

Detrital Zircon Geochronology of Early Jurassic Successions in the Central Yunnan Basin, Southwest China: Implications of Sedimentary Provenance and Tectonic Evolution

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ABSTRACT: The Central Yunnan Basin (CYB) that tectonically located on the southwest margin of the Yangtze Block and to the eastern segment of the Paleo-Tethys tectonic domain, is a typical 'red bed' sedimentary basin formed since Late Triassic. The CYB is composed of mega-thick fluvial and lacustrine facies successions. However, the tectonic evolution and sedimentary provenance studies on this basin are scarce. In this study, we report new detrital zircon ages of four sandstones from the Lower Jurassic Fengjiahe Formation (FJF), including four major clusters of 2 060–1 810, 870–760, 485–430, and 280–254 Ma, with sporadic Archean, Cambrian, and Triassic ages. We interpret that the Archean and Proterozoic zircons were mainly derived from the western Yangtze Block, which may recycle from the Jiangnan Orogen, the Cathaysia Block and the Proterozoic igneous rocks. Ordovician and Silurian zircons were probably from the Ailaoshan orogenic belt, and the Lancang Group in western Yunnan, as well as the Yangtze, Cathaysia and Indosinian blocks. Permian zircons probably came from the Ailaoshan orogenic belt and the Emeishan basalt. The youngest zircon age of ~212.9 Ma indicates that the depositional age of the FJF is younger than the Norian stage. We also proposed a geodynamic model of the CYB and the Ailaoshan orogenic belt during the Mesozoic. The Simao Block to the west of the CYB constituted the Ailaoshan orogenic belt and collaged with the Yangtze Block during the Early Triassic, provided sedimentary provenance to the CYB. The Changning-Menglian zone that composed of the Baoshan and the Simao Blocks, uplifted in the Late Triassic and provided provenance to the CYB. Collapse of the Ailaoshan orogenic belt in Late Triassic probably provided channel for source materials that transported from the Lancang granites to the CYB. We propose a transtensional tectonic setting of the central Yunnan during the Early Jurassic, after a short collision during the Indosinian Movement in the Late Triassic.

KEY WORDS: central Yunnan Basin, detrital zircon, Fengjiahe Formation, Jurassic, sedimentary provenance, Yimen area, sedimentation.

0 INTRODUCTION

Sedimentary records contain valuable information about the coupling relationship between a sedimentary basin and orogenic belt evolution (Gehrels, 2014; Geh-

rels et al., 2008). Sediment provenance analysis based on accessory minerals aims to identify potential provenances and understand the tectonic evolution of a basin. Zircon can retain its original provenance information under different transport conditions due to its robustness and resistance to weathering (Cawood et al., 2012; Weltje and von Eynatten, 2004; Fedo et al., 2003), making it an ideal mineral for provenance analysis (Gehrels, 2014; Fedo et al., 2003). *In-situ* zircon geochronology utilizing laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) is widely used in the provenance analysis of sedimentary basins (Gehrels, 2014;

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Gehrels et al., 2008).

The Central Yunnan Basin (CYB) is located on the southwest margin of the Yangtze Block and to the eastern segment of the Paleo-Tethys tectonic domain. It is surrounded by the Chenghai fault in the northwest that connected with the Songpan-Ganzi Block, the Redriver fault zone that is connected with the Indosinian Block in the southwest, and the Xiaojiang fault in the east (Yang, 2014; Yang et al., 2014; Li et al., 2013; Wang et al., 2007). The Paleo-Tethys Ocean around the Yangtze Block mainly closed during the Indosinian Period, forming a compressional background for multiple collision zones (Yang, 2014). The CYB was characterized as a Mesozoic 'red beds' sedimentary basin formed by the long-term uplift of the Sichuan-Yunnan paleocontinent core (also named as the Kang-Dian paleocontinent) and violent subsidence during the late Indosinian Period (Wang et al., 2007) (Figure 1). The tectonic evolution of the CYB was dominantly controlled by the development of surrounding orogenic belts. However, the evolution of the Paleo-Tethys Ocean and the Ailaoshan orogenic belt in the western part of the CYB remains controversial (Liu et al., 2022; Chen et al., 2021; Chang, 2016; Zhang and Cao, 2002), which can partially be attributed to the scarcity of sedimentary provenance analyses on this basin. The tectonic setting of CYB is also in debate, and it has been proposed as a foreland basin formed in a compression setting (Tan et al., 2004, 2000; Zhu et al., 2000; Xu et al., 1999; Liu et al., 1998; Pu et al., 1996), a rifted basin formed in an extensional setting (Fang, 2004), or a rifting basin formed in a compression setting (Yang, 2014).

To unveil the potential sedimentary provenance of the CYB and its tectonic evolution, this study performed detrital zircon LA-ICP-MS U-Pb geochronology on four typical sandstone samples from the Jurassic Fengjiahe Formation (FJF) near the Yimen County of the CYB has been reevaluated. Our age data also provide new evidence to inform geodynamic models of the CYB and the Ailaoshan orogenic belt during the Mesozoic.

1 GEOLOGICAL BACKGROUND

The CYB is tectonically located in the Wuding-Yimen area of the southern segment of the Kang-Dian microcontinent, which lies on the southwestern edge of the Yangtze Block (Figure 1). The study area belongs to the Kunming region situated to the east of the Luzhijiang fault and is mainly composed of Mesozoic terrestrial successions. These include three main units, the Lower Jurassic Fengjiahe Formation (FJF), the Middle Jurassic Zhanghe Formation (ZHF), and the Late Cretaceous Matoushan Formation (MTF) (Table 1) (Figure 2) (BGMRYN, 1982). The lower member of the FJF (J_1f) is equivalent to the Shawan Member of the Lufeng Formation (LFF) (J_1sh). The upper member of the FJF is equivalent to the Zhangjiao Member of the Lufeng Formation (J_2zh). The Lower FJF and the Upper Triassic Shezi Formation (T_3s) in this area were deposited mostly continuously, while

the MTF and the ZHF were in contact with a disconformity (Yu, 2020) (Figures 2, 3).

The 'red beds' in the CYB were traditionally referred to as the Middle Jurassic Lufeng series consisting of the Lufeng and Leibu layers (BGMRYN, 1982). NIGP et al. (1975) named the red beds the Lower-Lufeng Formation based on the sauropod footprint fossils and assigned it to Lower Jurassic and these sequences were the Middle Jurassic Lufeng Group that included the Shawan and Zhangjiao members. Later on, the FJF was defined as purplish-red to dark purplish-red mudstone and sandy mudstone, interbedded with multi-layer of gray-green and yellow-green quartz sandstone, as well as fine grained calcareous conglomerate (Yu, 2020).

2 SAMPLING AND ANALYTICAL METHODOLOGY

We collected four representative fine-grained sandstone samples GX1-1, YMS-15, YMS-16 and GX41-1 from the FJF (Figure 3). Detrital zircon grains were separated from the sandstones following standard procedures. Zircon grains were separated with 80–120 mesh, mounted and polished for microstructure observation, and then polished until 2/3 of the grain size was exposed for LA-ICP-MS analysis of typical zircons. Cathodoluminescence (CL) imaging was performed in the State Key Laboratory of Continental Dynamics, Northwestern University. Zircon LA-ICP-MS U-Pb dating was performed with Agilent 7500A in the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan). The laser ablation system is GeoLas 2005 produced by MicroLas, Germany. The laser beam diameter was 32 μm , with frequency of 5 Hz. Isotope ratios and element contents of samples were calculated by GLITTER (Ver. 4.0, Macquarie University). General Pb correction was done with ComPbCOR # 3-151. Age calculation and concordia diagrams were completed by Isoplot 3.0.

3 DETRITAL ZIRCON U-Pb AGE DATA

The morphology, internal structure and U-Pb ages of zircons vary among these four samples. The zircon grains range from 50 to 200 μm in size, with length-to-width ratios of 1–3. The CL images show that most zircons have oscillatory zonings typical of magmatic crystallization, and a few grains show planar or fan-shaped structures that indicate a metamorphism or hydrothermal origin (Figure 4). Grains with euhedral morphology and clear oscillatory zonings usually show higher Th/U ratios and are indicative of magmatic origins. Older rounded grains usually have relatively low Th/U ratios, indicating long-distance transportation or metamorphic origins (Wu and Zheng, 2004). $^{206}\text{Pb}/^{238}\text{U}$ ages were adopted for samples younger than 1 000 Ma, while $^{207}\text{Pb}/^{206}\text{Pb}$ ages were used for those older than 1 000 Ma. Zircon grain ages with discordance greater than 20% were excluded from the age analysis. Age data are shown in supplementary Table S1.

Seventy-one out of 76 analyses for the sandstone

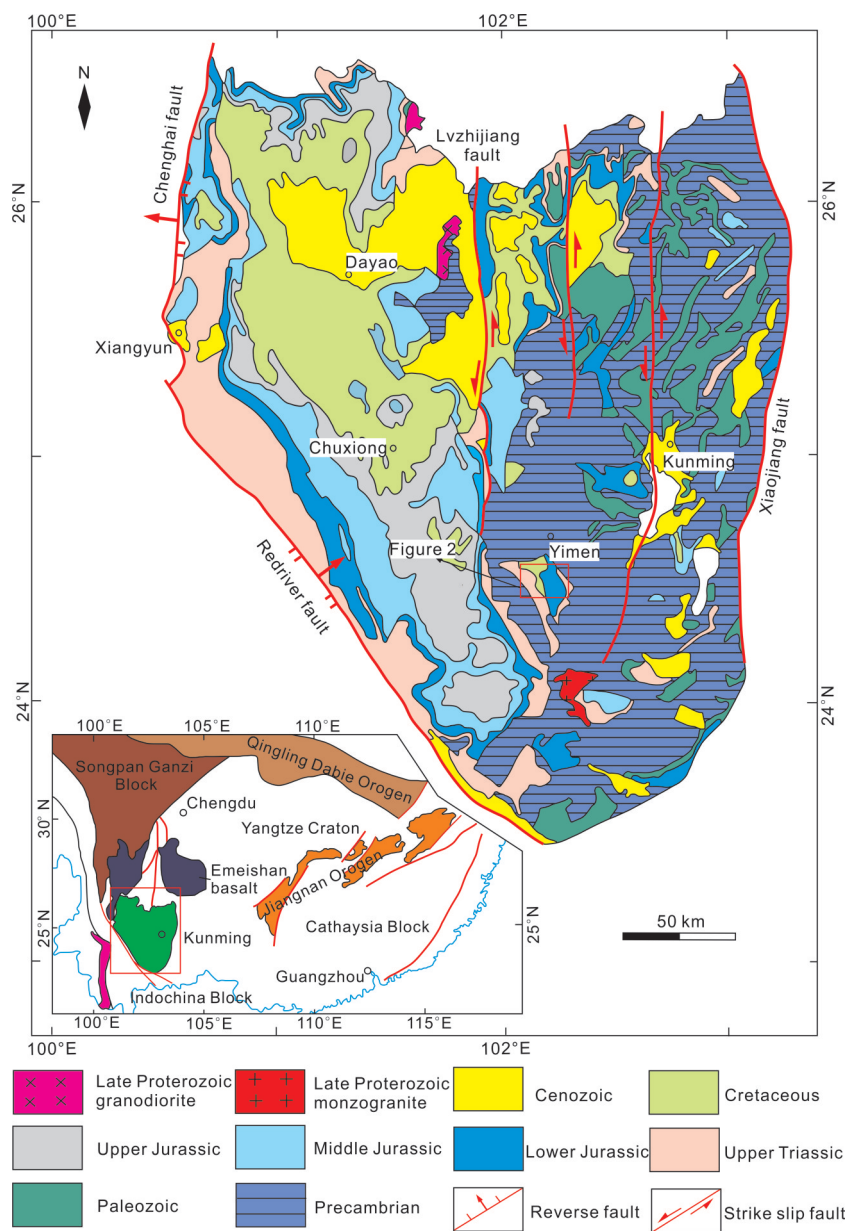


Figure 1. Geological map of the central Yunnan Basin (modified after the scale 1 : 500 000 geological map of Yunnan Province). The map of SW China (modified after Chen et al., 2020).

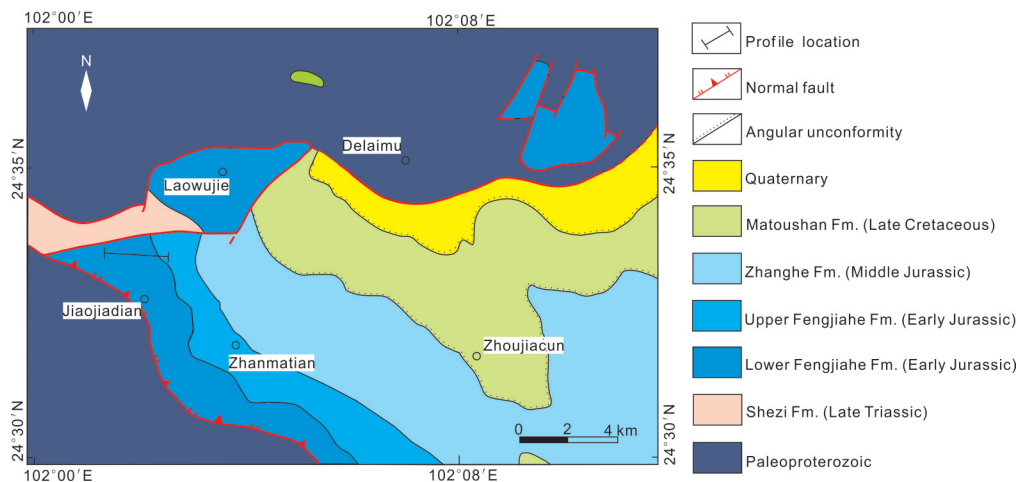


Figure 2. Geological map nearby the Yimen County, Yuxi City, Yunnan Province, SW China (modified after Yu, 2020). Fm. Formation.

Table 1 Stratigraphic division of the Central Yunnan Basin (modified from Fang and Li, 2008)

Earthem	Sytem	Series	Formation				Thickness (m)	Facies	Lithology description	
Mesozoic			Chuxiong		Kunming					
	Cretaceous	Lower	Tuodian	Upper	Anning	Upper(pl)	0 800	Lacustrine	Dark grey,yellow green mudstone, marlite	
		Upper		Middle		Lower		Lacustrine	Purolish red, yellow green sandstone	
				Lower	Madishan	Upper				Erythrinus silstone, mudstone
	Jurassic	Middle	Shedian			Lower	400 1 000	Lacustrine	Purolish red feldspathic quartz sandstone, mudstone	
			Zhanghe	Upper	Laoluocun				0 1 000	Celadon, purolish red sandstone, siltstone, mudstone
				Middle	Chuanjie					Purolish red mudstone,siltstone
				Lower	(I)					Green sandstone section
		Lower	Fengjiahe	Lufeng	Zhangjiaao	400 1 000	Lacustrine Fluvial		Dark purple, purolish red siltstone, sandy mudstone and mudstone	
					Shawan					
		Yubacun	Yubacun(pl)		0 400		Grayish yellow sandstone, purolish red siltstone, mudstone			
Notes: pl. partial lacuna; I. lacuna.										

Notes: pl. partial lacuna; l. lacuna.

sample GX1-1 collected from which part of FJF yield concordant ages, and most of them have Th/U ratios higher than 0.4, indicative of a magmatic origin (Li, 2009; Wu and Zheng, 2004). The major age peaks include Paleoproterozoic (2 497–1 731 Ma, $n = 32$) and Neoproterozoic (988–543 Ma, $n = 11$), and secondary age peaks occur at Archean (2 855–2 517 Ma, $n = 5$), Ordovician–Silurian (484–413 Ma, $n = 6$), Permian (296–257 Ma, $n = 6$) and Mesoproterozoic (1 500–1 022 Ma, $n = 5$). Sporadic Triassic (213 Ma) and Cambrian (524 Ma) ages have also been detected.

The zircon morphology, internal structures and U-Pb data of sandstone sample YMS-15 collected from the upper part of the bottom of the FJF are similar to those of sample GX1-1 (Figure 4). U-Pb analysis of 87 detrital zircons yielded 85 concordant ages with Th/U ratios > 0.4, typical of magmatic zircons. The major age peaks occur at the Paleoproterozoic (2 428–1 678 Ma, $n = 49$) and the Permian (298–258 Ma, $n = 8$), while secondary age peaks are Neoproterozoic (911–565 Ma, $n = 7$) and Mesoproterozoic (1 169–1 025 Ma, $n = 5$), with sporadic Late Triassic (221 Ma), Carboniferous (327 Ma), Devonian, Cambrian, and Archean (2 678.71 Ma) ages.

Zircon grains of YMS-16 are small in size (Figure 4). The 138 out of 139 ages are concordant with Th/U ratios mostly > 0.4. Ages of this sample mainly cluster around Paleoproterozoic (2 500–1 665 Ma, $n = 70$) and Neoproterozoic (983–580 Ma, $n = 29$), with subordinate clusters around Ordovician–Silurian (476–426 Ma, $n = 7$) and Permian (289–253 Ma, $n = 6$), middle Proterozoic (1 594–1 146 Ma, $n = 5$) and Carboniferous (350–303 Ma, $n = 5$), as well as sporadic Triassic (234 Ma), Devonian (384 Ma) ages.

The sample GX41-1 was collected from the top of the FJF. Zircon grains show similar characteristics to the other samples, with grain sizes of 50–200 μm . Seventy-four concordant ages were obtained from 77 zircons,

with major age peaks at Paleoproterozoic (2 461–1 683 Ma, $n = 32$), Neoproterozoic (992–628 Ma, $n = 12$) and Mesoproterozoic (1 411–1 062 Ma, $n = 6$). Secondary age peaks include Ordovician–Silurian (456–429 Ma, $n = 6$), and Permian (272–255 Ma, $n = 4$). There are also sporadic ages of Triassic (237.5 Ma), Carboniferous (316 Ma), Devonian (410 Ma) and Archean (2 943 Ma) ages.

The detrital zircon morphological characteristics and Th/U ratios of these four samples indicate that magmatic rocks dominated the potential sedimentary provenance. The major age peaks in the four samples include Paleoproterozoic (2 060–1 810 Ma), Neoproterozoic (870–760 Ma), Ordovician–Silurian (485–430 Ma), and Permian (280–254 Ma) (Figure 5). Sporadic ages of 2 943 Ma (Archean) and 221 Ma (Late Triassic) are also obtained.

4 DISCUSSION

4.1 Depositional Age of the FJF

A depositional discontinuity is present between the FJF and the ZHF. A large number of fossils have been discovered in these formations, especially dinosaur fossils, with the majority buried in the lower and upper members of the FJF (also named as the Shawan and Zhangjiaao Members of the LFF), including *Yannanosaurus Huangi*, *Yuannanosaurus robustus*, *Lufengosaurus Huenei*, and *Yimenosaurus Youngi*, *Coelurosauria Huenui* (Yu, 2020), *Irisosaurus Yimenensis* (Peyre de Fabrègues et al., 2020), etc. All these fossils were assigned to the Early Jurassic. Yu (2020) identified the palynological assemblage of *Pinuspollenites-Polypodiaceae-Athyriaceae* in the first member of the LFF and *Pinuspollenites-Taxodiaceae-Pter* in the second member of the LFF in the Yimen area. The age of the first and second members of the LFF were respectively assigned to Early Jurassic and mid–late Early Jurassic (Yu, 2020). Therefore, the lower and upper member of the FJF were stratigraphically correlated with the first and second members of the LFF, respectively. Similar

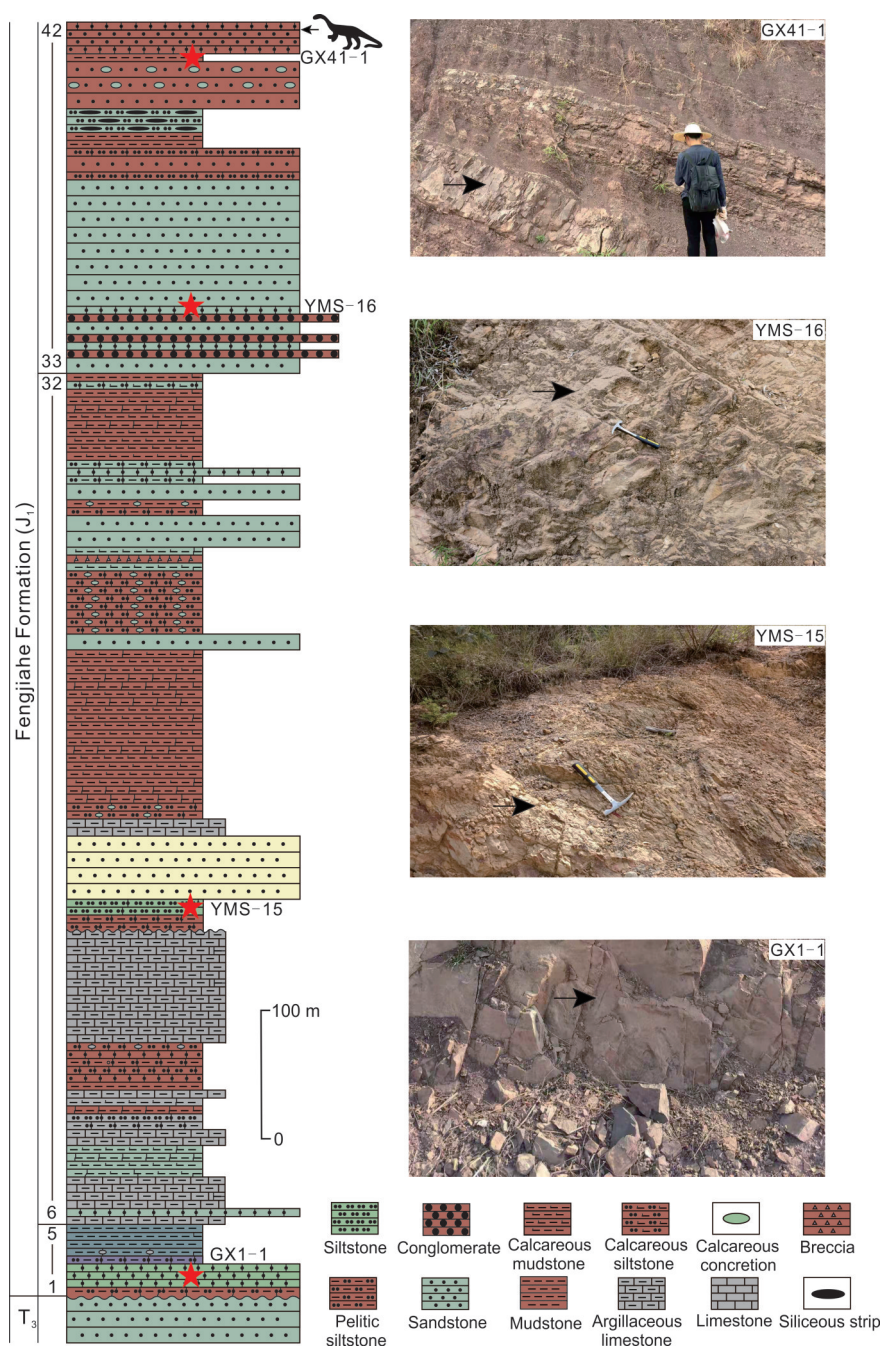


Figure 3. Lithology of the Early Jurassic Fengjiahe Formation and sampling locations nearby the Yimen County, Yuxi City, SW China.

biostratigraphic correlations among the successions in the CYB were widely accepted in previous studies. However, these biostratigraphic correlations might not be convincing due to the lack of index fossils and reliable absolute age constraints. In this study, we obtained the youngest detrital zircon age of 212.9 Ma from the sample GX1-1 for the FJF, indicating that its depositional age in the Yimen area was younger than the Norian Stage of the Late Triassic. As the CYB was an inland basin and relatively stable during the Late Triassic–Jurassic Period, contemporary volcanism can hardly be recorded in the basin. Therefore, the depositional age of the FJF still needs further constraints.

4.2 Sedimentary Provenance of the FJF

Sedimentary provenance analysis of the CYB is still lacking so far. Chang (2016) concluded that the sources of the Late Triassic to the Early Jurassic successions in the central of CYB came from the Ailaoshan orogenic belt based on detrital zircon geochronology of the Midu area, Chuxiong City.

Jurassic successions of considerable thickness in the Chuxiong area in the CYB cover the Triassic sedimentary units conformably, though they are sporadically distributed in the Kunming area with most in direct contact with the Proterozoic Kunyang Group and locally in contact with Late Triassic successions. The Lower Juras-

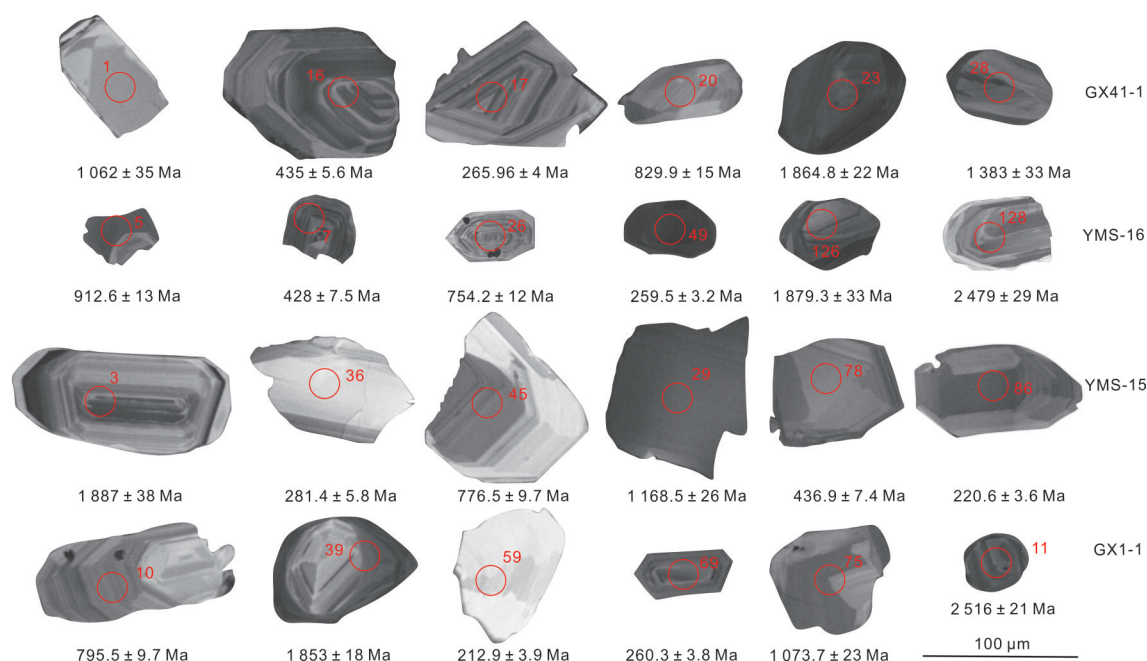


Figure 4. CL diagram of typical zircon grains.

sic FJF is unconformably over the Upper Triassic Shezhi Formation in the Yimen area. Based on the characteristics of the detrital zircon from the four samples and their high Th/U ratios, we concluded that magmatic rocks dominated the source area. The analyzed samples have revealed significant age peaks, with the majority falling within the Paleoproterozoic (2 060–1 810 Ma), Neoproterozoic (870–760 Ma), Ordovician–Silurian (485–430 Ma) and Permian (280–254 Ma). In addition, several sporadic zircon ages of 2 942.9 Ma (Archean) and 220.68 Ma (Late Triassic) have also been identified (Figure 5).

Previous studies hold that the Early Precambrian basement rocks are mainly exposed in the Yangtze Block but limited in the Cathaysia Block. Archean crystalline basement is mainly developed in the northern part of the Yangtze Block, represented by the Kongling Group, Huangtuling granite and Yudongzi Group (Zhang et al., 2019). The protolith ages of the Kongling Group gneiss are 3.3–2.7 Ga (Gao et al., 2011, 1999). The Zircon U-Pb age of the Huangtuling granite are 2.78–2.74 Ga, and the metamorphic ages of zircon rims are 2.0 Ga (Gao et al., 2011). Zircon ages of amphibolite and orthogneiss in Yudongzi Group are ~2.7 Ga (Wu et al., 2008). The Wuyishan area has limited Paleoproterozoic metamorphic rocks, which consist mainly of granite gneisses and a small amount of amphibolite, with zircon U-Pb ages ranging from 1 910 to 1 780 Ma (Xia et al., 2012; Yu et al., 2009). A zircon U-Pb age of 2.0 Ga was obtained from the albitite and metamorphic volcanic rocks of the Dahongshan Group (Kou et al., 2017). Zhang et al. (2019) reported 2.35 Ga granite gneisses in Shiping County of Yunnan Province, as well as $2\,347 \pm 4.9$, $2\,324 \pm 8.6$ and $2\,329 \pm 5.9$ Ma for granite basement. Liu et al. (2021c) obtained zircon ages of $2\,241 \pm 16$ and $2\,252 \pm 14$ Ma from tuff in the Luowazhi Formation of the Yimen

Group. Liu et al. (2021b) reported a zircon U-Pb age of 2.43 Ga from tonalite in the Yimen area, indicating an Early Paleoproterozoic magmatic activity on the southwest margin of the Yangtze Block. Zhang et al. (2019) obtained zircon ages of $1\,910 \pm 5.7$ and $1\,843 \pm 7.6$ Ma from mylonized granodiorite samples in Shiping County of Yunnan Province, supporting the existence of magmatic events on the western margin of the Yangtze Block. Liu et al. (2018) acquired ages of $1\,842 \pm 26$ Ma (MSWD = 7.6, $n = 29$) and $1\,860 \pm 25$ Ma (MSWD = 2.5, $n = 11$) from tuff in the Meidang Formation of the Kunyang Group in central Yunnan Province. Liu et al. (2020a) obtained zircon U-Pb ages of $1\,858 \pm 18$ Ma (MSWD = 0.90, $n = 13$) from diabase in Shizishan copper deposit in the Yimen area. In addition, the Phan Si Pan area in the North Vietnam Block gave ages of 2.6–2.1 Ga (Zhao et al., 2019). Peng et al. (2006) found a zircon age of $1\,977 \pm 44$ Ma from the biotite granite of the southern Lincang City, SW Yunnan Province, implying a Paleoproterozoic crystalline basement (Liu et al., 2021b). Combined with the CL images, we believe that the rounded shapes of Archean and Paleoproterozoic zircons were likely due to their recycling from nearby provenance regions. Further comprehensive analysis shows that Archean (2 945 Ma) and Paleoproterozoic (2 060–1 810 Ma) zircons mainly came from the Yangtze Block and the ancient basement on its western margin, and possibly from the Cathaysia Block and the western Yunnan Province (Figure 6).

The Neoproterozoic magmatic rocks are found across Southwest China, including the Sibei and Fanjingshan areas on the western margin of the South China Block (876–725 Ma) (Yao et al., 2019; Wang et al., 2012) and the Panxi-Hannan arc (Zhao et al., 2018) in NW Yunnan Province (864–735 Ma), and the Ailaoshan orogenic belt (814–750 Ma) (Cai et al., 2015, 2014). Liu et al.

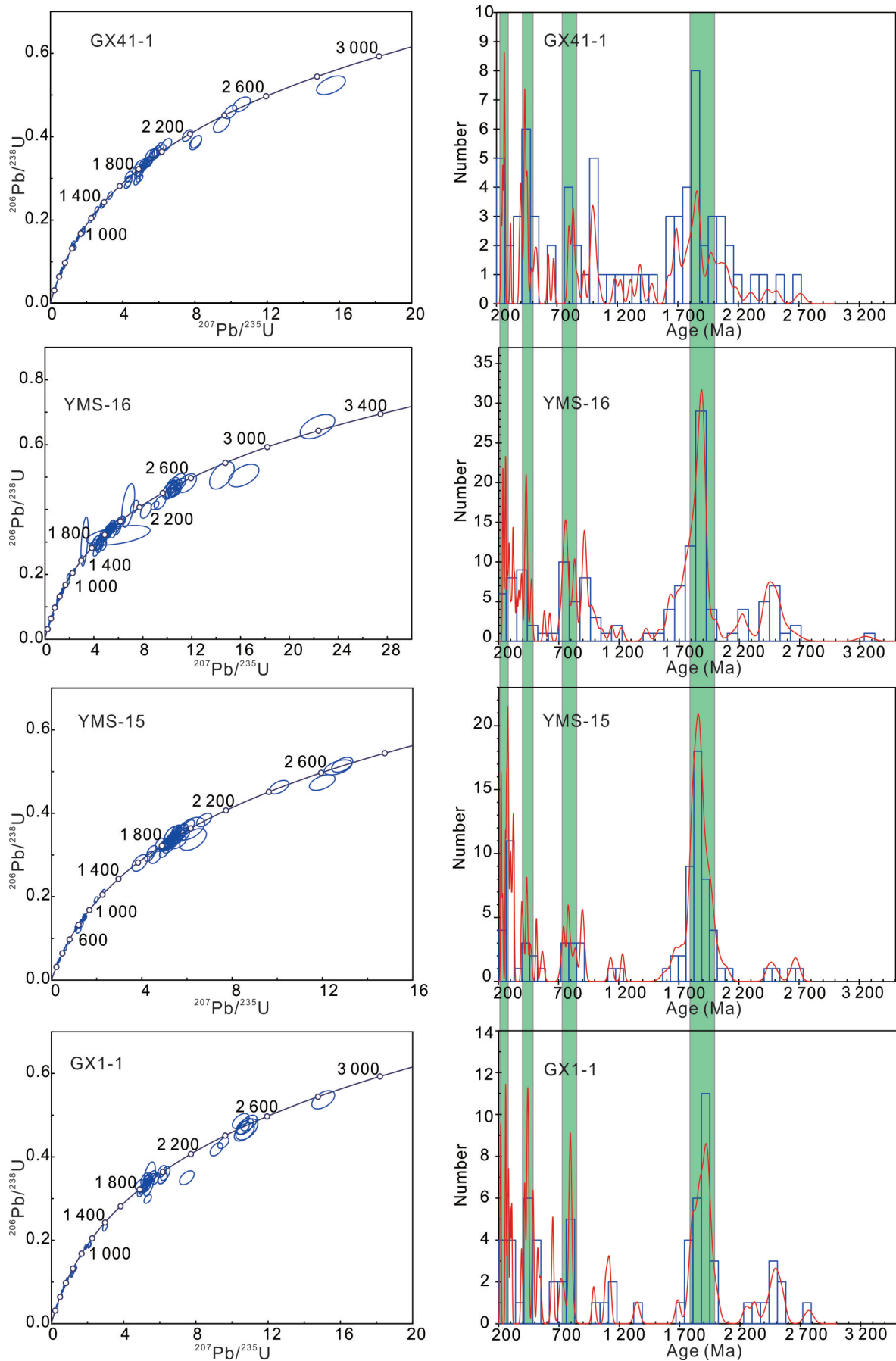


Figure 5. Age distribution histograms of the detrital zircon grains in this study.

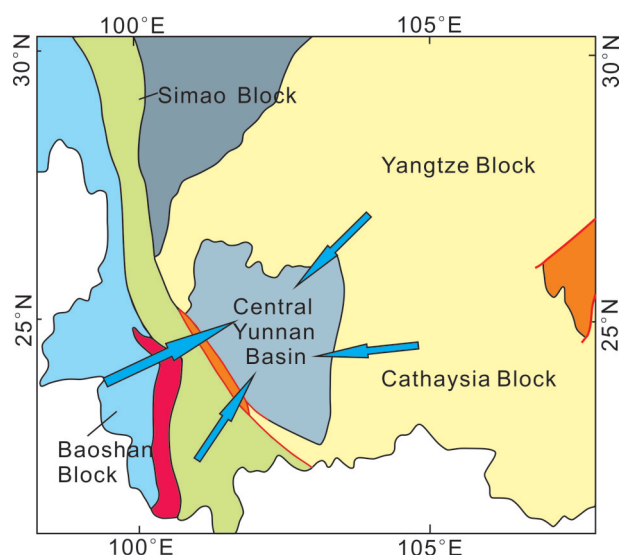


Figure 6. Possible sedimentary provenances of the Early Jurassic successions in the Central Yunnan Basin.

(2021a) conducted zircon U-Pb dating for a Syenite pluton on the southwestern margin of the Yangtze Block ($1\,007 \pm 10$ Ma, MSWD = 2.3, $n = 21$). Liu H G et al. (2019) obtained zircon ages of 879 ± 4.7 Ma and 878.0 ± 4.0 Ma from two tuff samples from the Lubiao Formation in Xiaojie Town of Yimen County. Liu S L et al. (2020) and Liu J P et al. (2019) used zircon U-Pb dating to determine the age of the tuff at the bottom of the Neoproterozoic Chengjiang Formation in the Yimen area as 812 ± 5.5 Ma (MSWD = 0.46, $n = 17$). These ages indicate the existence of magmatic activity during the Neoproterozoic. Kou et al. (2022) interpreted the age of 830 ± 7 Ma as the emplacement age of the Neoproterozoic gabbro in the Sibei area, northern Guangxi Province of SW China, which is tectonically located in the western section of the Jiangnan orogenic belt. Therefore, the Neoproterozoic (870–760 Ma) components in our samples were mainly sourced from the western margin of the Yangtze Block, with components from the Jiangnan orogenic belt and Cathaysia Block.

During the Ordovician – Silurian Period, magmatic rocks were exposed in the South China and Simao-Indosinian Block (Mao et al., 2012; Wang et al., 2007). Large amounts of intermediate to acidic magmatic rocks are exposed in the Yunkai area in the west of South China Block and the Laojunshan area in the Song Chay area on the China-Vietnam border (Zhou et al., 2017). A small amount of Ordovician–Silurian felsic magmatic rocks are also present on the western margin of the Simao Block (Liu J P et al., 2019; Mao et al., 2012). The Truong Son belt and Phuoc Son-Tam Ky belt in the southeastern part of the Indosinian Block also have a large number of Ordovician–Silurian felsic magmatic rocks. Some scholars obtained crystallization ages of 462–456 Ma from metamorphic volcanic rocks in the Lancang Group (Shi et al., 2015). Wang et al. (2016) found an Early Paleozoic diorite age of 468 Ma in the Niujingshan area of western

Yunnan Province. Nie et al. (2015) obtained ages of 456 ± 3 , 456 ± 7 and 459 ± 14 Ma from three metamorphic volcanic rocks of Huimin Formation of the Lancang Group in western Yunnan Province. Zircon U-Pb ages of 462 ± 6 and 454 ± 27 Ma for two metamorphic volcanic rocks in the Lancang Group were obtained (Xing et al., 2017, 2016). Considering that both of the western and central parts of Yunnan Province were located in the same passive continental rift setting during Ordovician–Silurian (484–430 Ma), we speculate that the detrital sources may come from the contemporaneous magmatic rocks in the Simao area and its vicinity, with potential provenances from the Lancang Group, Yangtze, Cathaysia and Indosinian blocks.

A large number of Permian to Triassic intermediate-acid magmatic rocks are exposed in the Ailaoshan-Jinshajiang orogenic belt (280–240 Ma), such as the Fengbieshan-Yangzong rhyolite porphyry in the Ailaoshan area (266–260 Ma) (Li, 2013; Zhao et al., 2013a, b), Zuobo granodiorite-quartz diorite porphyrites (265–263 Ma) (Li, 2013), and granitic rocks in Xinanzhai, Goutoupo and Tongtiange (252–244 Ma) (Liu et al., 2018, 2017, 2015, 2014, 2013), and rhyolite of the Renzhi-Xueshan and Pantiangge Formations in the Jinshajiang orogenic belt (~247 Ma) (Zi et al., 2012a, b, c). In addition, the Permian Yangxin-Leping epoch witnessed large-scale volcanic eruptions between 265 and 254 Ma in the Emeishan large igneous province across Yunnan, Guizhou and Sichuan provinces (Shen et al., 2019; Li et al., 2013). Combined with zircon ages and CL images, we conclude that the Permian to Triassic ages in our samples (study area) may come from the Emeishan basalt near the Ailaoshan orogenic belt. The sporadic Triassic and younger ages are coincident with the timing of the high-pressure metamorphism in the Lancang-Shuangjiang area in western Yunnan Province at 246–225 Ma (Wang et al., 2020, 2019), overlapping with the Ladinian Stage. Zircon U-Pb ages of the Mengku pluton are 236.2 ± 3.7 Ma (Liao et al., 2014). Meanwhile, Lincang granite is considered post-collision products with ages concentrated in 234–210 Ma (Dong et al., 2013; Peng et al., 2013; Kong et al., 2012), belonging to the Late Triassic Carnian and Norian stages. Fan et al. (2009) studied the main lithologic biotite monzogranite in the northern and southern sections of the Lincang granite and gave similar formation ages of 229.4 ± 3.0 and 230.4 ± 3.6 Ma, respectively, while the main lithologic biotite monzogranite in the middle section is 230.4 ± 3.6 Ma. Zhou et al. (2018) conducted zircon U-Pb dating for the Menghai granite in the Jinnan Section of the Lincang granite and obtained Late Triassic Ages (225–215 Ma). All these geochronological studies confirm that the Lincang batholith was formed in the Late Triassic. The younger Triassic ages (~220 Ma) obtained from our samples are consistent with the ages of Lincang granitoids in western Yunnan Province, whereas no magmatic rocks of this ages are found in the Ailaoshan orogenic belt. Therefore, the Middle Permian–Triassic provenance

of the FJF was supplied by the Lincang granite in western Yunnan Province and other contemporary units.

4.3 Tectonic Implications

The evolution of sedimentary basins are closely related to the evolution of surrounding orogenic belts (Gehrels, 2014; Gehrels et al., 2008). The Ailaoshan orogenic belt is an intracontinental orogenic belt developed on a passive continental margin (Zhang and Cao, 2002). It is believed that the Ailaoshan orogenic belt subducted to the west in Late Permian, and the collision occurred in Middle and Late Triassic. The Ailaoshan thrust uplifted in the Carnian Stage (Late Triassic, the first stage of the orogeny), providing source materials to the CYB, and the second thrust (the second stage of the orogeny) lasted from the Jurassic to Cretaceous (Chang, 2016; Zhang and Cao, 2002). Liu et al. (2022) believed that the Ailaoshan Ocean opened in Late Silurian to Early Devonian, eventually closed in Late Permian–Early Triassic and then expanded after the collision in Middle to Late Triassic. Chen et al. (2021) believed that the Ailaoshan Ocean closed at ~247 Ma and uplifted at ~235 Ma. The Changning-Menglian zone in the Sanjiang area (western Ailaoshan belt) is an important part of the eastern Paleo-Tethys, along which the Lincang granitic pluton, the largest orogenic belt in Yunnan Province, developed, serving as a vital site for investigating the subduction of the Paleo-Tethys Ocean (Yu et al., 2003; Chen, 1987). Fan et

al. (2009) proposed that the Paleo-Tethys Ocean Basin remained open until the late Early Triassic, followed by continental/continental-arc collision that may occur in the Late Triassic, and the tectonic evolution of the Paleo-Tethys in this region finally ended at the end of the Triassic. Liu et al. (2020b) and Wang et al. (2018) believed that the Changning-Menglian Paleo-Tethys in the Sanjiang area underwent subduction from the late Early Paleozoic to Late Paleozoic, the main collision occurred from Late Permian to Early Triassic, and the orogeny occurred since Late Triassic. However, controversies remain on the evolution of the Paleo-Tethys in western Yunnan Province the Ailaoshan orogenic belt and the Changning-Menglian boundary zone (Wang, 2020).

Some scholars considered that the CYB was a foreland basin or peripheral foreland basin (Tan et al., 2004, 2000; Pu et al., 1996). Recent studies have proposed the western CYB was a rifted basin based on sedimentary provenance and geochemical analysis (Liu et al., 2002). Wu (2003), Wu et al. (1993) believed that the Late Triassic Yunnanyi and Luojiadashan formations exposed in the west of the basin were formed in a bathyal and semi-bathyal rift environment and were connected with the Lanping-Simaoguo Basin until the late Middle Jurassic. Cheng (2004) believed that the Ailaoshan belt did not exist from Middle Triassic to the Jurassic, and mountains uplifted since the Early Cretaceous on a large scale. Yang (2014) believed that no foreland basin was formed

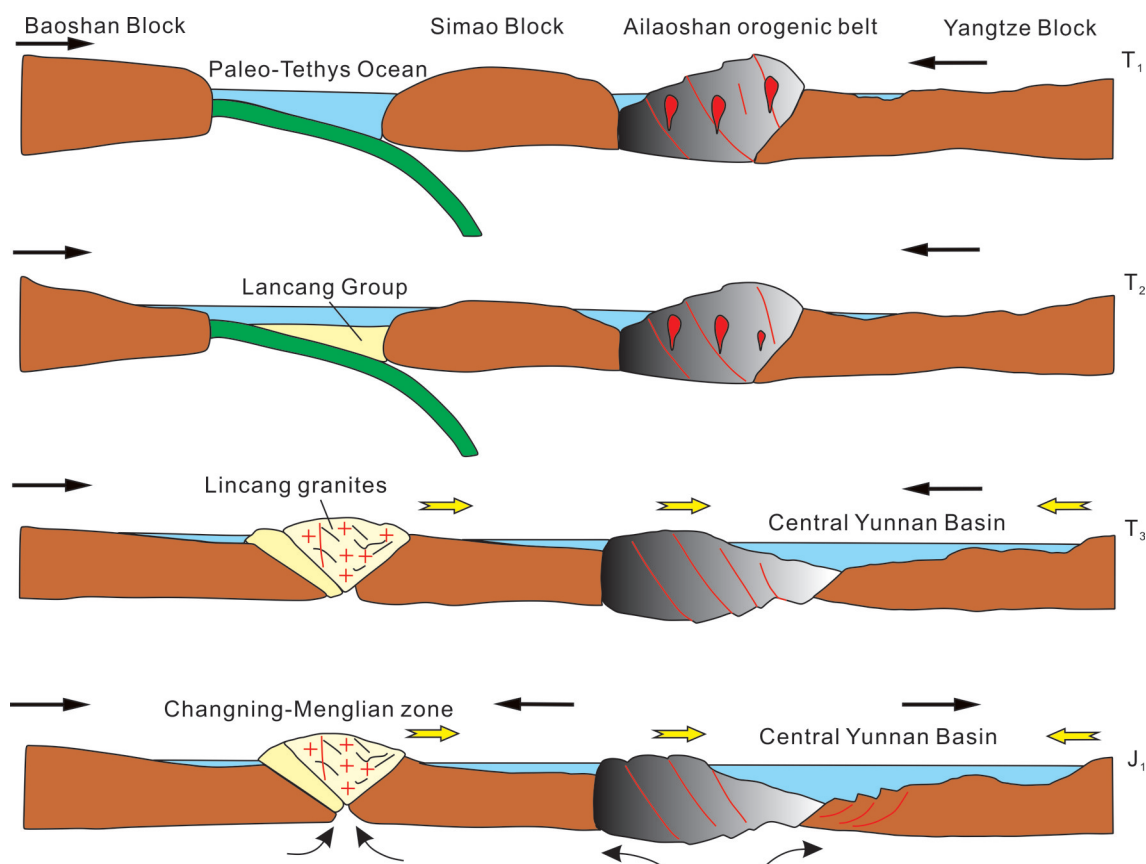


Figure 7. Evolution model of the central Yunnan Basin and its vicinity, moving direction of the blocks; transportation direction of the source materials (modified after Liu et al., 2022; Wang et al., 2020).

in the Chuxiong area of the CYB, and the compression resulting from collision was controlled by the strike-slip of the Redriver-Ailaoshan fault.

In this study, we detected a wide age spectrum for the samples from the FJF, indicating various potential sedimentary provenances. As the most dominant sedimentary provenance, Archean and Proterozoic sediments might be sourced from the Yangtze Block, where an ancient basement may have existed in the western margin of the Yangtze Block (Liu et al., 2020a). In addition, the Jiangnan and Sanjiang orogenic belts in western Yunnan Province were also substantial provenances for the CYB. Moreover, sporadic Late Triassic zircons possibly came from the Lincang granite in western Yunnan Province.

Furthermore, we speculate that the Ailaoshan orogenic belt and the Lincang granite provided the source materials for the CYB. A simple basin evolution model is shown in Figure 7. Combining with evidence in previous studies (e.g., Liu et al., 2022; Wang et al., 2020), we interpret that the Simao-Indosinian Block on the western Yimen area collided with the Yangtze Block and uplifted during the Early Triassic, forming the Ailaoshan orogenic belt. The Baoshan and Simao Blocks collided during the late Middle to Late Triassic, forming the Sanjiang zone, with the Lincang granite pluton forming along it, and uplifted in the end of the Late Triassic (Tian et al., 2021; Wang et al., 2020, 2019). The Simao Block and Yangtze Block first collided to form the Ailaoshan orogenic belt and then extended after the collision in the end of Late Triassic. The collapse of the Ailaoshan orogenic belt in the Late Triassic connected the central and western Yunnan Province. Synchronously, the uplifting of the Sanjiang orogenic belt since Late Triassic make it possible for transporting source materials from the Lincang granite through the Ailaoshan belt and subsequently depositing them in the CYB. In addition, the extensional tectonic setting lasted from the end of Late Triassic to Early Jurassic, thus we argue that the CYB was not a foreland basin that formed in a compressional setting.

5 CONCLUSIONS

Detrital zircon geochronology shows that the depositional age of the Lower Jurassic FJF in the Yimen area of the CYB is younger than 212.9 Ma. The Paleoproterozoic (2 060–1 810 Ma) and Neoproterozoic (870–760 Ma) zircons suggest source materials from the Yangtze Block, the Jiangnan orogenic belt, the Cathaysia Block and the western Yunnan Proterozoic basements. The Ordovician-Silurian zircons (485–430 Ma) were mainly from Ailaoshan orogenic belt in western Yunnan Province. The Permian zircons (280–254 Ma) may come from the Emeishan basalt and Permian magmatic rocks in the Ailaoshan orogenic belt. The Early–Middle Triassic zircons may come from the Ailaoshan orogenic belt, and the sporadic zircons younger than 220 Ma were from the Lincang granite in western Yunnan Province.

The Simao-Indosinian Block to the west of the

Yimen area in the CYB was collided with the Yangtze Block and then uplifted during the Early Triassic. The Ailaoshan orogenic belt formed due to this collision, then collapsed during the Middle–Late Triassic and provided source materials to the CYB. The Baoshan and the Simao-Indosinian Blocks collided in the east in the Late Triassic, thus the Changning-Menglian zone formed and then uplifted. The Ailaoshan orogenic belt collapsed during later extension since Late Triassic, make it possible to transport source materials from the Lincang granite to cross the mountain and deposited in the CYB. The extensional tectonic setting around the Ailaoshan orogenic belt lasted from the end of Late Triassic to Early Jurassic, indicating that the CYB was not a foreland basin that formed in a compressional setting.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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