Early Triassic Conversion from Source to Sink on the Southern Margin of the North China Craton: Constraints by Detrital Zircon U-Pb Ages

Yanpeng Wang, Wentao Yang *, Shenyuan Peng, Shuaishuai Qi and Deshun Zheng

School of Resources and Environment, Henan Polytechnic University, Jiaozuo, Henan 454000, China; wangyp2017@126.com (Y.W.); pshenyuan@foxmail.com (S.P.); qishuaishuaiqi@126.com (S.Q.); zhengdeshun@126.com (D.Z.)

* Correspondence: yangwt@hpu.edu.cn; Tel.: +86-180-6266-6268

Received: 12 November 2019; Accepted: 17 December 2019; Published: 19 December 2019

Abstract: Provenance analysis of sediments provides important constraints on basin formation and orogenic processes. With the aim to define the sedimentary provenance and tectonic evolution of the southern margin of the North China Craton, this paper presents new detrital zircon U-Pb data from Early Triassic sediments in the Yiyang area. The results showed major peaks at 1848, 458, 425, and 268 Ma and subordinate peaks at ca. 2500, 872, and 957 Ma on age spectra from the Liujiagou Formation. The Heshanggou Formation exhibited a major age peak at 445 Ma and subordinate peaks at 755 and 947 Ma. Integrated with the analysis of sandstone detrital compositions, we suggest that the sources of the Liujiagou Formation were mainly a mixture of the southern margin of the North China Craton and the North Qinling Orogenic Belt, whereas the Heshanggou Formation was derived primarily from the North Qinling Orogenic Belt. Age comparisons of detrital zircon geochronology collected from different basins in the North China Craton indicated that the paleogeography of the North China Craton during the Early Triassic was strongly asymmetric, wherein the uplifted highland along the southern margin of the North China Craton was relatively lower than the northern margin. Meanwhile, the marked shift in source region from the Liujiagou to the Heshanggou formations provides a constraint regarding the conversion from denuded zone to deposited zone along the southern margin of the North China Craton in the Early Triassic, which controlled the evolution of the provenance and sedimentary system.

Keywords: southern North China Craton; Early Triassic; detrital zircon; sedimentary provenance; source-to-sink systems

1. Introduction

Sedimentary basins and orogenic belts are two basic tectonic units that developed on the continental lithosphere surface, which are connected with each other in space and have a close coupling relationship in general [1–4]. The provenance analysis of sediments provides an effective point at which the basin and mountain interact, because the sediments preserved in basins are not only direct evidence of basin evolution, but also contain affluent dynamic information regarding adjacent orogenic belts. Zircon grains are robust and resistant to weathering, and due to high closure temperature record igneous events, their stable morphology and U-Pb ages provide powerful tools to trace the sources of deposition [5,6]. Therefore, it is of great significance to understand the spatio-temporal evolution between sedimentary basins and orogenic belts [7–9].

The tectonic evolution of the North China Craton (NCC) during the Late Paleozoic to Triassic is closely related to peripheral orogenic belts, as shown in Figure 1. These mainly refer to the Central...
Asian Orogenic Belt (CAOB), which formed via closure of the Paleo-Asian Ocean along its northern margin, and the Qinling–Dabie Orogenic Belt, which formed via the subduction and closure of the Paleo-Tethys ocean along its southern margin [10–13]. Influenced by alternate or simultaneous convergence of these orogenic belts, the sedimentary and tectonic paleogeography of the NCC underwent significant change [14–16]. At the same time, extensive magmatic activity occurred in the northern margin of the NCC, which was considered to be the beginning of the transition from stable deposition to tectonic activation [12,17,18]. In contrast, the southern margin of the NCC was believed to be inactive during the Late Paleozoic to Triassic ages. Some scholars thus regard it as a passive continental margin due to continuously sedimentary stratigraphic sequences and the lack of significant synchronous magmatic activity records [15]. However, this tectonic setting strongly competes with the conventional viewpoint that the tectonic evolution of the southern margin of the NCC was significantly controlled by the northward subduction and collision orogeny of the Qinling Orogenic Belt (QOB) [7,11,19–22]. In addition, the sediment provenances from the Upper Paleozoic and Middle–Upper Triassic eras focused on the southern NCC were comprehensively studied by the U-Pb isotopic analysis of detrital zircons [7–9,17,23], whereas the Early Triassic strata is still poorly understood. Therefore, a supplementary study of the provenance of the southern margin of the NCC can provide a potential clue to confirm the above-mentioned argument regarding the tectonic setting and evolutionary process.

In this paper, we present new sandstone petrography and detrital zircon U-Pb geochronology from the Early Triassic sedimentary strata, including the Liujiagou and Heshanggou formations in the Yiyang area of the southern NCC. These data, combined with previous work from other basins, provide important constraints into the sedimentary provenances and paleogeographic features of these areas, as well as offering a better understanding into the basin-mountain tectonic evolution between the southern NCC and the QOB during the Early Triassic period.

![Figure 1. Tectonic sketch of the North China Craton and the tectonic location of the Yiyang area (modified from [10]). The numbers represent the locations of previous investigations with detrital zircon geochronology during the Early Triassic period: 1—Pingquan area; 2—Xiabancheng basin; 3—Ningwu basin; 4—Xishan area, Taiyuan; 5—Qinshui basin; 6—Jiyuan basin; 7—Yan’an area. IMPU: Inner Mongolia Paleo-uplift; NQOB: North Qinling Orogenic Belt; SQOB: South Qinling Orogenic Belt.](image-url)
2. Geological Setting

The NCC is bound by the CAOB to the north and the Qinling–Dabie–Sulu Orogenic Belt to the south and southeast, as shown in Figure 1. The CAOB is a giant accretionary orogen that records long-term subduction and terminal closure of the Paleo-Asian ocean during the Late Paleozoic to Early Mesozoic eras [24,25]. The QOB is a major part of the central orogenic belt in China and connects the southern margin of the NCC via the Luonan-Luanchuan fault; in combination with the Shangdan and Mianlue suture zones, it divides into the North Qinling Orogenic Belt (NQOB) and the South Qinling Orogenic Belt (SQOB) [22]. It is well-established that the Paleozoic Shangdan suture zone reflects the closure of the Shangdan ocean and multistage amalgamation of the South and North China blocks prior to the Middle Devonian age [26], and the Triassic Mianlue suture zone represents the closure of a northern branch of the Eastern Paleo-Tethys ocean, which separates the SQOB from the South China block [22].

The Yiyang area in Western Henan is regarded as a part of the Paleozoic to Mesozoic superimposed intracratonic sedimentary basin on the southern margin of the NCC, which is adjacent to the northern end of the Qinling Orogenic Belt, as shown in Figure 1. During the Early Triassic period, the Yiyang area had the same sedimentary characteristics as the Late Permian period, mainly consisting of a succession of clastic rocks. With the development of the retreated epicontinental sea and the subsequent regional tectonic uplift, a transition was recorded from marine to non-marine deposition. After that, the sedimentation was dominated by the terrestrial redbed sequence with fluvial and lacustrine facies under the arid climate [14,15]. The profile measured in this study was situated in the Dayulin section, approximately 4 km south of Yiyang county, where the Upper Paleozoic to Lower Mesozoic successive sequences are well exposed, as shown in Figure 2a.

The Early Triassic stratigraphic units in the study area were composed of the Liujiagou and Heshanggou formations, which were conformably underlain by the Upper Permian Sunjiagou Formation and overlain by the Middle Triassic Ermaying Formation, as shown in Figure 2b. Among these, the Liujiagou Formation consisted of abundant brick-red sandstones with minor calcareous siltstones and mudstones, as shown in Figure 3a. In detail, fine-grained sandstones bearing several layers of interbedded conglomerates, as shown in Figure 3b, mainly appeared in the lower section. In the middle, the sandstones became coarser as they moved gradually upward and developed numerous ripple marks, as shown in Figure 3c,d, and parallel beddings, as shown in Figure 3e. The upper section of the Liujiagou Formation was dominated by thick, coarse-grained sandstones, which included abundant boulder clays, as shown in Figure 3f, and large tabular, trough, and wedge cross-bedding structures, as shown in Figure 3g. According to the typically reverse grain-size sequence, ripple marks, and large cross-bedding sedimentary structures, the Liujiagou Formation was interpreted to have been deposited in a lacustrine deltaic environment [27]. The Heshanggou Formation was mainly composed of reddish siltstones and mudstones with abundant calcareous nodules in the lower section, as shown in Figure 3h,i. Thick layers of interbedded mudstones and sandstones were found in the middle section, as shown in Figure 3j, with wedge cross-beding, as shown in Figure 3k, and interbedded argillaceous conglomerates, as shown in Figure 3l, both indicating fluvial deposits. The upper section of the Heshanggou Formation was dominated by thick-bedded mudstones, indicating a shore-shallow lacustrine sedimentary environment [28].

3. Sampling and Analytical Methods

A series of fresh samples were systematically collected from the Lower Triassic Liujiagou and Heshanggou formations (Yiyang, China), with the stratigraphic locations shown in Figure 2. For the petrographic analysis, the sandstones selected for the framework component statistics were basically medium- to coarse-grained, and quantitative calculations were performed on standard thin sections under a petrographic microscope. This study eliminated any samples containing more than 25% matrix or cement to minimize the influence of the composition. Each thin section contained more than 300 counted points following the Gazzi–Dickinson point counting method [29,30].

Two zircon samples were collected for U-Pb dating analysis and were separated by conventional heavy liquid and magnetic techniques at the Langfang Regional Geological survey, Hebei Province,
China. Sample Y-L was separated from the coarse sandstones in the Liujiagou Formation, while Sample Y-H was picked from the medium-grained sandstones in the Heshanggou Formation. The zircon grains were further purified by hand-sorting under a binocular microscope. More than 300 zircons from each sample were selected randomly and mounted in epoxy resin and polished approximately in half to expose the grain centers. The internal structures of the detrital zircons were examined using cathodoluminescence (CL) images with a scanning electron microscope (JSM-IT100, Tokyo, Japan) and the GATAN MINICL system (Gatan company, Pleasanton, CA, USA). Target points were selected according to the internal morphology of the zircons and to avoid inclusions, fractures, and metamict structures.

Figure 2. (a) Geological map showing the regional stratigraphy of the southern Yiyang area (modified from [31]). (b) Measured section histogram of the Lower Triassic Liujiagou and Heshanggou formations in the Yiyang area, showing the location of samples.

U-Th-Pb isotope analyses of the detrital zircons were conducted at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences in Wuhan, China. Laser sampling was performed using a pulsed Geolas 2005 M laser-ablation system (wavelength of 193 nm and maximum energy of 200 mJ), and an Agilent 7500 ICP-MS instrument was used to acquire ion-signal intensities. Argon was used as the make-up gas and mixed with the carrier gas via a T-connector before entering the ICP. The diameter and frequency of the laser spot size were set to 32 µm and 6 Hz. Standard zircon 91,500 and GJ-1 were used for external calibration of the U-Pb analyses and the zircon 91,500 was analyzed twice after every six analyses. Trace element concentrations were determined on the basis NIST610 as the external standard and Si as the internal standard. Each
analysis incorporated a background measuring duration of approximately 20 s followed by data acquisition of 50 s, respectively. The Excel-based software ICPMSDataCal (Version 10.0, China University of Geosciences, Wuhan, China) was used to perform off-line selection, background integration, time-drift correction, and quantitative calibration [32]. U-Pb concordia diagrams and weighted mean calculations were plotted using the software program Isoplot 3.0 [33].

![Figure 3. Outcrop photographs and typical geological attributes of the Lower Triassic succession in the Yiyang area.](image)

(a) The Liujiagou Formation was conformably in contact with the Sunjiagou Formation; (b) interbedded conglomerates in the lower section of the Liujiagou Formation; (c,d) numerous ripple marks and (e) parallel beddings in the middle section of the Liujiagou Formation; (f) purple, coarse-grained sandstones with abundant boulder clays and (g) large trough and wedge cross-beding structures in the upper section of the Liujiagou Formation; (h) reddish mudstones and siltstones and (i) abundant calcareous nodules in the lower section of the Heshanggou Formation; (j) interbedded layers of mudstones and sandstones with (k) wedge cross-beding in the sandstones; (l) mudstones with interbedded conglomerates in the middle section of the Heshanggou Formation.

4. Results

4.1. Sandstone Detrital Compositions

In this study, 17 samples met the statistical requirements, including 10 sandstones from the Liujiagou Formation and 7 sandstones from the Heshanggou Formation. The detrital modes were counted as (1) stable quartzose grains (Q), including both monocrystalline quartz (Qm) and polycrystalline quartzose lithic fragments (Qp); (2) feldspar grains (F), including plagioclase (P) and K-feldspar (K); (3) unstable lithic fragments (L), including volcanic/metavolcanic types (Lv) and...
sedimentary/metasedimentary types (Ls). The total lithic fragments (Lt) equaled the sum of L plus Qp. The results of the point-counting are shown in Table 1.

Overall, the sandstone samples of the Early Triassic exhibited similar clast components and textures, which were predominantly subangular-angular grains and characterized by argillaceous and calcareous cements with a mud matrix. Samples from the Liujiagou Formation contained high quartz (86%–93%), low feldspar (1%–4%) and low lithic fragments (3%–11%), as shown in Figure 4a–c. In contrast, the content of quartz (82%–87%) from the Heshanggou Formation decreased relatively, and feldspar (1%–5%, with the exception of one sample at 12%) and lithic fragments (4%–15%) slightly increased, as shown in Figure 4d–f. According to the statistical results, both the Liujiagou and Heshanggou formations were dominated by quartz with rare feldspar. The monocrystalline quartz was much more abundant than the polycrystalline quartz, and parts of them incorporated a number of mineral inclusions. The lithic fragments included sedimentary, metamorphic, and rare volcanic fragments.

Different provenance types have been shown on complementary standard triangular diagrams [29]. On the QFL diagram, as shown in Figure 5a, the samples fell principally in the recycled orogen provenance field, with a few exceptions falling in the continental block provenance field. On the QmFLt diagram, as shown in Figure 5b, samples from the Liujiagou Formation were derived equally from the continental block and recycled orogen provenance field, whereas the Heshanggou Formation mainly came from the recycled orogen provenance field. It is noteworthy that there was an obvious migration toward the recycled orogen field from the Liujiagou to Heshanggou Formation. Furthermore, all of the samples were plotted within the collisional orogen sources field on the QpLvLs diagram, as shown in Figure 5c.

### Table 1. Point-count data of detrital compositions for the sandstones in the Yiyang area.

| Sample No. | Qm | Qp | Qt | P | K | F | Lv | Ls | L | Lt | Total |
|------------|----|----|----|---|---|---|----|----|---|----|-------|
| BL01       | 326| 13 | 339| 5 | 10| 15| 2  | 40 | 42| 55 | 396   |
| BL02       | 288| 12 | 300| 1 | 5 | 6 | 0  | 36 | 36| 48 | 342   |
| BL04       | 348| 14 | 362| 7 | 10| 17| 2  | 11 | 13| 27 | 392   |
| BL05       | 333| 11 | 344| 5 | 5 | 10| 0  | 23 | 23| 34 | 377   |
| BL06       | 303| 13 | 316| 3 | 4 | 7 | 1  | 24 | 25| 38 | 348   |
| BL07       | 359| 27 | 386| 1 | 4 | 5 | 2  | 24 | 26| 53 | 417   |
| BL08       | 295| 29 | 324| 1 | 1 | 2 | 1  | 29 | 30| 59 | 356   |
| BL09       | 266| 22 | 288| 1 | 1 | 2 | 0  | 26 | 26| 48 | 316   |
| BL10       | 272| 24 | 296| 1 | 5 | 6 | 1  | 26 | 27| 51 | 329   |
| BL11       | 298| 15 | 313| 2 | 9 | 11| 0  | 19 | 19| 34 | 343   |
| BH01       | 275| 23 | 298| 2 | 10| 12| 0  | 37 | 37| 60 | 347   |
| BH02       | 269| 20 | 289| 3 | 8 | 11| 1  | 50 | 51| 71 | 351   |
| BH03       | 262| 50 | 312| 3 | 2 | 5 | 1  | 36 | 37| 87 | 354   |
| BH04       | 278| 27 | 305| 2 | 4 | 6 | 1  | 55 | 55| 82 | 366   |
| BH05       | 264| 33 | 297| 8 | 10| 18| 1  | 56 | 57| 90 | 372   |
| BH07       | 272| 33 | 305| 8 | 7 | 15| 0  | 29 | 29| 62 | 349   |
| BH08       | 288| 11 | 299| 17| 26| 43| 0  | 14 | 14| 25 | 356   |

Note: Qm: monocrystalline quartz; Qp: polycrystalline quartz; Qt: total quartz; P: plagioclase; K: K-feldspar; F: total feldspar; Lv: volcanic/metavolcanic lithic fragment; Ls: sedimentary/metasedimentary lithic fragment; L: lithic fragment; Lt: L + Qp.
Minerals 2020, 10, 7

Figure 4. Representative micrographs of sandstone detrital grains from the Yiyang area. (a–c) Sandstones from the Liujiagou Formation and (d–f) sandstones from the Heshanggou Formation. Qm: monocrystalline quartz; Qp: polycrystalline quartz; Pl: plagioclase; Kfs: K-feldspar; Lv: volcanic lithic fragment; Ls: sedimentary lithic fragment. Arrows indicate mineral inclusion.

Figure 5. Triangular diagrams for the Lower Triassic sandstones from the Yiyang area (modified from [29]). (a) QFL diagram; (b) QmFLt diagram; (c) QpLvLs diagram. Q: total quartz; F: total feldspar; L: lithic fragment; Qm: monocrystalline quartz; Qp: polycrystalline quartz; Lv: total volcanic/metavolcanic lithic fragment; Ls: sedimentary/metasedimentary lithic fragment; Lt: L + Qp.

4.2. Detrital Zircon U-Pb Ages

A total of 210 zircon grains from the two sandstone samples were analyzed for their U-Pb age. All of the original U-Pb isotopic data are presented in Supplementary Table S1. Due to the low radiogenic Pb concentrations and uncertainties associated with common Pb correction, ages younger than 1000 Ma were calculated from their more reliable 206Pb/238U ratios, whereas the older ages were based on the 207Pb/206Pb ratios [34]. In this study, only analytical data with discordances less than 10% were considered for use in the age statistical calculations and relative probability density diagrams. The uncertainties of individual analyses for the concordia age plots were conducted at 1σ level, and weighted average ages were conducted at 2σ values and 95% confidence levels.

In sample Y-L from the Liujiagou Formation, 102 of 104 analyses yielded concordant U-Pb ages with discordance less than 10%. The zircons were predominantly rounded to sub-rounded, and some of them showed euhedral prismatic or irregular shapes. The majority of the analyzed zircons exhibited obviously oscillatory zoning and sector textures, whereas a small portion displayed homogeneous internal structures and core-rim structures, as shown in Figure 6a. The Th/U ratios varied from 0.06 to 1.45, with three spots less than 0.1 (391 ± 6 Ma, 522 ± 5 Ma, and 1915 ± 31 Ma), as shown in Figure 7. The concordant ages ranged between 2748 and 259 Ma, which were grouped into five age populations: 2748–2167 Ma, 1972–1583 Ma, 1052–742 Ma, 583–391 Ma, and 377–259 Ma. These
clusters mainly yielded four major age peaks at 1848, 458, 425, and 268 Ma, and subordinate peaks at ca. 2500, 872, and 957 Ma, as shown in Figure 8.

The 106 analyses for sample Y-H from the Heshanggou Formation yielded 103 concordant data. The CL images showed that most of the zircons were stubby and prismatic in morphology and displayed narrow oscillatory zonation, as shown in Figure 6b. The Th/U ratios of analyzed zircons ranged from 0.09 to 2.14, with only one spot less than 0.1 (1085 ± 33 Ma), as shown in Figure 7. The concordant ages defined a broad range from 3227 to 417 Ma. Apart from minor decentralized ages falling into 3.2–1.0 Ga, the concordant ages of this sample yielded two distinct groups of 417–532 Ma and 633–915 Ma, with one major age peak at 445 Ma and subordinate peaks at 755 and 947 Ma, respectively, as shown in Figure 8.

**Figure 6.** Representative cathodoluminescence (CL) images and ages of detrital zircons from the two samples in this study, showing variations in size and morphology. (a) sample Y-L in the Liujiagou Formation; (b) sample Y-H in the Heshanggou Formation. The circles represent the testing spots in situ.

**Figure 7.** Th/U versus U-Pb age diagram for detrital zircons from the Early Triassic sediments in the Yiyang area. Y-L: Liujiagou Formation; Y-H: Heshanggou Formation.
Figure 8. U-Pb concordia age plots and relative age probability diagrams for detrital zircons of the Early Triassic analyses from the Yiyang area. Ages are in Ma and ellipses indicate 1σ uncertainties. (a,b) sample Y-L in the Liujiagou Formation; (c,d) sample Y-H in the Heshanggou Formation.

5. Discussion

5.1. Potential Source Area Age Signatures

Detrital zircons from the Early Triassic samples in the Yiyang area were grouped into four major clusters, ranging from the Neoarchean–Paleoproterozoic, Neoproterozoic, Early Paleozoic, and Late Paleozoic. Among these, the majority of the zircons showed typical oscillatory zones and high Th/U ratios, both indicating that most grains were magmatic in origin [35,36]. Therefore, the comparison of the U-Pb ages of the zircons with potential provenance areas was the general procedure for the detection of the source regions.

The Neoarchean–Paleoproterozoic zircons in this study yielded two dominant age peaks at ca. 2.5 Ga and ca. 1.85 Ga, which broadly coincided with the typical basement rock ages of the North China block [37–40]. The ca. 2.5 Ga represented the rapid accretionary period of major crustal growth that experienced widespread tectono-thermal events [41,42]. The ca. 1.85 Ga was correlated with the amalgamation of the Eastern and Western Blocks along the north–south trending Trans-North China Orogen, leading to the final assembly of the coherent basement of the North China block [43–46].

The Neoproterozoic zircons were mainly split into two groups at 1052–900 Ma and ~850–742 Ma, which showed the diagnostic age peaks for the QOB [47]. The former age cluster closely matched with the age distribution of large-scale Neoproterozoic magmatic activity in the NQOB [47,48]. This multiphase magmatism was represented by strongly deformed S-type granites at 979–911 Ma and weakly deformed I-type granites at 894–815 Ma [47], which were associated with the subduction and collision of the Kuanping Ocean [22,49]. Zircons aged ~850–700 Ma were widely preserved in the magmatic and low-grade metamorphic rocks of the SQOB along the northern margin of the Yangtze block [50,51]. Additionally, a small amount of detrital zircon at ca. 850–742 Ma were also found in the Kuanping Group [52] and paragneiss in the Qinling Complex of the NQOB [53–55].

Early Paleozoic zircons at 583–391 Ma were correlated with the magmatism records in the NQOB [47,56]. NQOB is characterized by a large volume of Early Paleozoic ophiolitic melanges in the
Shangdan suture and arc-related gabbroic and granitic intrusions to the north, which represent an important tectonic period of subduction and closure of the Shangdan ocean [57]. It is well documented that Paleozoic granitoid intrusions mainly comprised three stages of 507–470 Ma, 460–422 Ma, and ca. 415–400 Ma [47,56].

The Late Paleozoic magmatic activities were mainly preserved in the northern margin of the NCC [58–60]. Based on the U-Pb ages obtained from the magmatic rocks, at least three stages of 507–460 Ma, 460–422 Ma, and ca. 415–400 Ma [47,56]. The Late Paleozoic magmatic activities were mainly preserved in the northern margin of the NCC [58–60]. Based on the U-Pb ages obtained from the magmatic rocks, at least three stages of 507–460 Ma, 460–422 Ma, and ca. 415–400 Ma [47,56]. Therefore, most scholars propose that the magmatic zircons of the Late Paleozoic era were initially derived from the northern margin of the NCC [8,9,17,63,64]. However, partly recycled Paleozoic strata on the southern margin of the NCC could also have resulted in these observed ages [3,65].

5.2. Provenance Analysis of the Early Triassic Strata

5.2.1. Provenances of the Liujiagou Formation

The Liujiagou Formation contains Neoarchean–Paleoproterozoic zircons (peaks at 1848 and ca. 2500 Ma), Neoproterozoic zircons (subordinate peaks at 872 and 957 Ma), Early Paleozoic zircons (major peaks at 458 and 425 Ma), and Late Paleozoic zircons (peak at 268 Ma). As mentioned above, prominent zircons with major peaks at 458 and 425 Ma together with Neoproterozoic subordinate peaks at 872 and 957 Ma are two typical indicators of NQOB sources. These Early Paleozoic and Neoproterozoic ages were absent from the Liujiagou Formation in the Pingquan area, as shown in Figure 9b, the Xiabancheng basin, as shown in Figure 9c, the Ningwu basin, as shown in Figure 9d, the Taiyuan Xishan area, as shown in Figure 9e, the Yan’an area, as shown in Figure 9f, and the Qinhui basin, as shown in Figure 9g, which were all located north of the Yiyang area. This finding implied that these ages were not derived from the northern margin of the NCC. Furthermore, paleocurrent analyses revealed that the average paleocurrent direction of the Liujiagou Formation in Western Henan was 317° [66], which provided important evidence that these grains were sourced from the NQOB in the south margin of the NCC.

The detritus that recorded 1848 and ca. 2500 Ma age peaks were thus most likely inherited from the basement of the southern NCC. Although a small number of these grains were preserved within the NQOB, they could not form these age peaks. In contrast, the small quantity of Late Paleozoic grains with age peaks at 268 Ma were generally interpreted to derive from the northern margin of the NCC [8,17,61,63]. However, in view of the sampling locations and the paleocurrent direction, Late Paleozoic recycled clastics from the southern margin of the NCC need to be considered, because they could also provide similar age populations that dominated the Neoarchean–Paleoproterozoic major peaks and minor Late Paleozoic subordinate peaks, as shown in Figure 9j.

Therefore, based on the above evidence, we suggest that the provenances of the Liujiagou Formation in the Yiyang area were predominantly derived from both the southern margin of the NCC and from the NQOB.
Figure 9. Zircon U-Pb age spectra of potential provenance areas and the comparison of previously published data from different basins within the North China Craton (NCC) during the Early Triassic period. Data sources: (a) Carboniferous–Triassic strata in regions of the Yanshan belt [64]; (b) Liujiagou Formation in the Pingquan area [62]; (c) Liujiagou Formation in the Xiabancheng basin [67]; (d) Liujiagou Formation in the Ningwu basin [68]; (e) Liujiagou Formation in the Xishan area, Taiyuan [69]; (f) Early Triassic strata in the Yan’ an area, Ordos basin [70]; (g) third section of the Shiqianfeng Formation in the Qinshui basin [8]; (h) Liujiagou and Heshanggou formations in the Jiyuan basin [71]; (i) this study; (j) southern margin of the North China Craton [9,72–77]; (k) North Qinling Orogenic Belt [53,56,78,79]. The diagrams are arranged geographically from north to south.
5.2.2. Provenances of the Heshanggou Formation

Detrital zircon spectra of the Heshanggou Formation showed a significant Early Paleozoic major peak at 445 Ma, alongside several Neoproterozoic weak peaks (947–755 Ma), which corresponded well to the typical provenances derived from the NQOB [53,55,56]. Furthermore, although the Paleozoic sedimentary cover of the southern margin of the NCC, as shown in Figure 9f, may have also supplied materials which initially derived from the NQOB to contribute to these peaks, it could be excluded because the sample spectra did not record the concurrent Late Paleozoic and Neoarchean–Paleoproterozoic populations. Moreover, the QFL diagrams indicated that the detritus of the Heshanggou Formation was mainly derived from the recycled collisional orogenic source, which was also consistent with the magmatic rocks of the NQOB formed by the collision along the Kuanping and Shangdan suture [47,56]. Therefore, we suggest that the NQOB was the primary unique provenance of the Heshanggou Formation in the Yiyang area. This interpretation is supported by the average paleocurrent direction (316°4′) of the Heshanggou Formation in Western Henan [66].

5.3. Constraints on the Paleogeographic and Tectonic Evolution

Available literature suggest that a walled continental basin was formed, and continuous strata were deposited within the NCC from Late Paleozoic to the Early-Middle Triassic eras, as evidenced by prototype basin reconstruction [10,11,13,18,80]. Starting from the late Carboniferous, strong tectonic uplifting occurred at the northern margin of the NCC, with crustal rocks at least 15 km thick being eroded [59,61,81]. Consequently, the topographic slope of the whole NCC reversed to south-dipping and the depocenter significantly migrated southward [8,21,80] in response to the tectonic setting of syn-orogenic compression [11,24,61]. Subsequently, the NQOB and southern margin of the NCC started the uplift probably during the Late Permian period, possibly driven by the compression related to the northward subduction of the South Qinling terrane and the Mianlue Oceanic crust [22,47,77,82–84]. This uplift was proven by the transformation of the paleocurrent, which changed from southward to northward during the Middle-Late Permian era [85], statistical analysis of detrital compositions, sedimentary facies analysis and stratigraphic unconformity [21], and detrital zircon U-Pb data in the southern NCC, which displayed prominent ages from the NQOB [9,77].

The detrital zircons in this study showed similar age characteristics to Late Permian in the Yiyang area [77], suggesting that the southern margin of the NCC and the NQOB was still characterized by shortening and elevation during the Early Triassic period. Additionally, the provenance of Jiyuan basin, which is located in north of the Yiyang area, transformed from the IMPU during the Late Permian to the NQOB during the Early Triassic [17,71]. It is reasonable to infer that the uplift trend of the NQOB along the southern margin of the NCC may have gradually been enhanced and supplied detritus, thus gradually migrating southward. However, according to the age data of the detrital zircons collected from different basins, as shown in Figure 9, we noted significant differences in the provenances between the northern and southern regions of the NCC. The northern-central part of the NCC, as shown in Figure 9a–g, exhibited similar age compositions, with an obvious age gap from ~1600 to 450 Ma in all of the Early Triassic sedimentary strata samples, indicating that they might possess the same provenances as the IMPU. In contrast, only the Jiyuan basin, as shown in Figure 9h, and the Yiyang area, as shown in Figure 9i, exhibited Neoproterozoic and Early Paleozoic detrital zircons, suggesting that the typical provenance distribution of the NQOB was limited by the southern part of the NCC and could only reach as far as the Jiyuan basin.

In summary, the results of the detrital zircon geochronology comparisons provided an indication that the paleogeography of the NCC during the Early Triassic period was strongly asymmetric, whereby the uplifted highland along the southern margin of the NCC was still relatively lower than the northern margin. Thus, although most of the regions accepted the provenance of the IMPU from the northern margin of the NCC, the NQOB served as the major provenance area for the southern margin of the NCC.

5.4. Conversion of the Source-To-Sink System
The data presented in this study showed significant differences regarding the source components of the Liujiagou and the Heshanggou formations, as shown in Figure 8. Detrital zircons of the Liujiagou Formation included multimodal populations with mixed provenances of both the southern margin of the NCC and the NQOB. In contrast, the Heshanggou Formation displayed a unimodal provenance from the NQOB. The proportion of sediments from the NQOB increased remarkably and the detritus derived from the NCC tended to disappear.

Liu and Zhang [21] proposed that the retro-arc foreland basin system formed between the NQOB and southern margin of the NCC from the Permian to Triassic periods, during which the former displayed the wedge-top depozone and the latter displayed the foredeep depozone. According to this model, the significant shift in sediment source area from the dual provenances to the single orogenic provenance was generally interpreted as the result of the intense uplift of the orogenic belt. Thus, the southern margin of the NCC produced flexural subsidence due to the increased orogenic loading and accumulated sediments from the orogenic belt at the foredeep depozone. However, the age characteristics of the detrital zircons from the Heshanggou Formation indicated the uplift of the NQOB was contrary to actual sedimentological evidence as follows: (1) No large volume of denudation corresponding to the uplift of the NQOB was observed. Field observations showed that the Liujiagou Formation was characterized by overfilled deposition, which was mainly composed of coarse-grained sandstones, whereas the Heshanggou Formation was characterized primarily by underfilled deposition, which was dominated by mudstones; (2) a lack of deep-water sedimentary records and the presence of interbedded boulder clays formed by the fluvial process and massive calcareous nodules that developed in mudstones, all indicated that the Heshanggou Formation featured shallow-water deposits; (3) no typical foredeep sedimentary features were observed. The isopachous map of the Early Triassic sedimentary strata indicated that the thickness increased toward the intracontinental basin, suggesting that the center of the subsidence was still in the inner part of the NCC during the Early Triassic period [86]. In addition, there were no event deposits, such as turbidite deposition linking to the orogenic activity in the Heshanggou Formation.

Therefore, we suggest a new model, describing that the southern margin of the NCC went through a transition from the denuded zone to the deposited zone in the Early Triassic period, probably corresponding to the intracontinental craton basin influenced by the NQOB, as shown in Figure 10. The depositional stage of the Liujiagou Formation was likely the period of orogenic growth and rapid erosion of the NQOB, as shown in Figure 10a. Affected by this intense orogenic compression, the southern margin of the NCC also generated the uplift and supplied a large amount of proximal sediments as the source. Thus, the coarse sediments that developed in the overfilled deposition were consistent with the provenance of both the southern margin of the NCC and the NQOB. During the depositional stage of the Heshanggou Formation, as shown in Figure 10b, the orogenic compression reduced, leading to the relative fallback of the southern margin of the NCC, allowing regional isostatic rebound to occur in the inner basin. As a result, the lake basin expanded gradually and intruded southward to form the highstand system tract. The deposited zone therefore extended to the southern margin of the NCC, where it was previously dominated by erosion and accepted the underfilled provenance of the NQOB. In conclusion, the sedimentary records in the Yiyang area provided a constraint for the transition from the denuded zone to the deposited zone along the southern margin of the NCC in the Early Triassic period, which controlled the evolution of the provenance and sedimentary system.
6. Conclusions

(1) The Liujiagou Formation contained multiple sources derived from the southern margin of the NCC and NQOB, as evidenced by the integrate detrital composition and zircon U-Pb data. The Heshanggou Formation displayed a predominantly unimodal provenance from the NQOB.

(2) The compared results of the detrital zircon geochronology indicated that the paleogeography of the NCC during the Early Triassic was strongly asymmetric, of which most of the regions accepted the provenance of the IMPU from the northern margin of the NCC. In contrast, the NQOB served as the major provenance area for the southern margin of the NCC.

(3) The sedimentary records in the Yiyang area provided a constraint for the transition from the denuded zone to the deposited zone along the southern margin of the NCC in the Early Triassic period, which controlled the evolution of the provenance and sedimentary system in the Liujiagou and Heshanggou formations.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Table S1: Detrital zircon LA-ICP-MS U-Pb isotopic data from the Lower Triassic sandstones in the Yiyang area.

Author Contributions: conceptualization, W.Y. and D.Z.; Formal analysis, Y.W.; Funding acquisition, W.Y.; Investigation, Y.W., S.P., and S.Q.; Project administration, D.Z.; Writing-original draft, Y.W.; Writing-review & editing, Y.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (No. 41702106).

Acknowledgments: The authors wish to thank the anonymous reviewers and editorial board for their constructive comments that significantly improved the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References
1. Liu, S.F.; Zhang, G.W. Fundamental ideas, contents and methods in study of basin and mountain relationships. *Earth Sci. Front.* 2005, 12, 101–111. (In Chinese)

2. Wu, L.L.; Mei, L.F.; Liu, Y.S.; Luo, J.; Min, C.Z.; Lu, S.L.; Li, M.H.; Guo, L.B. Multiple provenance of rift sediments in the composite basin-mountian system: Constraints from detrital zircon U-Pb geochronology and heavy minerals of the early Eocene Jiangnan Basin, central China. *Sediment. Geol.* 2017, 349, 46–61.

3. Zhou, W.Y.; Jiao, Y.Q.; Zhao, J.H. Sediment provenance of the intracontinental Ordos Basin in North China Craton controlled by tectonic evolution of the basin-orogen system. *J. Geol.* 2017, 125, 701–711.

4. Yang, W.T.; Wang, M.; Zheng, D.S.; Du, Y.S. Late Triassic sedimentary record from the Nanzhao Basin and implications for the orogeny in the Qinling Orogenic Belt, central China. *J. Asian Earth Sci.* 2018, 166, 120–135.

5. Cawood, P.A.; Hawkesworth, C.J.; Dhuime, B. Detrital zircon record and tectonic setting. *Geology* 2012, 40, 875–878.

6. Gehrels, G. Detrital zircon U-Pb geochronology applied to tectonics. *Annu. Rev. Earth Planet. Sci.* 2014, 42, 127–149.

7. Yang, W.T.; Yang, J.H.; Wang, X.F.; Du, Y.S. Uplift-denudation history of the Qinling orogen: Constrained from the detrital-zircon U-Pb geochronology. *J. Asian Earth Sci.* 2014, 89, 54–65.

8. Zhu, X.Q.; Zhu, W.B.; Ge, R.F.; Wang, X. Late Paleozoic provenance shift in the south-central North China Craton: Implications for tectonic evolution and crustal growth. *Gondwana Res.* 2014, 25, 383–400.

9. Yang, D.B.; Yang, H.T.; Shi, J.P.; Xu, W.L.; Wang, F. Sedimentary response to the paleogeographic and tectonic evolution of the southern North China Craton during the late Paleozoic and Mesozoic. *Gondwana Res.* 2017, 49, 278–295.

10. Liu, S.F.; Su, S.; Zhang, G.W. Early Mesozoic basin development in North China: Indications of cratonic deformation. *J. Asian Earth Sci.* 2013, 62, 221–236.

11. Liu, Y.Q.; Kuang, H.W.; Peng, N.; Xu, H.; Zhang, P.; Wang, N.S.; An, W. Mesozoic basins and associated palaeogeographic evolution in North China. *J. Palaeogeogr.* 2015, 4, 189–202.

12. Wang, Y.; Zhou, L.Y.; Liu, S.F.; Li, J.Y.; Yang, T.N. Post-kratoniization deformation processes and tectonic evolution of the North China Craton. *Earth-Sci. Rev.* 2018, 177, 320–365.

13. Meng, Q.R.; Wu, G.L.; Fan, L.G.; Wei, H.H. Tectonic evolution of early Mesozoic sedimentary basins in the North China block. *Earth-Sci. Rev.* 2019, 190, 416–439.

14. Pan, G.T.; Lu, S.N.; Xiao, Q.H.; Zhang, K.X.; Yin, F.G.; Hao, G.J.; Luo, M.S.; Ren, F.; Yuan, S.H. Division of tectonic stages and tectonic evolution in China. *Earth Sci. Front.* 2016, 23, 1–23. (In Chinese)

15. Li, S.Z.; Jahn, B.M.; Zhao, S.J.; Dai, L.M.; Li, X.Y.; Suo, Y.H.; Guo, L.L.; Wang, Y.M.; Liu, X.C.; Lan, H.Y.; et al. Triassic southeastward subduction of North China Block to South China Block: Insights from new geological, geophysical and geochemical data. *Earth-Sci. Rev.* 2017, 166, 270–285.

16. Zhao, Y.; Zhai, M.G.; Chen, H.; Zhang, S.H. Paleozoic–early Jurassic tectonic evolution of North China Craton and its adjacent orogenic belts. *Geol. China* 2017, 44, 44–60. (In Chinese)

17. Li, H.Y.; He, B.; Xu, Y.G.; Huang, X.L. U–Pb and Hf isotope analyses of detrital zircons from Late Paleozoic sediments: Insights into interactions of the North China Craton with surrounding plates. *J. Asian Earth Sci.* 2010, 39, 335–346.

18. Zhu, R.X.; Yang, J.H.; Wu, F.Y. Timing of destruction of the North China Craton. *Lithos* 2012, 149, 51–60.

19. Chen, S.Y. The basin-range coupling in southern North China block during the Late Palaeozoic to Triassic. *Sedimentary Geol. Tethyan Geol.* 2000, 20, 37–43. (In Chinese)

20. Chen, S.Y. Sedimentary-tectonic evolution from Late Palaeozoic to Triassic in the south of North China Block. *J. China Univ. Min. Technol.* 2000, 29, 536–540. (In Chinese)

21. Liu, S.F.; Zhang, G.W. Evolution and geodynamics of basin/mountain systems in East Qinling Dabieshan and its adjacent regions, China. *Geol. Bull. China* 2008, 27, 1943–1960. (In Chinese)

22. Dong, Y.P.; Santosh, M. Tectonic architecture and multiple orogeny of the Qinling Orogenic Belt, Central China. *Gondwana Res.* 2016, 29, 1–40.

23. Meng, X.H.; Zhang, Y.; Wang, D.Y.; Zhang, X. Provenance analysis of the Late Triassic Yichuan Basin: Constraints from zircon U-Pb geochronology. *Open Geosci.* 2018, 10, 34–44.

24. Wilde, S.A.; Zhou, J.B. The late Paleozoic to Mesozoic evolution of the eastern margin of the Central Asian Orogenic Belt in China. *J. Asian Earth Sci.* 2015, 113, 909–921.

25. Liu, Y.J.; Li, W.M.; Feng, Z.Q.; Wen, Q.B.; Neubauer, F.; Liang, C.Y. A review of the Paleozoic tectonics in the eastern part of Central Asian Orogenic Belt. *Gondwana Res.* 2017, 43, 123–148.
26. Dong, Y.P.; Liu, X.M.; Neubauer, F.; Zhang, G.W.; Tao, N.; Zhang, Y.G.; Zhang, X.N.; Li, W. Timing of Paleozoic amalgamation between the North China and South China Blocks: Evidence from detrital zircon U-Pb ages. *Tectonophysics* 2013, 586, 173–191.

27. Zhang, L.W.; Yao, J.X.; Niu, Y.B. The genesis of conglomerate in Lower Triassic Liujiaogou Formation of western Henan province. *Geol. Bull. China* 2017, 36, 1056–1063. (In Chinese)

28. Chu, D.L.; Tong, J.N.; Bottjer, D.J.; Song, H.J.; Song, H.Y.; Benton, M.J.; Tian, L.; Guo, W.W. Microbial mats in the terrestrial Lower Triassic of North China and implications for the Permian–Triassic mass extinction. *Palaeogeogr. Palaeoclim. Palaeoecol.* 2017, 474, 214–231.

29. Dickinson, W.R.; Suczek, C.A. Plate tectonics and sandstone compositions. *Am. Assoc. Pet. Geol. Bull.* 1979, 63, 2164–2182.

30. Dickinson, W.R. Interpreting provenance relations from detrital modes of sandstone. *Springer* 1985, 148, 333–361.

31. Bureau of geology and mineral resources of Henan province. *Regional Geology of Henan Province; Geological Publishing House: Beijing, China, 1989.* (In Chinese)

32. Liu, Y.S.; Hu, Z.C.; Gao, S.; Günther, D.; Xu, J.; Gao, C.G.; Chen, H.H. In situ analysis of major and trace elements of anhydrous minerals by LA-ICP-MS without applying an internal standard. *Chem. Geol.* 2008, 257, 34–43.

33. Ludwig, K.R. *ISOPLOT 3.00: A Geochronological Toolkit for Microsoft Excel; Berkeley Geochronology Center: Berkeley, CA, USA, 2003;* p. 39.

34. Sircombe, K.N. Tracing provenance through the isotope ages of littoral and sedimentary detrital zircon, eastern Australia. *Sediment. Geol.* 1999, 124, 47–67.

35. Hoskin, P.W.; Schaltegger, U. The composition of zircon and igneous and metamorphic petrogenesis. *Rev. Mineral. Geochem.* 2003, 53, 27–62.

36. Wu, Y.B.; Zheng, Y.F. Genesis of zircon and its constraints on interpretation of U-Pb age. *Chin. Sci. Bull.* 2004, 49, 1554–1569.

37. Zhai, M.G.; Santosh, M. The early Precambrian odyssey of North China Craton: A synoptic overview. *Gondwana Res.* 2011, 20, 6–25.

38. Wan, Y.S.; Dong, C.Y.; Liu, D.Y.; Kroner, A.; Yang, C.H.; Wang, W.; Du, L.L.; Xie, H.Q.; Ma, M.Z. Zircon ages and geochemistry of late Neoarchean syenogranites in the North China Craton: A review. *Precambr. Res.* 2012, 222, 265–289.

39. Zhao, G.C.; Zhai, M.G. Lithotectonic elements of Precambrian basement in the North China Craton: Review and tectonic implications. *Gondwana Res.* 2013, 23, 1207–1240.

40. Santosh, M.; Teng, X.M.; He, X.F.; Tang, L.; Yang, Q.Y. Discovery of Neoarchean suprasubduction zone ophiolite suite from Yishui Complex in the North China Craton. *Gondwana Res.* 2016, 38, 1–27.

41. Diwu, C.R.; Sun, Y.; Guo, A.L.; Wang, H.L.; Liu, X.M. Crustal growth in the North China Craton at ~2.5 Ga: Evidence from in situ zircon U-Pb ages, Hf isotopes and whole-rock geochemistry of the Dengfeng complex. *Gondwana Res.* 2011, 20, 149–170.

42. Diwu, C.R.; Sun, Y.; Wang, Q. The crustal growth and evolution of North China Craton: Revealed by Hf isotopes in detrital zircons from modern rivers. *Acta Petrol. Sin.* 2012, 28, 3520–3530.

43. Zhao, G.C.; Wilde, S.A.; Guo, J.H.; Cawood, P.A.; Sun, M.; Li, X.P. Single zircon grains record two continental collisional events in the North China craton. *Precambr. Res.* 2010, 177, 266–276.

44. Zhao, G.C.; Cawood, P.A.; Li, S.Z.; Wilde, S.A.; Sun, M.; Zhang, J.; He, Y.H.; Yin, C.Q. Amalgamation of the North China Craton: Key issues and discussion. *Precambr. Res.* 2012, 222, 55–76.

45. Yang, Q.Y.; Santosh, M. Paleoproterozoic arc magmatism in the North China Craton: No Siderian global plate tectonic shutdown. *Gondwana Res.* 2015, 28, 82–105.

46. Yang, Q.Y.; Santosh, M. Charnockite magmatism during a transitional phase: Implications for Late Paleoproterozoic ridge subduction in the North China Craton. *Precambr. Res.* 2015, 261, 188–216.

47. Wang, X.X.; Wang, T.; Zhang, C.L. Neoproterozoic, Paleozoic, and Mesozoic granitoid magmatism in the Qinling Orogen, China: Constraints on orogenic process. *J. Asian Earth Sci.* 2013, 72, 129–151.

48. Dong, Y.P.; Yang, Z.; Liu, X.M.; Zhang, X.N.; He, D.F.; Li, W.; Zhang, F.F.; Sun, S.S.; Zhang, H.F.; Zhang, G.W. Neoproterozoic amalgamation of the Northern Qinling terrain to the North China Craton: Constraints from geochronology and geochemistry of the Kuanping ophiolite. *Precambr. Res.* 2014, 255, 77–95.
49. Dong, Y.P.; Zhang, X.N.; Liu, X.M.; Li, W.; Chen, Q.; Zhang, G.W.; Zhang, H.F.; Yang, Z.; Sun, S.S.; Zhang, F.F. Propagation tectonics and multiple accretionary processes of the Qinling Orogen. *J. Asian Earth Sci.* 2015, 104, 84–98.

50. Liu, R.Y.; Niu, B.G.; He, Z.J.; Ren, J.S. LA-ICP-MS zircon U-Pb geochronology of the eastern part of the Xiaomaoling composite intrusives in Zhashui area, Shansuxi, China. *Geol. Bull. China* 2011, 30, 448–460.

51. Zhang, R.Y.; Sun, Y.; Zhang, X.; Ao, W.H.; Santosh, M. Neoproterozoic magmatic events in the South Qinling Belt, China: Implications for amalgamation and breakup of the Rodinia supercontinent. *Geonova Res.* 2016, 30, 6–23.

52. Zhao, S.J.; Li, S.Z.; Liu, X.; Santosh, M.; Somerville, I.D.; Cao, H.H.; Yu, S.; Zhang, Z.; Guo, L.L. The northern boundary of the Proto-Tethys Ocean: Constraints from structural analysis and U-Pb zircon geochronology of the North Qinling Terrane. *J. Asian Earth Sci.* 2015, 113, 560–574.

53. Shi, Y.; Yu, J.H.; Santosh, M. Tectonic evolution of the Qinling orogenic belt, Central China: New evidence from geochemical, zircon U-Pb geochronology and Hf isotopes. *Precambr. Res.* 2013, 231, 19–60.

54. Diwu, C.R.; Sun, Y.; Zhao, Y.; Liu, B.X.; Lai, S.C. Geochronological, geochemical, and Nd-Hf isotopic studies of the Qinling Complex, central China: Implications for the evolutionary history of the North Qinling Oroganic Belt. *Geosci. Front.* 2014, 5, 499–513.

55. Liao, X.Y.; Wang, Y.W.; Liu, L.; Wang, C.; Santosh, M. Detrital zircon U-Pb and Hf isotopic data from the Liuling Group in the South Qinling belt: Provenance and tectonic implications. *J. Asian Earth Sci.* 2017, 134, 244–261.

56. Zhang, C.L.; Liu, L.; Wang, T.; Wang, X.X.; Li, L.; Gong, Q.F.; Li, X.F. Granitic magmatism related to early Paleozoic continental collision in North Qinling. *Chin. Sci. Bull.* 2013, 58, 4405–4410.

57. Dong, Y.P.; Zhang, G.W.; Neubauer, F.; Liu, X.M.; Genser, J.; Hauzenberger, C. Tectonic evolution of the Qinling orogen, China: Review and synthesis. *J. Asian Earth Sci.* 2011, 41, 213–237.

58. Zhang, S.H.; Zhao, Y.; Song, B.; Yang, Y.H. Zircon SHRIMP U-Pb and in-situ Lu-Hf isotope analyses of a tuff from western Beijing: Evidence for missing late Paleozoic arc volcano eruptions at the northern margin of the North China block. *Geonova Res.* 2007, 12, 157–165.

59. Zhang, S.H.; Zhao, Y.; Song, B.; Hu, J.M.; Liu, S.W.; Yang, Y.H.; Chen, F.K.; Liu, X.M.; Liu, J. Contrasting Late Carboniferous and Late Permian-Middle Triassic intrusive suites from the northern margin of the North China craton: Geochronology, petrogenesis and tectonic implications. *Geol. Soc. Am. Bull.* 2009, 121, 181–200.

60. Zhang, S.H.; Zhao, Y.; Liu, J.M.; Hu, Z.C. Different sources involved in generation of continental arc volcanism: The Carboniferous-Permian volcanic rocks in the northern margin of the North China block. *Lithos* 2016, 240, 382–401.

61. Zhang, S.H.; Zhao, Y.; Liu, J.M.; Hu, J.M.; Song, B.; Liu, J.; Wu, H. Geochronology, geochemistry and tectonic setting of the Late Paleozoic-Early Mesozoic magmatism in the northern margin of the North China Block: A preliminary review. *Acta Petrol. Et Mineral.* 2010, 29, 824–842. (In Chinese)

62. Ma, S.X.; Meng, Q.R.; Duan, L.; Wu, G.L. Reconstructing Late Paleozoic exhumation history of the Inner Mongolia Highland along the northern edge of the North China Craton. *J. Asian Earth Sci.* 2014, 87, 89–101.

63. Yang, J.H.; Wu, F.Y.; Shao, J.A.; Wilde, S.A.; Xie, L.W.; Liu, S.M. Constraints on the timing of uplift of the Yanshan Fold and Thrust Belt, North China. *Earth Planet. Sci. Lett.* 2006, 246, 336–352.

64. Cope, T. Phanerozoic magmatic tempos of North China. *Earth Planet. Sci. Lett.* 2017, 468, 1–10.

65. Xie, X.Y. Provenance and sediment dispersal of the Triassic Yanchang Formation, southwest Ordos Basin, China, and its implications. *Sediment. Geol.* 2016, 335, 1–16.

66. Xie, D.N. Tectono-sedimentary evolution since the Late Paleozoic and natural gas formation in the southern North-China Basin. Ph.D. Thesis, Northwest University, Xian, China, 2007. (In Chinese)

67. Meng, Q.R.; Wei, H.H.; Wu, G.L.; Duan, L. Early Mesozoic tectonic settings of the northern North China craton. *Tectonophysics* 2014, 611, 155–166.

68. Zhou, R.; Liu, D.N.; Zhou, A.C.; Zou, Y. Provenance analyses of early Mesozoic sediments in the Ningwu basin: Implications for the tectonic-paleogeographic evolution of the northcentral North China Craton. *Int. Geol. Rev.* 2019, 61, 86–108.

69. Liu, C.; Sun, B.L.; Zeng, F.G. Constraints on U-Pb dating of detrital zircon of the maximum depositional age for Upper Permian to Lower Triassic strata in Xishan, Taiyuan. *Acta Geol. Sin.* 2014, 88, 1579–1587. (In Chinese)
70. Bao, C.; Chen, Y.L.; Li, D.P.; Wang, S.H. Provenances of the Mesozoic sediments in the Ordos Basin and implications for collision between the North China Craton (NCC) and the South China Craton (SCC). J. Asian Earth Sci. 2014, 96, 296–307.
71. Peng, S.Y.; Yang, W.T.; Wang, Y.P.; Zhong, C.C. Detrital zircon Chronology of the Lower-Middle Triassic strata in Jiyuan Area and its implication for provenance analysis. Geol. Sci. Technol. Inf. 2019, 38, 126–137. (In Chinese)
72. Zhao, T.P.; Zhai, M.G.; Xia, B.; Li, H.M.; Zhang, Y.X.; Wan, Y.S. Zircon U–Pb SHRIMP dating for the volcanic rocks of the Xiong’er Group: Constraints on the initial formation age of the cover of the North China Craton. Chin. Sci. Bull. 2004, 49, 2495–2502.
73. Zheng, J.P.; Griffin, W.L.; O’Reilly, S.Y.; Lu, F.X.; Wang, C.Y.; Zhang, M.; Wang, F.Z.; Li, H.M. 3.6 Ga lower crust in central China: New evidence on the assembly of the North China craton. Geology 2004, 32, 229–232.
74. Xu, X.S.; Griffin, W.L.; Ma, X.; O’Reilly, S.Y.; He, Z.Y.; Zhang, C.L. The Taihuia group on the southern margin of the North China craton: Further insights from U–Pb ages and Hf isotope compositions of zircons. Mineral. Petrol. 2009, 97, 43–59.
75. Cui, M.L.; Zhang, B.L.; Zhang, L.C. U–Pb dating of baddeleyite and zircon from the Shizhaigou diorite in the southern margin of North China Craton: Constrains on the timing and tectonic setting of the Paleoproterozoic Xiong’er group. Gondwana Res. 2011, 20, 184–193.
76. Zhou, Y.Y.; Zhao, T.P.; Wang, C.Y.; Hu, G.H. Geochronology and geochemistry of 2.5 to 2.4 Ga granitic plutons from the southern margin of the North China Craton: Implications for a tectonic transition from arc to post-collisional setting. Gondwana Res. 2011, 20, 171–183.
77. Wang, Y.P.; Yang, W.T.; Zheng, D.S.; Zuo, P.F.; Qi, S.S. Detrital zircon U–Pb ages from the Middle to Late Permian strata of the Yiyang area, southern North China Craton: Implications for the Mianlue oceanic crust subduction. Geol. J. 2019, 54, 3527–3541.
78. Zhu, X.; Chen, F.K.; Li, S.Q.; Yang, Y.Z.; Nie, H.; Siebel, W.G.; Zhai, M.G. Crustal evolution of the North Qinling terrain of the Qinling Orogen, China: Evidence from detrital zircon U–Pb ages and Hf isotopic composition. Gondwana Res. 2011, 20, 194–204.
79. Cao, H.H.; Li, S.Z.; Zhao, S.J.; Yu, S.; Li, X.B.; Somerville, I.D. Detrital zircon geochronology of Neoproterozoic to early Paleozoic sedimentary rocks in the North Qinling Orogenic Belt: Implications for the tectonic evolution of the Kuanping Ocean. Precamb. Res. 2016, 279, 1–16.
80. Wang, Q.F.; Deng, J.; Liu, X.F.; Cai, S.H. Provenance of Late Carboniferous bauxite deposits in the North China Craton: New constraints on marginal arc construction and accretion processes. Gondwana Res. 2016, 38, 86–98.
81. Zhang, S.H.; Zhao, Y.; Song, B. Hornblende thermobarometry of the Carboniferous granitoids from the Inner Mongolia Paleo-uplift: Implications for the tectonic evolution of the northern margin of North China block. Mineral. Petrol. 2006, 87, 123–141.
82. Deng, Z.B.; Liu, S.W.; Zhang, W.Y.; Hu, F.Y.; Li, Q.G. Petrogenesis of the Guangtoushan Granitoid Suite, Central China: Implications for Early Mesozoic geodynamic evolution of the Qinling Orogenic Belt. Gondwana Res. 2016, 30, 112–131.
83. Zhou, Z.J.; Mao, S.D.; Chen, Y.J.; Santosh, M. U–Pb ages and Lu–Hf isotopes of detrital zircons from the southern Qinling Orogen: Implications for Precambrian to Phanerozoic tectonics in central China. Gondwana Res. 2016, 35, 323–337.
84. Wang, M.; Guo, W.F.; Yang, W.T. Detrital zircon trace elements from the Mesozoic Jiyuan Basin, central China and its implication on tectonic transition of the Qinling Orogenic Belt. Open Geosci. 2019, 11, 125–139.
85. Zheng, C.; Li, B.F.; Wen, X.D. Depositional characteristics of the late Permian braided channel-braided delta deposits in northern foothills of the Qinling Mountains, China. Geosciences 2003, 17, 415–420. (In Chinese)
86. Yang, W.T.; Wang, M.; Du, Y.S. The Depositional characteristics from Mesozoic Jiyuan Basin with its response to the uplift of Qinling Orogen and Thailang Mountains. Geol. Rev. 2014, 60, 260–274. (In Chinese) © 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).