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Detrital Zircon U-Pb Age Analysis of Late Pliocene Deposits from the Lower Yangtze River, South China: Implications for Sedimentary Provenance and Evolution of the Yangtze River

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ABSTRACT: The Yangtze River, with a length of approximately 6 300 km, holds the distinction of being the largest river in East Asia that empties into the Pacific Ocean. Its formation is intricately linked to regional tectonic activity and climate fluctuations. However, the exact timeline for the formation of the Yangtze River remains elusive. This study investigates the provenance of the Late Cenozoic strata in the Wangjiang Basin, situated in the Lower Yangtze River, through the application of detrital zircon U-Pb dating. Seven sand samples were analyzed, leading to the identification of new U-Pb detrital zircon ages (n = 577). Our study reveals that the sand materials found in the Pliocene gravel beds of the Anqing Formation originate predominantly from the Yangtze River. The findings of our study, along with the provenance tracing of boreholes in the Yangtze River Basin and the shelf sea in East China, provide compelling evidence for the continuous presence of the Yangtze River throughout the Pliocene period. The development of the Yangtze River during the Pliocene is intricately connected to both the tectonic adjustments occurring at the southeastern margin of the Tibetan Plateau and the intensification of the Asian Monsoon.
KEY WORDS: Yangtze River, Wangjiang Basin, Pliocene, Tibetan Plateau, Asian Monsoon, climate change.

0 INTRODUCTION

The formation of fluvial systems is a multifaceted process that is influenced by various geologic and climatic factors (Lin et al., 2024a; Burbank and Anderson, 2013; Li et al., 2001; Potter, 1978). Consequently, it is possible to establish a more accurate timeline for tectonic activity and climate change in the region by precisely determining the initiation of river systems (Lin et al., 2024b; Jolivet et al., 2021; Bentley et al., 2016; Latrubesse et al., 2010; Liu-Zeng et al., 2008). Specifically, studies on the chronology of the formation of large rivers spanning continents, like the Yangtze River connecting the Tibetan Plateau and the Pacific Ocean, provide valuable insights into the emergence of geomorphic patterns in East Asia (Zheng et al., 2013; Yang et al., 2009; Clark et al., 2004; Wang, 2004) as well as the evolution of the Asian Monsoon (Tian et al., 2025; Wan et al., 2012; Clift et al., 2008a).

The investigation into the timing of the formation of the Yangtze River has been ongoing for nearly a century (Willis et al., 1907). Nevertheless, the exact timing of the origin of the Yangtze River has been a matter of debate due to the extensive size of the Yangtze River Basin and the complex tectonic activities taking place within it. These debates predominantly emerge in three key research areas pertaining to the Yangtze River: the first bend of Shigu Town in the Upper Yangtze River, the Three Gorges in the Middle Yangtze River, and the delta in the Lower Yangtze River (Figure 1A). Based on zircon

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U-Pb dating results for provenance tracing (Feng et al., 2021; Zheng et al., 2021; Chen et al., 2017; Yan et al., 2012), heavy mineral analysis (He et al., 2021), and K-feldspar Pb isotopic compositions (Zhang Z J et al., 2017; Clift et al., 2008b), researchers have proposed that the Upper Yangtze River separated from the paleo-Red River system and began flowing eastward between 36 and 23 Ma (Figure 1a). However, alternative studies have suggested different timings for this event, proposing that it occurred during the Miocene (18–9 Ma, McPhillips et al., 2016), Pliocene (Zhao et al., 2021), or Early Pleistocene (1.5–1.3 Ma; Deng et al., 2021; Kong et al., 2012, 2009). The Three Gorges region serves as a crucial link between the upper and middle reaches of the Yangtze River (Lin et al., 2023a; Li et al., 2001; Figure 1a). Geologically, the Yangtze River cut through the Three Gorges during different time periods: 40 Ma (Richardson et al., 2010), 18 Ma (Jiao et al., 2021), and 3.6–3.4 Ma (Li et al., 2001). Provenance tracing, conducted through the utilization of borehole samples and surface sediments from the Jianghan Basin, indicates that Yangtze River material started to appear at specific time points: 23 Ma (Yang C Q et al., 2019; Wang P et al., 2014), 3.4–1.7 Ma (Li Y W et al., 2021; Zhang et al., 2016; Shao et al., 2012), and 1.2–0.7 Ma (Kang et al., 2021; Wei et al., 2020; Zhang et al., 2008; Xiang et al., 2007), respectively. The detrital zircon U-Pb dating of gravel beds in the vicinity of the Yangtze Estuary provides evidence that the formation of the Yangtze River occurred within the time range of 23–10 Ma (Wang et al., 2022; Zheng et al., 2013). However, detrital K-feldspar and muscovite geochemical dating studies indicate that the formation time of the Lower Yangtze River is unlikely to be no earlier than 10 Ma (Sun X L et al., 2021; Zhang Z J et al., 2021). Provenance tracing, conducted through the analysis of boreholes in the Yangtze River Delta, indicates that the formation of the Yangtze River occurred in two distinct phases: 3.2–2.6 Ma (Yu et al., 2020; Jia et al., 2010) and 1.2–1.1 Ma (Liu X B et al., 2018; Yue et al., 2018; Chen et al., 2009; Yang et al., 2006). The variations in the results of these studies arise from disparities in the methodologies and locations utilized by the researchers. Consequently, the exact timing of the formation of the Yangtze River still remains unclear.

Based on extensive research and hypotheses related to the source-to-sink framework, scholars have discovered that the sedimentary strata in the Lower Yangtze River provide detailed information about the origin and geological history of the upper and middle reaches of the river (Hao et al., 2023; Wang et al., 2022; Zhang Z J et al., 2021; Zheng et al., 2013). Consequently, these sedimentary records provide valuable insights into the evolutionary history of the entire Yangtze River Basin (Lin et al., 2023b). The detrital zircon U-Pb age dating method has been extensively employed in studying the developmental history of continental rivers, including the Nile (Morag et al., 2021), Amazon (Mapes, 2009), Mississippi (Craddock and Kylander-Clark, 2013), Yellow (Lin et al., 2022a, b; Nie et al., 2015), and Yangtze rivers (Wang et al., 2018; Zheng et al., 2013; Yang et al., 2012). Several studies have reported an abundance of detrital zircon U-Pb data regarding the Yangtze River Basin (Lin et al., 2022c; Liang et al., 2018; He et al., 2013). These data sets offer a valuable foundation for comparison and aid in the determination of provenance. Therefore, we conducted a U-Pb age analysis of detrital zircons in the Late Cenozoic sedimentary basin of the Lower Yangtze River. This analysis incorporated published paleomagnetic (Yu and Huang, 1996) and paleontological data (Wang P et al., 2014; Zhang et al., 2004; RAB, 1988) to assess the timing of deposition for detrital sediments from the Upper and Middle Yangtze River regions in the Lower Yangtze River area. Furthermore, we engage in a systematic discussion regarding the formation age of the Yangtze River based on the published findings in the region. The purpose of this study is to improve our understanding of the relationship between tectonic activity and climate change in the East Asia region.

1 GEOLOGICAL AND GEOMORPHIC SETTINGS

1.1 Yangtze River

The Yangtze River is the largest river in the East Asia, stretching approximately 6 300 km in length. It originates from the eastern Tibetan Plateau (Figure 1a), traverses through the Sichuan Basin and Jianghan Basin, and eventually empties into the East China Sea (Pacific Ocean). The upper reaches of the Yangtze River extend up to Yichang City, while the middle reaches of the river are situated between Yichang City and Hukou City (Figure 1a). The lower reaches of the Yangtze River are located to the east of Hukou City.

During the Mesozoic, South China exhibited a topography characterized by high elevation in the east and low elevation in the west (Wang, 2004). However, the subduction of the Indian Plate beneath the Eurasian Continent in the Cenozoic resulted in the uplift of the Tibetan Plateau (Liu-Zeng et al., 2008). Importantly, this topographic transformation played a crucial role in establishing the geomorphic framework that facilitated the flow of the Yangtze River from west to east (Lin et al., 2023c). The Yangtze River Basin extends between latitudes N25° and N34°. This region is primarily influenced by the South Asian and East Asian monsoons, contributing to its subtropical monsoon climate (Molnar, 2005). The origin of these monsoons can be traced back to the Neogene Period, as supported by studies conducted by Clift et al. (2008a), Guo et al. (2002), and An (2000). The development of the Yangtze River is intricately linked to both tectonic activities and climate changes occurring in East Asia (Lin et al., 2024a; Wang et al., 2022).

1.2 Wangjiang Basin

The Wangjiang Basin is situated in the lower reach of the Yangtze River (Figure 1b). It spans approximately 100 km in length and 30 km in width, covering a total area of about 4 176 km^2 (Xu et al., 2018; Figure 2a). During the Mesozoic and Early Cenozoic periods, the Wangjiang

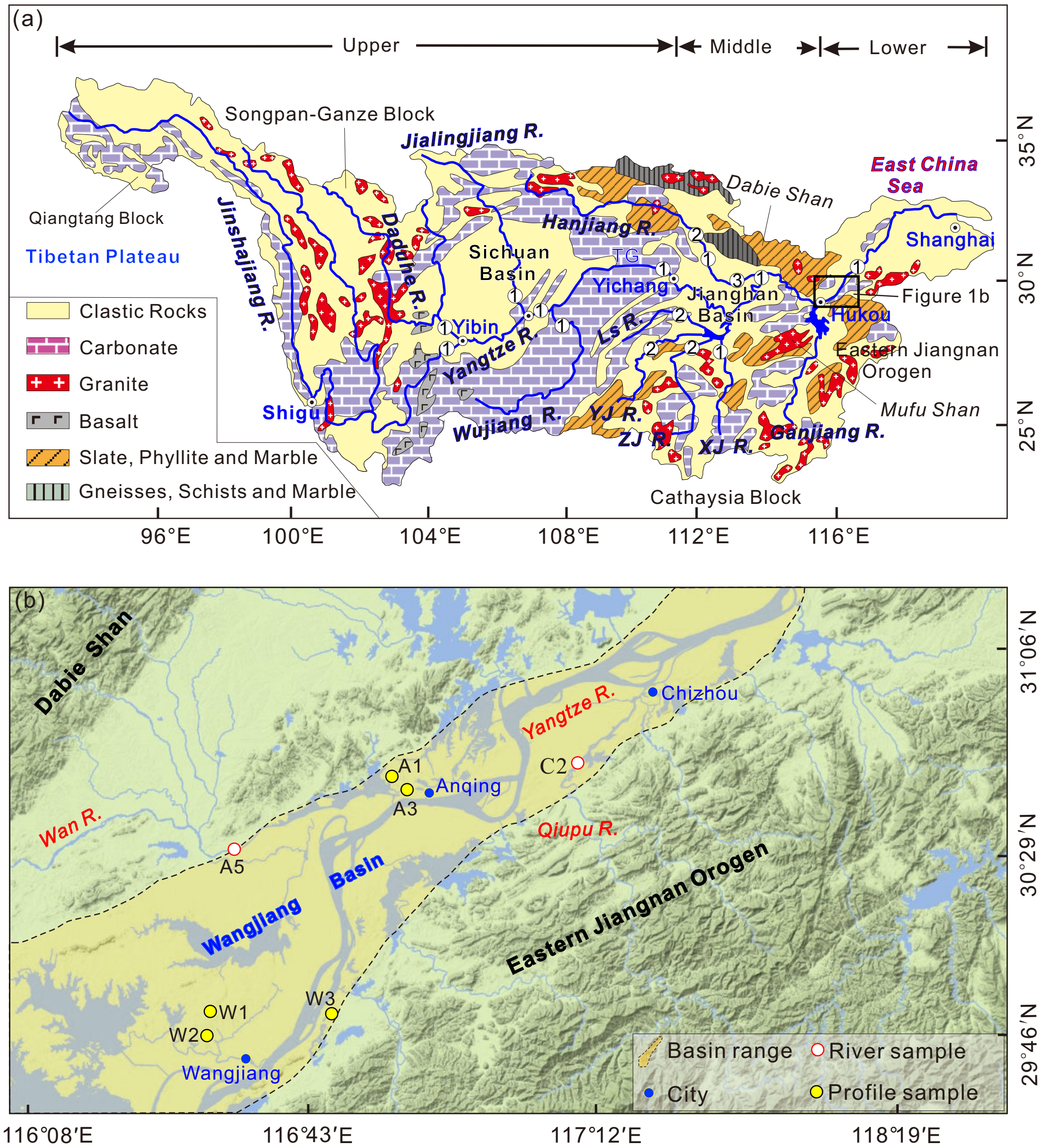

Figure 1. (a) The geological map of the Yangtze River Basin has been adapted from the work of Wei et al. (2020). Numbers represent results from the literature: 1. He et al. (2013); 2. Lin et al. (2022c); 3. Liang et al. (2018); 4. Li X C et al. (2016). (b) Location distribution map of Wangjiang Basin. Abbreviation: TG. Three Gorges; Ls R. Lishui River; YJ R. Yuanjiang River; ZJ R. Zijiang River; XJ R. Xijiang River; R. river.

Basin underwent extensional rifting (Xu et al., 2021, Figure 2b). The subsidence rate of the basin notably increased during this period, leading to the deposition of molasse from the Wanghudun (E_1*w*) and Doumu (E_1*d*) formations. These deposits originated from the piedmont of Dabie Shan and Eastern Jiangnan Orogen (RAB, 1988). Following the Eocene, the fault-depression filling of the Wangjiang Basin ceased, marking the onset of the decline stage wherein the dominant sedimentary units were the Pliocene Anqing Formation, along with fluvial and aeolian deposits from the Pleistocene Qijiaji and Xiashu formations (RAB, 1988). A notable unconformity is evident between the Anqing Formation and the underlying stratum, primarily attributed to the tectonic uplift (RAB, 1988).

1.3 Pliocene Gravel Beds in the Lower Yangtze River

During the Late Cenozoic, substantial fluvial sediments have accumulated along the Lower Yangtze River, with notable exposed sections in the cities of Wangjiang, Anqing, Tongling, and Nanjing, progressing from west to east (Figure 2a). Paleomagnetic dating of gravel beds in Huoshan, Xuancheng, Tongling, and Anqing cities (Yu and Huang, 1996; He, 1994), along with the presence of mammal (*Prosiphneus sp.*, RAB, 1988) and plant fossils (RAB, 1988), indicates that the deposition of the Anqing Formation occurred between 3.4 and 2.48 Ma (Figures 3a–3d). When compared to the Anqing Formation gravel beds in the Tongling and Anqing cities, the sedimentary age of Wangjiang gravel beds is exclusively constrained to the Pliocene (Yang Z L et al., 2019; RAB, 1988; Figure 3e). Since the Late Cenozoic, the Nanjing area has witnessed the accumulation of several formations. These in-

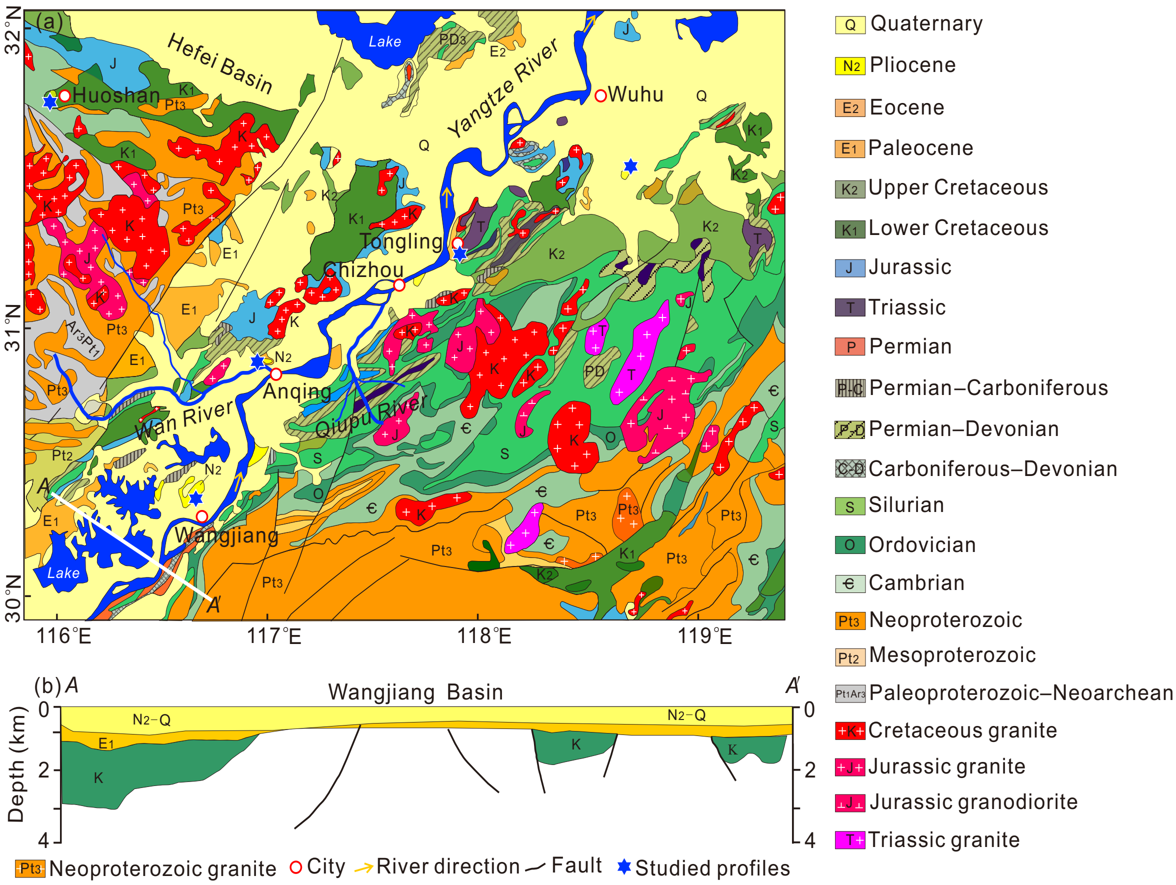

Figure 2. (a) Geological map of the study area, modified from 1 : 1 500 000 geological map (Yang et al., 2019b), *a–a'* presents the cross section. (b) Cross section of Wangjiang Basin (modified from Xu et al., 2021).

clude the Dongxuanguan Formation of the Lower Miocene (N_1), the Liuhe Formation (N_1), the Huanggang Formation (N_1) of the Upper Miocene, and the Yuhuatai Formation of the Pliocene (N_2) (Han et al., 2009; Zhang et al., 2004). The $^{40}Ar/^{39}Ar$ dating of the overlying basalt in the gravel strata provides evidence that the Dongxuanguan Formation (N_1), Liuhe Formation (N_1), and Huanggang Formation (N_1) occurred between 23 and 10 Ma (Wang et al., 2022; Yang et al., 2018; Zheng et al., 2013; Figure 3f). The paleomagnetic dating and analysis of paleontological fossils provide evidence that the Yuhuatai Formation near the Nanjing area was deposited approximately 3.5–3.0 Ma (Wang W M et al., 2014; Han et al., 2009; Zhang et al., 2003; He, 1994; Figure 3g). In general, the Pliocene gravel beds are widely distributed in the lower reaches of the Yangtze River.

2 SAMPLING AND METHOD

2.1 Sampling Strategy

The Anqing Formation in the Wangjiang Section has a total thickness ranging from 15 to 30 m and predominantly consists of gravels with a diameter of 4–8 cm (Figure 1b; Figure 4a). These gravels are primarily round or sub-round in shape and exhibit distinctive orientation patterns (Figure 4b). Moreover, the flat surfaces of the gravels tend to have a westward inclination, indicating the direction of paleocurrent flows from west to east (Figures 4c, 4d). The gravel deposits mainly comprise quartzite, chert, and quartz sandstone, with smaller proportions of volcanic rock and limestone. In the lower portion of the Anqing Formation, there is a presence of orangish-yellow gravel with a sandy lens and the mammal fossil *Prosiphneus sp*. (RAB, 1988; Figure 4e). The middle and upper sections of the formation consist of light-yellow fine sand with cross-bedding features (Figure 4f). Notably, the Anqing Formation displays unconformities both with the underlying Paleocene strata and the overlying Pleistocene strata.

The focus of our study was on the Wangjiang and Anqing sections, which are situated within the Wangjiang Basin (Figure 1b). We collected a total of five samples from the sand layers of the Anqing Formation at both the Wangjiang and Anqing sections. Additionally, two modern fluvial detrital samples were collected from the Wan River, located on the southeastern margin of Dabie Shan, and the Qiupu River, situated on the northern margin of the Eastern Jiangnan Orogen (Figure 1b). Each sample, weighing 3–5 kg, was collected specifically for the purpose of detrital zircon selection. Furthermore, we compiled published detrital zircon U-Pb ages from the Yangtze and Ganjiang rivers within the region (Table 1). We also obtained bedrock and modern river zircon U-Pb ages from Dabie Shan, Eastern Jiangnan Orogen, and Mufu Shan to facilitate a comparative analysis of potential prov-

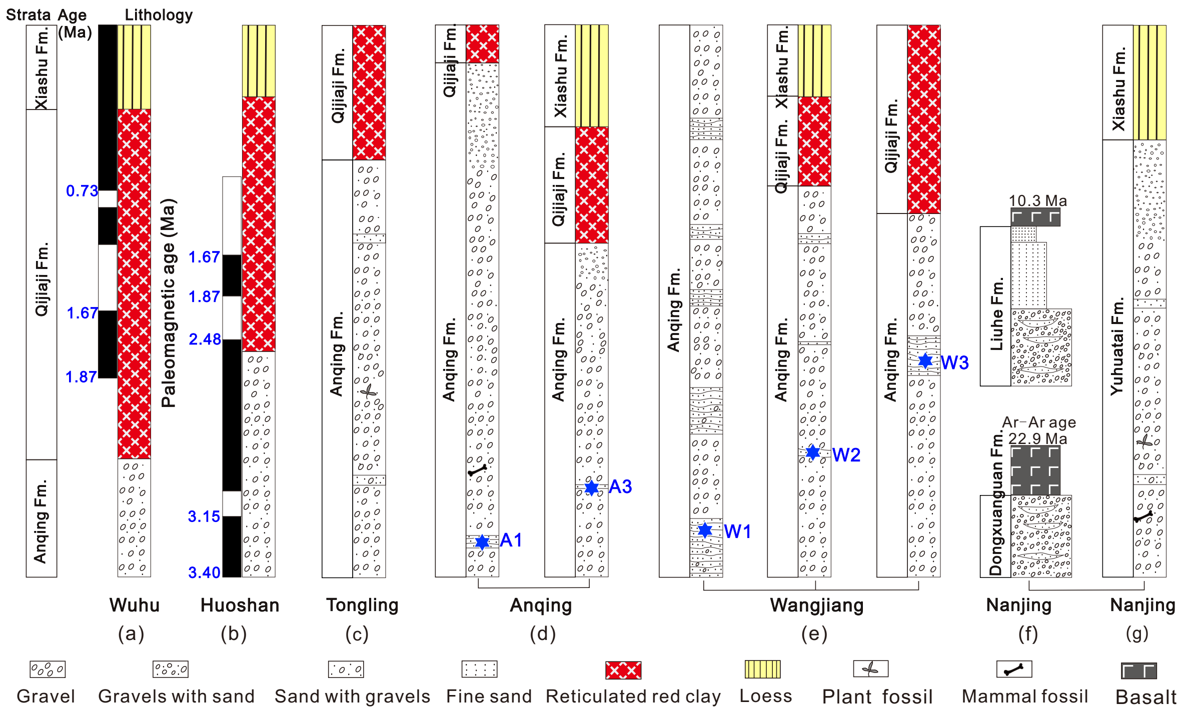

Figure 3. Neogene stratigraphic units in the lower reaches of the Yangtze River. Magnetostratigraphic age of the (a) Wuhu and (b) Huoshan sections are cited from Yu and Huang (1996). (c) Tongling Section (RAB, 1988); (d) Anqing Section; (e) Wangjiang Section; (f) Nanjing Section (Wang et al., 2022; Zheng et al., 2013); (g) Nanjing Section (Zhang et al., 2004). The blue hexagon denotes the location of the detrital zircon sample. Fm. Formation.

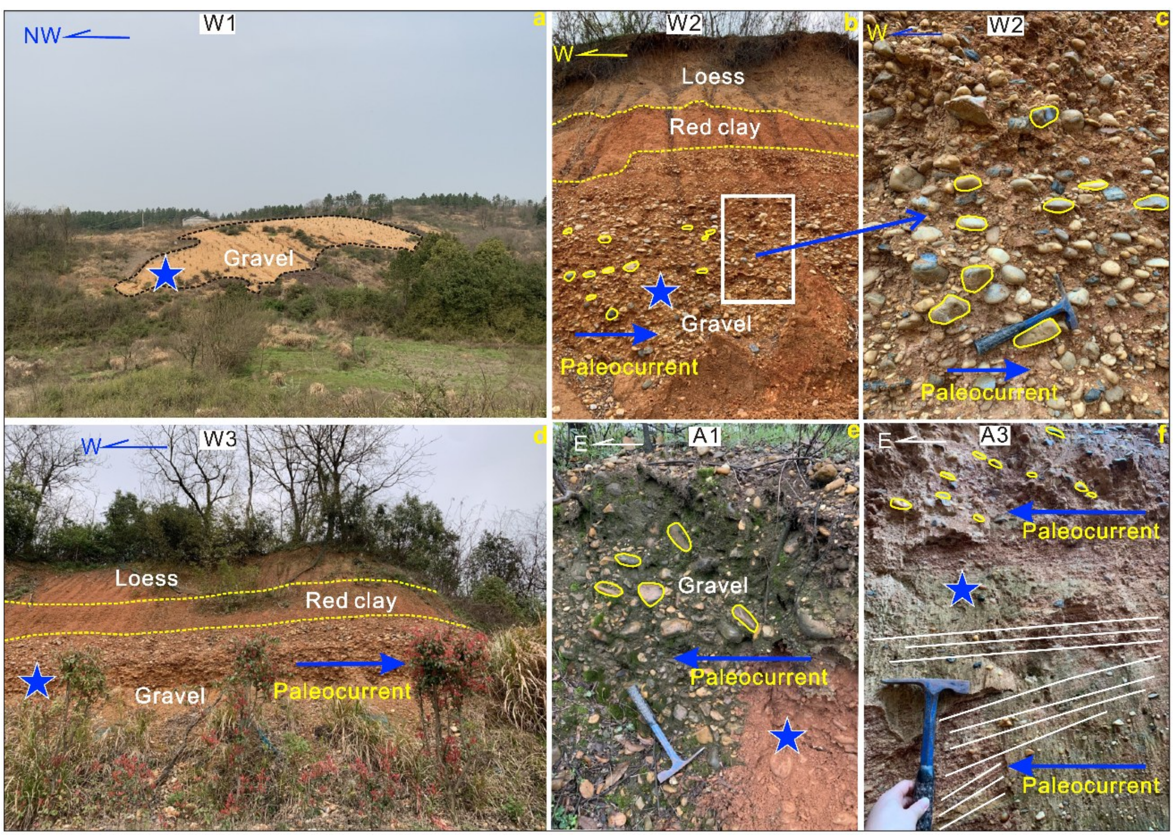

Figure 4. Field photos of Anqing Formation in Wangjiang Section (a)–(d) and Anqing Section (e)–(f), palaeocurrents indicate the rivers flowing from west to east. The pentacle represents sampling locations.

Table 1 Sample locations and published zircon U-Pb age data

Sample No.	Sample location		Nature of sample	Data source
	Longitude (E)	Latitude (N)		
Wangjiang (W1)	116°42′0.36″	30°9′23.76″	Pliocene sands	This study
Wangjiang (W2)	116°40′33.15″	30°8′46.59″	Pliocene sands	
Wangjiang (W3)	116°54′41.40″	30°14′3.48″	Pliocene sands	
Anqing (A1)	117°0′34.92″	30°15′9.11″	Pliocene sands	
Ainging (A3)	117°0′37.08″	30°32′9.24″	Pliocene sands	
Wan River (A5)	116°40′31.70″	30°24′43.92″	Modern river	
Qiupu River (C2)	117°18′52.20″	30°31′19.92″	Modern river	
Dabie Shan			Bedrock/modern river	Lin et al. (2022c), Li W T et al. (2021)
Eastern Jiangnan Orogen			Bedrock	Wu et al. (2012), Zheng et al. (2008)
Mufu Shan			Bedrock/modern river	Lin et al. (2022c), Xin et al. (2017), Li J H et al. (2016), He et al. (2013), Lin et al. (2000)
Yangtze River			Modern river	Lin et al. (2022c), Liang et al. (2018), He et al. (2013)
Ganjiang River			Modern river	Li X C et al. (2016), He et al. (2013)

enance areas. Detailed information regarding the sampling locations and data sources is provided in Table 1.

2.2 Analytical Methods

Zircon grains were separated from the sediments using standard mineral separation techniques, which involved heavy liquids, magnetic separation, and hand picking concentrates. Subsequently, approximately 200 grains were randomly selected from each sample and mounted in epoxy within 1-inch mounting cups. In order to avoid inclusions, fractures, and inherited cores in zircons, the spots for laser ablation were chosen based on cathodoluminescence (CL) images.

Zircon U-Pb dating was performed on Pliocene sand samples and modern fluvial sediments using laser ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS) at Nanjing Hongchuang Geological Exploration Technology Service Co., Ltd. in Nanjing, China. The laser ablation system was connected to an Agilent 7900 ICPMS instrument from Agilent, USA. The specific tuning parameters can be found in Thompson et al. (2018). The zircons were mounted in epoxy discs, meticulously polished to expose the grains, and then subjected to ultrasonic cleaning in ultrapure water. Prior to analysis, a thorough cleaning was conducted using AR grade methanol. To eliminate possible surface contamination, a pre-ablation procedure was executed for each spot analysis. This involved five laser shots, each approximately 0.3 μm in depth. The actual analysis was carried out using a spot diameter of 30 μm, with a repetition rate of 5 Hz and a fluence of 2 J/cm^2. Data reduction was performed using the Iolite software package (Paton et al., 2010). Zircon 91500 was used as the primary reference material, while GJ-1 served as the secondary reference material. Each sample analysis included two measurements of 91500 and one measurement of GJ-1 for every 10–12 sample analyses. The sample signals were typically acquired for 35–40 s after a gas background measurement of 20 s. To calibrate the down-hole fractionation, we employed the exponential function as described by Paton et al. (2010). For trace element concentrations, zircon 91500, NIST 610 and ^{91}Zr were utilized as external reference material and internal standard element, respectively. The ages of the reference materials in the batch were determined to be 1 061.5 ± 3.2 Ma for 91500 (Wiedenbeck et al., 1995) and 604 ± 6 Ma for GJ-1 (Jackson et al., 2004). These measured ages were in good agreement with the reference values, falling within an acceptable uncertainty range.

For U-Pb dating, a random selection of approximately 70–90 zircon grains from each sample was made. Zircon ages showing less than 10% discordance were considered. Age concordia diagrams and age distribution plots were then generated using ISOPLOT 3.0 (Ludwig, 2003) and DensityPlotter (Vermeesch, 2012) software, respectively. The zircon ages younger than 1 000 Ma were determined using ^{206}Pb/^{238}U ages, while for ages older than 1 000 Ma, ^{207}Pb/^{206}Pb ages were utilized. This approach was based on the methodology established by Liu et al. (1992).

3 RESULTS

The majority of the analyzed zircons exhibit shades of gray to light brown coloration. They display euhedral to subhedral shapes and show evidence of oscillatory growth zoning or weak banding, as observed during CL imaging. These characteristics strongly suggest a magmatic origin, which is supported by Figures 5a–5g. Furthermore, the high Th/U ratios observed in these zircons (ranging from 0.01 to 3.32, typically greater than 0.1) further support their magmatic nature, as shown in Figure 5h.

Figure 6 presents U-Pb concordant diagrams for the zircon grains, as well as U-Pb age kernel density estimation spectra for each sample. Sample W1 consisted of 90 zircons, of which 82 yielded concordant analyses (Figure 6a). Notably, six predominant peak ages were identified at 143, 219, 438, 789, 1 840, and 2 473 Ma (Figure 6a′). Similarly, sample W2 comprised 90 zircons, with 83 yielding concordant analyses (Figure 6b). The ages obtained from these analyses ranged from 2 674 to 90 Ma, as shown in Figure 6b′. Three of the 90 analyses of zircons from sample W3 were discordant (Figure 6c). These zircons define seven peak ages at 145, 222, 426, 773, 977, 1 837, and 2 447 Ma (Figure 6c′). The analysis of 90 zircons from sample A1 yielded 85 concordant analyses (Figure 6d). There are five peak ages observed at 221, 423, 770, 1 864, and 2 494 Ma (Figure 6d′). The analysis of 90 zircon grains from sample A3 yielded 89 concordant ages (Figure 6e), showing five significant peak ages at 143, 222, 435, 767, and 1 875 Ma and one minor peak

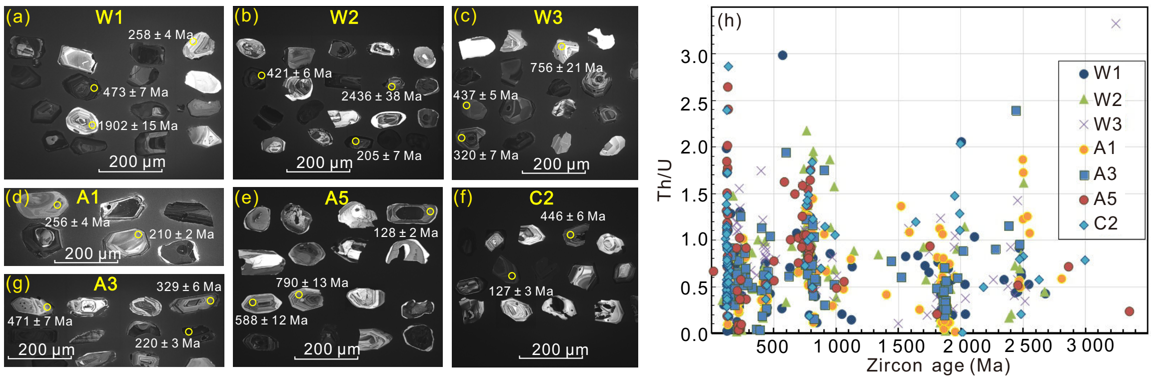

Figure 5. (a)–(g) Representative CL images of detrital zircon from the Pliocene sandstone and modern fluvial sediments; (h) diagram showing variations in zircon Th/U ratios and U-Pb ages.

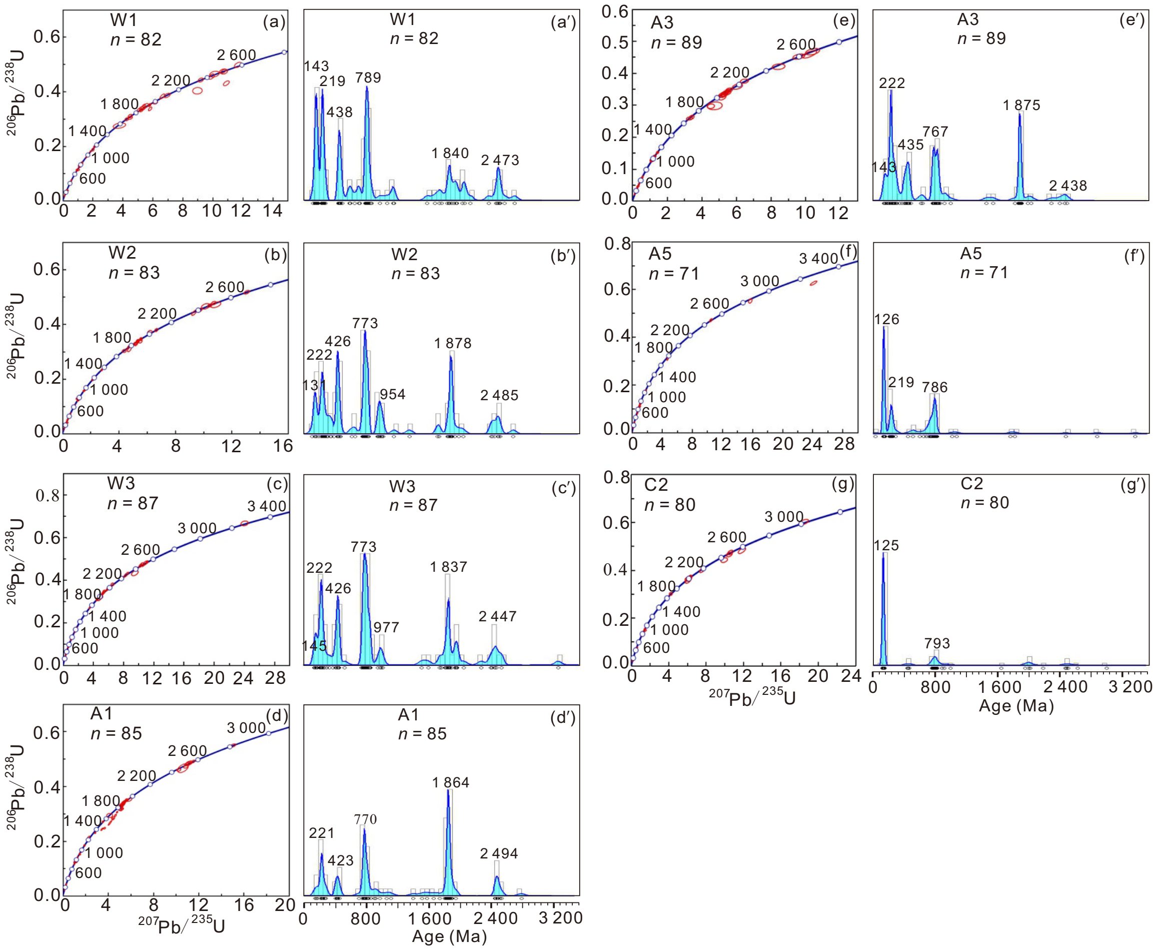

Figure 6. (a)–(g) U-Pb concordia diagrams constructed using ISOPLOT (Ludwig, 2003) of detrital zircon collected from this study. (a)–(c) Wangjiang Section; (d)–(e) Anqing Section; (f) Wan River; (g) Qiupu River. (a′)–(g′) detrital zircon U-Pb age shown as kernel density estimation spectra (Vermeesch, 2012). (a′)–(c′) Wangjiang Section; (d′)–(e′) Anqing Section; (f′) Wan River; (g′) Qiupu River. *n*. Number of concordant analyses.

age at 2 438 Ma (Figure 6e′). The 80 detrital zircons grains from sample A5 yielded 71 concordant ages (Figure 6f), with three peak ages: 126, 219, and 786 Ma (Figure 6f′). The analyzed 80 detrital zircons from sample C2 yielded 80 concordant ages (Figure 6g), including the peak ages concentrated at 125 and 793 Ma (Figure 6g′). In sample W3, out of the 90 zircon analyses conducted, three were found to be discordant, as demonstrated in Figure 6c. The remaining zircons yielded concordant ages ranging from 3 245 to 131 Ma. This dataset revealed the presence of seven peak ages at 145, 222, 426, 773, 977, 1 837, and 2 447 Ma (Figure 6c'). Sample A1 consisted of 90 zircon grains, of which 85 exhibited concordant ages. The obtained ages ranged from 2 811 to 134 Ma (Figure 6d). Significant peak ages were identified at 221, 423, 770, 1 864, and 2 494 Ma (Figure 6d'). The analysis of 90 zircon grains from sample A3 yielded 89 concordant ages (Figure 6e). This dataset exhibited five prominent peak ages at 143, 222, 435, 767, and 1 875 Ma, along with an additional minor peak age at 2 438 Ma (Figure 6e'). In sample A5, a total of 80 detrital zircon grains were analyzed, and 71 of them exhibited concordant ages (Figure 6f). The three peak ages observed in this dataset were 126, 219, and 786 Ma, as shown in Figure 6f'. Lastly, the analysis of 80 detrital zircon grains from sample C2 yielded 80 concordant ages (Figure 6g). The significant peak ages identified in this dataset were concentrated at 125 and 793 Ma (Figure 6g').

4 DISCUSSION

4.1 Provenance of Sand Layers in Anqing Formation

The determination of sedimentary material provenance involves comparing detrital zircon U-Pb ages with potential source areas or units that could have contributed sediment to the specific region under investigation (Gehrels, 2014). In the case of the Wangjiang Basin, it is situated adjacent to both the Dabie Shan and Eastern Jiangnan Orogen, as depicted in Figure 1b. Therefore, it is plausible that the Pliocene sediments in the Wangjiang Basin could contain material derived from these neighboring regions, namely the Dabie Shan and Eastern Jiangnan Orogen. The U-Pb ages of detrital zircons found in fluvial sediments within orogenic belts are often considered to be the most reliable representation of the zircon U-Pb age composition of those orogenic belts (e.g., Dickinson and Gehrels, 2003). In the case of the Wangjiang Basin, the Wan River, which originates from the southeastern margin of the Dabie Shan, is the largest river that flows into the Lower Yangtze River. In Figures 7a, 7b, the detrital zircon U-Pb peak age composition of the Wan River is observed to show a strong correlation with that of the Dabie Shan region. Specifically, it displays prominent peaks during the Late Mesozoic (126–134 Ma), Early Mesozoic (212–219 Ma), and Neoproterozoic (786–793 Ma) periods. The Qiupu River, a prominent river in the northern section of the Eastern Jiangnan Orogen, is a tributary that empties into the Lower Yangtze River. Analysis of the detrital zircon U-Pb ages of the Qiupu River has revealed a predominant peak during the Late Mesozoic Period (125 Ma), as well as a minor peak during the Neoproterozoic era (793 Ma, see Figure 7c). These age compositions align with those of the Eastern Jiangnan Orogen, as demonstrated in Figure 7d. Mufu Shan represents the primary orogenic belt found in the western region of the Wangjiang Basin. The Ganjiang River, an essential waterway that passes through Mufu Shan, serves as a significant tributary that converges with the southern bank of the Lower Yangtze River. Notably, both Mufu Shan and the Ganjiang River exhibit similar detrital zircon U-Pb age compositions, featuring three primary peak ages: 147, 413–427, and 772–808 Ma (Figures 7e,

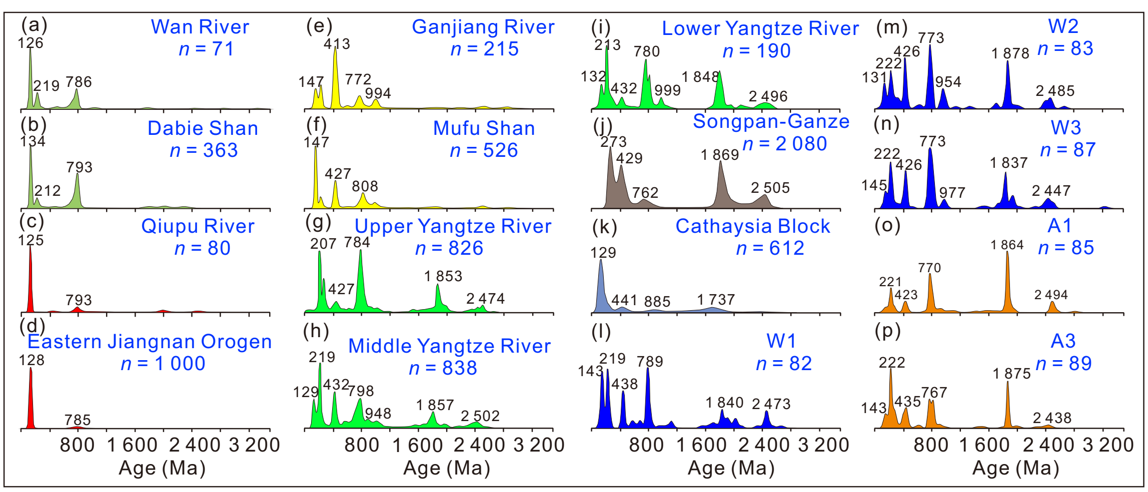

Figure 7. Kernel density estimation plots of Zircon U-Pb ages. (a) Wan River; (b) Dabie Shan (Lin et al., 2022c; Li W T et al., 2021); (c) Qiupu River; (d) Eastern Jiangnan Orogen (Wu et al., 2012; Zheng et al., 2008); (e) Ganjiang River (Li X C et al., 2016; He et al., 2013); (f) Mufu Shan (Lin et al., 2022c; Xin et al., 2017; Li J H et al., 2016; He et al., 2013; Lin et al., 2000); (g)–(i) Yangtze River (Lin et al., 2022c; Liang et al., 2018; He et al., 2013); (j) Songpan-Ganze Block (Weislogel et al., 2010); (k) Cathaysia Block (Zhang X C et al., 2017; Xu et al., 2007); (l)–(m) Wangjiang Section; (o)–(p) Anqing Section.

7f). The zircon U-Pb age peak composition of the upper, middle, and lower reaches of the Yangtze River exhibits a remarkable similarity (Figures 7g, 7h, 7i). The Songpan-Ganze Block exhibits five distinct peaks in zircon U-Pb ages: 273, 429, 762, 1 869, and 2 505 Ma (Figure 7j). However, the peak ages in the Late Mesozoic are not statistically significant. Conversely, it is worth noting that these Late Mesozoic peak ages are commonly observed in the Yangtze River Basin (Figures 7g, 7h, 7i). The most prominent peak in zircon U-Pb ages within the Cathaysian Block is concentrated in the Late Mesozoic at 129 Ma (Figure 7k). In contrast to the Wangjiang Section (Figures 7l, 7m, 7n) and the Anqing Section (Figures 7o, 7p), the Mufu Shan and Cathaysian Block exhibit weak peak ages of Paleoproterozoic and Neoarchean. Conversely, the detrital zircon U-Pb age composition of the sediments in the Yangtze River Basin clearly displays prominent peak ages of Paleoproterozoic and Neoarchean (Figures 7g, 7h, 7i). Furthermore, the Yangtze River Basin, as well as the Wangjiang and Anqing sections, share peak ages of Late Mesozoic (129–145 Ma), Early Mesozoic (216–222 Ma), Early Paleozoic (423–435 Ma), and Neoproterozoic (767–789 Ma). Based on the similar U-Pb age compositions of detrital zircons from Pliocene strata in the Wangjiang and Anqing sections, it is reasonable to infer that the detrital sand materials in the Wangjiang Basin during this period predominantly originated from the upper and middle reaches of the Yangtze River.

In order to visualize the similarities and dissimilarities between the zircon detrital age distributions, the nonmetric multidimensional scaling (MDS) statistical technique was employed for comparison (Vermeesch, 2013). As shown in Figure 8, the MDS plot reveals that Wan River and Dabie Shan, Qiupu River and Eastern Jiangnan Orogen, Ganjiang River, and Mufu Shan are in close proximity to each other, suggesting a connection in terms of provenance. The Cathaysian Block is located at a considerable distance from the Yangtze River Basin and the Wangjiang and Anqing sections. In the Wangjiang and Anqing sections, with the exception of Sample A1, which is in closer proximity to the Songpan-Ganze Block, the rest of the samples exhibit the closest distance to the Yangtze River Basin. This observation further suggests that the detrital sediments in these sections are significantly influenced by the Yangtze River.

4.2 Constraint on the Evolution of the Yangtze River

The Yangtze River, flowing across the Tibetan Plateau and terminating in the Pacific Ocean, is known to have existed during the Late Cenozoic. This claim is substantiated by the following pieces of evidence.

First, our detrital zircon U-Pb dating results demonstrate the presence of sedimentary materials from the Yangtze River in the Wangjiang Basin during the Pliocene (Figures 9a, 9b). Additionally, the Sr-Nd isotopic compositions of the Yuhuatai Formation (N_2) in Nanjing City align with the range of isotopic compositions observed in the modern Yangtze River, providing further confirmation of the stable provenance of the Yangtze River during the Pliocene (Zhang et al., 2019; Figure 9c). Furthermore, investigations into the detrital zircon U-Pb age provenance tracing by Hao et al. (2023), Cheng et

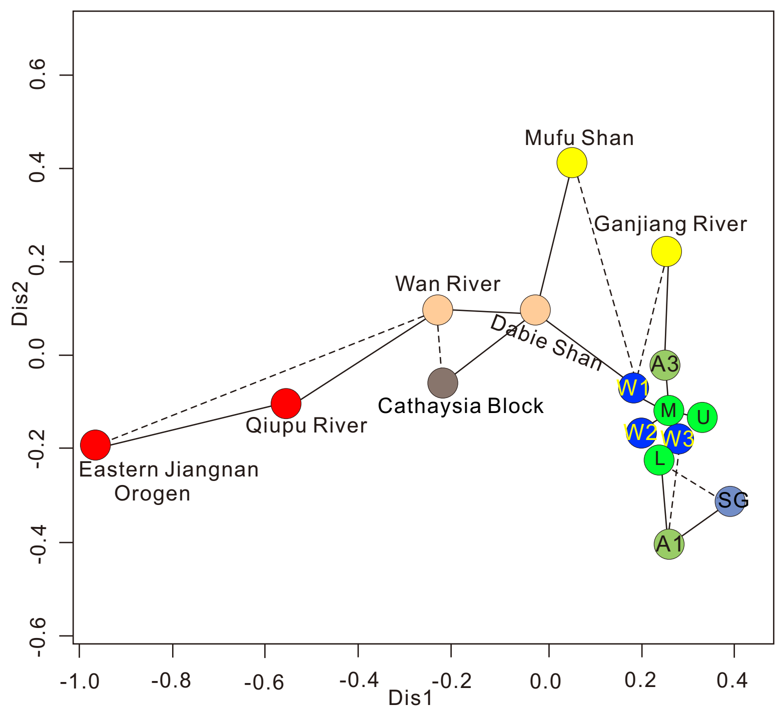

Figure 8. Multidimensional scaling (MDS) plot for potential areas and this study detrital zircon data, generated following methods outlined by Vermeesch (2013). Solid and dashed lines mark the nearest and second nearest neighbors, respectively. U, M, and L represent the upper, middle, and lower reaches of the Yangtze River, respectively. SG is the abbreviation of Songpan-Ganze.

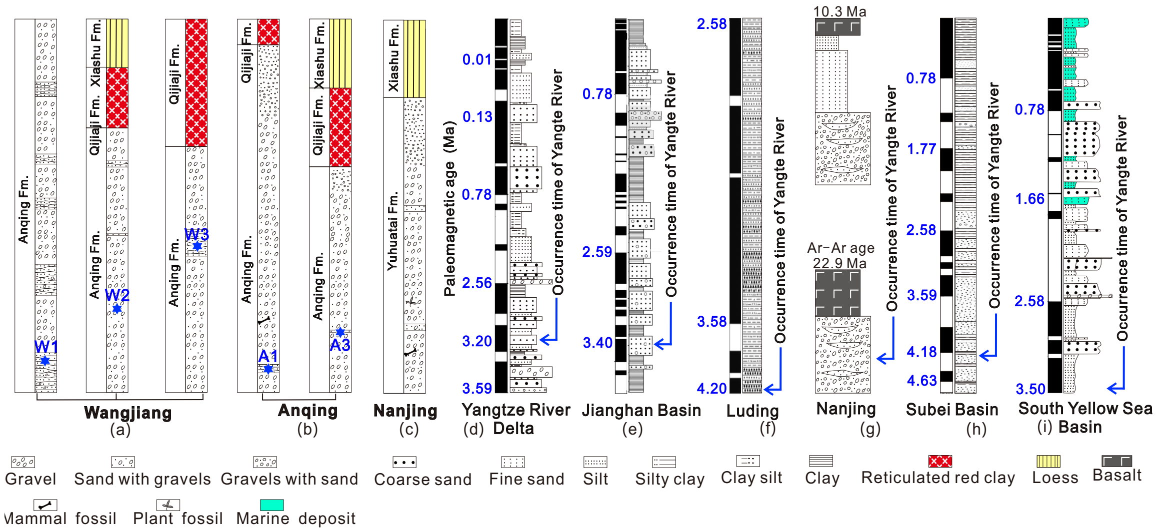

Figure 9. Correlation section showing the sedimentary facies characteristics of the Pliocene strata deposited. (a) Wangjiang; (b) Anqing; (c) Nanjing (Zhang et al., 2004); (d) Yangtze River Delta (Jia et al., 2010); (e) Jianghan Basin (Zhang et al., 2016), Nanjing (Zhang et al., 2004); (f) Luding (Wang et al., 2006); (g) Nanjing (Wang et al., 2022; Zheng et al., 2013); (h) Subei Basin (Shu et al., 2021); (i) South Yellow Sea Basin (Zhang et al., 2019; Liu et al., 2016).

al. (2018), and Jia et al. (2010) reveal the repetitive of detrital materials from the Yangtze River in the Yangtze River Delta within the time frame of 3.7–3.2 Ma (Figure 9d). Similarly, Wang et al. (2019) report that sediments in the South Yellow Sea Basin predominantly consist of silicate minerals sourced from the Yangtze River at 3.5 Ma. Similarly, Wang et al. (2019) found that a substantial portion of the sediment composition in the South Yellow Sea Basin consists of silicate minerals that originated from the Yangtze River around 3.5 Ma. Notably, the U-Pb dating of monazite and analysis of heavy mineral assemblage from the Yangtze River Delta indicate a shift in provenance during the Late Pliocene, primarily attributed to the influx of detrital materials from the Yangtze River (Yu et al., 2020; Yue et al., 2019; Fan et al., 2005).

Second, during the Late Pliocene (3.6–3.4 Ma), the Yangtze River actively eroded the Three Gorges, prompting the adjustment of its drainage network, as suggested by Li et al. (2001). This assertion is reinforced by the findings of provenance tracing studies utilizing whole-rock Nd and K-feldspar Pb isotopic compositions, as well as muscovite $^{40}Ar/^{39}Ar$ and zircon U-Pb ages from boreholes in the Jianghan Basin (Sun et al., 2018; Zhang et al., 2016; Shao et al., 2015; Figure 9e). These investigations establish that the Yangtze River assumed a prominent role as a significant supplier of materials to the Jianghan Basin during the Late Pliocene (3.4–2.7 Ma).

Third, by analyzing topographical and longitudinal river profiles, along with field observations and the paleomagnetic age of the strata, the formation of the Upper Yangtze River has been estimated to have occurred between 4.2 and 3.5 Ma (Zhang et al., 2024; Liu et al., 2019; Zhao et al., 2008; Wang et al., 2006; Li et al., 2005). The analysis of U-Pb data from detrital zircons obtained from the Pilocene Xigeda Formation, located in the southeastern margin of the Tibetan Plateau, provides further evidence supporting the occurrence of eastward flow in the upper reaches of the Yangtze River during the Pliocene (4.2–3.0 Ma; Deng et al., 2021; Zhao et al., 2021; Figure 9f). Therefore, it can be inferred that during the Pliocene, there was a connectedness between the lower, middle, and upper reaches of the Yangtze River.

However, detrital U-Pb results indicate that the sands found in the Miocene gravel layers of the Nanjing area originated from the Yangtze River (Wang et al., 2022; Zheng et al., 2013; Figure 9g). This finding indicates that the current morphology of the Yangtze River closely aligns with its configuration during the Miocene period (23–10 Ma). During this time, the lower reaches of the Yangtze River flowed southward, ultimately reaching the East China Sea (Fu et al., 2021; Zhang J Y et al., 2021; Zhang X C et al., 2017; Figure 10a). Conversely, the muscovite $^{40}Ar/^{39}Ar$ ages (Sun et al., 2021a) and the Pb isotopic compositions of K-feldspar provenance (Zhang Z J et al., 2021) provide evidence for a connection between the Lower Yangtze River and the Upper and Middle Yangtze River ranges spanning from 10 to 3.4 Ma. The presence of heavy and magnetic minerals observed in the borehole from the Subei Basin provides compelling evidence indicating that the formation of the Yangtze River drainage basin took place during the Pliocene Period (4.8–4.2 Ma; Shu et al., 2021; Figure 9h). The dating of clay minerals from the drilling holes suggests that Yangtze River sediments were present in the South Yellow Sea Basin around 3.5 Ma (Zhang et al., 2019; Figure 9i). This implies that the Lower Yangtze River might have had a different channel course during the Early Miocene compared to the Pliocene Yangtze River, possibly due to active channel migration (Wang et al., 2022; Fu et al., 2021; Zhang et al., 2019; Jia et al., 2010).

During the Pliocene, it is likely that two significant branches were present in the lower reaches of the Yang-

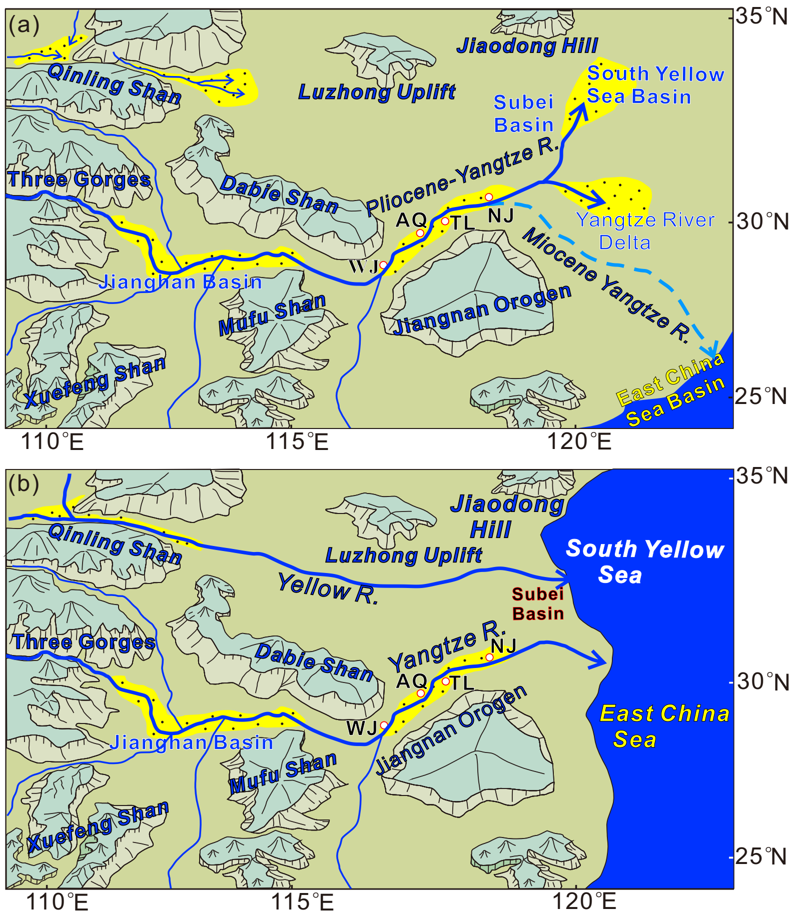

Figure 10. (a) Miocene–Pliocene and (b) Early Pleistocene reconstruction evolution map of the Lower Yangtze River. The results from several studies (Wang et al., 2022; Fu et al., 2021; Sun X L et al., 2021; Zhang Z J et al., 2021; Zhang J Y et al., 2021; Wang et al., 2019; Zhang J et al., 2019; Zheng et al., 2013; Jia et al., 2010; Li et al., 2001) were referred to in the creation of this map. WJ. Wangjiang; AQ. Anqing; TL. Tongling; NJ. Nanjing.

tze River. One of these tributaries flowed in a northerly direction and fed into the Subei Basin and the South Yellow Sea Basin. The other tributary followed a southerly course and extended into the Yangtze River Delta (Figure 10a). However, it has been consistently observed that the primary source of detrital materials in the South Yellow Sea Basin is the Yellow River since the Early Pleistocene (1.7 – 0.8 Ma; Huang et al., 2021; Zhang et al., 2019). The initial marine transgression of the South Yellow Sea Basin during the Quaternary took place between 1.66 and 0.89 Ma (Sun et al., 2022; Zhang et al., 2019; Liu et al., 2016). In the Pliocene, the northern branch of the Yangtze River, which had previously been flowing into the South Yellow Sea Basin, underwent a gradual abandonment during the Early Pleistocene (Wang et al., 2019). As a result, the main stream of the Yangtze River shifted to the southern branch, which became the dominant pathway (see Figure 10b). This shift ultimately led to the establishment of the current river form of the Yangtze River.

4.3 What Factors Control the Development of the Yangtze River?

The evolution of large rivers is generally attributed to a combination of tectonic and climatic factors (Lin et al., 2025; Jolivet et al., 2021; Liu W M et al., 2018; Liu-Zeng et al., 2008). Crustal deformation plays a pivotal role in generating elevated terrain in a regional context, thereby supplying the potential energy required for the development of rivers (Burbank and Anderson, 2013). Additionally, a humid climate with a robust summer monsoon promotes precipitation, discharge, and the migration of river channels (Leier et al., 2005; Clift et al., 2004; Zhang et al., 2001).

The changes in sedimentary facies (Li et al., 2014; Zheng et al., 2000; a, b in Figure 11) as well as the findings from low-temperature thermochronology (Godard et al., 2009; Kirby et al., 2002; Xu and Kamp, 2000; c, d in Figure 11) suggest that the Tibetan Plateau underwent a period of uplift during the Pliocene Epoch (5–3 Ma). Consequently, the uplifted Tibetan Plateau impeded the inflow of moist air from the Indian Ocean and the Pacific Ocean into the interior of the Asian Continent (Sun et al., 2008; Qiang et al., 2001; An, 2000). In addition, the Neo-Tethys ocean receded westward, resulting in the transition of sea-covered regions in Central Asia into terrestrial areas (Sun J M et al., 2021; Popov et al., 2006; e in Figure 11). Against the backdrop of global climate cooling (An et al., 2001; Kukla and Cílek, 1996; Raymo and Ruddiman, 1992), the temperature contrast between the Asian Continent and the Indian Ocean and the Pacific Ocean has intensified, thereby strengthening the South Asian Monsoon (Cai et al., 2020; Prell and Kutzbach, 1997; Prell et al., 1992; f, g, h in Figure 11) and the East Asian Monsoon (Wehausen and Brumsack, 2002; Zheng et al., 2004; i, j in Figure 11). The activation of the fault system in the southeastern Tibetan Plateau (Kirby et al., 2002; Xu and Kamp, 2000; Figure 12a), coupled with the initiation of crustal deformation through clockwise rotation around the eastern Himalayan syntaxis at 4–2 Ma (Wang and Burchfiel, 2000), established the geological conditions for the eastward flow of the Yangtze River (Liu et al., 2019; Kong et al., 2012; Zhao et al., 2008). The intensification of the monsoon in South Asia (Figures 12b, 12c) and East Asia (Figure 12d) creates a humid climate that is crucial for the sustainable development of the Yangtze River (Cai et al., 2020; Zheng et al., 2004; Wehausen and Brumsack, 2002; Prell et al., 1992). In this case, the Upper Yangtze River drainage system underwent adjustments during the Pliocene (Deng et al., 2021; Zhao et al., 2021; Kong et al., 2009; Wang et al., 2006, k in Figure 11). Additionally, evidence of corresponding clastic material from the Upper Yangtze River was found in boreholes from the Jianghan Basin (Zhang et al., 2016; l in Figure 11) and the Yangtze River Delta (Jia et al., 2010; m in Figure 11). The Wangjiang, Anqing, Tongling, and Nanjing sections have provided records indicating that the Yangtze River predominantly experienced braided river deposition during the Pliocene Period (Wang et al., 2022; Han et al., 2009; Zhang et al., 2004; He, 1994; RAB, 1988). Furthermore, it is worth noting that the fluvial deposition fluxes of the East China Sea continental shelf were significantly accelerated since the Pliocene, compared to the early Cenozoic (Métivier et al., 1999; Figure 12e). This suggests that the transportation capacity of the Yangtze River Basin was robust during this period, which is in line with the increased intensity of physical erosion and silicate weathering in East Asia between 4.0 and 2.5 Ma (Li F L et al., 2022; Zhang J et al., 2019; Zhang P et al., 2013; Wan et al., 2012; Figure 10n). During the Early Pleistocene, detrital materials from the Yellow River were transported into the East China Sea (Li et al., 2024; Huang et al., 2021; Zhang et al., 2019). The smaller size of rivers in the Korean Peninsula (Choi et al., 2013) suggests that these detrital materials were primarily transported from the Yangtze River during the Pliocene. Therefore, it is reasonable to conclude that the presence of the Yangtze River during the Pliocene is the result of the combined effects of tectonic uplift in the Tibetan Plateau and the influence of the Asian Monsoon and/or global climate change. Furthermore, the presence of thick and coarse clastic deposits in the Yellow River Basin suggests that the Yellow River began to form dur-

Figure 11. The distribution of Pliocene tectonic and climatic events around the Yangtze River Basin. The original map is sourced from: https://answers.syr.edu/display/EarthSci/Paleogeographic+Maps. Coarse grains deposited during the Pliocene can be found in various locations, including the Tarim Basin (a, Zheng et al., 2000), Qilian Shan (b, Li et al., 2014), Upper Yangtze River (k, Deng et al., 2021; Zhao et al., 2021), Jianghan Basin (l, Zhang et al., 2016), Yangtze River Delta (m, Jia et al., 2010), South Yellow Sea Basin (n, Zhang et al., 2019), and Yellow River Basin (o, Guo et al., 2018; p, Li Z Y et al., 2022; Lin et al., 2022a, Pan et al., 2011; q, Hu et al., 2017); c–d. low temperature thermochronology data (Godard et al., 2009; Kirby et al., 2002; Xu and Kamp, 2000); e. the New Tethys Ocean underwent a retreat towards western Eurasia (Sun J M et al., 2021; Popov et al., 2006). Drill cores from various locations have been obtained, including the Arabian Sea (g, Cai et al., 2020; f, Prell et al., 1992), Bay of Bengal (h, Prell and Kutzbach, 1997), and South China Sea (i, Zheng et al., 2004; j, Wehausen and Brumsack, 2002).

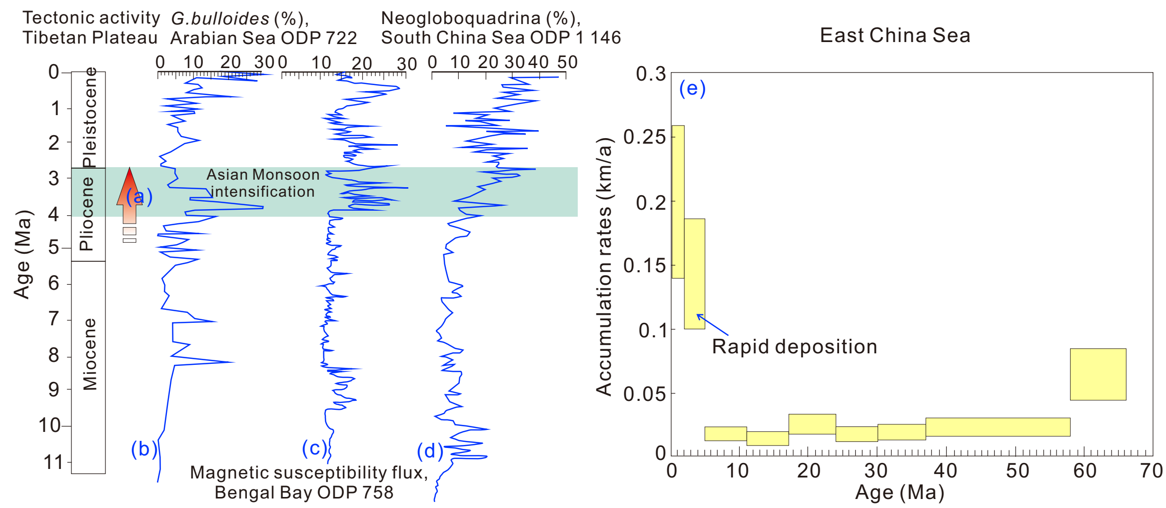

Figure 12. A summary of the major tectonic and climatic events in the Pliocene around the Yangtze River Basin. (a) The Tibetan Plateau underwent rapid uplift between 5 and 3 Ma (Li et al., 2014; Godard et al., 2009; Kirby et al., 2002; Xu and Kamp, 2000; Zheng et al., 2000); (b) the South Asian Monsoon (Prell et al., 1992) and East Asian Monsoon (Zheng et al., 2004) experienced intensification at 3.6 Ma, as evidenced by marine borehole records; (e) sedimentation rates on the continental shelf in the East China Sea significantly accelerated during the Pliocene (Métivier et al., 1999).

ing the Pliocene (3.7–3.5 Ma; Li Z Y et al., 2022; Lin et al., 2022a; Guo et al., 2018; Hu et al., 2017; Nie et al., 2015; Pan et al., 2011; o, p, q in Figure 11). During the Pliocene, large rivers originating from the Tibetan Plateau transported a significant amount of detrital material that was deposited in the South China Sea, the bay of Bengal, and the Arabian Sea (Clift et al., 2004; Métivier et al., 1999; Figure 11). These characteristics suggest that the uplift of the Tibetan Plateau, coupled with the influence of the Asian Monsoon, was paramount in the extensive deposition of coarse-grained material and the development of large rivers in East Asia during the Pliocene.

5 CONCLUSION

Detrital zircon U-Pb dating was used to determine the sedimentary provenance of Pliocene gravel layers in the lower reaches of the Yangtze River. The findings of our study indicate that the Yangtze River serves as the main source of sand materials in the Pliocene gravel beds located in the Wangjiang and Anqing sections. The emergence of the Yangtze River during the Pliocene can be attributed to the sedimentary response to the tectonic uplift of the Tibetan Plateau and the intensification of the Asian Monsoon.

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Conflict of Interest

The authors declare that they have no conflict of interest.

REFERENCES CITED

An, Z. S., 2000. The History and Variability of the East Asian Paleomonsoon Climate. *Quaternary Science Reviews*, 19(1/2/3/4/5): 171–187. https://doi.org/10.1016/S0277-3791(99)00060-8

An, Z. S., Kutzbach, J. E., Prell, W. L., et al., 2001. Evolution of Asian Monsoons and Phased Uplift of the Himalaya–Tibetan Plateau since Late Miocene Times. *Nature*, 411(6833): 62–66. https://doi.org/10.1038/35075035

Bentley, S. J., Blum, M. D., Maloney, J., et al., 2016. The Mississippi River Source-to-Sink System: Perspectives on Tectonic, Climatic, and Anthropogenic Influences, Miocene to Anthropocene. *Earth-Science Reviews*, 153: 139–174. https://doi.org/10.1016/j.earscirev.2015.11.001

Burbank, D. W., Anderson, R. S., 2013. Tectonic Geomorphology. *Environmental & Engineering Geoscience*, 19(2): 198–200. https://doi.org/10.2113/gseegeosci.19.2.198

Cai, M. J., Xu, Z. K., Clift, P. D., et al., 2020. Long-Term History of Sediment Inputs to the Eastern Arabian Sea and Its Implications for the Evolution of the Indian Summer Monsoon since 3.7 Ma. *Geological Magazine*, 157(6): 908–919. https://doi.org/10.1017/s0016756818000857

Chen, J., Wang, Z. H., Chen, Z. Y., et al., 2009. Diagnostic Heavy Minerals in Plio-Pleistocene Sediments of the Yangtze Coast, China with Special Reference to the Yangtze River Connection into the Sea. *Geomorphology*, 113(3/4): 129–136. https://doi.org/10.1016/j.geomorph.2009.03.010

Chen, Y., Yan, M. D., Fang, X. M., et al., 2017. Detrital Zircon U-Pb Geochronological and Sedimentological Study of the Simao Basin, Yunnan: Implications for the Early Cenozoic Evolution of the Red River. *Earth and Planetary Science Letters*, 476: 22–33. https://doi.org/10.1016/j.epsl.2017.07.025

Cheng, Y., Li, X. Q., Zhao, Z. Y., et al., 2018. Detrital Zircon U-Pb Ages and Its Provenance Significance in the TZK3 Core from the Yangtze River Delta. *Journal of Geomechanics*, 24(5): 635–644. https://doi. org/10.12090/j. issn. 1006-6616.2018.24.05.064 (in Chinese with English Abstract)

Choi, T., Lee, Y. I., Orihashi, Y., et al., 2013. The Provenance of the Southeastern Yellow Sea Sediments Constrained by Detrital Zircon U-Pb Age. *Marine Geology*, 337: 182–194. https://doi.org/10.1016/j.margeo.2013.01.007

Clark, M. K., Schoenbohm, L. M., Royden, L. H., et al., 2004. Surface Uplift, Tectonics, and Erosion of Eastern Tibet from Large-Scale Drainage Patterns. *Tectonics*, 23(1): TC1006. https://doi.org/10.1029/2002tc001402

Clift, P. D., Hodges, K. V., Heslop, D., et al., 2008a. Correlation of Himalayan Exhumation Rates and Asian Monsoon Intensity. *Nature Geoscience*, 1(12): 875–880. https://doi. org/10.1038/ngeo351

Clift, P. D., van Long, H., Hinton, R., et al., 2008b. Evolving East Asian River Systems Reconstructed by Trace Element and Pb and Nd Isotope Variations in Modern and Ancient Red River-Song Hong Sediments. *Geochemistry*, *Geophysics*, *Geosystems*, 9(4): Q04039. https://doi. org/10.1029/2007GC001867

Clift, P. D., Layne, G. D., Blusztajn, J., 2004. Marine Sedimentary Evidence for Monsoon Strengthening, Tibetan Uplift and Drainage Evolution in East Asia. In: Clift, P., Kuhnt, W., Wang, P., et al., eds., Continent-Ocean Interactions within East Asian Marginal Seas. American Geophysical Union, Washington, D. C. 255–282. https://doi.org/10.1029/149gm14

Craddock, W. H., Kylander-Clark, A. R. C., 2013. U-Pb Ages of Detrital Zircons from the Tertiary Mississippi River Delta in Central Louisiana: Insights into Sediment Provenance. *Geosphere*, 9(6): 1832–1851. https://doi. org/10.1130/ges00917.1

Deng, B., Chew, D., Mark, C., et al., 2021. Late Cenozoic Drainage Reorganization of the Paleo-Yangtze River Constrained by Multi-Proxy Provenance Analysis of the Paleo-Lake Xigeda. *GSA Bulletin*, 133(1/2): 199–211. https://doi.org/10.1130/b35579.1

Dickinson, W. R., Gehrels, G. E., 2003. U-Pb Ages of Detrital Zircons from Permian and Jurassic Eolian Sandstones of the Colorado Plateau, USA: Paleogeographic Implications. *Sedimentary Geology*, 163(1/2): 29–66. https://doi. org/10.1016/S0037-0738(03)00158-1

Fan, D. D., Li, C. X., Yokoyama, K., et al., 2005. Monazite Age Spectra in the Late Cenozoic Strata of the Changjiang Delta and Its Implication on the Changjiang Run-through Time. *Science in China Series D*: *Earth Sciences*, 48(10): 1718–1727. https://doi. org/10.1360/01yd0447

Feng, Y., Song, C. H., He, P. J., et al., 2021. Detrital Zircon U-Pb Geochronology of the Jianchuan Basin, Southeastern Tibetan Plateau, and Its Implications for Tectonic and Paleodrainage Evolution. *Terra Nova*, 33(6): 560–572. https://doi. org/10.1111/ter.12548

Fu, X. W., Zhu, W. L., Geng, J. H., et al., 2021. The Present-Day Yangtze River Was Established in the Late Miocene: Evidence from Detrital Zircon Ages. *Journal of Asian Earth Sciences*, 205: 104600. https://doi.org/10.1016/j.jseaes.2020.104600

Gehrels, G., 2014. Detrital Zircon U-Pb Geochronology Applied to Tectonics. *Annual Review of Earth and Planetary Sciences*, 42: 127–149. https://doi.org/10.1146/annurev-earth-050212-124012

Godard, V., Pik, R., Lavé, J., et al., 2009. Late Cenozoic Evolution of the Central Longmen Shan, Eastern Tibet: Insight from (U-Th)/He Thermochronometry. *Tectonics*, 28(5): TC5009. https://doi. org/10.1029/2008tc002407

Guo, B. H., Liu, S. P., Peng, T. J., et al., 2018. Late Pliocene Establishment of Exorheic Drainage in the Northeastern Tibetan Plateau as Evidenced by the Wuquan Formation in the Lanzhou Basin. *Geomorphology*, 303: 271–283. https://doi.org/10.1016/j. geomorph.2017.12.009

Guo, Z. T., Ruddiman, W. F., Hao, Q. Z., et al., 2002. Onset of Asian Desertification by 22 Myr ago Inferred from Loess Deposits in China. *Nature*, 416(6877): 159–163. https://doi. org/10.1038/416159a

Han, Z. Y., Li, X. S., Chen, Y. Y., et al., 2009. Evolution of Sedimentary Environment of Neogene Gravel Beds near Nanjing. *Quaternary Sciences*, 29(2): 361–369 (in Chinese with English Abstract)

Hao, S. F., Cheng, Y., Gao, B. F., et al., 2023. Provenance Changes of the Yangtze River Delta Sediments since ~3.6 Ma: Evidence from Heavy Mineral Assemblages and Detrital Zircon U-Pb Ages Spectra. *Quaternary International*, 671: 33–43. https://doi. org/10.1016/j.quaint.2023.09.019

He, M. Y., Zheng, H. B., Clift, P. D., 2013. Zircon U-Pb Geochronology and Hf Isotope Data from the Yangtze River Sands: Implications for Major Magmatic Events and Crustal Evolution in Central China. *Chemical Geology*, 360: 186–203. https://doi.org/10.1016/j.chemgeo.2013.10.020

He, M. Y., Zheng, H. B., Clift, P. D., et al., 2021. Paleogene Sedimentary Records of the Paleo-Jinshajiang (Upper Yangtze) in the Jianchuan Basin, Yunnan, SW China. *Geochemistry*, *Geophysics*, *Geosystems*, 22(6): e2020GC009500. https://doi. org/10.1029/2020GC009500

He, P., 1994. Quaternary Sedimentary Facies and Environmental Evolution of the Mainstream of the Yangtze River. Seismological Press, Beijing. 1–69 (in Chinese)

Hu, Z. B., Pan, B. T., Bridgland, D., et al., 2017. The Linking of the Upper-Middle and Lower Reaches of the Yellow River as a Result of Fluvial Entrenchment. *Quaternary Science Reviews*, 166: 324–338. https://doi.org/10.1016/j.quascirev.2017.02.026

Huang, X. T., Mei, X., Yang, S. Y., et al., 2021. Disentangling Combined Effects of Sediment Sorting, Provenance, and Chemical Weathering from a Pliocene-Pleistocene Sedimentary Core (CSDP-1) in the South Yellow Sea. *Geochemistry*, *Geophysics*, *Geosystems*, 22(5): e2020GC009569. https://doi. org/10.1029/2020GC009569

Jackson, S. E., Pearson, N. J., Griffin, W. L., et al., 2004. The Application of Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry to *in situ* U-Pb Zircon Geochronology. *Chemical Geology*, 211(1/2): 47–69. https://doi. org/10.1016/j. chemgeo.2004.06.017

Jia, J. T., Zheng, H. B., Huang, X. T., et al., 2010. Detrital Zircon U-Pb Ages of Late Cenozoic Sediments from the Yangtze Delta: Implication for the Evolution of the Yangtze River. *Chinese Science Bulletin*, 55(15): 1520–1528. https://doi. org/10.1007/s11434-010-3091-x

Jiao, R. H., Yang, R., Yuan, X. P., 2021. Incision History of the Three Gorges, Yangtze River Constrained from Inversion of River Profiles and Low-Temperature Thermochronological Data. *Journal of Geophysical Research*: *Earth Surface*, 126(3): 2020JF005767. https://doi.org/10.1029/2020JF005767

Jolivet, M., Braucher, R., Dovchintseren, D., et al., 2021. Erosion around a Large-Scale Topographic High in a Semi-Arid Sedimentary Basin: Interactions between Fluvial Erosion, Aeolian Erosion and Aeolian Transport. *Geomorphology*, 386: 107747. https://doi.org/10.1016/j.geomorph.2021.107747

Kang, C. G., Li, C. A., Wei, C. Y., et al., 2021. Heavy Mineral Assemblage Variation in Late Cenozoic Sediments from the Middle Yangtze River Basin: Insights into Basin Sediment Provenance and Evolution of the Three Gorges Valley. *Minerals*, 11(10): 1056. https://doi.org/10.3390/min11101056

Kirby, E., Reiners, P. W., Krol, M. A., et al., 2002. Late Cenozoic Evolution of the Eastern Margin of the Tibetan Plateau: Inferences from $^{40}Ar/^{39}Ar$ and (U-Th)/He Thermochronology. *Tectonics*, 21(1): 1-1-1-20. https://doi.org/10.1029/2000tc001246

Kong, P., Granger, D. E., Wu, F. Y., et al., 2009. Cosmogenic Nuclide Burial Ages and Provenance of the Xigeda Paleo-Lake: Implications for Evolution of the Middle Yangtze River. *Earth and Planetary Science Letters*, 278(1/2): 131–141. https://doi. org/10.1016/j.epsl.2008.12.003

Kong, P., Zheng, Y., Caffee, M. W., 2012. Provenance and Time Constraints on the Formation of the First Bend of the Yangtze River. *Geochemistry*, *Geophysics*, *Geosystems*, 13(6): Q06017. https://doi.org/10.1029/2012GC004140

Kukla, G., Cílek, V., 1996. Plio-Pleistocene Megacycles: Record of Climate and Tectonics. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 120(1/2): 171–194. https://doi.org/10.1016/0031-0182(95)00040-2

Latrubesse, E. M., Cozzuol, M., da Silva-Caminha, S. A. F., et al., 2010. The Late Miocene Paleogeography of the Amazon Basin and the Evolution of the Amazon River System. *Earth-Science Reviews*, 99(3/4): 99 – 124. https://doi. org/10.1016/j. earscirev.2010.02.005

Leier, A. L., DeCelles, P. G., Pelletier, J. D., 2005. Mountains, Monsoons, and Megafans. *Geology*, 33(4): 289–292. https://doi. org/10.1130/g21228.1

Li, F. L., Yang, S. Y., Breecker, D. O., et al., 2022. Responses of Silicate Weathering Intensity to the Pliocene-Quaternary Cooling in East and Southeast Asia. *Earth and Planetary Science Letters*, 578: 117301. https://doi.org/10.1016/j.epsl.2021.117301

Li, J. H., Dong, S. W., Zhang, Y. Q., et al., 2016. New Insights into Phanerozoic Tectonics of South China: Part 1, Polyphase Deformation in the Jiuling and Lianyunshan Domains of the Central Jiangnan Orogen. *Journal of Geophysical Research*: *Solid Earth*, 121(4): 3048 – 3080. https://doi. org/10.1002/ 2015JB012778

Li, J. J., Fang, X. M., Song, C. H., et al., 2014. Late Miocene – Quaternary Rapid Stepwise Uplift of the NE Tibetan Plateau and Its Effects on Climatic and Environmental Changes. *Quaternary Research*, 81(3): 400 – 423. https://doi. org/10.1016/j. yqres.2014.01.002

Li, J. J., Xie, S. Y., Kuang, M. S., 2001. Geomorphic Evolution of the Yangtze Gorges and the Time of Their Formation. *Geomorphology*, 41(2/3): 125 – 135. https://doi. org/10.1016/ S0169-555X(01)00110-6

Li, J., Yang, S. X., Liu, J., et al., 2024. Pollen Evidence of Enhanced Yellow River Provenance into the South Yellow Sea after the Middle Pleistocene Transition. *Quaternary Science Reviews*, 344: 108961. https://doi.org/10.1016/j.quascirev.2024.108961

Li, W. T., Jiang, S. Y., Fu, B., et al., 2021. Zircon HfO Isotope and Magma Oxidation State Evidence for the Origin of Early Cretaceous Granitoids and Porphyry Mo Mineralization in the Tongbai-Hong'an-Dabie Orogens, Eastern China. *Lithos*, 398: 106281. https://doi.org/10.1016/j.lithos.2021.106281

Li, X. C., Wang, A. D., Wan, J. J., et al., 2016. Tracing the Stream Sediment of the Ganjiang River(Nanchang Section): Constraint from the Detrital Zircon U-Pb Isotope Evidence. *Geoscience*, 30 (3): 514 – 527. https://doi. org/10.3969/j. issn. 1000-8527.2016.03.003 (in Chinese with English Abstract)

Li, Y. W., Zhao, J. X., Li, C. A., et al., 2021. Cadmium and Clay Mineral Analysis of Late Pliocene – Pleistocene Deposits from Jianghan Basin, Central China: Implications for Sedimentary Provenance and Evolution of the Yangtze River. *Quaternary International*, 598(10): 1 – 14. https://doi. org/10.1016/j. quaint.2021.04.009

Li, Y., Cao, S. Y., Zhou, R. J., et al., 2005. Late Cenozoic Minjiang Incision Rate and Its Constraint on the Uplift of the Eastern Margin of the Tibetan Plateau. *Acta Geologica Sinica*, 79(1): 28–37 (in Chinese with English Abstract)

Li, Z. Y., Zhang, K., Liang, H., et al., 2022. Large River Chronology along the Jinshaan Gorge on the Yellow River and Its Implications for Initialization. *Geomorphology*, 400: 108092. https://doi.org/10.1016/j.geomorph.2021.108092

Liang, Z. W., Gao, S., Hawkesworth, C. J., et al., 2018. Step-Like Growth of the Continental Crust in South China: Evidence from Detrital Zircons in Yangtze River Sediments. *Lithos*, 320: 155–171. https://doi.org/10.1016/j.lithos.2018.09.011

Lin, W., Faure, M., Monié, P., et al., 2000. Tectonics of SE China: New Insights from the Lushan Massif (Jiangxi Province). *Tectonics*, 19(5): 852 – 871. https://doi. org/10.1029/2000TC90 0009

Lin, X., Dröllner, M., Barham, M., et al., 2025. The Cenozoic Evolution of the Yellow River. *Earth-Science Reviews*, 261: 104997. https://doi.org/10.1016/j.earscirev.2024.104997

Lin, X., Li, L., Liu, H., et al., 2022a. Sediments from the Upper Reaches of Yellow River did not Enter into Shanxi-Shaanxi Gorge in the Neogene. *Journal of Palaeogeography*, 24(3): 568–582. https://doi.org/10.7605/gdlxb.2022.03.036 (in Chinese with English Abstract)

Lin, X., Liu, H., Liu, J., et al., 2022b. The Yellow River did not Enter the Bohai Bay Basin during the Miocene: Constraints from Detrital Zircon U-Pb Ages. *Acta Geologica Sinica*, 96(7): 2506–2518. https://doi. org/10.19762/j. cnki. dizhixuebao. 2022004 (in Chinese with English Abstract)

Lin, X., Wu, Z. H., Zhao, X. T., et al., 2022c. Detrital Zircon U-Pb Age Characteristics of Main Rivers around Jianghan Basin and Implications of Provenance Tracing. *Acta Geoscientica Sinica*, 43(1): 73 – 81. https://doi. org/10.3975/cagsb. 2021.091701 (in Chinese with English Abstract)

Lin, X., Liu, J., Liu, W., et al. 2023a. Development and Evolution of the Yellow River and the Yangtze River. Geological Publishing House, Beijing. 1–175 (in Chinse)

Lin, X., Liu-Zeng, J., Wu, L., et al., 2023b. Meso-Cenozoic Exhumation in the South Qinling Shan (Central China) Recorded by Detrital Apatite Fission-Track Dating of Modern River Sediments. *Minerals*, 13(10): 1314. https://doi.org/10.3390/ min13101314

Lin, X., Li, L. L., Liu, J., et al., 2023c. Yangtze River Contributed

Detrital Materials to Jianghan Basin during Early Pleistocene: Constraints from Detrital Zircon U-Pb Ages. *Earth Science*, 48 (11): 4214 – 4228. https://doi. org/10.3799/dqkx. 2022.018 (in Chinese with English Abstract)

Lin, X., Liu-Zeng, J., Jolivet, M., et al., 2024a. Sedimentary Provenance Constraints on the Cretaceous to Cenozoic Palaeogeography of the Western Margin of the Jianghan Basin, South China. *Gondwana Research*, 125: 343–358. https://doi. org/10.1016/j.gr.2023.09.001

Lin, X., Xu, Q. M., Barham, M., et al., 2024b. Tracing the Source Areas of Detrital Zircon and K-Feldspar in the Yellow River Basin. *Earth-Science Reviews*, 251: 104718. https://doi. org/ 10.1016/j.earscirev.2024.104718

Liu, D. Y., Nutman, A. P., Compston, W., et al., 1992. Remnants of $\geqslant$ 3800 Ma Crust in the Chinese Part of the Sino-Korean Craton. *Geology*, 20(4): 339 – 342. https://doi. org/10.1130/0091-7613 (1992)020<0339:romcit>2.3.co;2

Liu, F. L., Gao, H. S., Pan, B. T., et al., 2019. Quantitative Analysis of Planation Surfaces of the Upper Yangtze River in the Sichuan-Yunnan Region, Southwest China. *Frontiers of Earth Science*, 13(1): 55–74. https://doi.org/10.1007/s11707-018-0707-y

Liu, J. X., Liu, Q. S., Zhang, X. H., et al., 2016. Magnetostratigraphy of a Long Quaternary Sediment Core in the South Yellow Sea. *Quaternary Science Reviews*, 144: 1–15. https://doi.org/10.1016/ j.quascirev.2016.05.025

Liu, W. M., Hu, K. H., Carling, P. A., et al., 2018. The Establishment and Influence of Baimakou Paleo-Dam in an Upstream Reach of the Yangtze River, Southeastern Margin of the Tibetan Plateau. *Geomorphology*, 321: 167 – 173. https://doi. org/10.1016/j. geomorph.2018.08.028

Liu, X. B., Chen, J., Maher, B. A., et al., 2018. Connection of the Proto-Yangtze River to the East China Sea Traced by Sediment Magnetic Properties. *Geomorphology*, 303: 162–171. https://doi. org/10.1016/j.geomorph.2017.11.023

Liu-Zeng, J., Tapponnier, P., Gaudemer, Y., et al., 2008. Quantifying Landscape Differences across the Tibetan Plateau: Implications for Topographic Relief Evolution. *Journal of Geophysical Research*: *Earth Surface*, 113(F4): F04018. https://doi. org/ 10.1029/2007jf000897

Ludwig, K. R., 2003. User's Manual for Isoplot/Ex Version 3.00, a Geochronological Toolkit for Microsoft Excel. Berkeley Geochronology Center Special Publications, Berkeley. 72

Mapes, R. W., 2009. Past and Present Provenance of the Amazon River: [Dissertation]. The University of North Carolina, Chapel Hill. 1–177. https://www.proquest.com/openview/74bbd55dc2c13 2c09f076768e97c2da4/1?pq-origsite=gscholar&cbl=18750

McPhillips, D., Hoke, G. D., Liu-Zeng, J., et al., 2016. Dating the Incision of the Yangtze River Gorge at the First Bend Using Three-Nuclide Burial Ages. *Geophysical Research Letters*, 43 (1): 101–110. https://doi.org/10.1002/2015GL066780

Métivier, F., Gaudemer, Y., Tapponnier, P., et al., 1999. Mass Accumulation Rates in Asia during the Cenozoic. *Geophysical Journal International*, 137(2): 280–318. https://doi.org/10.1046/ j.1365-246X.1999.00802.x

Molnar, P., 2005. Mio-Pliocene Growth of the Tibetan Plateau and Evolution of East Asian Climate. *Palaeontologia Electronica*, 8 (1): 1–23

Morag, N., Avigad, D., Gerdes, A., et al., 2021. Detrital Zircon and Rutile U-Pb, Hf Isotopes and Heavy Mineral Assemblages of Israeli Miocene Sands: Fingerprinting the Arabian Provenance of the Levant. *Basin Research*, 33(3): 1967–1984. https://doi. org/10.1111/bre.12544

Nie, J. S., Stevens, T., Rittner, M., et al., 2015. Loess Plateau Storage of Northeastern Tibetan Plateau-Derived Yellow River Sediment. *Nature Communications*, 6(1): 1–10. https://doi. org/ 10.1038/ncomms9511

Pan, B. T., Hu, Z. B., Wang, J. P., et al., 2011. A Magnetostratigraphic Record of Landscape Development in the Eastern Ordos Plateau, China: Transition from Late Miocene and Early Pliocene Stacked Sedimentation to Late Pliocene and Quaternary Uplift and Incision by the Yellow River. *Geomorphology*, 125(1): 225 – 238. https://doi. org/10.1016/j. geomorph.2010.09.019

Paton, C., Woodhead, J. D., Hellstrom, J. C., et al., 2010. Improved Laser Ablation U-Pb Zircon Geochronology through Robust Downhole Fractionation Correction. *Geochemistry*, *Geophysics*, *Geosystems*, 11(3): Q0AA06. https://doi. org/10.1029/ 2009GC002618

Popov, S. V., Shcherba, I. G., Ilyina, L. B., et al., 2006. Late Miocene to Pliocene Palaeogeography of the Paratethys and Its Relation to the Mediterranean. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 238(1/2/3/4): 91–106. https://doi. org/10.1016/j. palaeo.2006.03.020

Potter, P. E., 1978. Significance and Origin of Big Rivers. *The Journal of Geology*, 86(1): 13–33. https://doi.org/10.1086/649653

Prell, W. L., Kutzbach, J. E., 1997. The Impact of Tibet-Himalayan Elevation on the Sensitivity of the Monsoon Climate System to Changes in Solar Radiation. In: Ruddiman, W, F., ed., Tectonic Uplift and Climate Change. Plenum Press, New York. 171–201. https://doi.org/10.1007/978-1-4615-5935-1_8

Prell, W. L., Murray, D. W., Clemens, S. C., et al., 1992. Synthesis of Results from Scientific Drilling in the Indian Ocean. American Geophysical Union, Washington, D. C. 447–469

Qiang, X. K., Li, Z. X., Powell, C. M., et al., 2001. Magnetostratigraphic Record of the Late Miocene Onset of the East Asian Monsoon, and Pliocene Uplift of Northern Tibet. *Earth and Planetary Science Letters*, 187(1/2): 83–93. https:// doi.org/10.1016/S0012-821X(01)00281-3

Raymo, M. E., Ruddiman, W. F., 1992. Tectonic Forcing of Late Cenozoic Climate. *Nature*, 359(6391): 117–122. https://doi.org/ 10.1038/359117a0

RAB (Regional Geological Survey Team of Anhui Bureau of Geology and Mineral Resources), 1988. Stratigraphy of Anhui Province (Tertiary). Anhui Science and Technology Press, Hefei. 1–202 (in Chinese)

Richardson, N. J., Densmore, A. L., Seward, D., et al., 2010. Did Incision of the Three Gorges Begin in the Eocene? *Geology*, 38 (6): 551–554. https://doi.org/10.1130/g30527.1

Shao, L., Li, C. A., Yuan, S. Y., et al., 2012. Neodymium Isotopic Variations of the Late Cenozoic Sediments in the Jianghan Basin: Implications for Sediment Source and Evolution of the Yangtze River. *Journal of Asian Earth Sciences*, 45: 57 – 64. https://doi.org/10.1016/j.jseaes.2011.09.018

Shao, L., Yuan, S. Y., Li, C. A., et al., 2015. Changing Provenance of Late Cenozoic Sediments in the Jianghan Basin. *Geoscience Frontiers*, 6(4): 605 – 615. https://doi. org/10.1016/j.

gsf.2014.04.010

Shu, Q., Zhao, Z. J., Zhao, Y. F., et al., 2021. Magnetic Properties of Late Cenozoic Sediments in the Subei Basin: Implications for the Yangtze River Run-through Time. *Journal of Coastal Research*, 37(1): 122 – 131. https://doi. org/10.2112/jcoastres-d-20-00039.1

Sun, J. M., Sheykh, M., Ahmadi, N., et al., 2021. Permanent Closure of the Tethyan Seaway in the Northwestern Iranian Plateau Driven by Cyclic Sea-Level Fluctuations in the Late Middle Miocene. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 564: 110172. https://doi.org/10.1016/j.palaeo.2020.110172

Sun, J. M., Zhang, L. Y., Deng, C. L., et al., 2008. Evidence for Enhanced Aridity in the Tarim Basin of China since 5.3Ma. *Quaternary Science Reviews*, 27(9/10): 1012 – 1023. https://doi. org/10.1016/j.quascirev.2008.01.011

Sun, J., Guo, F., Wu, H. C., et al., 2022. The Sedimentary Succession of the last 2.25 Myr in the Bohai Strait: Implications for the Quaternary Paleoenvironmental Evolution of the Bohai Sea. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 585: 110704. https://doi.org/10.1016/j.palaeo.2021.110704

Sun, X. L., Li, C. A., Kuiper, K. F., et al., 2018. Geochronology of Detrital Muscovite and Zircon Constrains the Sediment Provenance Changes in the Yangtze River during the Late Cenozoic. *Basin Research*, 30(4): 636 – 649. https://doi. org/ 10.1111/bre.12268

Sun, X. L., Tian, Y. T., Kuiper, K. F., et al., 2021. No Yangtze River Prior to the Late Miocene: Evidence from Detrital Muscovite and K-Feldspar $^{40}Ar/^{39}Ar$ Geochronology. *Geophysical Research Letters*, 48(5): e2020GL089903. https://doi. org/10.1029/ 2020GL089903

Thompson, J. M., Meffre, S., Danyushevsky, L., 2018. Impact of Air, Laser Pulse Width and Fluence on U-Pb Dating of Zircons by LA-ICPMS. *Journal of Analytical Atomic Spectrometry*, 33(2): 221–230. https://doi.org/10.1039/C7JA00357A

Tian, S. M., Guan, K. G., Lin, X., et al., 2025. The Geochemical Characteristics of Zircon and K-Feldspar Grains from the Lower Yellow and Yangtze Rivers: Implications for Provenance Tracing Studies in the Western Pacific Ocean. *Minerals*, 15(2): 121. https://doi.org/10.3390/min15020121

Vermeesch, P., 2012. On the Visualisation of Detrital Age Distributions. *Chemical Geology*, 312: 190 – 194. https://doi. org/ 10.1016/j.chemgeo.2012.04.021

Vermeesch, P., 2013. Multi-Sample Comparison of Detrital Age Distributions. *Chemical Geology*, 341: 140 – 146. https://doi. org/ 10.1016/j.chemgeo.2013.01.010

Wan, S. M., Clift, P. D., Li, A. C., et al., 2012. Tectonic and Climatic Controls on Long-Term Silicate Weathering in Asia since 5 Ma. *Geophysical Research Letters*, 39(15): L15611. https://doi. org/ 10.1029/2012GL052377

Wang, E., Burchfiel, B. C., 2000. Late Cenozoic to Holocene Deformation in Southwestern Sichuan and Adjacent Yunnan, China, and Its Role in Formation of the Southeastern Part of the Tibetan Plateau. *Geological Society of America Bulletin*, 112(3): 413 – 423. https://doi. org/10.1130/0016-7606(2000)112<413: LCTHDI>2.0.CO;2

Wang, K. S., Shi, X. F., Yao, Z. Q., et al., 2019. Heavy-Mineral-Based Provenance and Environment Analysis of a Pliocene Series Marking a Prominent Transgression in the South Yellow Sea. *Sedimentary Geology*, 382: 25–35. https://doi.org/10.1016/j. sedgeo.2019.01.005

Wang, P. X., 2004. Cenozoic Deformation and the History of Sea-Land Interactions in Asia. *Geophysical Monograph Series*, 149: 1–22. https://doi.org/10.1029/149GM01

Wang, P., Zheng, H. B., Liu, S. F., et al., 2018. Late Cretaceous Drainage Reorganization of the Middle Yangtze River. *Lithosphere*, 10(3): 392–405. https://doi.org/10.1130/l695.1

Wang, P., Zheng, H. B., Wang, Y. D., et al., 2022. Sedimentology, Geochronology, and Provenance of the Late Cenozoic "Yangtze Gravel": Implications for Lower Yangtze River Reorganization and Tectonic Evolution in Southeast China. *GSA Bulletin*, 134(1/ 2): 463–486. https://doi.org/10.1130/b35851.1

Wang, P., Zheng, H., Chen, L., et al., 2014. Exhumation of the Huangling Anticline in the Three Gorges Region: Cenozoic Sedimentary Record from the Western Jianghan Basin, China. *Basin Research*, 26(4): 505 – 522. https://doi. org/10.1111/ bre.12047

Wang, S. B., Zhao, Z. Z., Qiao, Y. S., et al., 2006. Age and Paleoenvironment of Xigeda Formation in Luding, Sichuan. *Quaternary Sciences*, 26(2): 257 – 264 (in Chinese with English Abstract)

Wang, W. M., Zhou, X. D., Shao, J. J., et al., 2014. A Study on Late Cenozoic Gravel Deposits and Fossils in Yuhua Pebbles nearby Nanjing, East China. *Journal of Stratigraphy*, 38(4): 425 – 432. https://doi. org/10.19839/j. cnki. dcxzz. 2014.04.006 (in Chinese with English Abstract)

Wehausen, R., Brumsack, H. J., 2002. Astronomical Forcing of the East Asian Monsoon Mirrored by the Composition of Pliocene South China Sea Sediments. *Earth and Planetary Science Letters*, 201(3/4): 621 – 636. https://doi.org/10.1016/S0012-821X (02)00746-X

Wei, C. Y., Voinchet, P., Zhang, Y. F., et al., 2020. Chronology and Provenance of the Yichang Gravel Layer Deposits in the Jianghan Basin, Middle Yangtze River Valley, China: Implications for the Timing of Channelization of the Three Gorges Valley. *Quaternary International*, 550: 39 – 54. https://doi. org/10.1016/j.quaint.2020.03.020

Weislogel, A. L., Graham, S. A., Chang, E. Z., et al., 2010. Detrital Zircon Provenance from Three Turbidite Depocenters of the Middle-Upper Triassic Songpan-Ganzi Complex, Central China: Record of Collisional Tectonics, Erosional Exhumation, and Sediment Production. *Geological Society of America Bulletin*, 122(11/12): 2041–2062. https://doi.org/10.1130/b26606.1

Wiedenbeck, M., Allé, P., Corfu, F., et al., 1995. Three Natural Zircon Standards for U-Th-Pb, Lu-Hf, Trace Element and REE Analyses. *Geostandards Newsletter*, 19(1): 1–23. https://doi.org/ 10.1111/j.1751-908X.1995.tb00147.x

Willis, B., Blackwelder, E., Sargent, R. H. 1907. Research in China. Press of Gibson Brothers, Washington, D. C. 278–339

Wu, F. Y., Ji, W. Q., Sun, D. H., et al., 2012. Zircon U-Pb Geochronology and Hf Isotopic Compositions of the Mesozoic Granites in Southern Anhui Province, China. *Lithos*, 150: 6 – 25. https://doi.org/10.1016/j.lithos.2012.03.020

Xiang, F., Zhu, L. D., Wang, C. S., et al., 2007. Quaternary Sediment in the Yichang Area: Implications for the Formation of the Three Gorges of the Yangtze River. *Geomorphology*, 85(3/4): 249 – 258. https://doi.org/10.1016/j.geomorph.2006.03.027

Xin, Y. J., Li, J. H., Dong, S. W., et al., 2017. Neoproterozoic Post-Collisional Extension of the Central Jiangnan Orogen: Geochemical, Geochronological, and Lu-Hf Isotopic Constraints from the Ca. 820 – 800 Ma Magmatic Rocks. *Precambrian Research*, 294: 91 – 110. https://doi. org/10.1016/j. precamres.2017.03.018

Xu, G. Q., Kamp, P. J. J., 2000. Tectonics and Denudation Adjacent to the Xianshuihe Fault, Eastern Tibetan Plateau: Constraints from Fission Track Thermochronology. *Journal of Geophysical Research*: *Solid Earth*, 105(B8): 19231 – 19251. https://doi. org/ 10.1029/2000jb900159

Xu, X. S., O'Reilly, S. Y., Griffin, W. L., et al., 2007. The Crust of Cathaysia: Age, Assembly and Reworking of Two Terranes. *Precambrian Research*, 158(1/2): 51–78. https://doi.org/10.1016/ j.precamres.2007.04.010

Xu, X., Zhu, X. Y., Shan, X. P., et al., 2018. Structure and Sedimentary Characteristics of the Meso-Cenozoic Basin Group along the Yangtze River in the Lower Yangtze Region. *Petroleum Geology & Experiment*, 40(3): 303 – 314. https://doi. org/10.11781/sysydz201803303 (in Chinese with English Abstract)

Xu, X., Zuza, A. V., Chen, L., et al., 2021. Late Cretaceous to Early Cenozoic Extension in the Lower Yangtze Region (East China) Driven by Izanagi-Pacific Plate Subduction. *Earth-Science Reviews*, 221: 103790. https://doi. org/10.1016/j. earscirev.2021.103790

Yan, Y., Carter, A., Huang, C. Y., et al., 2012. Constraints on Cenozoic Regional Drainage Evolution of SW China from the Provenance of the Jianchuan Basin. *Geochemistry*, *Geophysics*, *Geosystems*, 13(3): Q03001. https://doi. org/10.1029/ 2011GC003803

Yang, C. Q., Shen, C. B., Zattin, M., et al., 2019. Provenances of Cenozoic Sediments in the Jianghan Basin and Implications for the Formation of the Three Gorges. *International Geology Review*, 61(16): 1980 – 1999. https://doi. org/10.1080/ 00206814.2019.1576066

Yang, S. Y., Li, C. X., Yokoyama, K., 2006. Elemental Compositions and Monazite Age Patterns of Core Sediments in the Changjiang Delta: Implications for Sediment Provenance and Development History of the Changjiang River. *Earth and Planetary Science Letters*, 245(3/4): 762 – 776. https://doi. org/ 10.1016/j.epsl.2006.03.042

Yang, S. Y., Wang, Z. B., Guo, Y., et al., 2009. Heavy Mineral Compositions of the Changjiang (Yangtze River) Sediments and Their Provenance-Tracing Implication. *Journal of Asian Earth Sciences*, 35(1): 56 – 65. https://doi. org/10.1016/j. jseaes.2008.12.002

Yang, S. Y., Zhang, F., Wang, Z. B., 2012. Grain Size Distribution and Age Population of Detrital Zircons from the Changjiang (Yangtze) River System, China. *Chemical Geology*, 296: 26–38. https://doi.org/10.1016/j.chemgeo.2011.12.016

Yang, X. D., Zhao, X. T., Wu, Z. H., et al., 2018. Ar-Ar Geochronology of Basalts in Liuhe Area, Nanjing and Its Geological Significance. *Quaternary Sciences*, 38(3): 705 – 710. https://doi. org/10.11928/j. issn. 1001-7410.2018.03.15 (in Chinese with English Abstract)

Yang, Z. L., Gao, T. S., Ma, M. 2019. Geological Map of the People's Republic of China (East China, 1 : 1 500 000). Geological Publishing House, Beijing. 1–88 (in Chinese)

Yu, J. J., Yue, W., Liu, P., et al., 2020. Provenance Shift during the Plio-Pleistocene in the Vertex of Yangtze Delta and Its Geomorphological Implications. *Minerals*, 10(11): 996. https:// doi.org/10.3390/min10110996

Yu, Z., Huang, D. 1996. Formation Environment of Net-Veined Laterite and Xiashu Loess and Their Ages in the Area along the Yangtze River, Anhui Province. *Geology of Anhui*, 6(3): 48 – 56 (in Chinese with English Abstract)

Yue, W., Jin, B. F., Zhao, B. C., 2018. Transparent Heavy Minerals and Magnetite Geochemical Composition of the Yangtze River Sediments: Implication for Provenance Evolution of the Yangtze Delta. *Sedimentary Geology*, 364: 42 – 52. https://doi. org/ 10.1016/j.sedgeo.2017.12.006

Yue, W., Yang, S. Y., Zhao, B. C., et al., 2019. Changes in Environment and Provenance within the Changjiang (Yangtze River) Delta during Pliocene to Pleistocene Transition. *Marine Geology*, 416: 105976. https://doi. org/10.1016/j. margeo.2019.105976

Zhang, D., Li, C. A., Zhang, S. T., et al., 2024. Discovery of the Miocene Yuanmou Conglomerate and Its Significance for the Drainage Evolution in the Southeastern Tibetan Plateau. *Journal of Earth Science*, 35(6): 2067 – 2080. https://doi. org/10.1007/ s12583-023-1937-7

Zhang, J. Y., Krijgsman, W., Lu, Y. C., et al., 2021. Detrital Zircon Ages Reveal Yangtze Provenance since the Early Oligocene in the East China Sea Shelf Basin. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 577: 110548. https://doi. org/ 10.1016/j.palaeo.2021.110548

Zhang, J., Wan, S. M., Clift, P. D., et al., 2019. History of Yellow River and Yangtze River Delivering Sediment to the Yellow Sea since 3.5 Ma: Tectonic or Climate Forcing? *Quaternary Science Reviews*, 216: 74 – 88. https://doi. org/10.1016/j. quascirev.2019.06.002

Zhang, P. Z., Molnar, P., Downs, W. R., 2001. Increased Sedimentation Rates and Grain Sizes 2 – 4 Myr ago Due to the Influence of Climate Change on Erosion Rates. *Nature*, 410 (6831): 891–897. https://doi.org/10.1038/35073504

Zhang, P., Miao, Y. F., Zhang, Z. Y., et al., 2013. Late Cenozoic Sporopollen Records in the Yangtze River Delta, East China and Implications for East Asian Summer Monsoon Evolution. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 388: 153–165. https://doi.org/10.1016/j.palaeo.2013.08.014

Zhang, X. C., Huang, C. Y., Wang, Y. J., et al., 2017. Evolving Yangtze River Reconstructed by Detrital Zircon U-Pb Dating and Petrographic Analysis of Miocene Marginal Sea Sedimentary Rocks of the Western Foothills and Hengchun Peninsula, Taiwan. *Tectonics*, 36(4): 634 – 651. https://doi. org/10.1002/ 2016TC004357

Zhang, X. Y., Liu, Z. P., Fan, D. F., et al., 2003. Sandy Gravel Sequence in Neogene in Nanjing and Yizheng Area and Genesis and Evolution of the Old Yangtze River. *Jiangsu Geology*, 27(3): 140–147 (in Chinese with English Abstract).

Zhang, X. Y., Liu, Z. P., Fan, D. F., et al., 2004. Stratigraphic Sequence and Age of the Neogene in the Nanjing-Yizheng Area: A Discussion. *Chinese Geology*, 31(2): 179 – 185 (in Chinese with English Abstract)

Zhang, Y. F., Li, C. A., Wang, Q. L., et al., 2008. Magnetism

Parameters Characteristics of Drilling Deposits in Jianghan Plain and Indication for Forming of the Yangtze River Three Gorges. *Chinese Science Bulletin*, 53(4): 584 – 590. https://doi. org/10.1007/s11434-008-0111-1

Zhang, Z. J., Daly, J. S., Li, C. A., et al., 2017. Sedimentary Provenance Constraints on Drainage Evolution Models for SE Tibet: Evidence from Detrital K-Feldspar. *Geophysical Research Letters*, 44(9): 4064–4073. https://doi.org/10.1002/2017gl073185

Zhang, Z. J., Daly, J. S., Li, C. A., et al., 2021. Formation of the Three Gorges (Yangtze River) no Earlier than 10 Ma. *Earth-Science Reviews*, 216: 103601. https://doi. org/10.1016/j. earscirev.2021.103601

Zhang, Z. J., Tyrrell, S., Li, C. A., et al., 2016. Provenance of Detrital K-Feldspar in Jianghan Basin Sheds New Light on the Pliocene–Pleistocene Evolution of the Yangtze River. *Geological Society of America Bulletin*, 128(9/10): 1339 – 1351. https://doi. org/ 10.1130/b31445.1

Zhao, X. D., Zhang, H. P., Tao, Y. L., et al., 2021. Pliocene to Early Pleistocene Drainage Reorganization in Eastern Tibet Inferred from Detrital Zircons. *Geophysical Research Letters*, 48(20): e2021GL094563. https://doi.org/10.1029/2021GL094563

Zhao, X. T., Hu, D. G., Zhang, Y. S., 2008. Genesis and Age of the Gravels Underlying the Xigeda Formation of Panzhihua, Sichuan, China, and Valley Development of the Ancient Jinsha River. *Acta Geoscientica Sinica*, 29(1): 1 – 12. https://doi. org/ 10.3321/j.issn: 1006-3021.2008.01.001 (in Chinese with English Abstract)

Zheng, H. B., Clift, P. D., He, M. Y., et al., 2021. Formation of the First Bend in the Late Eocene Gave Birth to the Modern Yangtze River, China. *Geology*, 49(1): 35 – 39. https://doi. org/10.1130/ g48149.1

Zheng, H. B., Clift, P. D., Wang, P., et al., 2013. Pre-Miocene Birth of the Yangtze River. *Proceedings of the National Academy of Sciences of the United States of America*, 110(19): 7556–7561. https://doi.org/10.1073/pnas.1216241110

Zheng, H. B., Powell, C. M., An, Z. S., et al., 2000. Pliocene Uplift of the Northern Tibetan Plateau. *Geology*, 28(8): 715–718. https:// doi.org/10.1130/0091-7613(2000)028<0715:puotnt>2.3.co;2

Zheng, H. B., Powell, C. M., Rea, D. K., et al., 2004. Late Miocene and Mid-Pliocene Enhancement of the East Asian Monsoon as Viewed from the Land and Sea. *Global and Planetary Change*, 41(3/4): 147 – 155. https://doi. org/10.1016/j. gloplacha.2004.01.003

Zheng, Y. F., Wu, R. X., Wu, Y. B., et al., 2008. Rift Melting of Juvenile Arc-Derived Crust: Geochemical Evidence from Neoproterozoic Volcanic and Granitic Rocks in the Jiangnan Orogen, South China. *Precambrian Research*, 163(3/4): 351 – 383. https://doi.org/10.1016/j.precamres.2008.01.004