China Geology 6 (2023) 322−337

China Geology

Journal homepage: http://chinageology.cgs.cn
https://www.sciencedirect.com/journal/china-geology

Determination of the early Paleozoic accretionary complex in Southwestern Yunnan, China: Implications for the tectonic evolution of the Proto-Tethys Ocean

Guo-chuan Yan[a, b, d], Bao-di Wang[c,*], Han Liu[d], Juan He[e], Zhi-min Peng[d]

[a] *Graduate School of Chinese Academy of Geological Sciences*, *China Geological Survey*, *Ministry of Natural Resources*, *Beijing* 100037, *China*
[b] *Chinese Academy of Geological Sciences*, *China University of Geosciences*, *Beijing* 100083, *China*
[c] *China Aero Geophysical Survey and Remote Sensing Center for Natural Resources*, *China Geological Survey*, *Ministry of Natural Resources*, *Beijing* 100083, *China*
[d] *Chengdu Center of Geological Survey*, *China Geological Survey*, *Ministry of Natural Resources*, *Chengdu* 610081, *China*
[e] *West Yunnan University of Applied Sciences*, *Dali* 671006, *Yunnan China*

A R T I C L E   I N F O

Article history:
Received 1 January 2023
Received in revised form 5 March 2023
Accepted 28 March 2023
Available online 18 April 2023

Keywords:
Early Paleozoic
Accretionary complex
Langcang Group
Block + matrix
Proto-Tethys Ocean
Geological survey engineering
Eastern margin of Qinghai-Tibet Plateau

A B S T R A C T

Accretionary complex study provides important knowledge on the subduction and the geodynamic processes of the oceanic plate, which represents the ancient ocean basin extinction location. Nevertheless, there exist many disputes on the age, material source, and tectonic attribute of the Lancang Group, located in Southwest Yunnan, China. In this paper, the LA-ICP-MS detrital zircon U–Pb chronology of nine metamorphic rocks in the Lancang Group was carried out. The U–Pb ages of the three detrital zircons mainly range from 590−550 Ma, 980−910 Ma, and 1150−1490 Ma, with the youngest detrital zircons having a peak age of about 560 Ma. The U–Pb ages of the six detrital zircons mainly range from 440–460 Ma and 980−910 Ma, and the youngest detrital zircon has a peak age of about 445 Ma. In the Lancang Group, metamorphic acidic volcanic rocks, basic volcanic rocks, intermediate-acid intrusive rocks, and high-pressure metamorphic rocks are exposed in the form of tectonic lens in schist, rendering typical melange structural characteristics of "block + matrix". Considering regional deformation and chronology, material composition characteristics, and the previous data, this study thinks the Lancang Group may be an early Paleozoic tectonic accretionary complex formed by the eastward subduction of the Changning-Menglian Proto-Tethys Ocean, which provides an important constraint for the Tethys evolution.

©2023 China Geology Editorial Office.

1. Introduction

The Sanjiang Tethys tectonic domain, was formed by the breakup of Gondwana and the subsequent splice of landmass, mainly represented by the remnants of the Changning-Menglian Proto-Paleo Tethys Ocean basin (Pan GT et al., 1996, 2020; Mo XX et al., 1993; Metcalfe I, 2002, 2013; Deng J et al., 2014; Wang BD et al., 2018, 2021; Wang LQ et al., 2021; Sun ZB et al., 2020). The accretionary complex has been paid much attention, because it is the direct product of subduction and collision between plates (Hsü K, 1968; Hamilton W, 1978; Karig DE., 1983; Hsü KJ et al., 1995), which is helpful to explore the oceanic lithospheric subduction and the formation and evolution of continental margin arc-basin system at the plate convergent margin (Isozaki Y et al., 1990; Kusky TM et al., 1999, 2013; Kroner A., 2016; Li J et al., 2016; Zhang KX et al., 2016, 2017; Ren F et al., 2017; Feng YM et al., 2018; Pan GT et al., 2019). The accretionary complex records the evolution of ocean basin, ocean-continent transition and continental crust in orogenic belt (Li JL et al., 2004; Feng YM et al., 2018). The Lancang Group, located between the Changning-Menglian suture zone and Simao block, is an important part of the Sanjiang Tethyan tectonic domain. Recent studies have shown that the Lancang Group is an Early Paleozoic accretionary complex formed by the eastward subduction of the Changning-Menglian Tethyan Ocean (Wang BD et al., 2018; Peng ZM et al., 2022). Due to the complexity of the material composition and structure of the Lancang Group, researchers have been concerned more about its tectonic property.

The Lancang Group, located in the Sanjiang region, is a shallow metamorphic rock interlaced with metamorphic basic

First author: *E-mail address*: 18380334352@163.com (Guo-chuan Yan).

* Corresponding author: *E-mail address*: baodiwang@163.com (Bao-di Wang).

Literary editor: Xi-jie Chen
doi:10.31035/cg2023019
2096-5192/© 2023 China Geology Editorial Office.

Copyright © 2023 Editorial Office of China Geology. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd.
This is an open access article under the CC BY-NC-ND License (http://creativecommons.org/licenses/by-nc-nd/4.0/).

volcanic rocks. At present, there are still many disputes about Lancang Group, such as the stratigraphic age, material source, and structural attribute. The stratigraphic age of Lancang Group has been reported from Early to Mesoproterozoic to Devonian (Zhai MG et al., 1990; Zhong DL et al., 1998; Wang F et al., 2017; Peng ZM et al., 2022; Hu JF et al., 2020; Han WW et al., 2020). The provenance of clastic rocks in the Lancang Group is also controversial. Some hold the view that they come from the Simao block (Bureau of Geology and Mineral Resources of Yunnan Province., 1990), while others believe that they come from the Baoshan block (Zhao TY et al., 2017, 2019; Zhou ML et al., 2020; Liu BB et al., 2020; Bai XR et al., 2021; Wei YH et al., 2022), and some think they originated from the North India (Xing XW et al., 2016; Wu GH et al., 2022), and even some scholars express the opinion that they originated from the North India and Austrilia (Xing XW et al., 2016; Wu GH et al., 2022). The tectonic properties are also controversial. Lancang Group is regarded as a continental arc of the Simao Block during the Early Paleozoic by some researchers (Bureau of Geology and Mineral Resources of Yunnan Province, 1990) or as part of the Yangtze basement on the basis of whole-rock Sm-Nd isochron age of 1982 ± 41 Ma from the Huimin volcanic rocks (Zhong DL et al., 1998). Some believe that Lancang Group is a tiny landmass and contains old basement materials (Wang DD et al., 2014; Zhao TY et al., 2019; Wu GH et al., 2022; Wei YH et al., 2022; Liu YM et al., 2019). In recent years, according to the materials in Lancang Group, some scholars have obtained the stratigraphic age of Lancang Group, and think it was formed in the Early Paleozoic, belonging to Proto-Tethys Ocean subduction-accretion orogenic materials (Xing XW et al., 2016; Wang BD et al., 2018; Peng ZM et al., 2022; Hu JF et al., 2020; Han WW et al., 2020; Bai XR et al., 2021). These discrepancies largely reflect the complexities of tectonic history in the region and also highlight the lack of consensus with regard to the age and nature of the Lancang Group.

To address these issues, this study preliminarily determined the Lancang Group material composition by field geological survey, and identified the deformation of the Lancang Group. Meanwhile, we defined the sedimentary age and main material sources of the Lancang Group and analyze their tectonic nature by U–Pb geochronology, which may provide a basis for elucidating the Tethys tectonic evolution in Sanjiang area.

2. Geological background and petrology

The Sanjiang area in Southwest China, located in the East Tethyan tectonic domain, is an important region for studying the Tethyan evolution (Liu BP et al., 1993,2002; Zi JW et al., 2012, 2013; Metcalfe I, 2013; Metcalfe CM et al., 2017; Wang BD et al., 2018; Li J et al., 2017; Pan GT et al., 1996, 2012, 2016, 2020; He J et al., 2020; Wang BD et al., 2021; Wang LQ et al., 2021), The region experienced Proto-Paleo Tethys tectonic evolution and accretive orogeny, and later suffered from the Cenozoic Indo-Eurasian plate collision orogeny superposition and transformation (Deng J et al., 2014, 2016; Fig. 1a). Several metamorphic complex belts developed, most of which are distributed north-south along the orogenic belt and have undergone multi-stage metamorphism. The complex belt is adjacent to Lincang-Menghai magmatic arc belt in the east and Changning-Menglian suture belt in the west, which are partially covered by Sanchahe Formation (T_3sc) and Huakaizuo Formation (J_2h).

The Changning-Menglian Suture Zone runs from Tongchangjie to Yunxian in the North via Shuangjiang and Lancang to Menglian in the south and into Myanmar (Wang BD et al., 2021). There are relatively few complete ophiolite mélanges in the Suture Zone, long considered the location of the Paleo-Tethys Ocean, which opened during the Devonian and closed at least during the Late Triassic. The Changning-Menglian Suture Zone contains ophiolites from Devonian to Carboniferous. MORB-type basalts dated at ca. 385–272 Ma developed in the Suture Zone, along with OIB-Type basalt dated at ca. 307–323 Ma, and the associated siliceous rocks include pelagic assemblages of non-compensatory basin siliceous rocks, which contain radiolaria (Zhang RY et al., 1990; Cong BL et al., 1994; Wang F et al., 2017; Duan XD et al., 2006; Yang WQ et al., 2007; Jian P et al., 2009a, b; Deng J et al., 2014).

The Lincang-Menghai magmatic arc belt lies to its east. This magmatic arc is dominated by Middle-to-Late Triassic magmatic activity (ca. 238–212 Ma), which was formed by continent-continental or arc-continental collision after the closure of the Paleo-Tethys Ocean (Yu SY et al., 2003; Peng TP et al., 2006; Kong HL et al., 2012).

The Lancang Group, located between the Changning-Mengshan zone and the Lincang-Menghai magma arc, starts from Fengqing County in the north, passes through Yunxian County, Lincang County, Shuangjiang County and Lancang County, and reaches Xishuangbanna Prefecture in the south. It is about 400 km long and 25–50 km wide, and extends to Myanmar (Fig. 1b). The east of Lancang Group is in fault and intrusive contact with Lincang compound granites, and is partially covered Sanchahe Formation (T_3sc) and Huakaizuo Formation (J_2h), the western is in fault contact with Nanduan Formation (D-C*n*) (Fig. 2).

In this paper, we selected the northern region of Lancang Group as the research area, and focused on Yunxian County, Yunnan (Fig. 1b). Detailed field geological survey was conducted in Xingfu Town and Nanmei Town (Fig. 2). And nine representative samples were selected for study, including meta-feldspar quartz sandstone (17LC-1, 17LC-2), two mica quartz schist (17-LC-3) and quartz schist (17LC-4) in the Xingfu Town, meta-feldspar quartz sandstone (17LC-6, 17LC-10),Two mica quartz schist (17LC-7, 17LC-9), quartz schist (17LC-5) in the Nanmei Town (Fig. 2). Some typical rocks are as follows.

Meta-feldspar quartz sandstone (17LC-1), green gray, quartz veins are commonly developed in rocks, which are crumpled and strongly displaced by late activity. Quartz veins

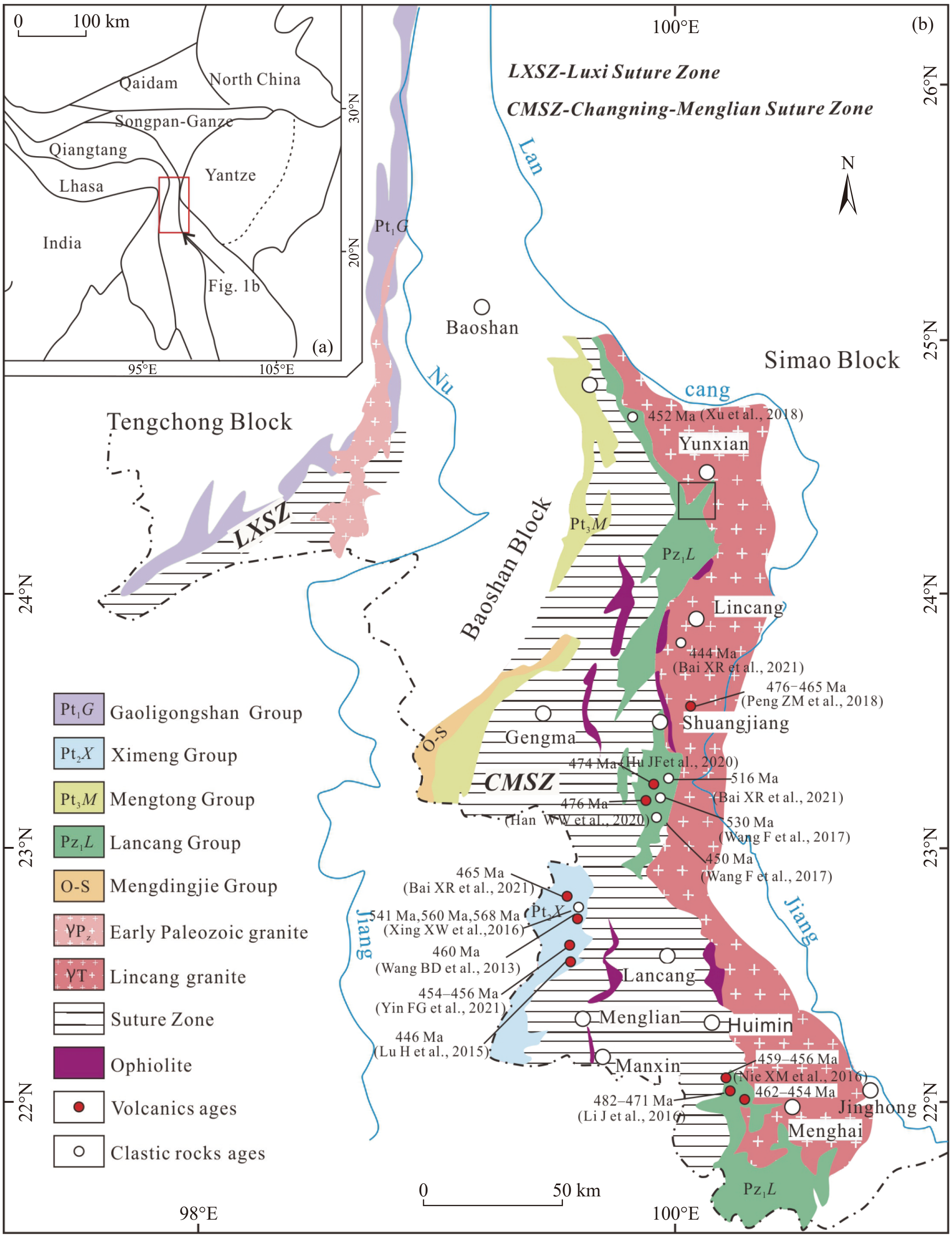

Fig. 1. a–Tectonic outline of Southeast Asia; b–geological map of the study area, showing the locations of the collected samples of this and previous research.

are mostly extruded to form structural lenses and form “pudding” structure, with uneven size and sand-like structure, massive structure and weak bedding (Figs. 3a, b). Under the microscope, the main minerals are are quartz, feldspar, and biotite. The particle size of quartz debris varies, with a total content of 60%–70% (Fig. 4a).

Two mica quartz schist (17LC-3), gray black, quartz veins are also found in the rock, which are sheared to a structural lenticular body (Figs. 3c, d). Microscopically, the mica was arranged in a directional way. The main minerals were quartz (about 70%), and the secondary minerals were biotite (about 5%–10%) and muscovite (about 15%–20%; Fig. 4b).

Quartz schist (17LC-4), gray and black, quartz veins developed in the rock, which were sheared by later tectonic shear to structural lenticular body with different sizes, generally 5–10 cm. Green schist (metamorphic basalt) was also found, which was produced in structural lenticular body with a long axis of about 2.5 m and a short axis of about 1m, reflecting the metamorphic basalt blocks development in Lancang Group (Figs. 3e, f). Microscopically, the structure was medium to fine granular and massive. It is mainly composed of quartz, muscovite, plagioclase (Figs. 4c, d). The main minerals were quartz (about 40%), and the secondary minerals were biotite and plagioclase muscovite (about 40%).

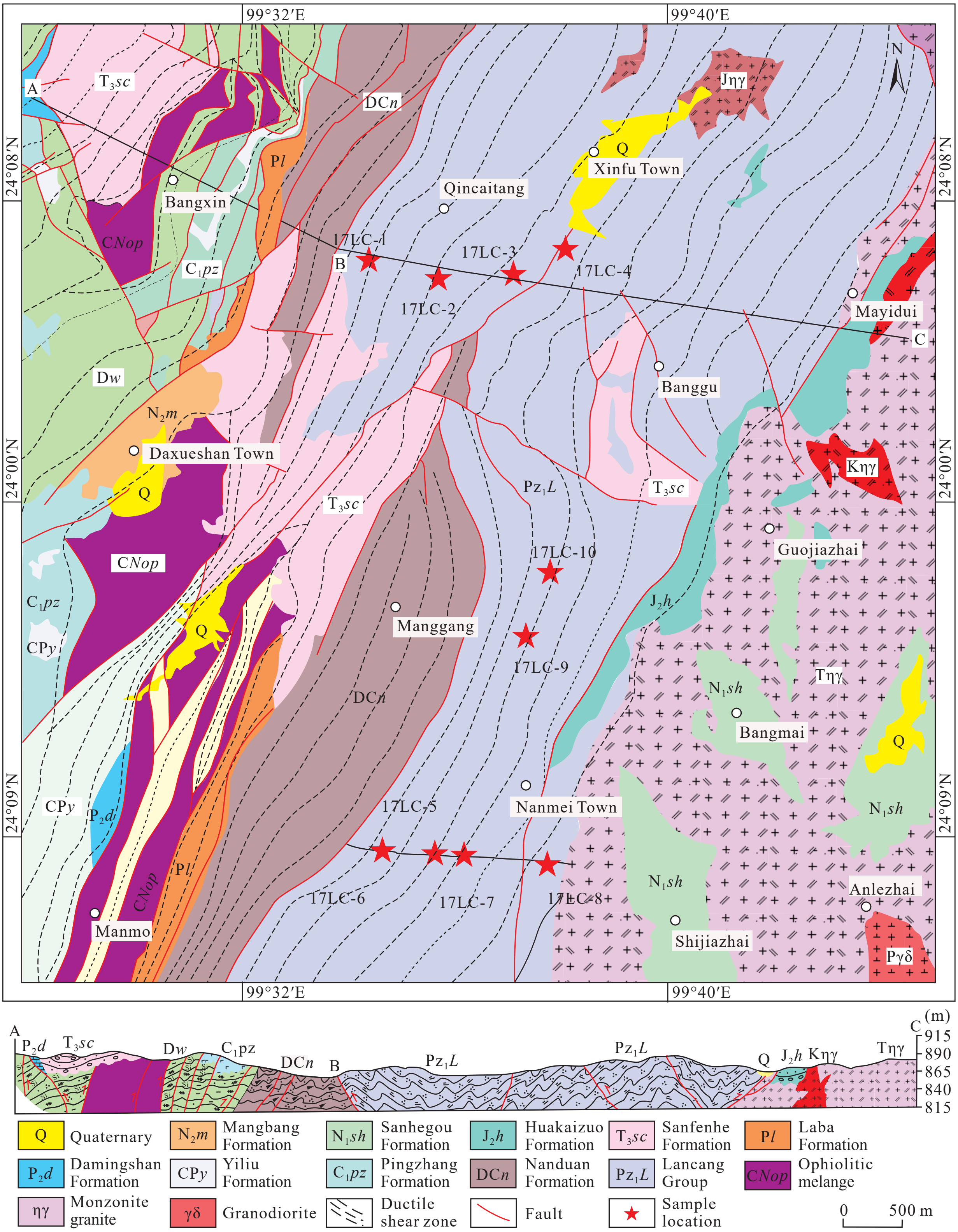

Fig. 2. Geological map and section map of the Lancang Group in the Yunnan, China .

3. Analytical methods and results

Zircon was separated at the Geological Laboratory of Langfang Institute of Regional Geological Survey in Hebei Province, China. Zircon U–Pb isotope results were determined using LA-inductively-coupled plasma mass spectrometry (LA-ICP-MS) at the Experimental Center of Chengdu Geological Survey Center, China Geological Survey (Chengdu, China). LA-ICP-MS zircon U–Pb analyses were conducted on an Agilent 7500 ICP-MS, equipped with a GeoLas 2005 laser system. Temporal analysis included interpretation of blank signals of 20–30 s and sample signals of 50 s. The detected spot diameter was 32 μm. Detailed instrument operating conditions and data processing methods

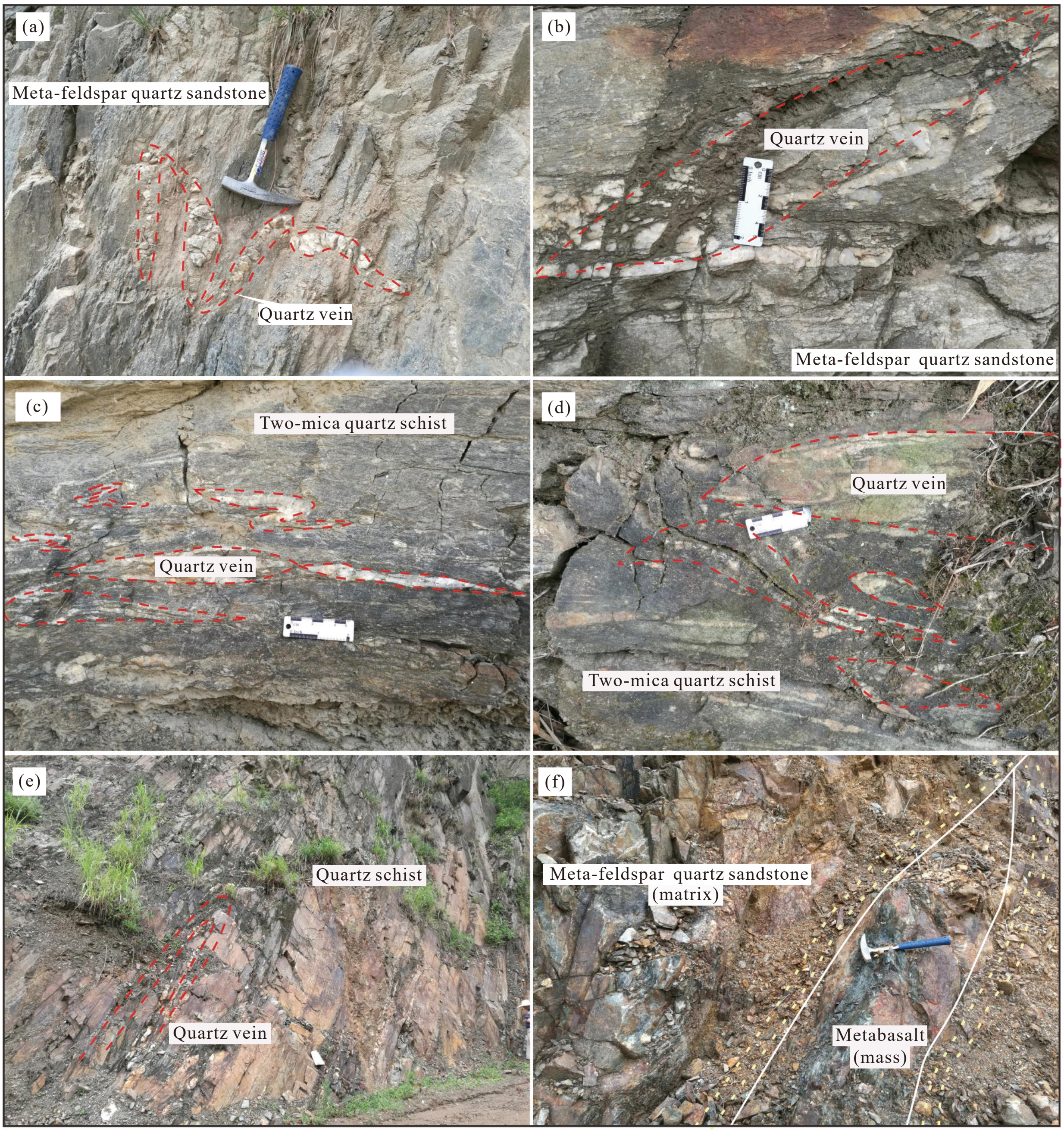

Fig. 3. Representative field photos of samples analyzed in this research. (a, b , d, e) wacke with quartz vein. (c) two-mica quartz schist with quartz vein (f) matrix (metagreywacke)+block (metabasalt) .

can be found in Liu YS et al. (2008, 2010), and the results are summarized in Supplementary Table S1.

Zircons older than 1000 Ma were selected as $^{207}Pb/^{206}Pb$ age, while zircons younger than 1000 Ma were selected as $^{206}Pb/^{238}U$ age. The results of 8 samples are shown in Supplementary Table S1. The uniformity of zircon particles involved in the age calculation is higher than 90%. The major axis is 200–300 μm, and the minor axis is 100–150 μm. The length/width of zircon grains is mostly 2∶1. Cathodoluminescence images show that some zircons have clear magmatic rings, some have clear core-edge structures, and some have uniform gray unzoned inner structures (Fig. 5). The U–Pb ages of the three detrital zircons mainly range from 590–550 Ma, 980–910 Ma, and 1150–1490 Ma, with the youngest detrital zircons having a peak age of about 560 Ma. These zircon grains exhibit a wide range of Th (10×10^{-6}–2125×10^{-6}) and U (26×10^{-6}–2143×10^{-6}) contents, with Th/U ratios generally >0.1. The U–Pb ages of the six detrital zircons mainly range from 440–460 Ma and 980–910 Ma, and the youngest detrital zircon has a peak age of about 445 Ma, These zircon grains exhibit a wide range of Th (10×10^{-6}–1338×10^{-6}) and U (23×10^{-6}–1627×10^{-6}) contents, with Th/U ratios generally > 0.1 (Fig. 6; Supplementary Table S1).

4. Discussions

4.1. The structural attribute of Lancang Group

There has been a great dispute about the structural

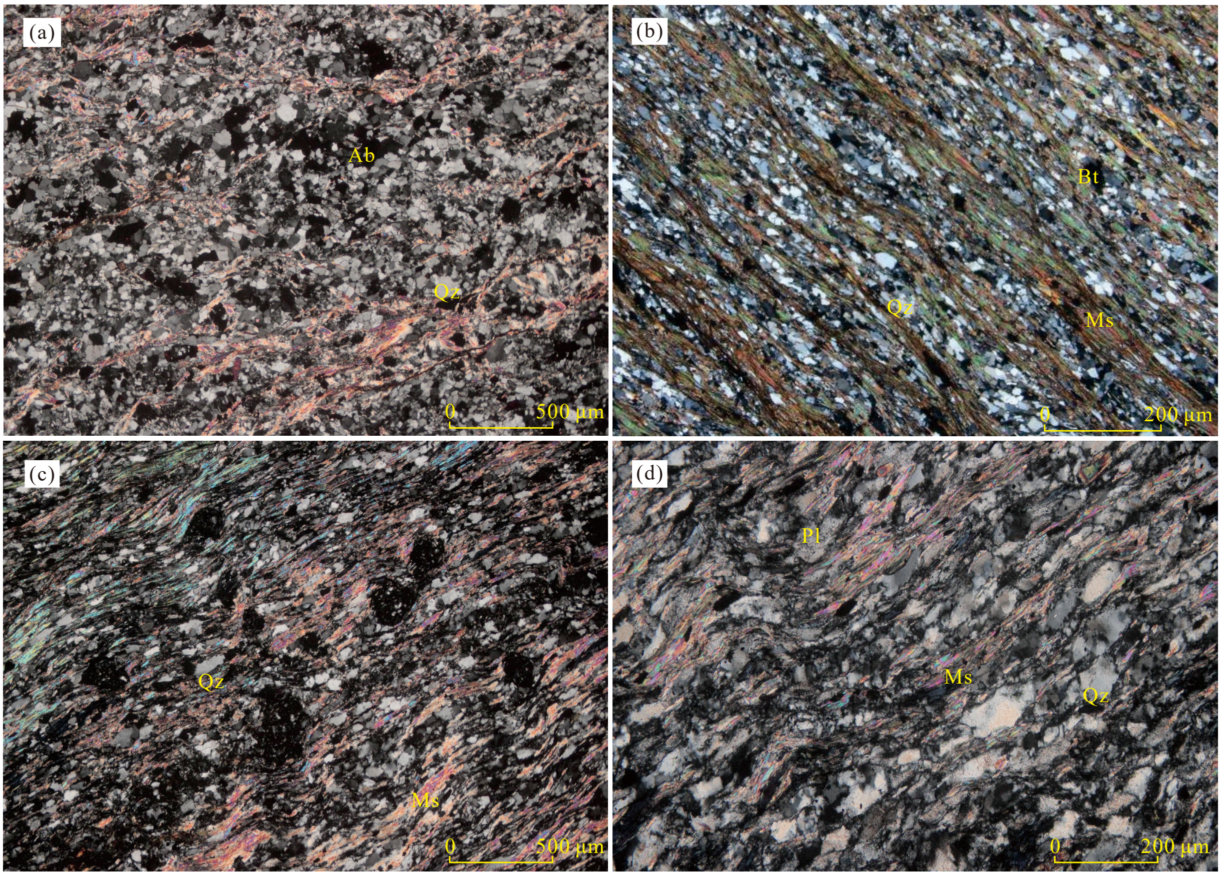

Fig. 4. Photomicrographs of representative samples of the Lancang Group showing the mineral assemblage. Qz–Quartz, Ab–Albite, Ms–Muscovite, Bt–Biotite, Pl–plagioclase, Ab–Albite .

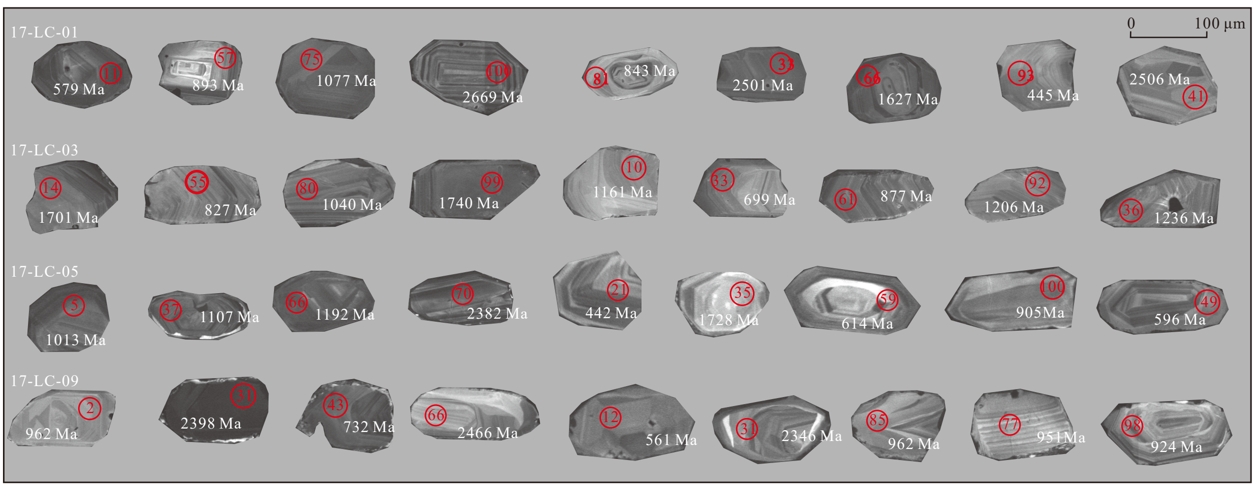

Fig. 5. Cathodoluminescence images of representative zircon grains showing analytical spots of U–Pb age.

attribute of Lancang Group. It is traditionally believed that the Lancang Group was a part of the Simao block during Paleozoic, representing a continental arc (Bureau of Geology and Mineral Resources of Yunnan Province, 1990; Metcalfe I, 2013; Metcalfe CM et al., 2017; Wu HR et al., 1994) or an allochthonous microcontinent accreted to the latter during the Late Permian (Feng QL et al., 1996; Jia HR, 1994; Liu BP et al., 1993; Zeng WT et al., 2017). But recent studies believe that the Lancang Group is a geological record of the subduction and extinction of the Proto-Paleo Tethys Ocean, with the characteristics of accretionary complex (Wang BD et al., 2018; Pan GT et al., 2019; Hu JF et al., 2020; Peng ZM et al., 2022; Han WW et al., 2020). Generally speaking, the accretionary complex and ophiolites coexist closely in the orogenic belt, which is considered to be the final location of subduction and extinction of the oceanic basin (Isozaki Y et al., 1990; Shervais JW, 2006), and are composed of different types and ages rocks intermingled by many secondary deformations and metamorphic processes. In the Lancang Group, strongly deformed basalt, greenschist and other rocks

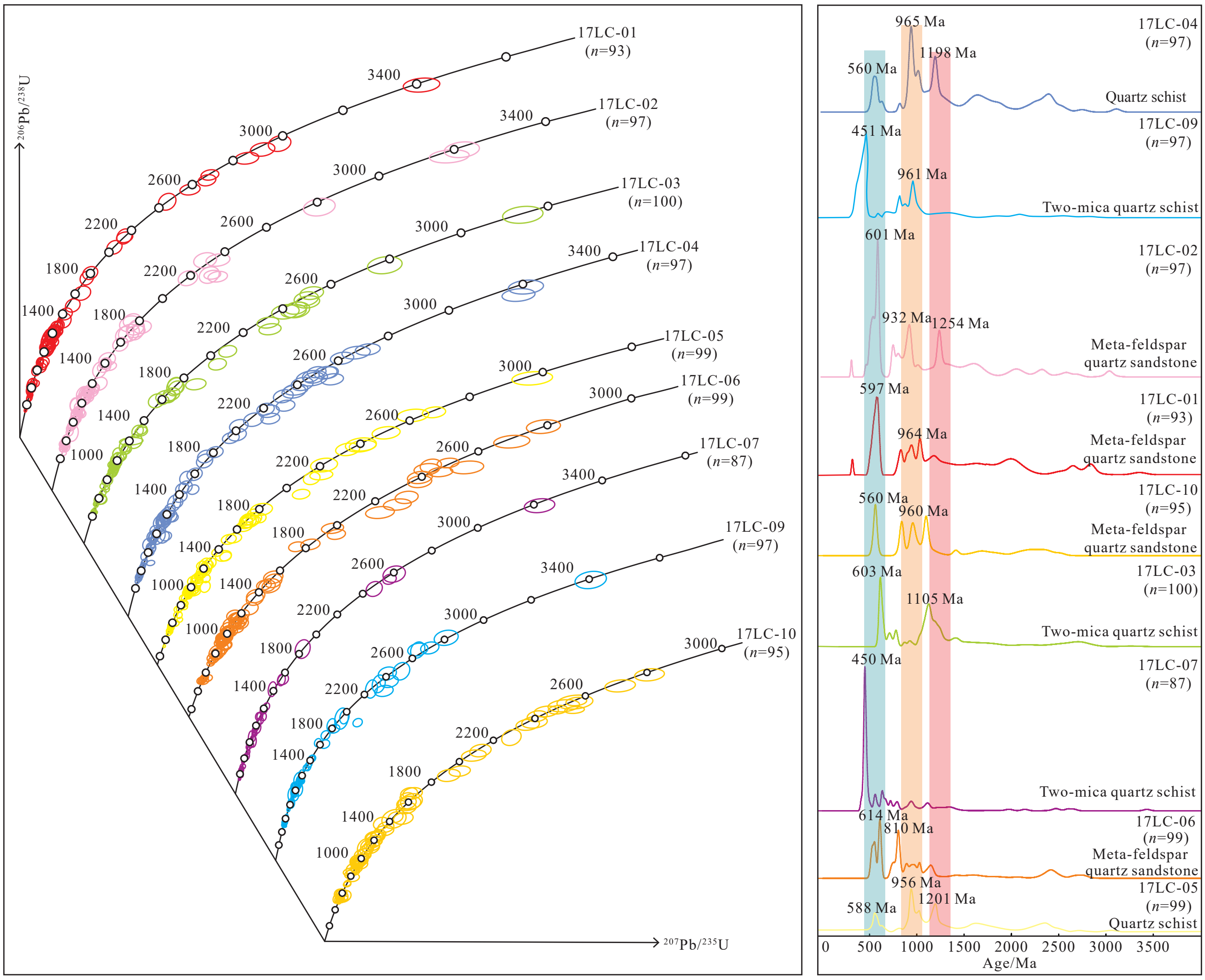

Fig. 6. Concordia diagrams and age histograms for detrital zircon grains from and sedimentary rocks collected from the Lancang Group.

develop as block (Fig. 2), with oceanic crust and magmatic arc characteristic. Due to multiple periods tectonic action, it is difficult to recognize the boundary between most blocks and surrounding rocks, but overall with “matric+block” feature (Fig. 2). The accretionary complex is associated with high-pressure metamorphic rocks (blue schist, eclogite), and the space-time distribution of blue schist and eclogite is an important symbol of plate convergence boundary, ocean subduction and continental collision, recording the entire process of subduction and reentry (Zhang LD et al., 2008). More and more blueschist and eclogite have been found in the Lancang Group. The protolith of blueschist has the arc volcanic rocks characteristics, and eclogite has E-MORB and OIB properties (Fan WM et al., 2015; Wang F et al., 2016; Wang HN et al., 2018). And for high-pressure metamorphic rocks, the protolith forms in different ages, the eclogite formed at different time, including 801 Ma, 451 Ma, 429–463 Ma (Li J et al., 2017; Sun ZB et al., 2017a, b; Wang HN et al., 2018; Wang HN et al., 2018), which is consistent with the age of the oceanic crust in the Changning-Menglian Suture Zone (Wang BD et al., 2013, 2018; Wang F et al., 2016; Sun ZB et al., 2017a, b; Liu GC et al., 2017,2021; Peng ZM et al., 2018, 2019).The results indicate that the protoliths of the high pressure metamorphic rocks in this zone are complex and diverse, which represent the subduction, extinction and accretion orogenic processes of the Changing-Menglian ocean, and the Lancang Group has undergone deep subduction, and the blue schist and eclogite have returned to their positions by arc-continental and continent-continental collision.

In addition, in terms of deformation, previous studies on the accretionary complex have found that it generally has the structure form of mutual shear between matrix and block, as well as dual structure and thrust imbriculate assemblage structure, thus forming a series of structural zones, including thrust faults and different types folds (von Huene R et al., 1994; Taira A, 2001; Niitsuma N, 2004). Some imbricate thrust nappe faults with a tendency to the west are mainly developed on the west side of Lancang Group, and there are shear deformation and detachment deformation structures in the thrust fault zones, and some different types of folds can be seen (Fig. 2). And in its east, the main structure is imbricate thrust nappe with east tendency, and the thrust slices are dominated by broad and gentle structures (Fig. 7). Due to the superposition of multi-stage metamorphism and deformation, a series of asymmetric shear rheological quartz veins can be

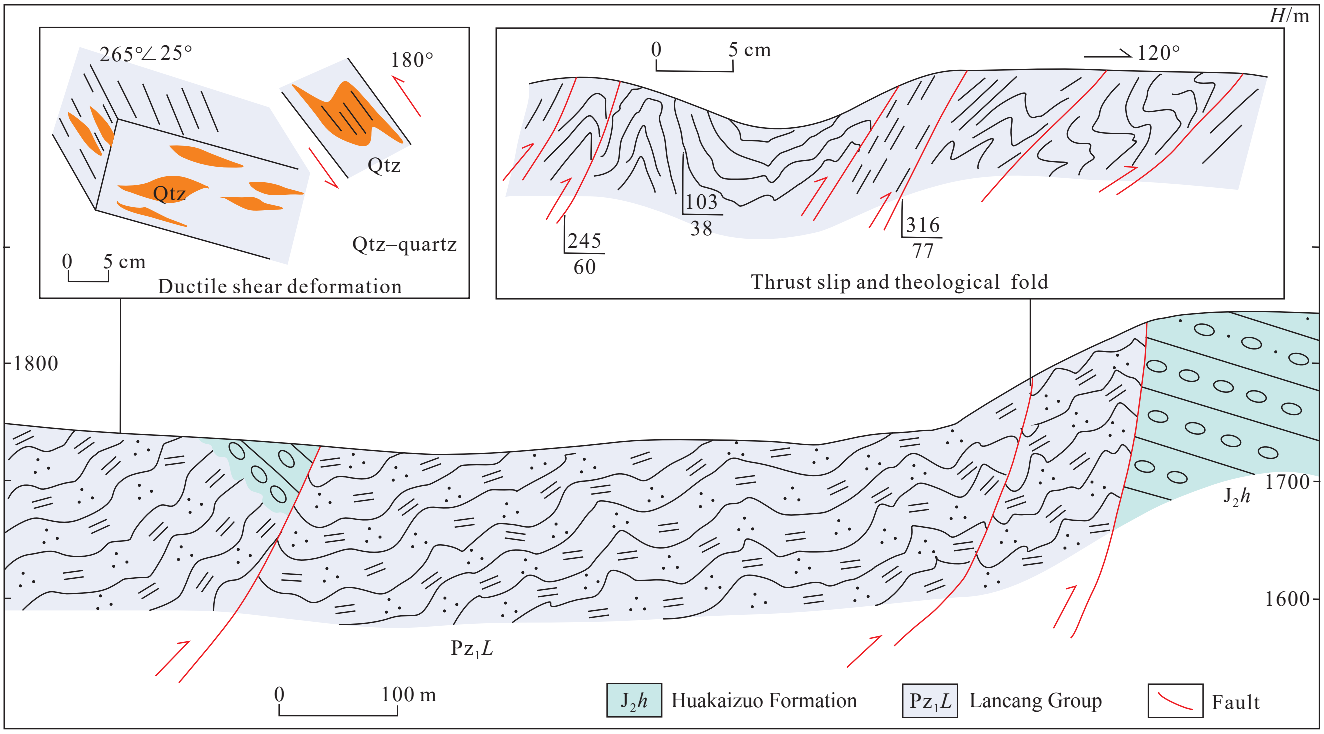

Fig. 7. The main structural deformation patterns of the thrust-slip-fold structural belt in Lancang Group.

seen (Fig. 8).

In conclusion, according to the material and deformation characteristics of the Lancang Group, it is believed that the material composition of the Lancang Group is complex and diverse, and the rocks with different properties and ages have undergone late metamorphic deformation and transformation, and the present thrust faults from east to west are developed, and the overall performance is characterized by thrust-nappe and accretive structure. We believe that it has similar characteristics to accretionary complex belt, and its primary structure and sedimentary characteristics have been changed by the later tectonic activities, and it is composed of different lithologic fragments by collage and accumulation. Based on the above and features in the zone, we hold the opinion that Lancang Group is an Early Paleozoic accretionary complex, formed by Changing-Menglian Proto-Tethys Ocean eastward subduction, collision, orogenic, instead of basement rock series or continental blocks, and some basement rock series are likely to be involved in the Changing-Menglian Proto-Tethys Ocean evolution process and mixed into the Lancang Group by the late tectonic movement.

4.2. The material and age of the Lancang Group

There are many studies on Lancang Group material, mainly including sericite quartz schist, dolomite quartz schist, sericite microcrystalline schist, phyllite and slate, with local iron, phosphorus and siliceous rocks in the Lancang Group. The protolith is feldspar-bearing quartz sandstone, feldspar-quartz sandstone, argillaceous sandstone, siltstone, shale and carbonaceous shale, with flysite characteristics. It is considered as basement metamorphic rocks (Bureau of Geology and Mineral Resources of Yunnan Province, 1990; Zhang RY et al., 1990; Zhai MG et al., 1990; Zhong DL et al., 1998; Wang Q et al., 2014; Zhao TY et al., 2019; Wu GH et al., 2022; Wei YH et al., 2022; Liu YM et al., 2019). However, as intensive study grows in recent years, some new rocks such as blueschist and eclogite have been discovered in the zone (Peng ZM et al., 2019, 2022), and a new understanding of the material composition of the Lancang Group has been gained. Based on previous data and field surveys, this study suggest that: The Lancang Group is an intermediate and shallow metamorphic rock with different lithologic assemblages. The metamorphism grade is proved to be low greenschist facies, low amphibolite facies, blue schist facies and eclogite facies. The material composition of Lancang Group is diverse and complex, covering shallow metamorphic rock series with metamorphic basic volcanic rocks. The main types include mica quartz schist, two mica schist and other metasandstone (Fig. 3); The chlorite albite schist, chlorite two-mica schist and other metamorphic medium acid volcanic rock (Xu YF et al., 2018); green schist, albite schist, amphibolite and other metamorphic mafic-medium volcanic rocks; locally developed metamorphic intermediate-acid intrusive rocks such as granitic gneiss and albite shallow granulite (Han WW et al., 2020; Hu JF et al., 2020), low temperature and high pressure metamorphic rocks such as blue schist and eclogite, and a small amount of marble and carbonaceous quartz schist (Peng ZM et al., 2019, 2022). Metamorphic acidic volcanic rock, basic volcanic rocks, intermediate-acid intrusive rocks and high-pressure metamorphic rocks are exposed in the form of tectonic lens in schist, rendering melange typical structure characteristics of the "block + matrix". Matrix in our study area includes

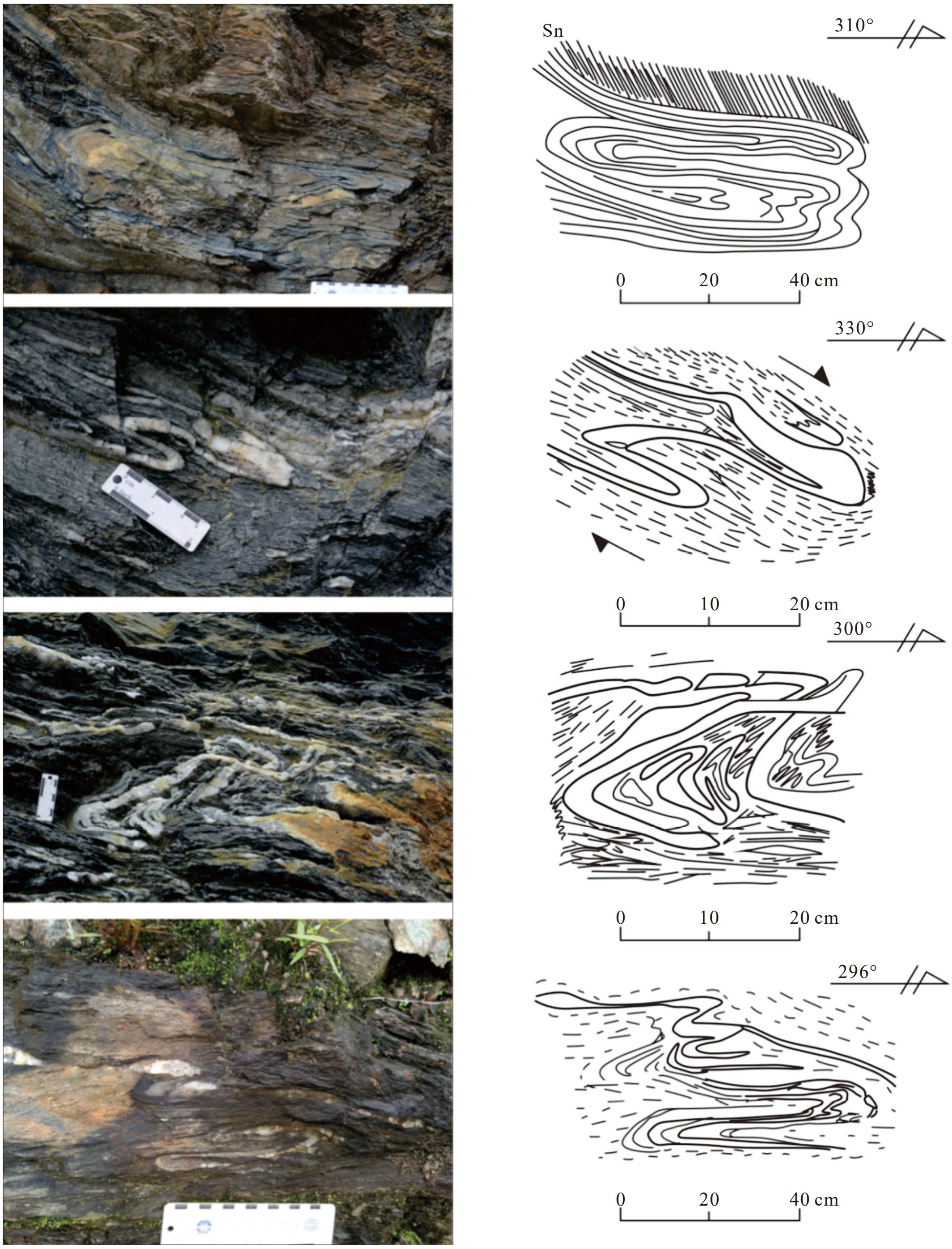

Fig. 8. The micro-fold in the thrust detachment segment in Lancang Group (crumpled structure formed in schist).

various types of schist, and block mainly includes metabasalt (Fig. 3).

Compared with Lincang granite chronology, the study on the sedimentary age of Lancang Group is relatively weak. The Lancang Group was named by the survey team of Yunnan Geological Bureau, belonging to Cambrian or Early Cambrian. Later, some researchers classified it as Paleoproterozoic or Mesoproterozoic (Bureau of Geology and Mineral Resources of Yunnan Province, 1990). Wei GY et al. (1984) also believed that the Lancang Group belonged to the Paleoproterozoic, possibly partly to the Cambrian, on the grounds of paleo-algae and micropaleo-plant fossils. In the recent years, some think the depositional time of the Lancang Group should be Early Paleozoic according to the detrital zircons and metavolcanite age in the Lancang Group (Wang F et al., 2017; Wang HN et al., 2018; Xu YF et al., 2018; Peng ZM et al., 2022; Hu JF et al., 2020; Han WW et al., 2020; Wei YH et al., 2022).

In this research, we obtained the ages of detrital zircons of nine rocks in the Lancang Group. In general, the youngest detrital zircon ages of sedimentary strata can represent the oldest ages of sedimentary strata (Andersen T, 2005). The U–Pb ages of the three detrital zircons mainly range from 590–550 Ma, 980–910 Ma, and 1150–1490 Ma, with the youngest detrital zircons having a peak age of about 560 Ma. The U–Pb ages of the six detrital zircons mainly range from 440–460 Ma and 980–910 Ma, and the youngest detrital zircon has a peak age of about 445 Ma (Fig. 6). This is consistent with recent findings (Wang F et al., 2017; Xu YF et al., 2018; Peng ZM et al., 2022; Wei YH et al., 2022). This is in line with recent findings by Nie XM et al (2015), LA-ICPMS U–Pb chronology of zircons in three metamorphic volcanic rocks from Huimin formation of Lancang Group was conducted, and the ages of 456 ± 3 Ma, 456 ± 7 Ma and 459 ± 14 Ma were obtained, respectively. Xing XW (2016) also conducted a chronological study on two metamorphic volcanic rocks in the Lancang Group, and obtained U–Pb ages of 462 ± 6 Ma and 454 ± 27 Ma, respectively. Han WW (2020) obtained an age-weighted average age of 476.5±1.6 Ma for the formation of Albite shallow granulite from Lancang Group by zircon U–Pb dating, and Hu JF (2020) obtained an age of 474.1 ± 1.7 Ma for the formation of albite-actinolite-schist from Lancang Group. The metavolcanic rocks samples (about 495 Ma) in the Manlai Formation, five metavolcanic samples from the Huimin Formation yielded zircon U–Pb ages between 478±5 Ma and 442 ± 5 Ma (Wei YH et al., 2022), and Liu BB (2020) obtained the age of volcanic rocks in Manlai Formation of Lancang Group was 494–495 Ma (Fig. 1). Combined with previous research results, the Lancang Group was inferred to formed in the Late Ordovician, or Early Paleozoic.

4.3. The source characteristics of the Lancang Group rocks

The distribution patterns of U–Pb ages recorded in detrital zircon grains are helpful for seeking for the source regions and are widely used to probe sediment provenance (DeCelles PG et al., 2000; Chen FK et al., 2021; Zhu DC et al., 2011a; Nebel O et al., 2014). And detrital zircons clustered mainly around 520–550 Ma in the Lancang Group (Fig. 9). Zircon grains with U–Pb ages <500 Ma largely retain oscillatory zoning and show euhedral to subhedral shape (Fig. 5), indicating a magmatic texture and short-distance provenance. The Early Paleozoic rocks (about 450 Ma), including granitic gneiss and some granitoid rocks that intruded into the Paleozoic sedimentary rocks in the Lancang Group and adjacent Baoshan block, respectively (Chen F et al., 2007; Peng ZM et al., 2018; Zhao TY et al., 2019; Han WW et al., 2020), could be potential sources for the youngest (about 445 Ma) sedimentary materials. However, igneous rocks older

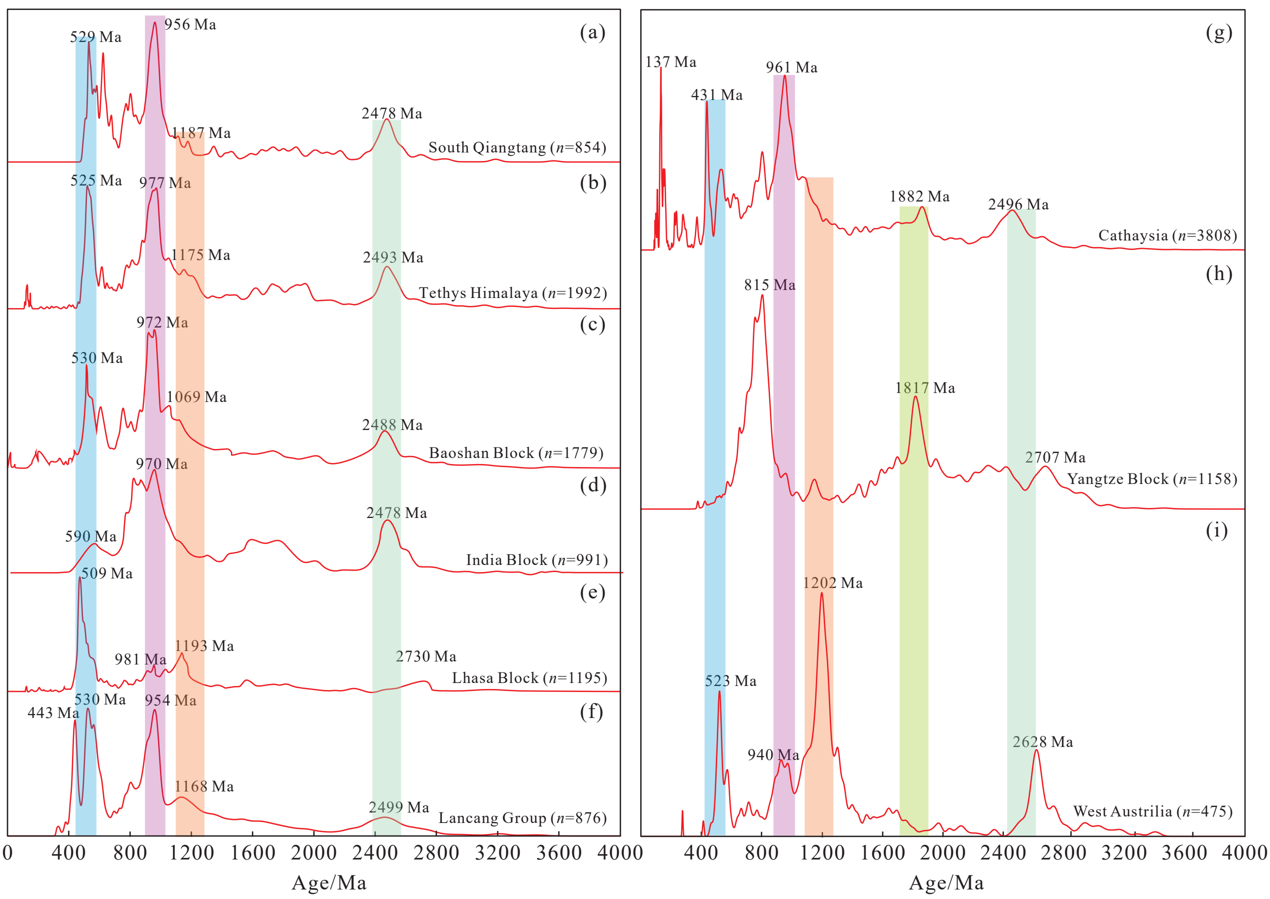

Fig. 9. Distribution diagrams of detrital zircon U–Pb ages: (a) South Qiangtang (after Dong CY et al., 2011; Zhu DC et al., 2011a; Liu YM et al., 2016; (b) Tethyan Himalayan Block (after Myrow PM et al., 2010; Zhu DC et al., 2011a); (c) Baoshan Block (after Zhao TY et al., 2017; Xu et al., 2019; Chen FK et al., 2021); (d) India Block (after McQuarrie N et al., 2008; Myrow PM et al., 2010; Mckenzie, NR et al., 2011); (e) Lhasa Block (after Leier AL et al., 2007; Zhu DC et al., 2011a); (f) Lancang group (this study); (g) Cathaysia Block (after Yu JH et al., 2010; Yao WH et al., 2015; Chen Q et al., 2018) ; (h) Yangtze Block (after Greentree MR et al., 2006; Zheng JP et al., 2006; Duan L et al., 2011; Wang Q et al., 2014); (i) West Australia (after Cawood PA and Nemchin AA, 2000; Veevers JJ et al., 2005).

than 500 Ma have not been reported in the Lancang Group or adjacent blocks. What is noteworthy is that some zircon grains older than 500 Ma in the Lancang Group are nearly circular or short columnar in shape, indicating long-distance transportation or recycling of sediments. In this paper, Lancang samples show a clear age peak between about 550 Ma and 520 Ma (Fig. 10), which is distinctly different from the peak age of about 500 Ma to 400 Ma in the Yangze and Huaxia block (Fig. 9; Xia XP et al., 2016; Chen Y et al., 2017; Yang L et al., 2018). However, there are several orogenic belts related to 620–520 Ma Pan-African magmatic activity in East Gondwana, including the Kuunga (between India and West Australia) and Pinjarra (between West Australia and Antarctic) (Fitzsimons ICW, 2000; Goscombe B et al., 2020), and detrital zircons of this period also exist in the Baoshan block, Lhasa block, Tethyan Himalayan, and West Australian block (Fig. 9; Cawood PA and Nemchin AA, 2000; Veevers JJ et al., 2005; Gehrels GE et al., 2006; Pullen A et al., 2008; Myrow PM et al., 2009, 2010; Zhu DC et al., 2011b; Chen FK et al., 2021; Li DP et al., 2015). So, according to the age correlation of detritonal zircons in the Lancang Group, the provenance of the Lancang Group may be different from the Lanping block. The Lancang Group was likely adjacent to the Gondwana continent during the Early Paleozoic and received a large amount of Pan-African material (Fig. 10).

Notably, the Lancang Group contains many detrital zircons cluster of 910 Ma to 1100 Ma and 1150 Ma to 1490 Ma, with peaks at about 960 Ma and about 1168 Ma (Fig. 9). The Grenvillian orogens are commonly exited in the East Gondwana, including the 1330–1130 Ma Albany-Fraser (Australia)-Wilkes (East Antarctic) belt (Cawood PA and Nemchin AA, 2000; Clark DJ et al., 2000; Veevers JJ et al., 2005), the 1090–1030 Ma Namaqua-Natal (Africa)-Maud

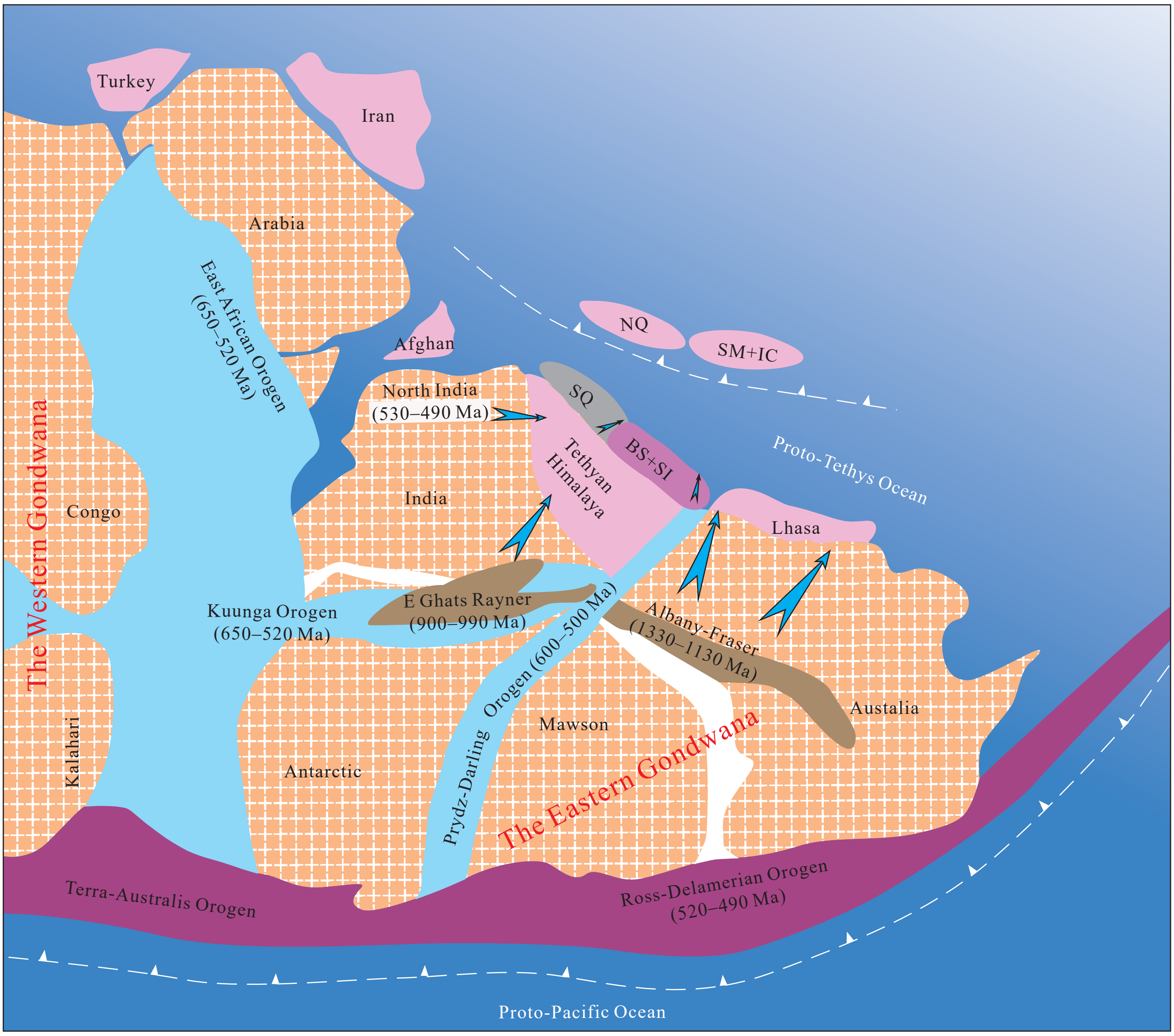

Fig. 10. Early Paleozoic reconstruction of the Proto-Tethys and adjoining continental blocks along the northern margin of the Eastern Gondwana (after Zhao TY et al., 2017; Liu YM et al., 2019). NQ–North Qiangtang; SQ–South Qiangtang; SM– Simao Block; IC–Indochina Block; BS– Baoshan Block; SI-Sibumasu Block .

(East Antarctic) belt (Eglington BM, 2006; Ksienzyk AK and Jacobs, 2015; Hokada T et al., 2019), and the 990–900 Ma Eastern Ghats (India)-Rayner (East Antarctic) belt (Boger SD et al., 2000; DeCelles PG et al., 2000; Fitzsimons ICW, 2000; Halpin JA et al., 2012; Fig. 10). So, the Eastern Ghats-Rayner belt in India may have provided abundant sedimentary materials of about 910–1100 Ma of the Lancang Group likely with some contribution of about 1150–1490 Ma materials from the Albany-Fraser belt in West Australia.

The detrital zircon age cluster of 2600 Ma to 2400 Ma are generally present in the detrital zircon age maps (Fig. 9), the Lancang Group, similar to the Baoshan, Southern Qiangtang, Himalayan and Indian blocks, has a peak age of younger than 2500 Ma, while the Western Australia and Lhasa blocks have a peak age of about 2700 Ma. In the Aravalli Craton and the Bundelkhand Massif of Northern India, magmatic activity occurred in the ca. 2500 Ma (Wiedenbeck M et al., 1996; Mondal MEA et al., 2002; Wang W et al., 2019), while the magmatic activity is about 2800–2600 Ma in the Yilgarn Craton of Australia (Pidgeon RT and Wilde SA, 1990; Griffin WL et al., 2004). In general, the North India might have provided Late Neoarchean and Early Paleoproterozoic components for the Lancang Group (Fig. 10).

Above all, the U–Pb ages presented in this paper suggest that the Lancang Group has different origins and complex provenance. this paper proposes that in the Early Paleozoic the Lancang Group mainly received material composition from India and their adjacent cratons, they are similar to the detrital zircons in the metassedimentary rocks or strata of Baoshan block, the Southern Qiangtang block, Tethys Himalayas, and may have the same source.

5. Conclusions

(i) Combined with the material and deformation characteristics of the Lancang Group, the Lancang Group may be accretionary complex, overall with matric+block feature, which is the material record of subduction of Proto-Paleo Tethys Ocean.

(ii) The youngest detrital zircon in the Lancang Group has a peak age of about 445 Ma, which indicates that the depositional age should be no earlier than the Late Ordovician, Combined with volcanic rocks U–Pb age in the Lancang Group, the accretionary complex of Lancang Group may form in the Early Paleozoic.

(iii) The sedimentary sources of the Lancang Group metamorphic rocks may be mainly magmatic rocks formed during the polymerization and cleavage of the Pan-African and Rodinia supercontinent. The age distribution characteristics of detrital zircons in Qiangtang, Tethys Himalayan and Baoshan block metassedimentary rocks or strata are compared with those in the Lancang Group, suggesting that they may have similar source.

CRediT authorship contribution statement

Bao-di Wang, Guo-chuan Yan conceived of the presented idea, Guo-chuan Yan wrote the manuscript under supervision of Bao-di Wang, Han Liu, Juan He,and Zhi-min Peng. Juan He helped the English polishing of the manuscript. Bao-di Wang, Guo-chuan Yan and Han Liu participated in field work. All authors discussed the results and contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflicts of interest.

Acknowledgements

This research was supported by the Second Comprehensive Scientific Investigation and Research Program on the Qinghai-Tibet Plateau (2019QZKK0702), the China Geological Survey Program (DD20221715, DD20190053).

Supplementary data set

Supplementary data (Table. S1) to this article can be found online at doi: 10.31035/cg2023019.

References

Andersen T. 2005. Detrital zircons as tracers of sedimentary provenance: Limiting conditions from statistics and numerical simulation. Chemical Geology, 216(3–4), 249–270. doi: 10.1016/j.chemgeo. 2004.11.013.

Boger SD, Carson CJ, Wilson CJL, Fanning CM. 2000. Neoproterozoic deformation in the Radok Lake region of the northern Prince Charles Mountains, east Antarctica; evidence for a single protracted orogenic event. Precambrian Research, 104(1−2), 1–24. doi: 10.1016/s0301-9268(00)00079-6.

Bai XR, Dong YS, Chen Z, Jia RY. 2021. Geochronology of "Precambrian " meta-sedimentary rocks in Changning: Menglian tectonic belt and its geological significanc. Global Geology, 4(10), 743–758+792 (in Chinese with English abstract).

Bureau of Geology and Mineral Resources of Yunnan Province. 1990. Wuhan, China University of Geosciences Press, 1–366 (in Chinese).

Cong BL, Wu GY, Zhang Q, Zhang RY, Zhai MG, Zhao DS, Zhang WH. 1994. Petrotectonic evolution of Paleo-Tethys in Western Yunnan, China. Science in China (Series B), 37(08), 1016–1024 (in Chinese with English abstract). doi: 10.1007/BF00703717.

Cawood PA, Nemchin AA. 2000. Provenance record of a rift basin: U/Pb ages of detrital zircons from the Perth Basin, Western Australia. Sedimentary Geology, 134(3–4), 209–234. doi: 10.1016/s0037-0738(00)00044-0.

Clark DJ, Hensen BJ, Kinny PD. 2000. Geochronological constraints for a two-stage history of the Albany-Fraser Orogen. Western Australia. Precambrian Research, 102(3–4), 155–183. doi: 10.1016/s0301-9268(00)00063-2.

Chen F, Li XH, Wang XL, Li QL, Siebel W, 2007. Zircon age and Nd-Hf isotopic composition of the Yunnan Tethyan belt, southwestern China. International Journal of Earth Sciences, 96(6), 1179–1194. doi: 10.1007/s00531-006-0146-y.

Chen Y, Yan MD, Fang XM, Song CH, Zhang WL, Zan JB, Zhang ZG, Li BS, Yang YP, Zhang DW. 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. doi: 10.1016/ j.epsl.2017.07.025.

Chen Q, Sun M, Long XP, Zhao GC, Wang J, Yu Y, Yuan, C. 2018. Provenance study for the Paleozoic sedimentary rocks from the west

Yangtze Block: Constraint on possible link of South China to the Gondwana supercontinent reconstruction. Precambrian Research, 309, 271–289. doi: 10.1016/j.precamres.2017.01.022.

Chen FK, Wu GH, Nie H, He S, Huang XG. 2021. Precambrian crustal evolution of the Tethyan Yunnan, Southwest China: Records in detrital zircons from Paleozoic sedimentary rocks of the Baoshan block. Precambrian Research, 354, 106057. doi: 10.1016/j.precamres.2020.106057.

DeCelles PG, Gehrels GE, Quade J, LaReau B, Spurlin M. 2000. Tectonic implications of U-Pb zircon ages of the Himalayan orogenic belt in Nepal. Science, 288, 497–499. doi: 10.1126/science.288.5465.497.

Duan, XD, Li, J, Zeng, WT, Feng, WJ, 2006. The discovery of ganlongtang tectionic melange in the middle section of Changning-Menglian zone. Yunnan Geology, 25(1), 53–62 (in Chinese with English abstract).

Duan L, Meng QR, Zhang CL, Liu XM. 2011. Tracing the position of the South China block in Gondwana: U-Pb ages and Hf isotopes of Devonian detrital zircons. Gondwana Research, 19(1), 141–149. doi: 10.1016/j.gr.2010.05.005.

Dong CY, Li C, Wan YS, Wang W, Wu YW, Xie HQ, Liu DY. 2011. Detrital zircon age model of Ordovician Wenquan quartzite south of Lungmuco-Shuanghu Suture in the Qiangtang area, Tibet: Constraint on tectonic affinity and source regions. Science China Earth Sciences, 54(7), 1034–1042. doi: 10.1007/s11430-010-4166-x.

Deng, J, Wang, QF, Li, GJ, Li, CS, Wang, CN. 2014. Tethys tectonic evolution and its bearing on the distribution of important mineral deposits in the Sanjiang region, SW China. Gondwana Research, 26(2), 419–437. doi: 10.1016/j.gr.2013.08.002.

Deng J, Wang QF, Li GJ, Li CS. 2016. Superimposed orogeny and composite metallogenic system: Case study from the Sanjiang Tethyan belt, SW China. Acta Petrologica Sinica, 32(8), 2225–2247 (in Chinese with English abstract).

Eglington BM, 2006. Evolution of the Namaqua-Natal Belt, southern Africa–A geochronological and isotope geochemical review. Journal of African Earth Sciences, 46 (1–2), 93–111. doi: 10.1016/j.jafrearsci.2006.01.014.

Feng QL, Liu BP, Ye M, Yang WP. 1996. Age and tectonic setting of the Nanduan Formation and the Laba Group in Southwestern Yunnan. Journal of Stratigraphy, 20(3), 183–189 (in Chinese with English abstract). doi: 10.19839/j.cnki.dcxzz.1996.03.004.

Fitzsimons ICW. 2000. Grenville-age basement provinces in East Antarctica: Evidence for three separate collisional orogens. Geology, 28, 879–882. doi: 10.1130/0091-7613(2000)28<879:gbpiea>2.0.co;2.

Fan WM, Wang YJ, Zhang YH, Zhang YZ, Jourdan F, Zi JW, Liu HC. 2015. Paleotethyan subduction process revealed fromTriassic blueschists in the Lancang tectonic belt of Southwest China. Tectonophysics, 662, 95–108. doi: 10.1016/j.tecto.2014.12.021.

Feng YM, Zhang Y. 2018. Introduction and commentary on ocean plate stratigrapgy. Geological Bulletin of China, 37(4), 523–531 (in Chinese with English abstract).

Griffin WL, Belousova EA, Shee SR, Pearson NJ, O’Reilly SY. 2004. Archean crustal evolution in the northern Yilgam Craton: U-Pb and Hf-isotope evidence from detrital zircons. Precambrian Research, 131, 231–282. doi: 10.1016/j.precamres.2003.12.011.

Greentree MR, Li ZX, Li XH, Wu H. 2006. Late Mesoproterozoic to earliest Neoproterozoic basin record of the Sibao orogenesis in western South China and relationship to the assembly of Rodinia. Precambrian Research, 151 (1–2), 79–100. doi: 10.1016/j.precamres.2006.08.002.

Gehrels GE, DeCelles PG, Ojha TP, Upreti BN. 2006. Geologic and U-Pb geochronologic evidence for early Paleozoic tectonism in the Dadeldhura thrust sheet, far-west Nepal Himalaya. Journal of Asian Earth Sciences, 28 (4–6), 385–408. doi: 10.1016/j.jseaes.2005.09.012.

Goscombe B, Foster DA, Gray D, Wade B. 2020. Assembly of central Gondwana along the Zambezi Belt: Metamorphic response and basement reactivation during the Kuunga Orogeny. Gondwana Research, 80, 410–465. doi: 10.1016/j.gr.2019.11.004.

Hsü K, 1968. Principles of melanges and their bearing on the Franciscan-Knoxville Paradox. Geological Society of America Bulletin, 79, 1063–1074. doi: 10.1130/0016-7606(1968)79[1063:POMATB]2.0.CO;2.

Halpin JA, Daczko NR, Milan LA, Clarke GL. 2012. Decoding near-concordant U-Pb zircon ages spanning several hundred million years: recrystallisation, metamictisation or diffusion? Contributions to Mineralogy and Petrology, 163 (1), 67–85. doi: 10.1007/s00410-011-0659-7.

Hsü KJ, Pan GT, Sengör AM. 1995. Tectonic evolution of the Tibetan Plateau: A working hypothesis based on the archipelago model of orogenesis. International Geology Review, 37(6), 473–508. doi: 10.1080/00206819509465414.

Hu JF, Peng, ZM, Fu YZ. 2020. Zircon U-Pb age, geochemistry and Hf isotopes from albite-schist of the Early Palaeozoic accretionary complex in western Yunnan. China Geology, 1–13 (in Chinese with English abstract).

Hamilton W. 1978. Mesozoic tectonics of the western United States. Reviews of Geophysics, 4(4), 509–549.

Hokada T, Grantham G. H, Arima M, Saito S, Shiraishi K, Armstrong RA, Eglington B, Misawa K, Kaiden H. 2019. Stenian A-type granitoids in the Namaqua-Natal Belt, southern Africa, Maud Belt, Antarctica and Nampula Terrane, Mozambique: Rodinia and Gondwana amalgamation implications. Geoscience Frontiers. 10(6), 2265–2280. doi: 10.1016/j.gsf.2019.04.003.

Han, WW, Peng, ZM, Zhang, J Guan JL, Hu JF, Liu YP. 2020. U-Pb dating of zircon, Hf isotope composition and tectonic significance of the albite-leptite of the Lancang rock group in the Shuangjiang area of western Yunnan, China. Acta Geologica Sinica, 94(4), 1282–1294 (in Chinese with English abstract).

He Juan, Wang, BD, Wang QY, 2020. Subduction and collision of the Jinsha River Paleo-Tethys: Constraints from Zircon U-Pb dating and geochemistry of the Ludian batholith in the Jiangda-Deqen-Weixi continental margin arc. Acta Geologica Sinica (English Edition), 94(04), 972–987. doi: 10.1111/1755-6724.14554.

Isozaki Y, Maruyama S, Fukuoka F. 1990. Accreted oceanic materials in Japan. Tectonophysics, 181, 179–205. doi: 10.1016/0040-1951(90)90016-2.

Jia JH. 1994. Sedimentary characteristics and tectonic palaeogeography of the Nanduan Group in the Changning-Menglian Zone, Southwestern Yunnan, with discussions on the features of the Lincang Terrane. Lithofacies Palaeogeography 04, 42–48 (in Chinese with English abstract).

Jian P, Liu D, Kröner A, Zhang Q, Wang Y, Sun X, Zhang W, 2009a. Devonian to Permian plate tectonic cycle of the Paleo-Tethys Orogen in Southwest China (I), geochemistry of ophiolites, arc/back-arc assemblages and within-plate igneous rocks. Lithos 113(3-4), 748–766. doi: 10.1016/j.lithos.2009.04.004.

Jian P, Liu D, Kröner A, Zhang Q, Wang Y, Sun X, Zhang W. 2009b. Devonian to Permian plate tectonic cycle of the Paleo-Tethys Orogen in Southwest China (II), insights from zircon ages of ophiolites, arc/back-arc assemblages and within-plate igneous rocks and generation of the Emeishan CFB province. Lithos, 113, 767–784. doi: 10.1016/j.lithos.2009.04.006.

Kong HL, Dong GC, Mo XX, Zhao ZD, Zhu DC, Wang S, Li R, Wang QL. 2012. Petrogenesis of Lincang granites in Sanjiang area of western Yunnan Province: Constraints from geochemistry, zircon U–Pb geochronology and Hf isotope. Acta Petrologica Sinica, 28(5), 1438–1452 (in Chinese with English abstract).

Ksienzyk AK, Jacobs J. 2015. Western Australia-Kalahari (Walahari) connection in Rodinia: Not supported by U/Pb detrital zircon data from the Maud Belt (East Antarctica) and the Northampton Complex (Western Australia). Precambrian Research. 259, 207–221. doi: 10.1016/j.precamres.2014.11.020.

Karig DE. 1983. Temporal relationships between back arc basin formation and arc volcanism with special reference to the Philippine Sea. Washington DC American Geophysical Union Geophysical Monograph Series, 27, 318–325.

Kusky TM, Bradley DC. 1999. Kinematics of mélange fabrics: Examples and applications from the Mc-Hugh Complex, Kenai Peninsula. Alaska. Journal of Structual Geology, 21, 1773–1796. doi: 10.1016/S0191-8141(99)00105-4.

Kusky TM, Windley BF, Safonova I, Wakita K, Wakabayashi J, Polat A. and Santosh M. 2013. Recognition of ocean plate stratigraphy in accretionary orogens through Earth history: A record of 3.8 billion years of sea floor spreading, subduction, and accretion. Gondwana Research, 24(2), 501–547. doi: 10.1016/j.gr.2013.01.004.

Kroner A. 2016. The Central Asian Orogenic Belt : Geology, Evolution, Tectonics and Models. Suttgart, Germany, Bornttaeger Science Publishers, 1–104.

Liu BP, Feng QL, Fang NQ, Jia JH, He FX. 1993. Tectonic evolution of paleo-tethys poly-island ocean in Changning-menglian and Lancangjiang belts, Southwestern Yunnan, China. Earth Science —Journal of China University of Geosciences, 18(05), 530–539 (in Chinese with English abstract).

Liu BP, Feng QL, Chonglakmani C, Helmcke D. 2002. Framework of paleo-tethys archpelago ocean of Western Yunnan and its elongation towords North and South. Earth Science Frontiers, 9(3), 529–538 (in Chinese with English abstract).

Liu YS, Hu ZC, Gao S, Günther D, Xu J, Gao CG, Chen HH. 2008. *In situ* analysis of major and trace elements of anhydrous minerals by LA-ICP-MS without applying an internal standard. Chemical Geology, 257(1–2), 0–43. doi: 10.1016/j.chemgeo.2008.08.004.

Liu YS, Hu ZC, Zong KQ, Gao CG, Gao S, Xu J, Chen HH. 2010. Reappraisement and refinement of zircon U-Pb isotope and trace element analyses by LA-ICP-MS. Chinese Science Bulletin, 55(15), 1535–1546. doi: 10.1007/s11434-010-3052-4.

Li DP, Chen YL, Hou KJ, Lu Z, Cui D. 2015. Detrital zircon record of Paleozoic and Mesozoic meta-sedimentary strata in the eastern part of the Baoshan block: Implications of their provenance and the tectonic evolution of the southeastern margin of the Tibetan plateau. Lithos, 227, 194–204. doi: 10.1016/j.lithos.2015.04.009.

Li J, Zhang J, Zhao X, Jiang M, Li Y, Zhu Z, Feng Q, Wang L, Sun G, Liu J, Yang T. 2016. Mantle subduction and uplift of intracontinental mountains: A case study from the Chinese Tianshan mountains within Eurasia. Scientific Reports, 6(1), 28831. doi: 10.1038/srep 28831.

Liu YM, Li C, Xie CM, Fan JJ, Wu H. 2016. Detrital zircon U-Pb ages and Hf isotopic composition of the Ordovician Duguer quartz schist, central Tibetan Plateau: constraints on tectonic affinity and sedimentary source regions. Geological Magazine, 154(3), 558–570. doi: 10.1017/s0016756816000212.

Liu YM, Xie CM, Li C, Li SZ, Santosh M, Wang M, Fan JJ. 2019. Breakup of the northern margin of Gondwana through lithospheric delamination: Evidence from the Tibetan Plateau. GSA Bulletin, 131(3–4), 675–697. doi: 10.1130/b31958.1.

Liu GC, Sun ZB, Zi JW, Santosh M, Zhao TY, Feng QL, Chen GY, Nie XM, Li J, Zhang ST. 2021. Proto-Tethys ophiolitic mélange in SW Yunnan: Constraints from zircon U-Pb geochronology and geochemistry. Geoscience Frontiers, 12(5), 101200. doi: 10.1016/j. gsf.2021.101200.

Li JL. 2004. Basic characteristics of accretion-type orogens. Geological Bulletin of China, 23(9), 947–951 (in Chinese with English abstract). doi: 10.3969/j.issn.1671-2552.2004.09.018.

Leier AL, Kapp P, Gehrels GE, DeCelles PG. 2007. Detrital zircon geochronology of carboniferous-cretaceous strata in the Lhasa terrane. Southern Tibet. Basin Research, 19(3), 361–378. doi: 10.1111/j.1365-2117.2007.00330.x.

Li J, Sun ZB, Huang L, Xu GX, Tian SM, Deng RH, Zhou K. 2017. P-T-t path and geological significance of retrograded eclogites from Mengku area in western Yunnan Province, China. Acta Petrologica Sinica, 33(7), 2285–2301 (in Chinese with English abstract).

Liu GC, Sun ZB, Zeng WT, Feng QL, Huang L, Zhang H. 2017. The age of Wanhe ophiolitic mélange from Mengku area, Shuangjiang county, Western Yunnnan Province, and its geological significance. Acta Petrologica ET Mineralogica, 36(2), 163–174 (in Chinese with English abstract). doi: 10.3969/j.issn.1000-6524.2017.02.003.

Liu BB, Peng TP, Fan WM, Zhao GC, Gao JF, Dong XH, Peng BX. 2020. Tectonic evolution and paleoposition of the Baoshan and Lincang blocks of West Yunnan during the Paleozoic. Tectonics, 39(10), 2019tc006028. doi: 10.1029/2019tc006028.

Mondal MEA, Goswami JN, Deomurari MP, Sharma KK. 2002. Ion microprobe Pb^{207}/Pb^{206} ages of zircons from the Bundelkhand massif, northern India: implications for crustal evolution of the Bundelkhand-Aravalli protocontinent. Precambrian Research, 117(1), 85–100. doi: 10.1016/s0301-9268(02)00078-5.

McQuarrie N, Robinson D, Long S, Tobgay T, Grujic D, Gehrels G, Ducea M. 2008. Preliminary stratigraphic and structural architecture of Bhutan: Implications for the along strike architecture of the Himalayan system. Earth and Planetary Science Letters, 272(1–2), 105–117. doi: 10.1016/j.epsl.2008.04.030.

Myrow PM, Hughes NC, Searle MP, Fanning CM, Peng SC, Parcha SK. 2009. Stratigraphic correlation of Cambrian-Ordovician deposits along the Himalaya: Implications for the age and nature of rocks in the Mount Everest region. Geological Society of America Bulletin, 121 (3–4), 323–332. doi: 10.1130/b26384.1.

Myrow PM, Hughes NC, Goodge JW, Fanning CM, Williams I. S, Peng S, Bhargava ON, Parcha SK, Pogue KR, 2010. Extraordinary transport and mixing of sediment across Himalayan central Gondwana during the Cambrian-Ordovician. Geological Society of America Bulletin, 122 (9–10), 1660–1670. doi: 10.1130/b30123.1.

Mckenzie NR, Hughes NC, Myrow PM, Xiao S, Sharma M. 2011. Correlation of Precambrian-Cambrian sedimentary successions across northern India and the utility of isotopic signatures of Himalayan lithotectonic zones. Earth and Planetary Science Letters, 312(3–4), 471–483. doi: 10.1016/j.epsl.2011.10.027.

Metcalfe I. 2002. Permian tectonic framework and palaeogeography of SE Asia. Journal of Asian Earth Sciences, 20(6), 551–566. doi: 10.1016/s1367-9120(02)00022-6.

Metcalfe I, 2013. Gondwana dispersion and Asian accretion: Tectonic and palaeogeographic evolution of eastern Tethys. Journal of Asian Earth Sciences, 66, 1–33. doi: 10.1016/j.jseaes.2012.12.020.

Metcalfe CM, Henderson KW. 2017. Lower Permian conodonts from Palaeo-Tethys Ocean plate stratigraphy in the Chiang Mai-Chiang Rai Suture Zone, northern Thailand. Gondwana Research, 44, 54–66. doi: 10.1016/j.gr.2016.12.003.

Niitsuma N. 2004. Japan trench and tectonics of the Japanese Island Arcs. The Island Arc, 13(1), 306–317. doi: 10.1111/j.1440-1738. 2003.00427.x.

Nebel O, Rapp RP, Yaxley GM. 2014. The role of detrital zircons in Hadean crustal research. Lithos 190, 313–327. doi: 10.1016/j.lithos. 2013.12.010.

Nie XM, Feng QL, Qian X, WangYJ. 2015. Magmatic record of Prototethyan evolution in SW Yunnan, China: Geochemical, zircon U-Pb geochronological and Lu-Hf isotopic evidence from the Huimin metavolcanic rocks in the southern Lancangjiang zone. Gondwana Research, 28(2), 757–768. doi: 10.1016/j.gr.2014.05.011.

Pidgeon RT, Wilde SA. 1990. The distribution of 3. 0-Ga and 2. 7-Ga volcanic episodes in the Yilgarn Craton of Western-Australia. Precambrian Research, 48(3), 309–325. doi: 10.1016/0301-9268(90) 90015-i.

Pan GT, Chen ZL, Li XZ, Xu Q, Jiang XS. 1996. Models for the evolution of the polyarc-basin systems in eastern tethys. Lithofacies Paleogeography, 16(02), 52–65 (in Chinese with English abstract).

Peng TP, Wang YJ, Fan WM, Liu DY, Shi YR, Miao LC. 2006. SHRIMP zircon U-Pb dating of Early Mesozoic acidic igneous rocks in the southern part of the Lancang River and its tectonic implications. Science in China Series D Earth Sciences, 49 (10), 1032–1042. doi: 10.1007/s11430-006-1032-y.

Pullen A, Kapp P, Gehrels GE, Vervoort JD, Ding L. 2008. Triassic continental subduction in central Tibet and Mediterranean-style closure of the Paleo-Tethys Ocean. Geology, 36(5), 351–354. doi: 10.1130/g24435a.1.

Pan GT, Wang LQ, Li RS, Yin FG, Zhu DC, 2012. Tectonic model of archipelagic arc-basin systems: The key to the Continental geology. Sedimentary Geology and Tethyan Geology, 32(3), 2–17 (in Chinese with English abstract). doi: 10.3969/j.issn.1009-3850.2012.03.001.

Pan GT, Wang LQ, Geng QR, Yin FG, Wang BD, Wang DB, Peng ZM, Ren F. 2020. Space-time structure of the Bangonghu-Shuanghu-Nujiang-ChangningMenglian Mega-suture zone: A discussion on geology and evolution of the Tethys Ocean. Sedimentation and Tethyan geology, 40(03), 1–19 (in Chinese with English abstract). doi: 10.19826/j.cnki.1009-3850.2020.07001.

Pan GT, Lu SN, Xiao QH. 2016. Division of tectonic stages and tectonic evolution in China. Earth Science Frontiers, 23(6), 1–23 (in Chinese with English abstract). doi: 10.13745/j.esf.2016.06.001.

Peng ZM, Zhang J, Guan JL, Zhang Z, Han WW, Fu Y. 2018. The discovery of Early Middle Ordovician granitic gneiss from the giant Lincang batholith in Sanjiang area of western Yunnan and its geological implications. Earth Science, 43, 2571–2585 (in Chinese with English abstract).

Pan GT, Xiao QH, Zhang KX, Yin FG, Ren F, Peng ZM, Wang JX. 2019. Recognition of the oceanic subduction-accretion zones from the orogenic belt in continents and its important scientific significance. Earth Science, 44(5), 1544–1561 (in Chinese with English abstract).

Peng ZM., Zhang J*, Guan JL, Zhang Z, Han WW, Fu YZ. 2019. The glaucophane eclogite was found in the Pangpang Lancang rock group, Yunnan Province. Journal of Chengdu University of Technology (Science and Technology Edition), 46(5), 639–640 (in Chinese with English abstract). doi: 10.3969/j.issn.1671-9727.2019.05.14.

Peng ZM, Wang BD, Hu JF, Fu YZ, Wang GZ, Zhang J, Liu YH, Zhang Z, Guan JL, Han WW. 2022. Determination and oceanic crust subduction of Early Palaeozoic accretionary complexes in the western Yunnnan Province—New cognition based on the geological survey of Wendong sheet (1∶50000). China Geology, 49(5), 1656–1672 (in Chinese with English abstract).

Taira A. 2001. Tectonic evolution of the Japanese Island Arc system. Annual Review of Earth and Planetary Sciences, 29(1), 109–134. doi: 10.1146/annurev.earth.29.1.109.

Veevers JJ, Saeed A, Belousova EA, Griffin WL. 2005. U-Pb ages and source composition by Hf-isotope and trace-element analysis of detrital zircons in Permian sandstone and modem sand from southwestern Australia and a review of the paleogeographical and denudational history of the Yilgam Craton. Earth-Science Reviews, 68(3–4), 245–279. doi: 10.1016/j.earscirev.2004.05.005.

von Huene R, Klaeschen D, Cropp B, Miller J. 1994. Tectonic structure across the Accretionary and Eros ional parts of the Japan trench margin. Journal of Geophysical Research Solid Earth, 99(B11), 22349–22361. doi: 10.1029/94JB01198.

Wei GY, Feng GR, Luo ZW, Wu SZ, Tao YY. 1984. Stratigraphic sequences of the Lancang and Chongshan groups in western Yunnan and their volcanism andmetamorphism. Journal of Chengdu University of Technology, 2, 12–20 (in Chinese with English abstract).

Wu HR, Du Y. 1994. A discussion on some problems concerning stratigraphic geology of southern part of the Changning-Menglian Belt, Western Yunnan. Journal of Stratigraphy, 18(3), 221–227 (in Chinese with English abstract). doi: 10.19839/j.cnki.dcxzz.1994.03.012.

Wiedenbeck M, Goswami JN, Roy AB. 1996. Stabilization of the Aravalli Craton of northwestern India at 2.5 Ga: An ion microprobe zircon study. Chemical Geology, 129 (3–4), 325–340. doi: 10.1016/0009-2541(95)00182-4.

Wang DD, Li BL, Ji JQ, Liu YH. 2014. Zircon SHRIMP U–Pb geochronology and it tectonic implication of the metamorphic rocks in southern Lancang River tectonic zone, West Yunnan Province. Acta Petrologica Sinica, 30(9), 2725–2738 (in Chinese with English abstract).

Wang Q, Deng J, Li C, Li G, Yu Li, Qiao L. 2014. The boundary between the Simao and Yangtze blocks and their locations in Gondwana and Rodinia: Constraints from detrital and inherited zircons. Gondwana Research, (2), 438–448. doi: 10.1016/j.gr.2013.10.002.

Wang F, Liu FL, Ji L, Liu PH, Cai J, Tian ZH, Liu LS. 2016. Petrogenesis and metamorphic evolution of blueschist from Xiaoheijiang-Shangyun area in Lancangjiang metamorphic complex. Acta Petrologica Et Mineralogica, 35, 804–820 (in Chinese with English abstract).

Wang F, Liu, FL, Ji, L, Liu, LS. 2017. LA-ICP-MS U-Pb dating of detrital zircon from low-grade metamorphic rocks of the Lancang rock group in the Lancangjiang Complex and its tectonic implications. Acta Petrologica Sinica, 33(9), 2975–2985 (in Chinese with English abstract).

Wang BD, Wang LQ, Pan GT, Yin FG, Wang DB, Tang Y. 2013. U-Pb zircon dating of Early Paleozoic gabbro from the Nantinghe ophiolite in the Changning-Menglian suture zone and its geological implication. Chinese Science Bulletin, 58(8), 920–930. doi: 10.1007/s11434-012-5481-8.

Wang BD, Wang LQ, Wang DB, He J, Peng ZM, Yan GC. 2018. Tectonic Evolution of the Changning-Menglian Proto-Paleo Tethys ocean in the Sanjiang Area, Southwestern China. Earth Science, 43(8), 2527–2550 (in Chinese with English abstract).

Wang HN, Liu FL, Li J, Sun ZB, Ji L, Tian ZH, Liu LS, Santosh M. 2018. Petrology, geochemistry and P-T-t path of lawsonite-bearing retrograded eclogites in the Changning-Menglian orogenic belt, Southeast Tibetan Plateau. Journal of Metamorphic Geology, 37(4), 439–478.

Wang W, Cawood PA, Pandit MK, Zhou MF, Zhao JH. 2019. Evolving passiveand active-margin tectonics of the Paleoproterozoic Aravalli Basin, NW India. Geological Society of America Bulletin, 131(3–4), 426–443. doi: 10.1130/b35027.1.

Wang BD, Wang LQ, Zhou DQ, Wang DB, Yu YP, Yan GC, Wu Z. 2021. Longmuco-Shuanghu-Changning-Menglian suture zone: The boundary between Gondwanaland and Pan-Cathaysia mainland in the Qinghai-Tibet Plateau. Geological Bulletin of China, 40(11), 1783–1798 (in Chinese with English abstract).

Wang LQ, Wang BD, Li GM, Wang DB, Peng ZM. 2021. Major progresses of geological survey and research in East Tethys: An overview. Sedimentary Geology and Tethyan Geology, 41(02), 283–296 (in Chinese with English abstract). doi: 10.19826/j.cnki.1009-3850.2021.01008.

Wu GH, Zhang H, Hu A, Li W, Huang X, Cheng H, He J, Chen F. 2022. Provenance of the Early Paleozoic sedimentary succession in the Lancang Block, SW China: Implications for the tectonic evolution of the northern margin of Gondwana. Journal of Asian Earth Sciences, 231, 105229. doi: 10.1016/j.jseaes.2022.105229.

Wei YH, Zi JW, Liu GC, Sun ZB, Chen GY, Zhao TY, Nie XM, Yang Z. 2022. Reconstructing the Lancang Terrane (SW Yunnan) and implications for Early Paleozoic Proto-Tethys evolution at the northern margin of Gondwana. Gondwana Research, 101, 278–294. doi: 10.1016/j.gr.2021.08.009.

Xia XP, Nie XS, Lai CK, Wang YJ, Long XP, Meffre S. 2016. Where was the Ailaoshan Ocean and when did it open: A perspective based on detrital zircon U-Pb age and Hf isotope evidence. Gondwana Research, 36, 488–502. doi: 10.1016/j.gr.2015.08.006.

Xu YF, Cong F, Liu JP, Sun ZB, Huang XM. 2018. U-Pb dating of the detrital zircons from the Lancang rock group Complex in western Yunnan and its geological significance. Sedimentary Geology and Tethyan Geology, 38(2), 105–114 (in Chinese with English abstract).

Xu, BY, Li, DP, Kang, H, Song, LJ, Chen, YL, Zhang, YL, Geng, JZ, Somerville, I. 2019. Detrital zircon record of Cambrian (meta-)

sedimentary strata in the western part of the Baoshan Block: Constraints on its eastern boundary and Early Palaeozoic palaeoposition. Geological Journal, 55(5), 3416–3429. doi: 10.1002/gj.3593.

Xing XW. 2016. Early Paleozoic Tectonic Nature in SW Yunnan: Constraints from Magmatism and Sedimentation, Beijing, University of Chinese Academy of Sciences, PhD Thesis, 1–187 (in Chinese with English abstract).

Yu SY, Li KQ, Shi YP, Zhang HH. 2003. A study on the granodiorite in the middle part of Lincang granite batholith. Yunnan Geology, 22, 426–442 (in Chinese with English abstract). doi: 10.3969/j.issn.1004-1885.2003.04.009.

Yang WQ, Feng QL, Duan XD. 2007. Late Devonian pillow basalt and bedded chert in Changning-Menglian tectonic belt of Southwestern Yunnan. China. Geological Bulletin of China, 26(06), 739–747 (in Chinese with English abstract). doi: 10.3969/j.issn.1671-2552.2007.06.016.

Yu JH, O'Reilly, SY, Wang L, Griffin WL, Zhou MF, Zhang M, Shu L. 2010. Components and episodic growth of Precambrian crust in the Cathaysia Block, South China: Evidence from U-Pb ages and Hf isotopes of zircons in Neoproterozoic sediments. Precambrian Research, 181(1–4): 97–114. doi: 10.1016/j.precamres.2010.05.016.

Yao WH, Li ZH, Li WX. 2015. Was there a Cambrian ocean in South China? –Insight from detrital provenance analyses Geological Magazine, 152(1), 184–191. doi: 10.1017/S0016756814000338.

Yang L, Wang QF, Wang YN, Li GJ. 2018. Proto- to Paleo-Tethyan evolution of the eastern margin of Simao block. Gondwana Research, 62, 61–74. doi: 10.1016/j.gr.2018.02.012.

Ren F, Pan GT, Yin FG, Cheng MY, Xiao QH. 2017. Oceanic plate stratigraphy and tectonic evolution of the Nujiang-Lancangjiang-Jinshajiang area in southwestern China. Sedimentary Geology and Tethyan Geology, 37(4), 9–16 (in Chinese with English abstract). doi: 10.3969/j.issn.1009-3850.2017.04.003.

Mo XX, Shen SY. 1993. Sanjiang Tethyan Volcanism and Related Mineralization. Beijing, Beijing Geological Publishing Press, 1–267 (in Chinese).

Shervais JW. 2006. The significance of subduction-related accretionary complexes in early earth processes. Geological Society of America Special Papers, 405, 173–192.

Sun ZB, Li J, Zhou K, Zeng WT, Duan XD, Zhao JT, Xu GX, Fan YC. 2017a. Geochemical characteristics and geological significance of retrograde eclogite in Mengku Area, Shuangjiang County, Western Yunnan Province, China. Geoscience, 31(4), 746–756 (in Chinese with English abstract).

Sun ZB, Li J, Zhou K, Zeng WT, Wu JL, Hu SB, Liu GC, Zhao JT. 2017b. Zircon U-Pb age and geological significance of retrograded eclogites from Mengku area in western Yunnan Province. Geological Bulletin Of China, 37(11), 2032–2043 (in Chinese with English abstract).

Sun ZB, Hu SB, Li J, Duan XD, Liu FL, Zhou K, Zhao JT, Li XJ, Bao JF, Wang YX. 2020. Petrology and metamorphism of blueschist in the Damenglong, Jinghong, Southwest Yunnan and its response to Paleotethyan tectonics. Geology in China, 1–20. http://kns.cnki.net/kcms/detail/11.1167.P.20200804.0852.002.html.

Zhang RY, Cong BL, Li YG. 1990. Petrology of blueschist in western Yunnan Province, China and its tectonic significance. Science in China, 33(09), 1110–1123. doi: 10.1163/156856790X00265.

Zheng JP, Griffin WL, O 'Reilly SY, Zhang M, Pearson N, Pan YM. 2006. Widespread Archean basement beneath the Yangtze craton. Geology, 34(6), 417–420. doi: 10.1130/g22282.1.

Zhang LD, Lv Z, Zhang GB, Song SG. 2008. The geological characteristics of oceanic-type UHP metamorphic belts and their tectonic implications: Case studies from Southwest Tianshan and North Qaidam in NW China. Chinese Science Bulletin, 53(20), 3120–3130. doi: 10.1007/s11434-008-0386-2.

Zhang KX, He WH, Xu YD, Luo MS, Song BW, Kou XH, Zhang ZY, Xiao QH, Pan GT. 2016. Palaeogeographic distribution and tectonic evolution of OPS in China. Earth Science Frontiers, 23(6), 24–30 (in Chinese with English abstract). doi: 10.13745/j.esf.2016.06.002.

Zhang KX, He WH, Luo MS. 2017. Sedimentary Rock Construction and Sedimentary Tectonic Evolution in China. Beijing, Geological Publishing Press, 1–604 (in Chinese).

Zhai MG, Cong BL, Qiao GS. 1990. Sm-Nd and Rb-Sr geochronology of metamorphic rocks from SW Yunnan orogenic zones, China. Acta Petrologica Sinica, 6(4), 1–11 (in Chinese with English abstract). doi: 10.3321/j.issn:1000-0569.2000.01.011.

Zhong DL, 1998. Paleo-Tethyan Orogenic Belt in West Sichuan and West Yunnan. Beijing, Science Press. 1–231 (in Chinese).

Zhu DC, Zhao ZD, Niu Y, Dilek Y, Mo XX. 2011a. Lhasa terrane in southern Tibet came from Australia. Geology, 39(8), 727–730. doi: 10.1130/g31895.1.

Zhu DC, Zhao ZD, Niu Y, Mo XX, Chung SL, Hou ZQ, Wang LQ, Wu FY. 2011b. The Lhasa Terrane: Record of a microcontinent and its histories of drift and growth. Earth and Planetary Science Letters, 301(1–2), 241–255. doi: 10.1016/j.epsl.2010.11.005.

Zi JW, Peter AC, Fan WM, Wang YJ, Eric TT, Campbell M, Peng TP. 2012. Triassic collision in the Paleo-Tethys Ocean constrained by volcanic activity in SW China. Lithos. 144–145. doi: org/10.1016/j.lithos.2012.04.020.

Zi JW, Peter AC, Eric TT. 2013. Late Permian-Triassic magmatic evolution in the Jinshajiang orogenic belt, SW China and implications for orogenic processes following closure of the Paleo-Tethys. American Journal of Science, 313(2), 81–112. doi: 10.2475/02.2013.02.

Zeng WT, Liu GC, Feng QL, Zhao TY, Yu SY, Deng RH, Mo XX. 2017. The relationship between Lincang Block and provenance of Nanduan Formation: Evidence of detrital zircon U-Pb dating from metasandstone of Devonian Carboniferous Nanduan Formation. Geological Bulletin of China, 36(7), 1175–1187 (in Chinese with English abstract).

Zhao TY, Feng QL, Metcalfe I, Milan LA, Liu GC, Zhang ZB. 2017. Detrital zircon U-Pb-Hf isotopes and provenance of Late Neoproterozoic and Early Paleozoic sediments of the Simao and Baoshan blocks, SW China: Implications for Proto-Tethys and Paleo-Tethys evolution and Gondwana reconstruction. Gondwana Research, 51, 193–208. doi: 10.1016/j.gr.2017.07.012.

Zhao TY. 2019. Early Paleozoic Proto-Tethys Tectonic Evolution in SW Yunnan: Constraints from Detrital Zircon U-Pb Geochronology and Granite Associations. Wuhan, China University of Geosciences. PhD Thesis, 1–149 (in Chinese with English abstract).

Zhou ML, Xia XP, Peng TP. 2020. Detrital zircon U-Pb-Hf isotope studies for the Paleozoic sandstones from the Baoshan Block, western Yunnan, and their constraints on the Gondwana continental reconstruction. Acta Petrologica Sinica, 36(2), 469–483 (in Chinese with English abstract). doi: 10.18654/1000-0569/2020.02.09.