2] The Qiling-Tongbai-Dabie Orogen records Triassic and Jurassic northwest-directed subduction and subsequent exhumation of the South China Craton during collisional suturing with the North China Craton (Figure 1) [Ames et al., 1993; Meng and Zhang, 1999; Yin and Nie, 1993; Zhang, 1997]. Studies have focused on rock units within the suture zone, including the nature and origin of protolith assemblages, and the pressure-temperature record and thermochronology of collisional metamorphism and exhumation [Ames et al., 1996; Ayers et al., 2002; Bryant et al., 2004; Hacker et al., 1998, 2000; Li et al., 1993; Maruyama et al., 1998; Qiu and Wijbrans, 2006, 2008; Nie et al., 1994; Rowley et al., 1997; Tsai and Liou, 2000; Wu et al., 2006; Xie et al., 2001; Xue et al., 1997; Z. F. Zhao et al., 2008; Y.-F. Zheng et al., 2003, 2006]. In this paper, we move beyond the suture to look at the provenance record preserved within syn-tectonic sedimentary basins and their link to the history of collisional amalgamation. Our data show a mixed provenance with input of Phanerozoic detritus from the orogenic hinterland and Precambrian material from the cratonic foreland. The proportion of detritus derived from the collisional suture increases up section consistent with progressive exhumation of the mountain belt.

[3] Mesozoic syn-orogenic fluvial and lacustrine deposits to the Dabie Mountains occur in the Hefei Foreland Basin along the southern margin of the North China Craton and in the Huangshi-Yueshan Foreland Basin on the northern margin of South China Craton (Figure 1) [Wang et al., 1985; Liu et al., 2003; Zhang, 1997]. The Huangshi segment of the Huangshi-Yueshan Basin lies immediately to the south of the Dabie Mountains whereas the Yueshan segment lies to the east. The Yueshan segment is separated from the Dabie Orogen and its inferred western extent in the Huangshi segment by the Tanlu Fault (Figure 1).

[4] Studies on the sedimentary evolution and detrital provenance record of the foreland basins have concentrated on the northern Hefei Basin and have suggested that detritus was mainly sourced from the Dabie Mountains [R. W. Li et al.,

¹Key Laboratory of Biogeology and Environmental Geology of Ministry of Education, China University of Geosciences, Wuhan, China.

²State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan, China.

³School of Earth and Environment, University of Western Australia, Crawley, Western Australia, Australia.

⁴Also at Department of Earth Sciences, University of St. Andrews, St. Andrews, UK.

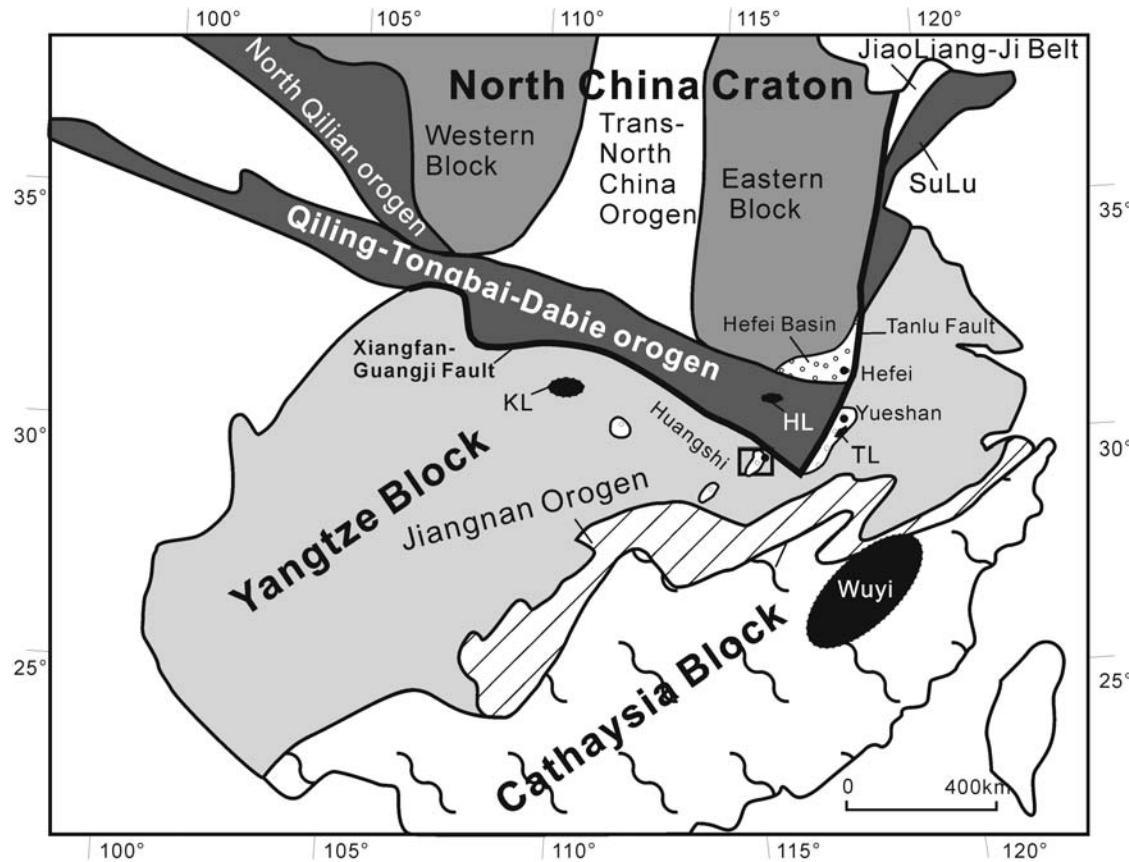


Figure 1. Simplified tectonic map of eastern China showing major tectonic elements within the Qiling-Tongbai-Dabie Orogen, which marks the Mesozoic collisional suture between the North China Craton and the South China Craton; the latter consisting of the Yangtze and Cathaysia blocks separated by the Jiangnan Orogen. The Hefei, Yueshan and Huangshi foreland basins lie along the northern, eastern and southern margins, respectively of the Dabie Mountains. Areas in solid black are major Paleoproterozoic outcrops in the South China Craton and include Wuyi, Huangtuling (HL), Tongling (TL) and Kongling (KL). Box in Huangshi Basin shows area of Figure 3.

1999; Li *et al.*, 2000; R. W. Li *et al.*, 2003; Li *et al.*, 2005; S. Y. Li *et al.*, 2004; Li *et al.*, 2001a, 2001b; Z. Li *et al.*, 1999; Liu *et al.*, 2001; Wan *et al.*, 2005; Wang *et al.*, 2003; Meng *et al.*, 2007]. In contrast, limited studies on Jurassic sandstones from the southern Huangshi-Yueshan Basin suggest input from a recycled orogenic source, probably the South China Craton as well as the Dabie Mountains [Grimmer *et al.*, 2003; Z. Li *et al.*, 2003; Li *et al.*, 2006]. We report new U-Pb dating and trace element analysis of detrital zircons, as well as modal analysis of framework components, from Early and Middle Jurassic sandstones south of Dabie Mountains. This work highlights the contrasting provenance of Huangshi Basin in comparison to the Hefei Basin, which we relate to contrasting evolving basin paleogeography with the former incorporating input from the South China Craton as well as the mountain range. Comparison of the Jurassic Huangshi Basin data with time equivalent material from Mino Terrane in southwest Japan suggests this basin occupies an analogous tectonic setting and that the Hida high pressure belt

to the north of the terrane is an extension of the Dabie Mountains.

2. Geologic Framework of the Dabie Orogen and Surrounding Basement Blocks

2.1. North China

[5] The North China Craton consists of Eastern and Western blocks of Archean age that were amalgamated along the Trans-North China Orogen, which is characterized by end Archean to early Paleoproterozoic magmatism (Figure 2; 2.6–2.4 Ga) and late Paleoproterozoic metamorphism (1.9–1.8 Ga [Wan *et al.*, 2006a; Wilde *et al.*, 2005; Zhao, 2001; Zhao *et al.*, 2002, 2007; G. C. Zhao *et al.*, 2008a, 2008b; Zhao *et al.*, 2010]). Along the southern margin of the craton are felsic and mafic granulites, amphibolites, granitoids gneisses, marbles and subordinate metapelites of the Qinling Group, and a greenschist to amphibolite facies metavolcanic complex of the Erlangping

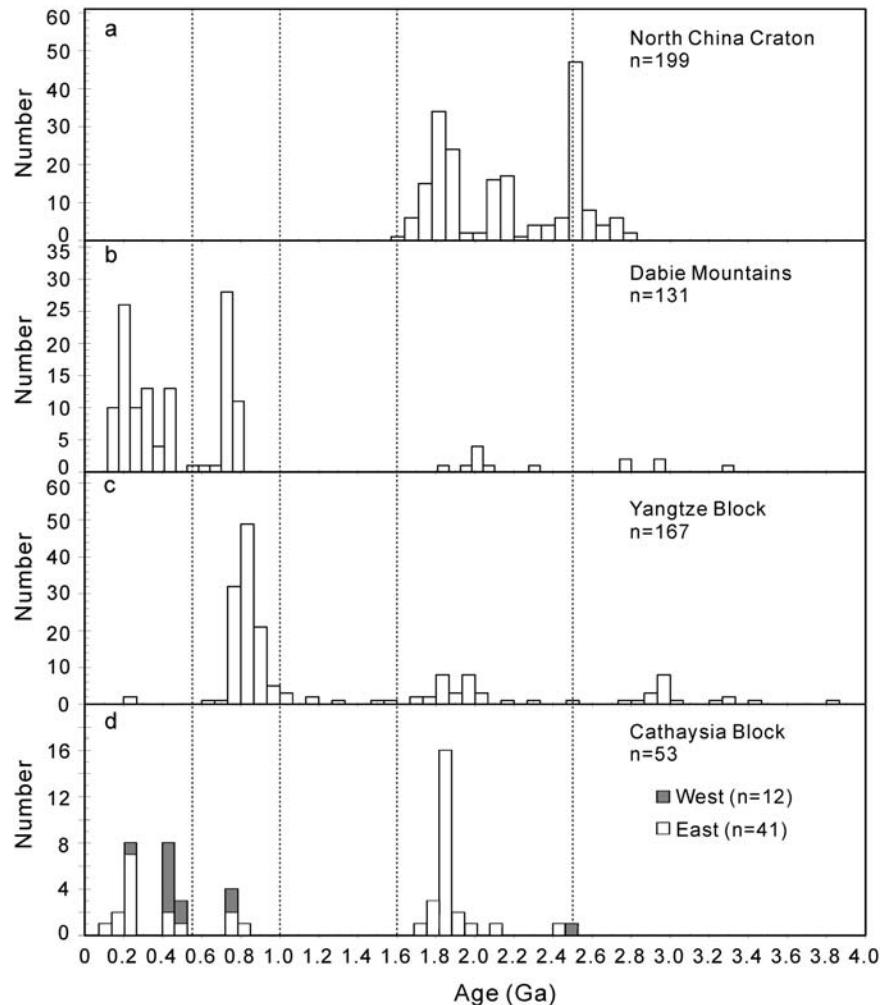


Figure 2. Histograms summarizing published zircon U-Pb ages of major magmatic and tectonothermal events in (a) North China Craton; (b) Dabie Mountains; (c) Yangtze Block; and (d) Cathaysia Block. The zircon ages were largely obtained by SHRIMP and LA-ICP-MS analysis, with minor data from conventional TIMS U-Pb dating. Data sources: North China Craton - Zhao et al. [2007, and references therein], Lu et al. [2002], Wan et al. [2006b], Xia et al. [2006], Y. J. Wang et al. [2007b], G. C. Zhao et al. [2008b], Guo et al. [2005], S. H. Zhang et al. [2007], Santosh et al. [2007], Wan et al. [2006a], Hou et al. [2006, and references therein]; Dabie Mountains - Gao et al. [2002], Hacker et al. [1998], Jian et al. [2000], Jiang et al. [2005], S. Y. Li et al. [2004], Liu et al. [2006], Liu et al. [2004], Ma et al. [2004, 2005], Rowley et al. [1997], Sun et al. [2002], Wu et al. [2008a, 2008b, 2004], Yang and Jian [1998], J. Zhang et al. [2007], Zheng et al. [2003, 2004], and Y.-F. Zheng et al. [2006]; Yangtze Block - Peng et al. [2009], Qiu et al. [2000], Wu et al. [2009a], Xiong et al. [2009], Zhang et al. [2006a, 2008, 2006b, 2006c], Zhou et al. [2009, and references therein], Greentree et al. [2006], Greentree and Li [2008], Huang et al. [2008], Li et al. [2008a, 2008b], Li et al. [2009, 2002], Li [1999], Li et al. [2007], Ling et al. [2001], Ling et al. [2003], Wang et al. [2008], X.-L. Wang et al. [2007], Xiao et al. [2007], Ye et al. [2007], Zheng et al. [2008], Zhou et al. [2004], Zhou et al. [2007], and Zhou et al. [2006, 2002]; Cathaysia Block - Li [1997], Liu et al. [2009], Wan et al. [2007], Y. J. Wang et al. [2007a], Xiang et al. [2008], Xu et al. [2007], Yu et al. [2005, 2009a, 2009b], and Zeng et al. [2008].

Group [Zhai et al., 1998]. These rocks have yielded single zircon Pb/Pb evaporation ages of 488 ± 10 Ma to 470 ± 20 Ma for deformed meta-igneous rocks and 410 ± 10 Ma to 395 ± 6 Ma for undeformed plutons [Hacker et al., 1998]. They are considered to represent an early Paleozoic active margin succession that formed along the southern North

China Craton [Hacker et al., 1998; Meng and Zhang, 1999; Ratschbacher et al., 2003].

2.2. South China

[6] The South China Craton is composed of the Yangtze and Cathaysia blocks, which were assembled along an early

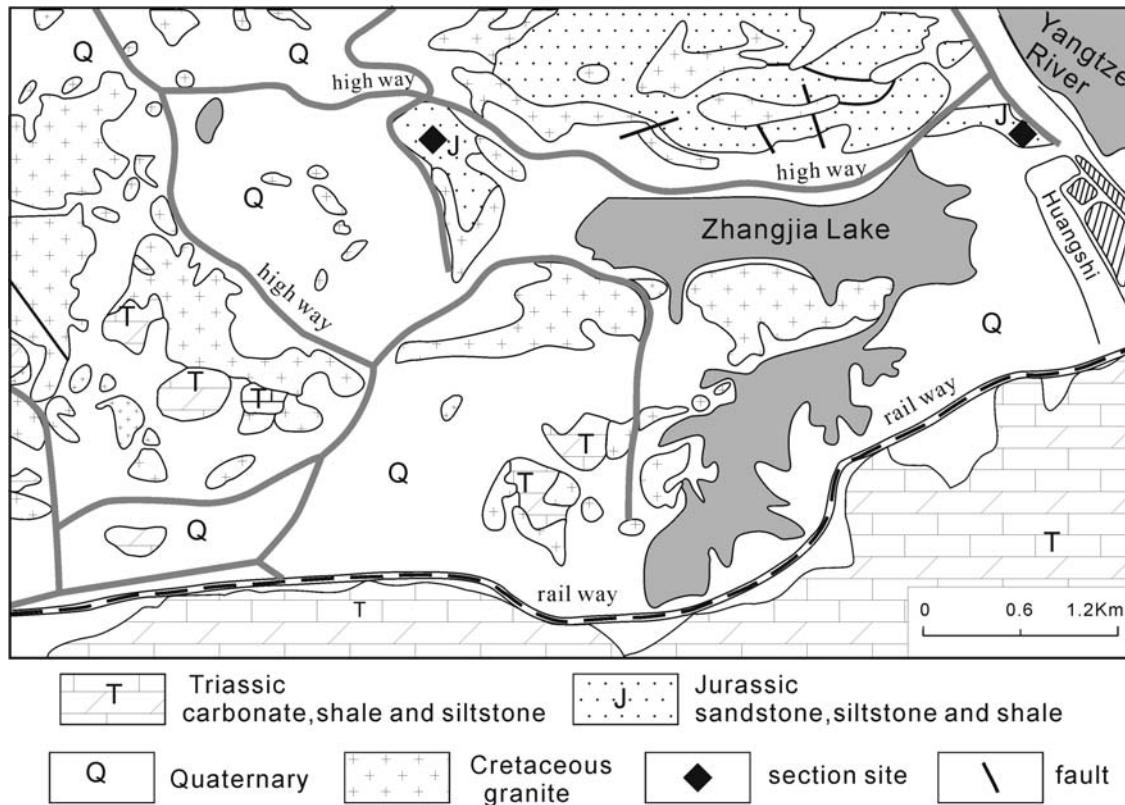


Figure 3. Geologic map of the eastern Huangshi Basin showing location of measured sections and associated sample sites.

Neoproterozoic suture zone, the Jiangnan (or Sibao) orogen (Figure 1) [Charvet et al., 1996; Zhao and Cawood, 1999; X.-L. Wang et al., 2007; Li et al., 2007; Li et al., 2009]. Each block shows a contrasting record of tectonothermal events (Figure 2).

[7] Pre-Neoproterozoic basement outcrops in the Yangtze Block are rare and yield largely Late Archean and Paleoproterozoic ages for magmatic and tectonothermal events (Figure 2) [Greentree and Li, 2008; Peng et al., 2009; Qiu et al., 2000; Wu et al., 2009a; Xiong et al., 2009; Yang et al., 2006; Zhang et al., 2006a, 2006b]. Rocks of this age are however, inferred to be widespread within the Yangtze Block on the basis of Nd model ages from Mesozoic igneous rocks and U-Pb ages and Hf isotopic data on zircons from rocks reworked within the Dabie-Sulu orogen, from Paleozoic volcaniclastic diatremes and from detritus of this age in Neoproterozoic sedimentary rocks [Chen et al., 2001; Huang et al., 2006; X. P. Li et al., 2004; Sun et al., 2009; Greentree et al., 2006; Wang et al., 2009; Zhou et al., 2009; Wu et al., 2008b; J. P. Zheng et al., 2006; Y.-F. Zheng et al., 2006]. Neoproterozoic igneous and sedimentary rocks with ages from 1000 Ma to 700 Ma are widespread across the Yangtze Block, especially along the margins [Huang et al., 2008; X.-L. Wang et al., 2007; Greentree and Li, 2008; Li, 1999; Wang et al., 2008; Li

et al., 2002; X. H. Li et al., 2003; Ling et al., 2003; Xiao et al., 2007; Li et al., 2008a; Sun et al., 2008; Sun et al., 2009; Greentree et al., 2006; Wu et al., 2007; Xue et al., 2006; Ye et al., 2007; Zheng et al., 2008, 2007; Zhou et al., 2007; Zhou et al., 2002, 2006].

[8] The Cathaysia Block can be divided into northeastern and southwestern segments [Xu et al., 2007; Yu et al., 2009a]. The northeast segment contains a Paleoproterozoic assemblage of pelitic and felsic gneiss, quartzite, amphibolite, calc-silicate rock and marble with protolith ages in the range 2200 to 2000 Ma that underwent amphibolite facies metamorphism, deformation and magmatism at around 1890–1800 Ma [Gan et al., 1995, 1993; Hu, 1994; Hu et al., 1992, 1993; Li, 1997; Wan et al., 2007; Xu et al., 2007; Yu et al., 2009a, 2009b; Zhao and Cawood, 1999]. U-Pb dating and Hf isotopic composition of detrital zircon from modern river sands indicate basement is dominantly Paleoproterozoic (~1850 Ma and 2400–2100 Ma) with minor Archean components [Xu et al., 2007]. In contrast, the southwestern portion of the Cathaysia Block comprises largely Neoproterozoic sedimentary rocks with mainly Neoarchean and late Mesoproterozoic detrital ages, and minor Paleo- and Mesoproterozoic components [Xu et al., 2007]. The Proterozoic basement succession has been intensely reworked by later events, especially during

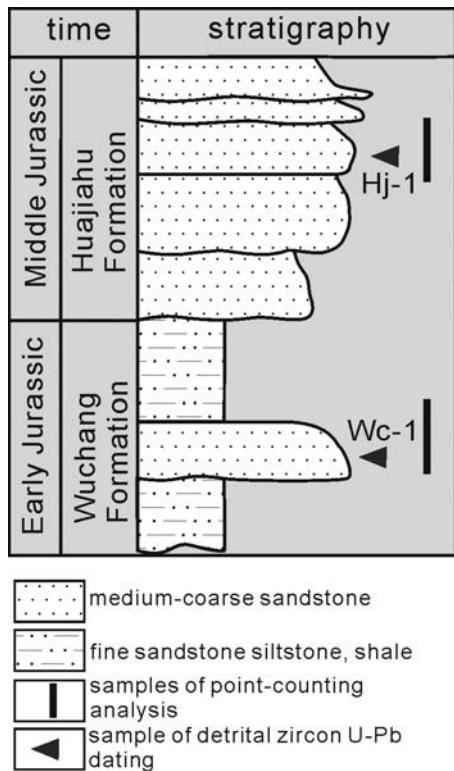


Figure 4. Compiled measured section through the Early Jurassic Wuchang Formation and the Middle Jurassic Huajiahu Formation of the Huangshi Basin showing position of detrital zircon sample sites.

the early Paleozoic Caledonian orogeny (Figure 2) [Li, 1997; Xu et al., 2007; Yu et al., 2005; Zeng et al., 2008; Y. J. Wang et al., 2007a, and references therein].

2.3. Dabie Orogen

[9] The Dabie-Sulu Orogen forms the major geologic as well as physiographic divide between North and South China that contains a variety of terranes of different ages (Figure 2b). The high pressure and ultra-high pressure rocks of the belt incorporate 800–700 Ma continental and 430–400 Ma oceanic protolith lithologies that underwent metamorphism at around 250–210 Ma and 330–300 Ma, respectively [Ames et al., 1996; Ayers et al., 2002; Hacker et al., 2000, 1998; Liu et al., 2006; Maruyama et al., 1998; Rowley et al., 1997; Tsai and Liou, 2000; Wu et al., 2006; Xue et al., 1997; Z. F. Zhao et al., 2008; Zheng et al., 2003; Y.-F. Zheng et al., 2006; Sun et al., 2002; Wu et al., 2009b]. An earlier phase of Caledonian eclogite-facies metamorphism is recognized on the basis of 470–440 Ma ages from zircons, garnets and phengites [Gao et al., 2002; Jian et al., 2000, 1997; Qiu and Wijbrans, 2006, 2008]. Also incorporated within the Dabie suture zone are ~2.0 Ga granulites with protolith ages of 2.77 Ga [Wu et al., 2008b], Neoproterozoic crust (800–700 Ma) representing segments of the Yangtze block [Bryant et al., 2004; Chen et al., 2003; Xie et al., 2001], and 500–400 Ma Caledonian terranes

[R. Li et al., 2004; Ma et al., 2004, 2005; J. Zhang et al., 2007]. Cretaceous intrusions are widespread across the region [Hacker et al., 1998].

3. Sampled Stratigraphy

[10] The Huangshi Foreland Basin, along the northern margin of the Yangtze Block (Figures 1 and 3), overlies Triassic shallow marine and paralic deposits [Z. Li et al., 2003]. It consists of Upper Triassic siltstones, mudstones and shales, passing up into Lower to Middle Jurassic fluvial sandstones and silty mudstones that contain abundant bivalves and plant fossils [Huang and Lu, 1988; Wang, 1993]. These in turn are unconformably overlain by Upper Jurassic to Lower Cretaceous volcanic and volcaniclastic rocks, and Upper Cretaceous coarse clastic deposits. Cenozoic deposits are widespread across the region such that the remnant Mesozoic outcrops are constrained to the south and southeastern margin of the Dabie Mountains (Figure 3).

[11] Samples for modal analysis and U-Pb dating of detrital zircons were collected from the Lower Jurassic Wuchang Formation and the Middle Jurassic Huajiahu Formation (Figures 3 and 4). The sampled section of the Wuchang Formation consists of grayish thick-bedded sandstone, yellow-grayish medium-thick-bedded siltstones, sandy-mudstones and gray medium-thick-bedded muddy siltstones and mudstones, and is interpreted to represent point bar, natural levee and floodplain facies of a meandering river succession. The sampled section of the Huajiahu Formation lies some 3.7 km west of the Wuchang Formation measured section and consists of fining upward cycles of coarse sandstone to fine-sandstones and siltstones in lower part and thin-layered siltstones and silty mudstones in the upper part. This sequence is attributed to channel and inter-channel deposition in a braided river [Yang et al., 2009].

4. Methods

[12] Modal analyses were undertaken on fifty medium-coarse sandstone samples including 21 from the Wuchang Formation and 29 from the Huajiahu Formation. Point-counting followed standard procedures. A point spacing of 0.4 to 0.5 mm was used to traverse half of each thin section along equally spaced lines, fixed by a vernier-caliper. For analysis, framework grains were divided into quartz (Q), including monocrystalline (Qm) and polycrystalline (Qp , composed mainly of chert), feldspar (F), and unstable lithic fragment (L) subdivided into (meta)volcanic (Lv) and (meta)sedimentary (Ls) types. Framework grains are subangular to subrounded. The matrix, which generally forms less than 15% of samples, consists of phases such as clay and sericite. Siliceous cement is present in some samples. A minimum of 300 grains were counted per sample and a summary of the data is given in Data Set S1.¹

[13] Detrital zircon grains from sandstone samples of the Wuchang Formation (Wc-1) and Huajiahu Formation (Hj-1)

¹Auxiliary materials are available at <ftp://ftp.agu.org/apend/tc/2009tc002600>.

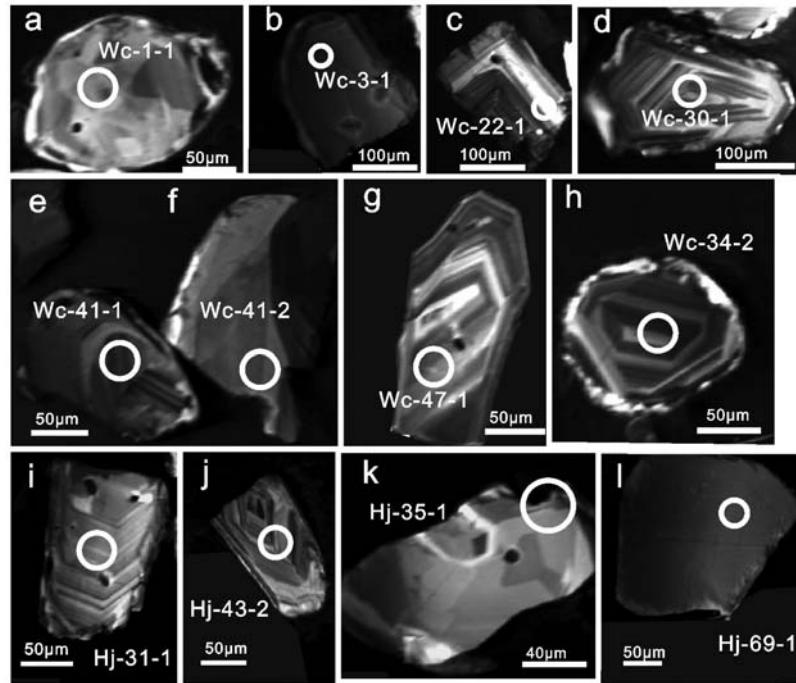


Figure 5. Representative cathodoluminescence (CL) images of zircons. The circles denote the LA-ICPMS U-Pb age and trace element analysis spots. (a) Sector zoning with thin discrete lighter rim; (b) dark homogeneous grain; (c) thin magmatic oscillatory zoned core with lighter and thicker zoned mantle; (d) magmatic oscillatory zoned grain; (e) oscillatory zoned core enclosed by planar zoned or unzoned zircon; (f) planar zoned or unzoned grain; (g) oscillatory zoned core surrounded by darker zoned mantle; (h) thin oscillatory zoned grain overgrown by noncontinuous lighter rim; (i) magmatic oscillatory zircon; (j) magmatic oscillatory zircon; (k) sector zoning or patchy structure; and (l) homogeneous dark grain.

were mounted on a double-sided tape, cast in epoxy resin and polished down to expose surfaces suitable for U-Pb and trace element analysis. Zircon morphology and internal structures were determined through optical microscopy and cathodoluminescence (CL) imaging. All the operations were conducted at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences in Wuhan.

[14] The in situ LA-ICPMS zircon U-Pb dating and trace element analysis were conducted at China University of Geosciences, Wuhan. A pulsed 193 nm ArF Excimer laser with 50 mJ energy at a repetition ratio of 10 Hz coupled with an Agilent 7500 quadrupole ICP-MS was used for data collection. Repetition rate was 6 Hz and the Laser spot size was 32 μm in diameter. All measurements were normalized relative to standard zircons 91500 and GJ-1. Standard silicate glass NIST SRM610 was used to calibrate the contents of trace elements. The average analytical error ranges from ca. $\pm 10\%$ for light rare earth elements (LREE) to ca. $\pm 5\%$ the other REE. The detailed analytical procedure for LA-ICP-MS analysis follows Yuan *et al.* [2004]. Off-line selection and integration of background and analysis signals, and time-drift correction and quantitative calibration were conducted by ICPMSDataCal [Liu *et al.*, 2008]. The ages were calculated using ISOPLOT 3.00 [Ludwig, 2003]. Our

measurements of standard 91500 yielded a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ ages of 1062 ± 2.4 Ma (2σ , $MSWD = 0.0068$, $n = 67$), in good agreement with the ID-TIMS $^{206}\text{Pb}/^{238}\text{U}$ age of 1062.4 ± 0.4 (2σ) [Jackson *et al.*, 2004]. Uncertainties reported for individual ages are at ± 1 sigma. On histogram-probability density diagrams only analyses with concordance of greater than 90% are shown.

5. Results

5.1. Modal Composition of Sandstones

[15] All the sandstones are rich in quartz and can be classified as quartz arenites [cf. Z. Li *et al.*, 2003]. The quartz content ranges from 74.5% to 97.3% with an average of 85.9% for the 21 sandstones of the Wuchang Fm., and from 65.4 to 82% with an average of 74.7% for the 29 sandstones of the Huajiahu Formation (Data Set S1). Unstable feldspar grains and lithic fragments constitute a minor proportion of the sandstones; the former average 2.1% and the latter 12.0% respectively, for the Wuchang Formation and 11.6% and 13.8% for the Huajiahu Formation. Lithic fragments are mainly metasedimentary in the Wuchang Formation but a little less than 50% in the Huajiahu Formation.

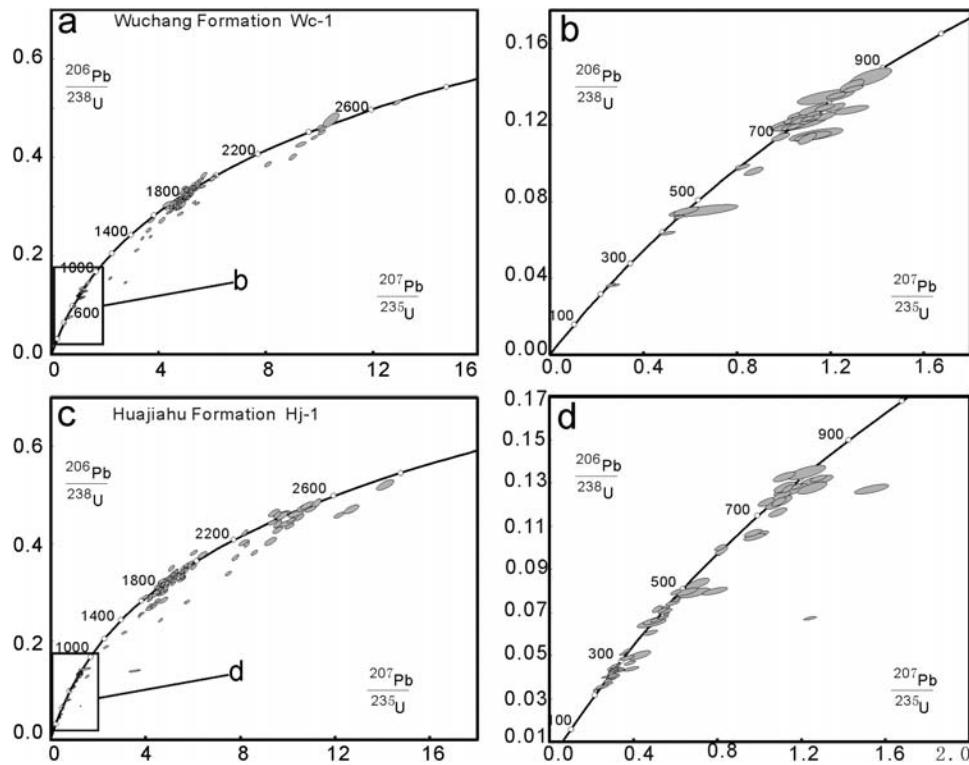


Figure 6. (a–d) Concordia diagrams of U-Pb ages for sample Wc-1 from Wuchang Formation and Hj-1 from Huajiahu Formation.

5.2. Detrital Zircon U-Pb Ages

[16] A total of 306 U-Pb ages form 306 detrital grains for the two formations are listed in Data Set S2. Ages older than 1000 Ma are calculated from their $^{207}\text{Pb}/^{206}\text{Pb}$ ratio whereas

younger ages are based on their $^{206}\text{Pb}/^{238}\text{U}$ ratio, which provides a more reliable age estimate for these grains due to uncertainties in the common Pb correction.

[17] Sample Wc-1 (N 30.2264°, E 115.0595°), from the Wuchang Formation, is a gray medium-grained, point-bar

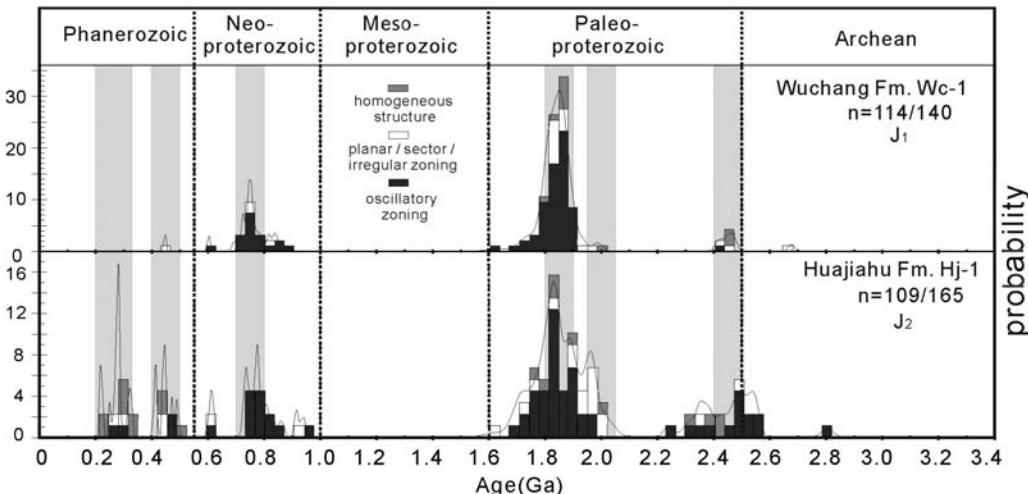


Figure 7. Combined zircon age histogram-probability density diagram for the ages with concordance $>90\%$, showing the relationship between age groups and zircon CL internal structures. Dashed vertical lines separate boundaries of Archean – Paleoproterozoic – Mesoproterozoic – Neoproterozoic – Phanerozoic and are taken at 2500 Ma, 1600 Ma, 1000 Ma and 545 Ma; n, number of zircons; J₁, Early Jurassic; J₂, Middle Jurassic. Shaded regions represent age ranges of 2500–2400 Ma, 2050–1950 Ma, 1900–1800 Ma, 800–700 Ma, 500–400 Ma and 330–200 Ma.

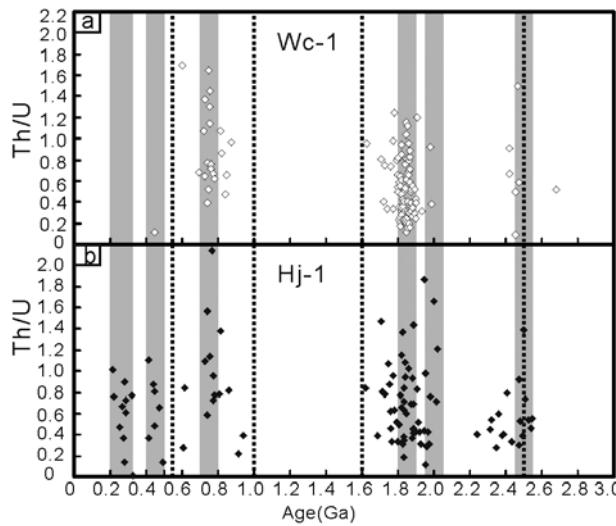


Figure 8. (a and b) Diagram showing Th/U ratios corresponding with each age group. Dashed vertical lines separate boundaries of Archean – Paleoproterozoic – Mesoproterozoic – Neoproterozoic – Phanerozoic are taken at 2500 Ma, 1600 Ma, 1000 Ma and 545 Ma. Shaded regions represent age ranges of 2500–2400 Ma, 2050–1950 Ma, 1900–1800 Ma, 800–700 Ma, 500–400 Ma and 330–200 Ma.

sandstone. Sample Hj-1 (N:30.22129°, E:115.0118°), from the Huajiahu Formation, represents a medium-coarse channel deposit from a braided river. Detrital zircons are surrounded to well-rounded with minor subangular or euhedral grains reflecting the high maturity of the sandstone composition. On the basis of CL imaging three types of internal structures are distinguished: planar/sector/irregular zoning (Figures 5a, 5e and 5k), homogeneous (Figures 5b, 5f and 5l), and clear oscillatory zoning (Figures 5c, 5d, 5g, 5h, 5i and 5j). The latter is typical of grains of igneous origin whereas the patterns of the other two are characteristic of metamorphic or recrystallized grains [Corfu *et al.*, 2003].

[18] Of the 141 analyses of Wc-1 (Figure 6a), 114 grains yielded ages with a concordance >90% and are plotted on a probability density diagram (Figure 7, top). These zircons yielded ages ranging from 2677 Ma to 447 Ma. The sample is dominated by grains in the range 2.0 Ga to 1.6 Ga with some 67% of analyses between 1.9–1.8 Ga. Subsidiary peaks occur at 2.5–2.4 Ga and 0.9–0.7 Ga along with individual analyses at ~2.65 Ga, 0.60 Ga and 0.45 Ga. CL images of each analyzed grain enable division of ages into the three types of internal zircon structure (Figure 7, top). The sole Paleozoic grain shows an unzoned uniform internal structure with a low Th/U ratio of 0.12, indicative of a metamorphic origin. Neoproterozoic grains show typical igneous oscillatory zoning, sometimes enveloped by structureless rims too thin to analyze. The corresponding Th/U ratios vary from 0.39 to 1.69, with most >0.6 (Figure 8a). Grains with igneous oscillatory zoning also dominate the late Paleoproterozoic groups, whereas grains with ages of ~2.0 Ga show sector/planar zoned or unzoned internal structures. Most of the Th/U ratios are >0.3 (Figure 8a). All three types of internal structures are presented in the early

Paleoproterozoic grains, with Th/U ratios from 0.09 to 1.50. The Archean grains show a dark homogenous core enclosed by lighter unzoned rim.

[19] For sample Hj-1, 165 spots were analyzed on 165 grains (Figure 6b) and 109 analyses with a concordance of >90% are shown in a probability density diagram (Figure 7, bottom). Ages range from 2804 Ma to 210 Ma. The distribution of age peaks within the sample shows broad similarities with Wc-1 but the sample is differentiated by the presence of late Paleozoic to Triassic ages in the range 327 Ma to 215 Ma, the more extended range of late Archean to early Paleoproterozoic ages (2.6 Ga to 2.3 Ga), and a subsidiary peak at 1.95 Ga shouldering the main one at 1.9 Ga to 1.8 Ga, and which constitutes some 34% of analyses (Figure 7, bottom). The CL characteristics of the Neoproterozoic and late Paleoproterozoic populations are dominated by the zircons showing oscillatory zoning with high Th/U ratios (Figures 7, bottom, and 8b), indicating an igneous origin. Grains in the range ~2.0 Ga, 0.5–0.4 Ga and 0.33–0.21 Ga mainly have a homogenous structure, or sector/planar zoning and few grains display oscillatory zoning, suggesting a largely metamorphic origin (Figure 7, bottom). The oldest grain at 2804 Ma shows an igneous core surrounded by an overgrowth rim of light luminescence. Integration of age data and CL images suggest the source region records two major magmatic phases at 1.9–1.8 Ga and 0.8–0.7 Ga with metamorphic events at 2.0–1.9 Ga, 0.5–0.4 Ga and 0.33–0.21 Ga.

5.3. Zircon Trace Elements

[20] Trace elements for 202 detrital zircon grains from samples Wc-1 and Hj-1 are listed in Data Set S3. Grains which show significant depth-related fractionation during data-acquisition [Yuan *et al.*, 2004], or yield strongly discordant U-Pb ages, were excluded. Chondrite normalized results of 196 analyses are plotted under broad age grouping in Figure 9.

[21] Magmatic zircons are usually characterized by high REE contents and Th/U ratios, and distinct enrichment of HREE (high La_N/Yb_N), positive Ce anomaly and negative Eu anomaly [Hoskin and Ireland, 2000]. For metamorphic zircons, however, their trace element composition is influenced by the concurrent growth of other minerals, which can be relevant for the identification of metamorphic conditions [Bingen *et al.*, 2004; Rubatto, 2002; Schaltegger *et al.*, 1999; Whitehouse and Platt, 2003]. Plagioclase is the main sink for Eu, resulting in Eu depletion of the simultaneous zircon [Bingen *et al.*, 2004; Schaltegger *et al.*, 1999]. Garnet incorporates HREE, and its crystallization in a metamorphic environment causes a depletion of HREE in metamorphic zircon [Bingen *et al.*, 2004; Rubatto, 2002].

[22] The Carboniferous to Triassic and early Paleozoic grains have high U/Nb ratios (78–2010), and show chondrite normalized patterns with steep HREE (Gd_N/Yb_N = 0.04–0.13 and 0.02–0.16, respectively), a small negative Eu anomaly (Eu/Eu* = 0.05–0.48 and 0.06–0.54) and various Ce anomalies (Ce/Ce* = 5.92–132.66 and 2.80–121.12) (Figures 9a and 9b). The zircon grain dated at 327 ± 3 Ma is characterized by a low Th/U ratio (0.01) and very high U/Nb

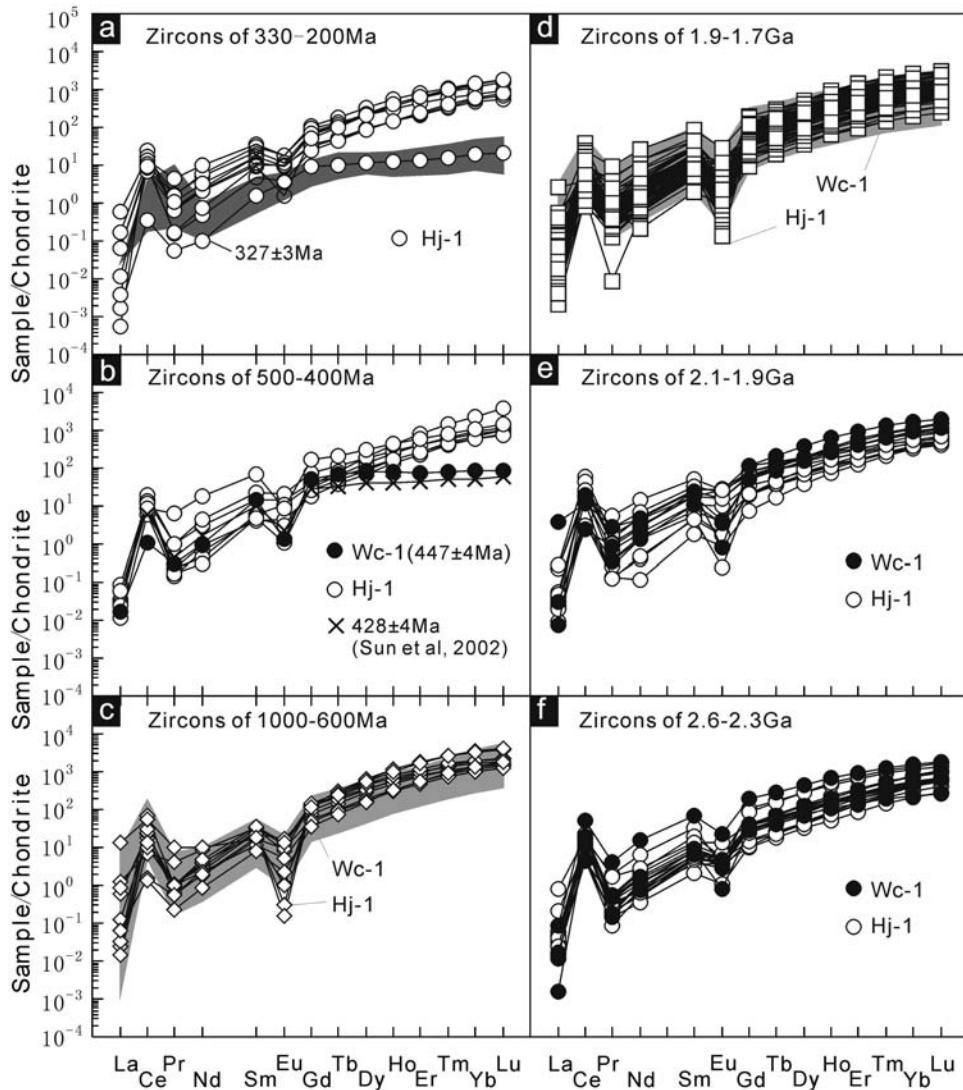


Figure 9. Chondrite normalized REE patterns for zircons of (a) 330–215 Ma, (b) 500–400 Ma, (c) 1000–600 Ma, (d) 1.9–1.7 Ga, (e) 2.1–1.9 Ga, and (f) 2.6–2.3 Ga. Chondrite REE values are from Taylor and McLennan [1985].

ratio (2010), Y and Nb values of 35.08 and 0.13 ppm, respectively, and has a chondrite normalized flat HREE pattern ($Gd_N/Yb_N = 0.52$), a small negative Eu anomaly ($Eu/Eu^* = 0.63$), and a positive Ce anomaly ($Ce/Ce^* = 12.05$). These features match those of zircon rims generated during Carboniferous eclogite-facies metamorphism in the western Dabie Mountains (Figure 9a) [Wu et al., 2009b]. One of the early Paleozoic grains, dated at 447 ± 4 Ma, has a chondrite normalized flat heavy rare earth element (HREE) pattern, high U/Nb (292), a small positive Ce anomaly ($Ce/Ce^* = 6.43$) but a strong Eu anomaly ($Eu/Eu^* = 0.04$) (Figure 9b), suggestive of the presence of garnet and feldspar during its genesis [Rubatto, 2002; Whitehouse and Platt, 2003]. Combined with the dark unzoned structure, this grain may be derived from granulite-facies metamorphic rocks [Wu et al., 2008b]. Its age and REE pattern are

comparable with those of the zircons with a dark core from the Carboniferous eclogite of the western Dabie [Sun et al., 2002].

[23] In contrast to the Phanerozoic grains, the Neoproterozoic grains have variable but generally higher chondrite normalized REE contents with steep HREE ($Gd_N/Yb_N = 0.2\text{--}0.14$), lower ratios of U/Nb (most are <100), and a large negative Eu anomaly (most Eu/Eu^* are <0.2) (Figure 9c). The chondrite normalized patterns of zircons in the age range 1.9–1.7 Ga show a large negative Eu anomaly (most Eu/Eu^* are <0.2) and are enriched in HREE (Figure 9d). Both these groups of Proterozoic grains are dominated by zircons of igneous origin as indicated by their internal CL images (Figure 5). In contrast, zircons in the age range 2.1–1.9 Ga and 2.6–2.3 Ga have lower REE values and higher U/Nb ratios (most are >100), and the normalized REE pat-

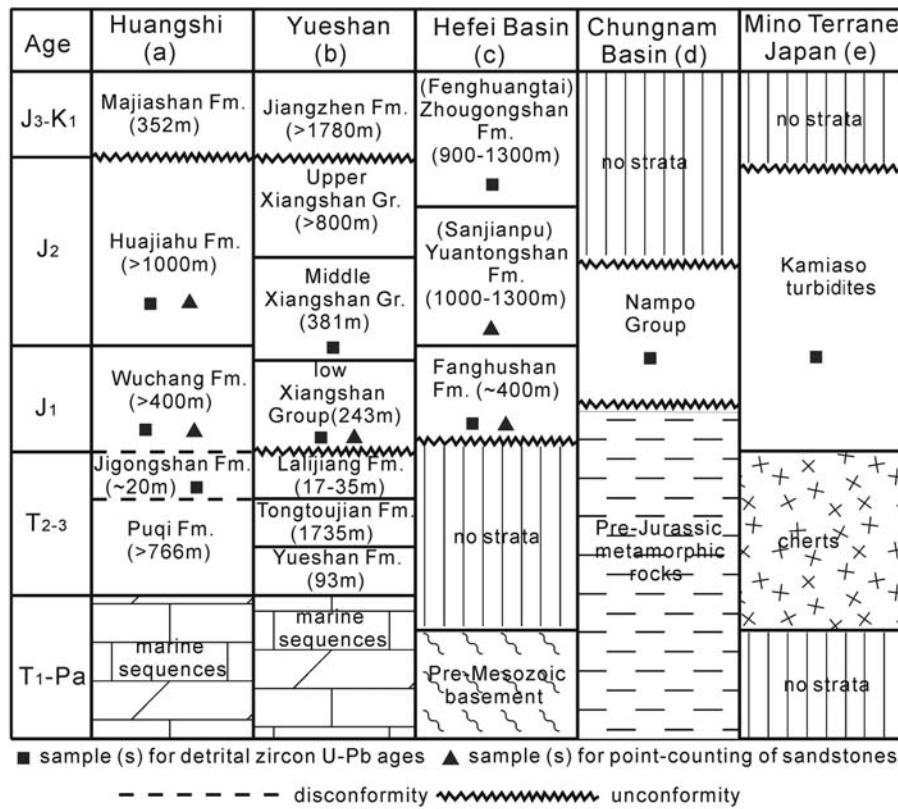


Figure 10. Comparative stratigraphy and tectonic positions for the Late Triassic through Jurassic strata in the Huangshi, Yueshan and Hefei basins in China, Chungnam Basin from Korean Peninsula and the Kamiaso area, Mino terrane, Japan [Bureau of Geology and Mineral Resources of Anhui Province, 1997; Adachi and Suzuki, 1994; Du and Zhang, 1998; Jeon et al., 2007; Meng et al., 2007; Oh, 2006]. Abbreviations: J₃-K₁: Late Jurassic to Early Cretaceous; J₂: Middle Jurassic; T₂₋₃: Middle – Late Triassic; T₁-Pa: Paleozoic to Early Triassic.

terns show variable Eu anomalies ($\text{Eu/Eu}^* = 0.02\text{--}0.62$) and Ce anomalies ($\text{Ce/Ce}^* = 2\text{--}196$) (Figures 9e and 9f).

6. Discussions

6.1. Comparison With Hefei Basin

[24] Comparison of modal and U-Pb detrital zircon age data from the Huangshi Basin with time equivalent data from

the Hefei and Yueshan basins, which lie along the northern and eastern margins of the Dabie Mountains, respectively [Grimmer et al., 2003; Li et al., 2005; Li, 1999] reveals inter-basin variations in provenance (Figure 10).

[25] On the QFL diagram most samples from the foreland basins fall in the recycled orogen field with a few extending into the continental block and magmatic arc fields (Figure 11) [Dickinson et al., 1983; Dickinson and Suczek, 1979]. The

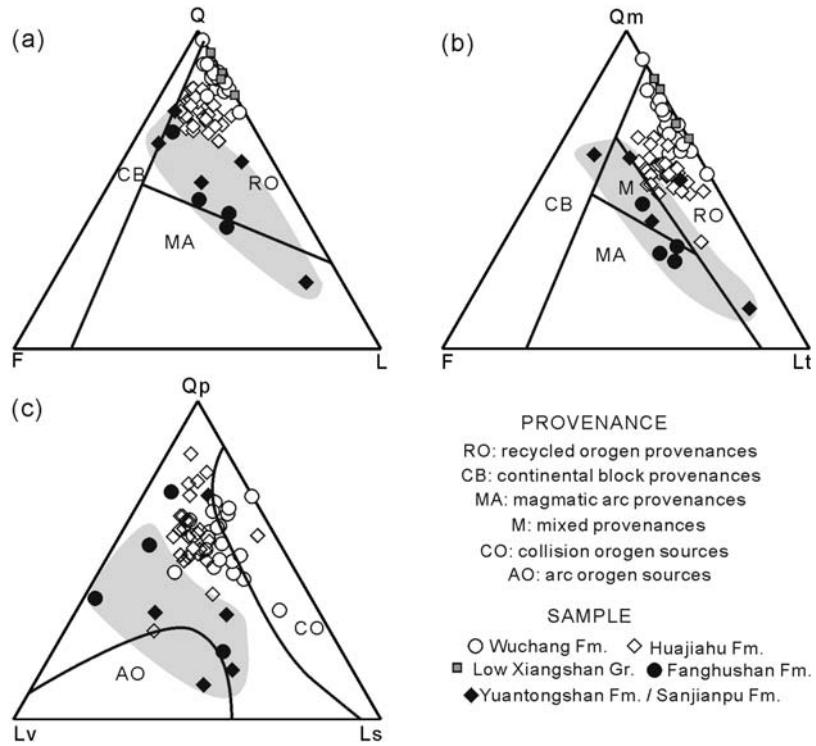


Figure 11. Ternary diagrams of (a) QFL , (b) Q_mFL_t and (c) Q_pLvL_s [Dickinson and Suczek, 1979; Dickinson et al., 1983], displaying point-counting data from sandstones from Huangshi, Yueshan and Hefei basins. Abbreviations: Q – quartz, F – feldspar; L – lithic fragments; Q_m – quartz monocrystalline; L_t – total lithic fragments; Q_p – quartz polycrystalline; L_v – volcanic lithic fragment; L_s – sedimentary lithic fragment.

majority of the samples plot close to the Q apex but are divisible into three associations trending parallel to the Q - L tie; 1) Wuchang Formation from the Huangshi Basin and the time equivalent lower Xiangshan Group of the Yueshan Basin, which lie closest to the Q apex, 2) samples of Huajiahu Formation from the Huangshi Basin, and 3) samples from the Hefei Basin (Figure 11a). On the Q_mFL_t diagram all of the samples from the Huangshi and Yueshan basins lie with the recycled orogen field (Figure 11b). By contrast, the Jurassic samples of Hefei Basin constitute an expanded range extending over the continental block, recycled orogen, mixed and magmatic arc fields (Figure 11b). Samples plot in groups parallel to the Q_m - L_t tie. On the Q_pLvL_s diagram (Figure 11c), the higher Q_p of the Huangshi Basin samples results in a cluster near the upper apex of the diagram within, or near, the collisional orogen field. In contrast, samples from the Hefei Basin fall near or within the field of arc orogen sources. In summary, samples from the Hefei Basin incorporated a component of material from a magmatic arc source, which is largely absent from the Huangshi Basin and Yueshan Basin samples.

[26] Comparison of detrital zircon U-Pb age data for the Hefei, Yueshan and Huangshi basins reveals similar overall age patterns (Figures 12a–12g) but with variations in the proportion of each major age group. The early Jurassic section of the lower Xiangshan Group in the Yueshan Basin shows a relatively high concentration of 1.9–1.8 Ga grains

(38% [Grimmer et al., 2003]) similar to the Huangshi Basin but lacks early Paleoproterozoic and Archean detritus. A late Triassic sample from the Huangshi Basin [She, 2008] yielded a similar age population. Samples from the Hefei Basin generally contain only a minor proportion of late Paleoproterozoic material and more pronounced Neoproterozoic and Phanerozoic age groups at 800–700 Ma, 500–400 Ma, and 300–200 Ma.

6.2. Provenance of Detrital Zircons

[27] From the mid-Neoproterozoic to the Triassic, the Yangtze Block was the site of stable marine sedimentation [Wang et al., 1985; Liu and Xu, 1994]. Middle-Late Triassic orogenesis associated with formation of the Dabie Orogen resulted in a major regression across the block and the initiation of terrestrial conditions within the Huangshi Foreland Basin [Wang et al., 1985; Liu and Xu, 1994].

[28] Phanerozoic detrital zircon grains range in age from 500 Ma to 210 Ma with peaks at ~450 Ma, 330–315 Ma and 250–215 Ma (Figures 7 and 13). CL and trace element data indicate that most are of metamorphic origin and correspond with documented metamorphic events in the Dabie Mountains (Figures 7, 8 and 9). The peak at ~450 Ma corresponds with early Paleozoic high-grade granulite facies metamorphism in the Dabie orogen [Qiu and Wijbrans, 2006, 2008; Gao et al., 2002; Jian et al., 2000] and the Carboniferous

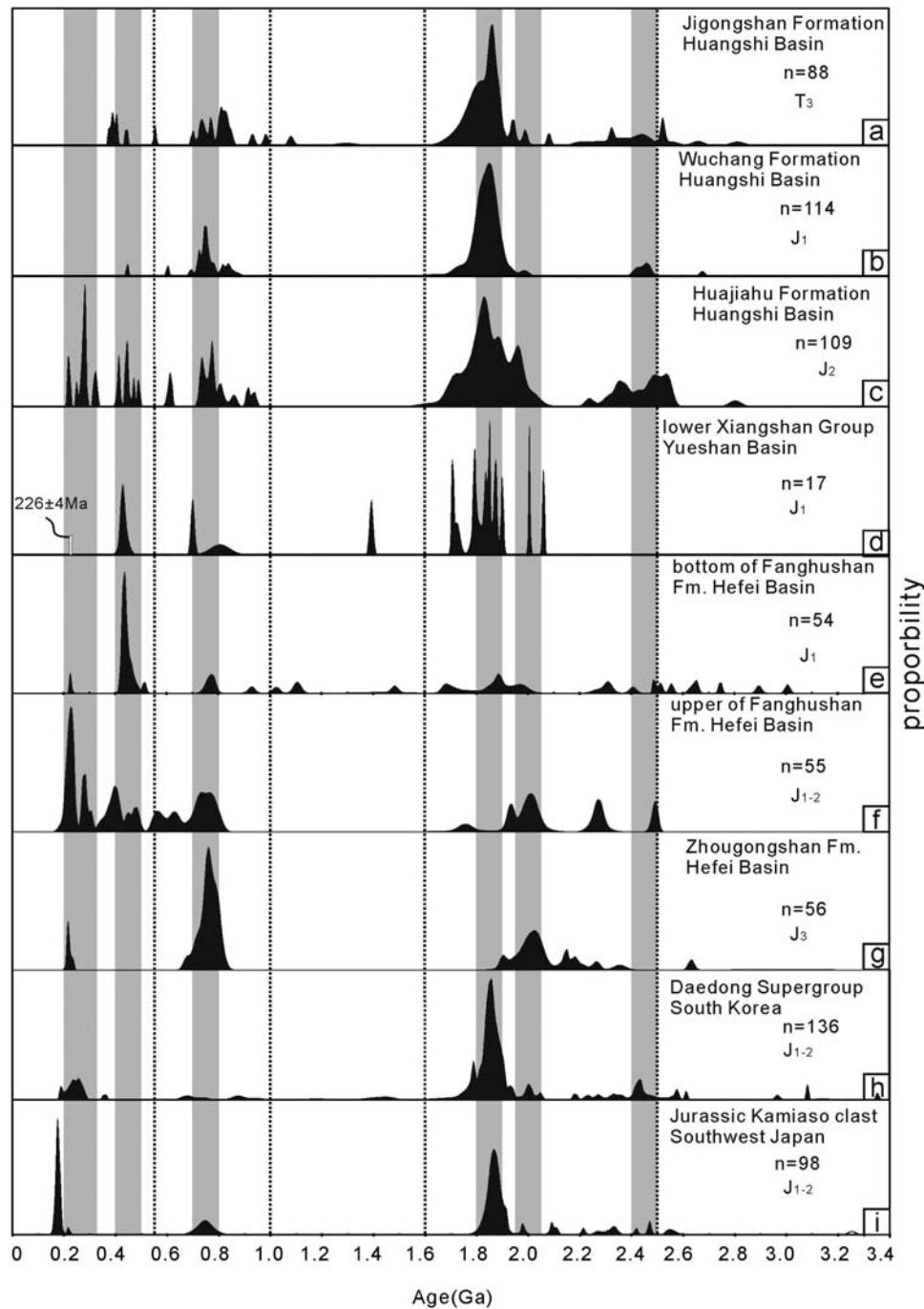


Figure 12. Probability density diagram comparing analyzed detrital zircons of (b and c) Early Middle Jurassic sandstones from the Huangshi Basin with data for detrital zircons from (a) late Triassic sandstone of Huangshi Basin [She, 2008], (d) Early Jurassic sandstone of the Yueshan Basin [Grimmer et al., 2003], (e, f and g) sandstones of Early Middle Jurassic Fanghushan and Zhougongshan formations in the Hefei Basin [Li et al., 2005], (h) Early Middle Daedong Supergroup sandstones in South Korea [Jeon et al., 2007], and (i) Early Middle Jurassic Kamiaso conglomerates in southwest Japan [Hidaka et al., 2002; Nutman et al., 2006]. Dashed vertical lines separate boundaries of Archean – Paleoproterozoic – Mesoproterozoic – Neoproterozoic – Phanerozoic are taken at 2500 Ma, 1600 Ma, 1000 Ma and 545 Ma. Note, in Figure 12d, the grain dated at 226 ± 4Ma (marked by open rectangle) from Middle Jurassic sandstone (the upper part of Xiangshan Group) of Yueshan Basin. Shaded regions represent age ranges of 2500–2400 Ma, 2050–1950 Ma, 1900–1800 Ma, 800–700 Ma, 500–400 Ma and 330–200 Ma.

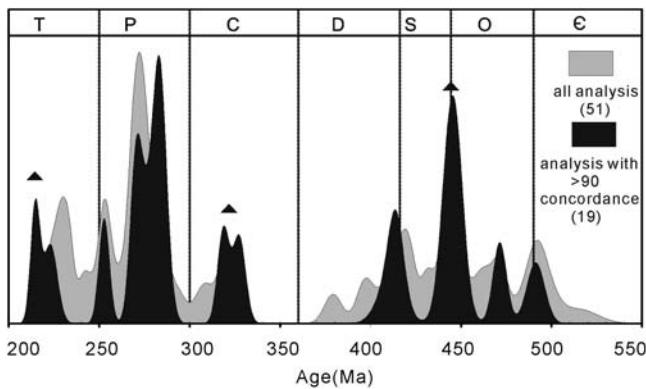


Figure 13. Age spectra of grains in the range 550 Ma to 200 Ma, showing peaks in early Paleozoic, Carboniferous, Permian and Triassic. Abbreviations: T – Triassic; P – Permian; C – Carboniferous; D – Devonian; S – Silurian; O – Ordovician; and E – Cambrian. The numbers of detrital zircons are bracketed in the parentheses. Small triangles indicate age of major tectonothermal events in the Dabie Orogen.

and Triassic peaks correlate with the timing of high pressure to ultra high pressure metamorphism [Wu et al., 2009b, 2008a; Sun et al., 2002; Hacker et al., 2000; Liu et al., 2006].

[29] Carboniferous and Triassic ages are rare or absent from the Triassic Jigongshan Formation (Figure 12a) [She, 2008] and early Jurassic Wuchang Formation samples (Figure 12b) from the Huangshi Basin suggesting that the UHP metamorphic rocks of the Dabie Mountains were not a significant source for the southern foreland basin during the early stages of its development. The Early Jurassic sandstone from the Yueshan Basin shows a similar pattern (Figure 12d) [Grimmer et al., 2003], with one grain dated at 226 ± 4 Ma in a Middle Jurassic sample. This contrasts with the northerly basin where detritus of this age is present in the early Jurassic strata (Figures 12e and 12f) [Li et al., 2005].

[30] Neoproterozoic grains fall into two broad groups at 940–850 Ma and 820–600 Ma. The former group overlaps with the timing of arc related magmatism and sedimentation recorded in the Jiangnan Orogen that joins the Yangtze and Cathaysia blocks and the latter with widespread Neoproterozoic rift related magmatism across the South China Craton [Greentree et al., 2006; Li, 1999; Zhao and Cawood, 1999; Li et al., 2007; X.-L. Wang et al., 2007; Li et al., 2008a, 2008b; Zheng et al., 2008].

[31] Late Paleoproterozoic detrital zircon grains are the dominant component of samples from the Huangshi Basin, as well as the early Jurassic sample from the Yueshan Basin, and this age component differentiates them from temporally equivalent samples from the Hefei Basin to the north (Figure 12). The grains range in age from ~1930 Ma to 1620 Ma with most lying between 1900 Ma to 1800 Ma. The South China Craton, which experienced a series of thermal events between 1.9–1.8 Ga [Greentree et al., 2006; Peng et al., 2009; Sun et al., 2009; Wang et al., 2009; Xiong et al., 2009; Xu et al., 2007; Yang et al., 2006; Yu et al.,

2009b, and references therein; Zhou et al., 2009], provides a likely source for this detritus. Yuan et al. [1991] and Xiong et al. [2009] obtained an emplacement age of ~1.85 Ga for the A-type Quanyishang granite, which intrudes into Archean basement in Kongling area of the Yangtze Block. Detrital zircons of magmatic origin and with similar ages occur in the Proterozoic sedimentary units of the Fanjingshan, Dahongshan, Huili, and Kunyang groups in the western and southern areas of the Yangtze [Greentree et al., 2006; Greentree and Li, 2008; Sun et al., 2009; Wang et al., 2009]. The Nd and Hf isotopic data have also indicated magmatism of similar ages in the northeastern Yangtze [Huang et al., 2006; Y.-F. Zheng et al., 2006; Z. F. Zhao et al., 2008; Chen et al., 2001]. Recently, Yu et al. [2009a] have dated S-type and A-type granites in the Cathaysia Block in the range 1890–1855 Ma, which together with Hf isotopic data suggests this magmatism developed on Archean basement.

[32] The North China Craton also contains rocks of appropriate age to have acted as a source for the Paleoproterozoic detritus (Figure 2). However, uplift of Qinling-Dabie-Sulu orogen would have constituted a physical barrier to the southward transport of debris from North China. Furthermore, the igneous origin of the Paleoproterozoic detritus in the Huangshi Basin, as ascertained from CL imaging and trace element geochemistry (Figures 5 and 9), contrasts with this being a period of regional metamorphism in North China Craton [Zhao, 2001; Zhao et al., 2002, 2007; G. C. Zhao et al., 2008a, 2008b; Zhao et al., 2010]. In addition, the age spectra of detrital zircon from Hefei Basin (Figure 12e, 12f and 12g), indicate that the Precambrian basement of North China was not a major source into the basin.

[33] Collectively, all the Jurassic samples south of the Dabie UHP belt show a common major detrital zircon age peak in the range 1.9 Ga to 1.7 Ga. They may all be derived from the eastern Yangtze Block and/or Cathaysia Block. The decrease in proportion of 1.9 Ga to 1.7 Ga grains from ~71% in the Early Jurassic sample Wc-1 to ~40% in the Middle Jurassic sample Hj-1 and corresponding increase in Neoproterozoic to Phanerozoic detritus suggests increasing input of material from the Dabie orogen, consistent with the occurrence of southward paleocurrent data in the uppermost Huajiahu Formation [Z. Li et al., 2003].

[34] Late Archean to mid-Paleoproterozoic ages (~2800–1940 Ma) for detrital zircon grains from the Huangshi Basin were also likely derived from a Yangtze Block source. Archean grains with ages around 2800 Ma and 2680 Ma correspond to magmatic events in the Kongling complex and Huangtuling granulites of the Yangtze Block [Grimmer et al., 2003; Qiu et al., 2000; Wu et al., 2009a, 2008b; Zhang et al., 2006b]. The broad spectrum of ages between 2550 Ma to 2235 Ma are consistent with the records of the detrital zircons in the Neoproterozoic sedimentary rocks in the Yangtze Block, such as the Fanjingshan and Xiajiang groups [Wang et al., 2009; Zhou et al., 2009], the Huili and Kunyang groups [Sun et al., 2009], the Sibao Group [X.-L. Wang et al., 2007]. Detrital ages between 2020–1937 Ma are of metamorphic derivation on the basis of CL imaging and trace element data (Figures 6 and 7) and correspond with the phase of high-grade metamorphism in the Yangtze

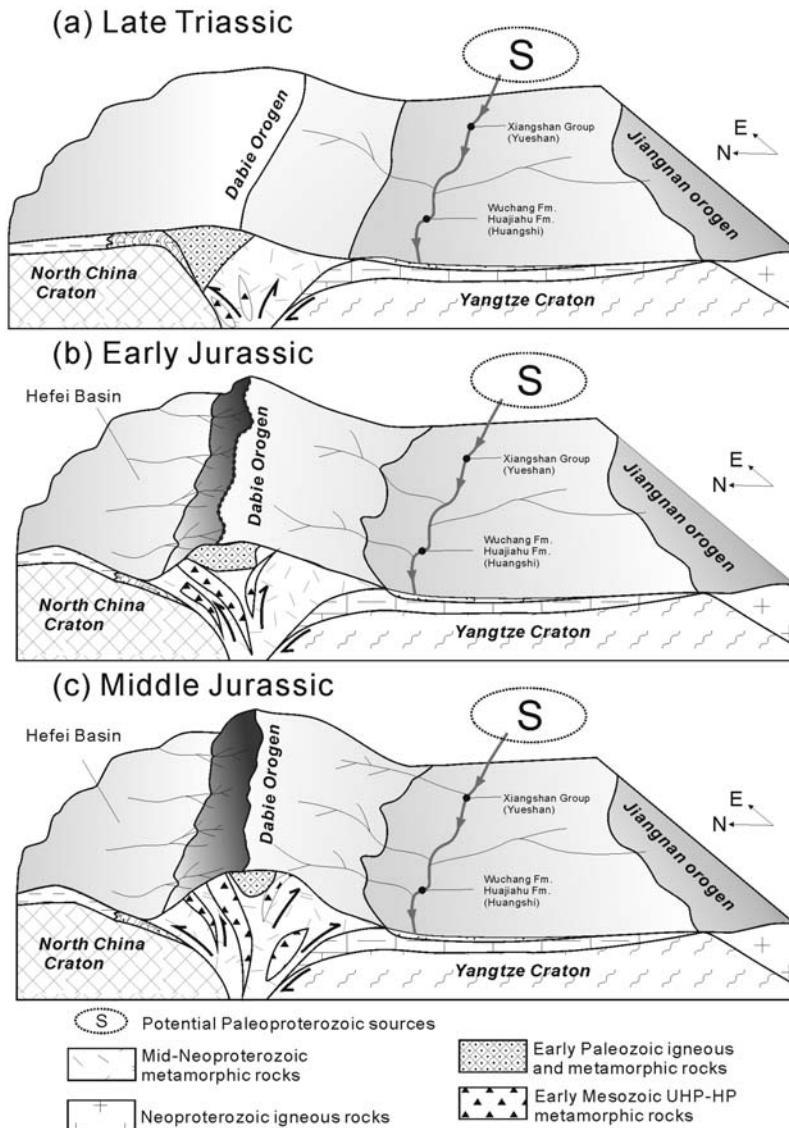


Figure 14. Model for schematic paleogeographic reconstruction of northeastern South China during the Late Triassic to Middle Jurassic, showing the exhumed sequences in Dabie Mountains, the potential sources and an inferred westward-flowing truck river system to the Huangshi Foreland Basin. The river system drains the eastern and southern parts of the South China Craton along with short south flowing tributaries draining off the Dabie Mountains. Abbreviations: UHP – ultra-high pressure; HP – high pressure.

Block at ~2.0–1.95 Ga [Wu *et al.*, 2009a; Zhang *et al.*, 2006a, 2006b, 2006c; Grimmer *et al.*, 2003; J. P. Zheng *et al.*, 2006].

6.3. Basin Paleogeography

[35] Modal and detrital zircon age data suggest a multi-component source for the Huangshi Foreland Basin with input from both the South China Craton and Dabie Orogen. Samples are predominantly quartz arenites derived, on the basis of framework compositions, from a recycled orogen source (Figure 11). High component maturity was also

noted by Grimmer *et al.* [2003] and Z. Li *et al.* [2003], and was related to the reworking of older sediments or protracted transportation. The predominance of late Paleoproterozoic detrital zircons along with the minor component of older material suggests derivation from the south and east within the South China Craton. The Neoproterozoic and younger detrital zircons were largely derived from a metamorphic source, consistent with input from the exhumed Dabie Orogen. Analysis of detrital white mica's from the foreland basin sedimentary rocks of the Huangshi Basin by Grimmer *et al.* [2003] yielded mainly Triassic and Jurassic $^{40}\text{Ar}/^{39}\text{Ar}$ ages with a scattering of Paleozoic and late

Neoproterozoic ages, suggesting to them that as much as 80% of the detritus was derived from the HP-UPH rocks in Dabie Mountains [cf. Li *et al.*, 2006]. Grimmer *et al.* [2003] also carried out U-Pb evaporation zircon ages which yielded largely Paleoproterozoic ages. They suggested the paucity of Triassic zircons was due to the lack of syn-metamorphic zircon growth and of syn- to post-collisional magmatism. However, Mesozoic detrital zircons, which correlate with the age of metamorphism in the Dabie Mountains, are relatively well developed, and indeed dominant, in some foreland samples, notably the Fanghushan Formation in the Hefei Basin (Figure 12f), indicating material of this age was present in the Dabie Mountains but just not in the source area for the Huangshi-Yueshan Basin.

[36] We envisage sediment supply to the basin by a trunk river system aligned approximately parallel to the Qiling-Dabie orogenic belt. The Jiangnan Orogen within the South China Craton may have acted as a physiographic barrier resulting in the trunk system flowing westward [Liu and Xu, 1994; She, 2008], consistent with the main westerly northwesterly paleocurrents occurring in the Lower-Middle Jurassic of Huangshi Basin [Z. Li *et al.*, 2003]. Transport, reworking and recycling of Paleoproterozoic and older material, ultimately from the Paleoproterozoic basement to the South China Craton, was mixed with detritus carried in short southward flowing rivers draining from the orogenic welt bounding the northern margin of the foreland basin (Figure 14).

6.4. Lateral Continuity of Collision Zone and Foreland Basin

[37] The Hongseong-Odesan Belt (or “Korean collision belt”) in Korea (Figure 10), which contains late Paleozoic to Triassic eclogite facies metamorphism, is considered to represent an along strike extension of the Dabie-Sulu collision belt [Oh *et al.*, 2005; Oh, 2006; Kwon *et al.*, 2009]. The Hida Belt (Figure 10) in Japan is a likely further extension [Tsujimori *et al.*, 2006; Oh, 2006]. Sedimentary basins occupying an analogous tectonic position to the Huangshi foreland basin lie to the south of these collisional belts and all contain Early to Middle Jurassic sedimentary infill. In Korea this succession is represented by the Nampo Group and equivalent strata [Jeon *et al.*, 2007; Egawa and Lee, 2009] and in Japan by the Kamiaso turbidites in the Mino terrane (Figure 10) [Isozaki, 1997; Hidaka *et al.*, 2002; Nutman *et al.*, 2006; Tsujimori *et al.*, 2006]. Detrital zircon data from these Korean and Japanese successions are similar to the Huangshi strata and include a major component of late Paleoproterozoic detritus (Figures 12h and 12i) likely derived from the South China Craton and Phanerozoic debris from the exhumed collisional belt. Thus, the foreland basin along the southern margin of the North China – South China collision zone (and equivalents) may

extend up to 2000 km further to the west beyond the Huangshi Basin.

7. Summary

[38] Modal analysis integrated with detrital zircon U-Pb and trace element data from Early and Middle Jurassic sandstones of the Huangshi Foreland Basin, located along the southern side of the Dabie Mountains, indicate input from both the orogen to the north and the South China Craton to the south and east. Significantly, the age of the detrital zircon detritus within the foreland basin matches pulses of activity in both the craton and orogen.

[39] The predominant zircon group ranges in age from 1.9 Ga to 1.7 Ga, overlapping with the inferred Paleoproterozoic basement source in the South China Craton, notably that preserved within the eastern Yangtze Block, to the east of the basin. Phanerozoic detritus is divisible into three age groups, Ordovician, Carboniferous and Triassic, corresponding to pulses of metamorphism in the Dabie Mountains, which lies to the north of the basin. This source forms a larger component of the Middle Jurassic sample than the Lower Jurassic sample perhaps indicative of increased exhumation the orogenic source perhaps associated with foreland propagation of the mountain front with time. The foreland sediments are considered to have accumulated in an axial flowing truck river system in which Paleoproterozoic components from the South China Craton to the south and east were mixed with detritus from the nearby Dabie Orogen immediately to the north (Figure 14). Our results from the Huangshi Basin are similar to those from the Yueshan area, which lies immediately to the east of the Dabie Mountains and represents a fragment of the originally continuous Huangshi-Yueshan Basin displaced along the Tanlu Fault (Figure 1). These results contrast with provenance data from the foreland basin to the north of the Dabie Mountains which are dominated by Phanerozoic metamorphic debris, inferred to be derived directly from the Dabie Mountains and in which the input of Paleoproterozoic detritus is considerably reduced. The provenance of the Jurassic sandstones in the Huangshi Basin is similar to temporally equivalent units in Korea and Japan which occupy an analogous tectonic position to the south of the Hongseong-Odesan and Hida high pressure belts, respectively.

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P. A. Cawood, School of Earth and Environment, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia.

Y. Du and J. Yang, Key Laboratory of Biogeology and Environmental Geology of Ministry of Education, China University of Geosciences, Wuhan, 430074, China. (duyuansheng126@126.com)