The U-Pb Geochronology and Lu-Hf Isotope Compositions of Detrital Zircons from the Nanhua Group of the Longsheng Region, South China and their Implications for Pan-African Events

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Abstract: It is unclear whether the South China blocks have an affinity with continental Gondwana due to a lack of direct Pan-African magmatic and metamorphic features. In this study, we conducted U-Pb geochronological and Lu-Hf isotopic analyses for detrital zircons from a sandstone of the Chang’an Formation of the Nanhua Group in the Longsheng region of northern Guangxi, with the aim of constraining the timing of sedimentation and information as to its source, as well as seeking evidence for Pan-African events in the South China blocks. The results show that the ages of detrital zircons peaked at 654.7 ± 6.2 Ma, 773.2 ± 4.1 Ma and 821.9 ± 6.5 Ma, with some at 920–870 Ma; the youngest age indicates the existence of the Pan-African thermal event. The εHf(t) and TDM2 values demonstrate that the study area has experienced three stages of crustal growth at 3.0–2.4 Ga, 2.1–1.5 Ga and 1.3–0.9 Ga. With intensively distributed Neoproterozoic mafic-ultramafic and granitic plutons emplaced at 830–810 Ma along the southwestern section of the Jiangnan Orogenic Belt and positive εHf(t) values from a large group of zircon grains, it is proposed that the sediments of the Chang’an Formation (of Nanhua Group) were largely sourced from the southeastern margin of the Yangtze block. Comparison with the zircon age spectra of the Cathaysian block shows that about 79% of the Pan-African aged detrital zircon grains that have TDM2 = 1352–1031 Ma and εHf(t) = 3.68–8.79, were sourced from the recycled Grenvillian crust of the Cathaysian block, suggesting that the Cathaysian block had a close connection with Gondwana.

Key words: detrital zircon, Lu-Hf isotope, Pan-African event, Guangxi, South China

1 Introduction

The term ‘Pan-African events’ refers to global-scale orogenic events that involved tectonic, magmatic and metamorphic activities that led to the formation of a number of mobile belts and the amalgamation of continental domains during the Neoproterozoic to the earliest Paleozoic time (900–500 Ma or 550 ± 100 Ma) (Kennedy, 1964; Krober, 1993; Santosh and Yoshida, 2001; Lu, 2004; Xu et al., 2005). The Pan-African events culminated in the formation of the supercontinent Gondwana. For several decades, geologists have been looking for evidence to prove the presence of Gondwana in South China. Unfortunately, no direct magmatic and metamorphic features have ever been found or confirmed. In other regions in China, for example, in northeast China and Tibet, there have been reports of Gondwana-related magmatic features (Wilde et al., 2001; Xu et al., 2005; Li et al., 2008; Yao et al., 2011; Yao, 2016). Advances in paleontology (Li et al., 2000; Servais et al., 2003; Steiner et al., 2007), paleomagnetism (Han et al., 2015), and detrital zircon geochronology (Yao et al., 2011; Wu et al., 2013; Yao, 2016; Zhang et al., 2016; Han et al., 2017) in recent years, however, have provided lines of evidence that suggest an affinity of South China to Gondwana.

Detrital zircon geochronology has become an important method in constraining the timing of sedimentation, tracing the source of sediments, reconstructing paleogeography and revealing tectonic evolutionary history (Wang et al., 2008; Yu et al., 2008; Yu J H et al., 2010; Liang et al., 2020; Zhou et al., 2020). Several workers have applied the method in analysis of the detrital zircons contained in Neoproterozoic and early Paleozoic strata in South China, in particular in southeastern and southern Hunan Province and the northeastern Guangxi Zhuang Autonomous Region, reported sizable geochronological data for Gondwana-related events, and
suggested that the Pan-African events apparently affected the Cathaysian block of South China and the neighboring areas (Wu et al., 2013; Zhang et al., 2016; He, 2016).

The Nanhua Group is a package of upper Neoproterozoic strata deposited in the so-called Nanhua rift along the southwestern section of the Jiangnan Orogenic Belt, which was formed as a result of subduction and collision between the Yangtze and Cathaysian blocks in the early Neoproterozoic. The Group is underlain by the older Danzhou and Sibao groups of the late Mesoproterozoic and early Neoproterozoic ages. In theory, sources of sediments in the Nanhua Group could be from either the Yangtze or Cathaysian blocks, or from both. In our study, we collected a sandstone sample from the Chang’an Formation of the Nanhua Group in the Longsheng region of northern Guangxi and selected a large number of detrital zircon grains for U-Pb geochronological and Lu-Hf isotopic analyses, with the aim of constraining the timing of sedimentation and the source of sediments, so as to seek evidence for Pan-African events in South China.

2 Geological Setting

The Longsheng region is located in western and central South China and northern Guangxi. Tectonically, it is situated in the southwestern section of the Jiangnan Orogenic Belt (Fig. 1a). The section is made up predominantly of the lower and middle Neoproterozoic Sibao and Danzhou groups, which form the basement of the Orogenic Belt. Both groups are unconformably overlain by the Nanhua Group, Sinian Group and Paleozoic rocks of the cover strata (Hua, 1995; Ma, 1997; Wang et al., 2017). The cover strata are thick sedimentary successions deposited in the northeast-trending Nanhua rift system that formed as a result of extension along the Jiangnan Orogenic Belt. The Longsheng region is largely underlain by both Danzhou and Nanhua-Sinian groups with the Danzhou Group occurring in the core area of several NE-trending anticlines and the Nanhua-Sinian groups forming the limbs of the anticlines. The Danzhou Group in the region is divided into the Hetong and Gongdong formations; the Nanhua Group is divided into the Chang’an, Fulu and Silikou formations, and the Sinian Group consists of the Laobao and Doushantuo formations (Fig. 1b).

The Sibao Group, which is largely exposed in the area of southwest Longsheng region, consists of formations of predominantly lightly-metamorphosed turbidite successions of sandstone, siltstone, slate, phyllite and minor volcanic rocks. The Sibao Group are emplaced by a number of granitic plutons such as the Sanfang and Yuanbaoshan granite plutons, as well as mafic-ultramafic intrusions in the Baotan region. These igneous rocks have been regarded as products of subduction and collision between the Yangtze and Cathaysian blocks (Li et al., 1995, Li and Mu, 1999; Ge et al., 2001b; Li X H et al., 2003; Zhou et al., 2003, 2009, 2014; Wang X L et al., 2006; Zhou et al., 2007; Li et al., 2012; Wang et al., 2017).

The Danzhou Group in Longsheng region is composed of sandstone, slate, conglomerate, mudstone, with minor limestone and volcanic rocks. It also contains more than 100 mafic and ultramafic igneous intrusions (Gan et al., 1996; Ge et al., 2000b, 2001a, b; Zhang, 2004; Zhou et al., 2007), which are collectively referred to as the Longsheng
Mafic-Ultramafic Suite. Based on our recent geochronological and geochemical analyses (Liu et al., 2021), the Suite originated from partial melting of the enriched upper, asthenospheric mantle (EM-I type) due to asthenospheric underplating and lithospheric extension during the incipient stage of the Rodinia breakup.

The Chang’an Formation of the Cryogenian Nanhua Group consists of a greyish green thickly-layered pebble-bearing sandstone of diamictite (Cai et al., 2018); it has a parallel unconformity with the underlying Gongdong Formation of the Danzhou Group. Because of its glacial origin, previous workers focused on studies of its age and sedimentary source from a glaciation perspective and on a global-scale comparison (Zhang and Chu, 2007; Lan et al., 2014, 2015; Han et al., 2016; Cai, 2018; Cai et al., 2018).

Structurally, in addition to several large-scale NE-trending folds, in particular several anticlines, a number of predominantly NE-striking ductile shear zones and faults are also developed in the region (Fig. 1b). Most of them are confined within the pre-Cambrian strata of the region. However, they are considered to have been produced during the Caledonian Orogeny (Liang and Huang, 1997; Zhang et al., 2003; Zhang, 2004; Yu K P et al., 2010; Yu, 2010; Tang et al., 2014; Zhang et al., 2015; Zhang, 2015; Qin et al., 2018).

3 Sampling and Analytical Methods

A sandstone sample was collected from the Chang’an Formation of the Nanhua Group (Fig. 2a). The sampling site is located south of Hekou Village in the Longsheng region (E109°47′57″, N25°49′38″) (Fig. 1b). The sandstone consists predominantly of quartz with minor quantities of plagioclase feldspar and clay minerals (Fig. 2b). The quartz clasts have a diameter between 0.05 and 0.4 mm, with 80% of them at a grade of 0.05–0.25 mm. The clasts are sub-angular in shape with moderate sorting, indicative of moderate transportation. Some quartz clasts show slight recrystallization and undulose extinction as a result of low-grade metamorphism and deformation. The clay minerals show some degree of sericitization.

Detrital zircon grain selection, mounting, photography and CL imaging were performed at the Beijing GeoAnalysis Co. Ltd., while zircon U-Pb analysis was conducted at the LA-ICP-MS Laboratory of the Guangxi Key Laboratory of Hidden Metallic Ore Exploration, Guilin University of Technology. The beam diameter for both zircon U-Pb analysis and Hf isotopic analysis was 32 μm. Standard samples GJ-1 and Plešovice were used for external calibration. A GL-1 standard sample was also used during zircon Hf isotopic analysis. Data processing was carried out by ICPMSDataCal 11 (Liu et al., 2010). Isoplot 3.0 (Ludwig, 2003) was used to generate concordia diagrams, distribution histograms and Hf isotopic diagrams. The 207Pb/206Pb age is reported where the age was greater than 1000 Ma otherwise the 206Pb/238U ages were used if the age was younger than 1000 Ma.

4 Results

4.1 LA-ICP-MS zircon U-Pb ages

120 detrital zircon grains were selected from the sandstone sample (Gb1807) for U-Pb analysis by LA-ICP-MS (Appendix 1). Among them were 107 grains that show a concordance value between 90 and 110, that were used for data analysis in this study.

A group of zircon grains that exhibit the youngest U-Pb ages have a variety of complex forms, such as oval, prismatic and irregular shapes. They also have a higher degree of roundness (Fig. 3a). Their diameter ranges between 50 and 120 μm. They showed various zonation patterns, including magmatic oscillatory zoning, patched zoning and irregular zoning (Fig. 3a). The contents of Th and U are 134.36–1619.07 ppm and 116.79–1494.30 ppm, respectively, with Th/U ratios of 0.54–2.01. These zircon grains have complicated origins and have experienced significant transportation.

Zircon grains with other ages have a relatively simple shape, with most of them being long or short prismatic and less rounded (Figs. 3b–d). Their diameters are in the range 50–180 μm. Most of them show a typical magmatic oscillatory zoning pattern with only some showing dark relict cores (Figs. 3b–d). The contents of Th and U are 67.21–1664.15 ppm and 91.39–2037.66 ppm, respectively, with Th/U ratios of 0.34–2.38. These zircon grains are not far from their original sources.

In summary, the varying morphological features of the detrital zircon grains of different ages suggest their
differing origins and sources.

In the U-Pb concordia diagram, all 107 grains are plotted on or in the vicinity of the concordance line (Fig. 4a). In the distribution frequency histogram (Fig. 4b), the zircon ages are clustered at three peaks of 654.7 ± 6.2 Ma (MSWD = 0.0064, $n = 24$), 773.2 ± 4.1 Ma (MSWD = 0.073, $n = 55$), and 821.9 ± 6.5 Ma (MSWD = 0.0086, $n = 22$). Four zircon grains show U-Pb ages of 920–870 Ma, and two show 1697 Ma and 2119 Ma. The youngest U-Pb age of 654.7 ± 6.2 Ma, from a group of zircon grains corresponds well with the age of the Pan-African events.

4.2 Zircon Lu-Hf isotopic analysis

The Hf isotopic analysis was carried out at each laser
targeting spot for U-Pb analysis as shown in Figure 3 (Appendix 2). Generally, positive \( \varepsilon_{Hf}(t) \) values indicate a source from juvenile or mostly crustal, whereas negative \( \varepsilon_{Hf}(t) \) values suggest a source from recycled or mostly recycled crust (Griffin et al., 2000; Dhuime et al., 2011; Kou et al., 2017).

For the 24 zircon grains that provided a weighted mean \(^{206}\text{Pb}^{238}\text{U}\) age of 654.7 ± 6.2 Ma, their \(^{176}\text{Hf}^{177}\text{Hf}\) values are in the range 0.281889–0.282637, \( \varepsilon_{Hf}(t) = -17.32–8.79 \), and \( T_{DM2} = 1031–2673 \) Ma. Among these 24 grains (79.17%), 19 of them have \( T_{DM2} = 1031–1352 \) Ma and \( \varepsilon_{Hf}(t) = 3.68–8.79 \) which are all positive and indicative of a possible source from a relatively juvenile crust of 1031 – 1352 Ma age (Fig. 5a). The remaining 5 grains have \( T_{DM2} \) greater than 1352 Ma and \( \varepsilon_{Hf}(t) = -17.32–1.13 \). The \( \varepsilon_{Hf}(t) \) values are either positive or negative, suggesting that their sources are from both recycled and juvenile crustal sources (Fig. 5a).

There are 22 zircon grains that give a weighted mean \(^{206}\text{Pb}^{238}\text{U}\) age of 821.9 ± 6.5 Ma. These grains have \(^{176}\text{Hf}^{177}\text{Hf}\) values in the range 0.281944–0.282604, \( \varepsilon_{Hf}(t) = -11.75–11.22 \) and \( T_{DM2} = 1006–2451 \) Ma. Among these 22 grains, six of them (27.27%) have their \( T_{DM2} \) = 1006–1287 Ma and \( \varepsilon_{Hf}(t) = 6.74–11.22 \). The positive \( \varepsilon_{Hf}(t) \) values suggest a juvenile crustal source aged at 1006–1287 Ma (Fig. 5a). The rest of the grains (16 of them) have \( T_{DM2} = 1389–2451 \) Ma and \( \varepsilon_{Hf}(t) = -11.75–5.13 \), which are either positive or negative, indicative of both recycled and juvenile crustal sources (Fig. 5a).

Four detrital zircon grains give weighted mean \(^{206}\text{Pb}^{238}\text{U}\) ages of 870–920 Ma. Their \(^{176}\text{Hf}^{177}\text{Hf}\) values are in the range 0.281743–0.282512, \( \varepsilon_{Hf}(t) = -16.90–10.16 \) and \( T_{DM2} = 1130–2844 \) Ma. One of them has its \( T_{DM2} \) = 1130 Ma and \( \varepsilon_{Hf}(t) = 10.16 \) which is indicative of a juvenile crustal source (Fig. 5a). The other three grains have \( T_{DM2} \) = 1872–2844 and \( \varepsilon_{Hf}(t) = -16.90–2.38 \). The positive and negative \( \varepsilon_{Hf}(t) \) values suggest both recycled and juvenile crustal sources for the zircon grains (Fig. 5a).

Two detrital zircon grains that yield the oldest ages have \( T_{DM2} = 2832–3036 \) Ma and \( \varepsilon_{Hf}(t) = -7.25–5.34 \). The negative \( \varepsilon_{Hf}(t) \) values suggest a recycled old crustal source (Fig. 5a).

Among the 107 detrital zircon grains, 90 of them (84.11%) show positive \( \varepsilon_{Hf}(t) \) values and the remaining 17 grains have negative values, suggesting that the majority of them have a juvenile crustal source and the rest a recycled old crustal source (Fig. 5b). There are 60 grains (56.07%) that show \( T_{DM2} = 1000–1352 \) Ma and positive \( \varepsilon_{Hf}(t) \) values, suggesting that a significant amount of sediments in the Chang’an Formation of the Nanhua Group were derived from juvenile crust sources aged 1000 – 1352 Ma.

5 Discussion

5.1 Age limits of the Chang’an Formation (of Nanhua)

The Cryogenian-to-Ediacaran stratigraphic successions of the Nanhua rift basin in South China provide a nearly complete sedimentary record of the Cryogenian, including a continuous succession of interglacial sedimentation. The successions are best exposed at the border area between Hunan, Guangxi and Guizhou provinces, including the Longsheng region of northern Guangxi. This area is one of the hotspots for study of the Cryogenian in China (Zhang and Chu, 2007; Cai, 2018). The Chang’an Formation, being the lowest strata of the Nanhua Group, records the early stage of the Cryogenian glaciation and sedimentation. Therefore, previous workers conducted significant studies of the formation, but mostly from a glaciation perspective (Zhang and Chu, 2007; Lan et al., 2014, 2015; Han et al., 2016; Bao, 2016; Cai, 2018), although the related issues remain debatable.

There are two methods used to constrain the lower age limit of the Chang’an Formation. The first method uses detrital zircon grains collected from the Chang’an Formation to obtain the maximum sedimentation age of the formation. The second method uses the upper limit age of the underlying Danzhou Group to constrain the lower age limit of the formation. Among the published geochronological data for the lower age limit of the Chang’an Formation, there are ~780 Ma (Gao et al., 2013; Yin and Gao, 2013; Liu et al., 2015; Han et al., 2016), ~720 Ma (Zhang, 2014; Lan et al., 2014; Cui et al., 2016; Bao, 2016; Cai, 2018), and ~760 Ma (Sun et al., 2014). The 720 Ma age limit has been supported by more high-precision age data published in recent years (Gan et al., 1996; Wang X C et al., 2012; Wang et al., 2013a, b; Wu et al., 2013; Lan et al., 2014, 2015; Fan et al., 2015). This 720 Ma age correlates well with the Sturtian age (Lan et al., 2013; Lan et al., 2014, 2015; Fan et al., 2015).}

![Fig. 5. Diagram of \( \varepsilon_{Hf}(t) \) vs. U-Pb ages (a) and distribution histogram of \( \varepsilon_{Hf}(t) \) values (b).](image-url)
Fewer reports have been published on the upper age limit of the Chang’an Formation, which is generally considered to be 660 Ma (Zhou et al., 2004; Bao, 2016). This 660 Ma age is consistent with the end date of the Sturtian glaciation (Fanning and Link, 2008; Hoffman and Li, 2009; Rooney et al., 2015; Bao, 2016). The detrital zircon grains analyzed in this study yield no age from around 720 Ma. This is likely because the northern Guangxi has not recorded any magmatic events aged at around 720 Ma or the study area is far from the areas where the 720 Ma thermal events occurred. The weighted mean U-Pb age of 654.7 ± 6.2 Ma obtained from a group of the youngest zircon grains in this study, however, is within the margin of error for the upper age limit of the commonly accepted 660 Ma age.

5.2 Crustal growth

Generally, Hf model ages can be used to infer when crustal material was first derived from a depleted mantle, therefore to help understand crustal growth process and timing (Diuw et al., 2012; Kou et al., 2017). In practice, the two-stage Hf model ages (TDM2) are used to show the timing of a newly-grown crust (i.e. juvenile crust) (Hawkesworth et al., 2010; Belousova et al., 2010). In addition, εHf(t) values are used to infer whether a zircon grain is sourced from juvenile crust or from recycled crust (Griffin et al., 2000; Dhuime et al., 2011; Kou et al., 2017).

As shown in Figure 6, there exist two apparent peaks of the TDM2 values at 0.9–1.3 Ga and 1.5–2.1 Ga; the third small peak occurs at 2.4–3.0 Ga. The zircon grains with TDM2 values at 0.9–1.3 Ga have positive εHf(t) values of 4.77–11.22, indicative of a juvenile crustal source. The zircon grains with TDM2 values at 1.5–2.1 Ga have εHf(t) values of ~5.75–3.17. Most of them (65.38%) show positive εHf(t) values, with the rest exhibiting negative values. This suggests that they were sourced from both juvenile crust and recycled old crust, but mainly from juvenile crust. The zircon grains with TDM2 values at 2.4–3.0 Ga have negative εHf(t) values, indicative of a recycled old crustal source.

Based on the previously published data (Wang X C et al., 2012; Kou et al., 2017) and the zircon data obtained in this study, it is proposed that the crust in the study area has experienced three stages of growth: the first stage in 2.4–3.0 Ga, which corresponds to global-scale nucleation of crust cores (Ma et al., 2014); the second stage at 1.5–2.1 Ga, which corresponds to plate convergent and divergent events associated with the Columbia supercontinent (Li and Mu, 1999; Rogers and Santosh, 2002); and the third stage at 0.9–1.3 Ga, which corresponds to the plate convergent and divergent events related to the Rodinia supercontinent (McMenamin and McMenamin, 1990; Wang et al., 2007).

5.3 Sources of the sediments and their association with Pan-African events

In Cl images (Fig. 3), the zircon grains aged around ~654 Ma are oval or irregular in shape and well-rounded, suggesting that they have experienced long-distance transportation. However, the majority of the zircon grains that are aged at ~773 Ma, ~821 Ma, and 920–870 Ma, show a long or short prismatic shape and are largely angular, indicative of short-distance transportation. In summary, the sediments in Chang’an Formation were largely proximally-sourced, with only some from afar.

Two suites of extensively-developed mafic and ultramafic igneous intrusions occur respectively in the Sibao and Danzhou groups of the basement of the Nanhua Group in northern Guangxi; they have been dated at 870–830 Ma and 770–750 Ma, respectively (Gan et al., 1996; Li et al., 1999; Li, 1999b; Ge et al., 2000a, b, 2001a, b; Li Z X et al., 2003; Wang et al., 2007; Zhou et al., 2007; Wang X L et al., 2012). This area also contains several large granitic plutons dated at 830–810 Ma, for example, the Sanfang and Yuanbuoshan granitic plutons (Li, 1999a; Li X H et al., 2003; Wang J et al., 2006). In summary, it is widely accepted that northern Guangxi saw significant magmatic thermal events between 900–750 Ma (Gan et al., 1996; Li et al., 1999; Li, 1999a; Ge et al., 2000a, b, 2001a, b; Li Z X et al., 2003; Li X H et al., 2003; Wang X L et al., 2006, 2012; Wang et al., 2007; Zhou et al., 2007). The detrital zircon grains dated at ~773 Ma, ~821 Ma, and 920–870 Ma in this study, as discussed above, were proximally-sourced; they could have been sourced specifically from these mafic-ultramafic and granitic plutons.

Previous workers proposed that the Neoproterozoic sedimentary rocks in the Cathaysian block contain a large number of Grenvillian (1.3–0.9 Ga) and Neoarchean (~2.5 Ga) detrital zircon grains (Yu et al., 2008; Wang et al., 2008; Yu J H et al., 2010; Xiang and Shu, 2010) and that a Grenvillian orogeny likely occurred to the south of the Cathaysian block (Wang et al., 2008). The Yangtze block is, however, characterized by widespread magmatic events associated with the Rodinia breakup at 860–780 Ma as stated above. In addition, the Yangtze block contains igneous rocks emplaced at 2.0 Ga, which do not occur in the Cathaysian plate. Therefore, the zircon grains with ages peaking at 860–780 Ma and 2.0 Ga must have been sourced from the Yangtze block. The zircon grains with ages at 1.3–0.9 Ga were sourced from the Cathaysian block (Xiang and Shu, 2010; Zhang et al., 2016). In the distribution frequency histogram (Fig. 4b) of the U-Pb ages obtained in this study, the detrital zircon grains aged

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Fig. 6. Distribution histogram of Hf TDM2 values of detrital zircon grains analyzed in this study.
at ~773 Ma, ~821 Ma, and 920–870 Ma, which are considered as near-sourced, were highly likely sourced from the southeastern margin of the Yangtze block. In northern Guangxi, this source includes the extensively developed and distributed mafic-ultramafic and granitic intrusions emplaced in both Sibao and Danshou groups.

The weighted mean U-Pb age of 654.7 ± 6.2 Ma obtained from a group of the youngest zircon grains in this study corresponds to the Pan-African events reported in other places (Kennedy, 1964; Kroner, 1993; Santosh and Yoshida, 2001; Lu, 2004; Xu et al., 2005). Our recently obtained, but unpublished, geochronological data for the Caledonian Longsheng granitic pluton in the study area show a large number of inherited xenocrystal zircon grains aged at around 655 Ma. Some workers recently also reported a large number of the Pan-African aged zircon grains contained in the Neoproterozoic and early Paleozoic strata in southeastern and southern Hunan and northeastern Guangxi (Wu et al., 2013; Zhang et al., 2016; He, 2016). These zircon data collectively indicate that the study area, the northern Guangxi, has a close connection with Gondwana. The Hf data obtained in this study show that 79.17% of the Pan-African-aged detrital zircon grains were derived from the Grenvillian juvenile crust aged at 1352–1000 Ma. These detrital zircon grains were largely sourced from the Cathaysian block.

Although there are a few confirmed Pan-African tectonic-thermal events recorded in South China, some authors still maintain that the tuff and detrital zircon grains used in their studies recorded Pan-African tectonic-thermal events to some extent (Yin et al., 2005; Yu et al., 2008; Xiang and Shu, 2010; Yao et al., 2011; Yao, 2016; Zhang et al., 2016). Yao et al. (2016) believed that some detrital zircon grains contained in the Precambrian rocks in the Cathaysian block were sourced from Pan-African volcanic rocks of Cathaysia. Zhang et al. (2016) also proposed that some of the detrital zircon grains aged at around 520 Ma and contained in the Cambrian and Ordovician strata of southern Hunan and northeastern Guangxi were probably derived from Pan-African igneous rocks of the Cathaysian block.

In summary, the Pan-African aged detrital zircon grains (at ~654 Ma) contained in the Chang’an Formation of the Nanhua Group in northern Guangxi were largely sourced from the recycled Grenvillian crust material of the Cathaysian block therefore, the Cathaysian block has a close connection with Gondwanaland.

6 Conclusions

(1) The ages of the detrital zircon grains contained in the Chang’an Formation of the Nanhua Group peak at 654.7 ± 6.2 Ma, 773.2 ± 4.1 Ma, and 821.9 ± 6.5 Ma, with some at 920–870 Ma. The detrital zircon grains and the sediments in the formation were largely sourced from the Neoproterozoic mafic-ultramafic and granitic rocks along the southeastern margin of the Yangtze block while some were sourced from the recycled Grenvillian crustal material of the Cathaysian block.

(2) Based on εHf(t) and TDMc data obtained in this study, the study area, the northern Guangxi, has experienced three stages of crustal growth respectively at 3.0–2.4 Ga, 2.1–1.5 Ga, and 1.3–0.9 Ga.

(3) About 79% of the Pan-African aged detrital zircon grains analyzed in this study were sourced from the recycled Grenvillian crust of the Cathaysian block, suggesting that the Cathaysian block has a close connection with the Gondwanaland.

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