Acta Geologica Sinica (English Edition), 2020, 94(4): 1060–1070

An Early Paleozoic Tectonic Mélange at the Western Margin of West Cathaysia: Constraints from Organic-walled Microfossils

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Abstract: The Jiangshan-Shaoxing-Pingxiang Fault (JSP Fault) is traditionally considered as the boundary between the Yangtze and Cathaysia blocks in South China. Whether the previously defined Shenshan and Kuli formations located along the JSP fault and near the Xinyu City, Jiangxi Province, are continuous strata or parts of a tectonic mélange is important for understanding the geological history of South China. A carbonaceous phyllite from the area, previously considered as part of the Neoproterozoic Shenshan and Kuli formations, is analyzed palynologically in this study. The *Asteridium-Comasphaeridium* acritarch assemblage found in the slate can be correlated with the basal Cambrian *Asteridium-Heliosphaeridium-Comasphaeridium* (*AHC*) acritarch assemblage in Tarim and the Yangtze Block. The early Cambrian biostratigraphical age assignment for the carbonaceous phyllite indicates the presence of both Neoproterozoic and Cambrian rocks in the sedimentary package, and supports that the package is a part of tectonic mélange rather than a continuous Neoproterozoic strata. The Cambrian slate is the youngest known lithology in the mélange at present.

Key words: Acritarch, Shenshan and Kuli formations, Shenshan tectonic mélange, West Cathaysia

Citation: Wang et al., 2020. An Early Paleozoic Tectonic Mélange at the Western Margin of West Cathaysia: Constraints from Organic-walled Microfossils. Acta Geologica Sinica (English Edition), 94(4): 1060–1070. DOI: 10.1111/1755-6724.14558

1 Introduction

South China consists of the Yangtze Block to the northwest and the Cathaysia Block to the southeast (Fig. 1) and has a complicated geological history (Zhang et al., 2013; Wang et al., 2013; Lin et al., 2018). The Jiangshan-Shaoxing-Pingxiang Fault (JSP Fault) is considered as the boundary between the two blocks. However, when and where the two blocks were amalgamated is still controversial. One group of researchers suggest that the two blocks collided during the Neoproterozoic, forming the Jiangnan Orogen (e.g., Zhao, 2015; Zhang et al., 2013), and the JSP Fault is considered as a Neoproterozoic suture zone (Shu et al., 2006; Yao et al., 2016). In this model, South China underwent extension following the collision, forming the Neoproterozoic Nanhua Rift Basin (Li et al., 2003; Wang et al., 2003). Another group of researchers believe that there was still an ocean (the Huanan Ocean) between the Yangtze and Cathaysia blocks during the early Paleozoic and suggest that the JSP Fault was an early Paleozoic suture zone (Dong, 2016; Zhang et al., 2016; Pan et al., 2016; He et al., 2014). They report a mélange (called the Shenshan mélange) in Xinyu city (Fig. 1), Jiangxi Province, and consider it as an early Paleozoic subduction-accretionary mélange at the west margin of the Cathaysia Block and along the JSP Fault (Pan et al., 2016 Zhang et al., 2016). However, the presence of the Shenshan mélange is controversial, as the various rocks interpreted by these authors as parts of the mélange have been regarded by others as a continuous stratum developed in the Neoproterozoic Nanhua Rift Basin and divided into the lower Shenshan Formation and the higher Kuli Formation (Fig. 2; DJMRJP, 1997; Ling et al., 2004; Yang et al., 2012;). Therefore, testing whether it is a mélange is important for understanding the tectonic history of South China.

In this paper, we focus on a biostratigraphic study of a carbonaceous phyllite in the "Shenshan and Kuli formations". The biostratigraphical ranges of acritarchs present in the phyllite provide an early Cambrian age. This result shows that the "Shenshan and Kuli formations" include mixed rocks of both Neoproterozoic and Cambrian ages and are therefore not part of a continuous stratum. We support that these rocks are parts of the Shenshan tectonic mélange.

2 Geological Settings

2.1 Regional geology

The Yangtze Block exposes sparse Archean and

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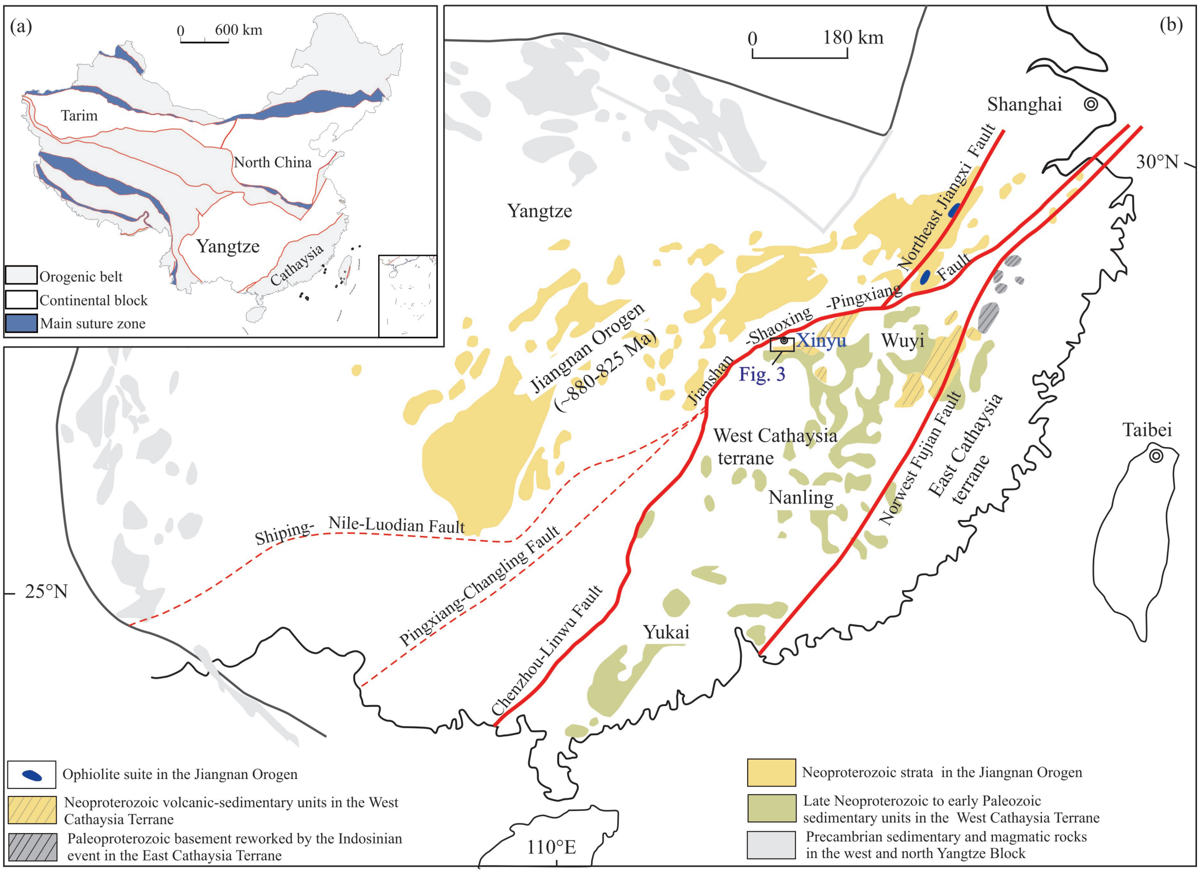

Fig. 1. (a) Map showing the tectono-stratigraphic divisions of China (modified after Zhang et al., 2016). (b) Simplified geological map showing the major divisions and the distribution of pre-Devonian rocks in South China (modified after Zhao and Cawood, 2012; Lin et al., 2018).

Paleoproterozoic rocks (Zhao and Cawood, 2012). Its circumferentia is characterized by widespread Neoproterozoic igneous and sedimentary rocks (Wang et al., 2016; Zhang et al., 2018; Zhao et al., 2018).

The Jiangnan Orogen along the southeastern margin of the Yangtze Block is featured by Neoproterozoic arc/back-arc basin assemblages. It has been divided into the Mesoproterozoic to Neoproterozoic composite Huaiyu terrane and the Neoproterozoic Jiuling and Southwest terranes (Yao et al., 2019; Lin et al., 2018). Shortly after the amalgamation of these terranes in the Neoproterozoic, the Jiangnan Orogen underwent regional extension, resulting in the development of the Neoproterozoic Nanhua Rift Basin (Li et al., 2003; Wang and Li, 2003; Shu, 2011). This was followed by the deposition of Cryogenian to Early Paleozoic successions in this basin, characterized by platform and basin and slope facies (He et al., 2014)

Across the JSP Fault, the Cathaysia Block is divided into the West Cathaysia terrane and the East Cathaysia terrane by Northwest Fujian Fault (Fig. 1; Lin et al., 2018). The West Cathaysia terrane is characterized by ca. 1.0–0.9 Ga meta-rhyolite, amphibolite and meta-basaltic rocks, sparsely exposed in the Yunkai and Wuyi domains (Fig. 1). Thick volcanic and sedimentary rocks (including turbidite) with ages of 850–700 Ma were broadly distributed in the Wuyi domain (Guo et al., 2018; Yu et al., 2018; Jiang et al., 2019; Qi et al., 2019). The late Neoproterozoic to early Paleozoic sedimentary sequences in the West Cathaysia terrane are dominated by thick sequences of clastic rocks, with detritus derived from Gondwana sources (Yao et al., 2014).

The Neoproterozoic volcanic and sedimentary rocks are widely distributed in the Jiangxi Province. They are divided into the north and south strata by the JSP Fault (Geological Survey of Jiangxi Province, 2018; Yang et al., 2012). Those in northern Jiangxi belong to the Jiangnan Orogen, named the Shuangqiaoshan Group in the Jiuling terrane and the Shuangxiwu Group in the Huaiyu terrane. They are unconformity overlain by the Dengshan Group and the Heshangzheng Group which were formed in the Nanhua Rift Basin. The Neoproterozoic strata in central and southern Jiangxi belong to the West Cathaysia terrane, including the lower Shenshan Formation and the upper Kuli Formation. These rocks are characterized by a series of bathyal facies turbidite sequences and have experienced greenschist-facies metamorphism (DGMRJP, 1997; Yang et al., 2012; Guo et al., 2018).

2.2 Regional geology

The study area is located in the Shenshan area, Xinyu city, in the central Jiangxi Province near the JSP Fault,

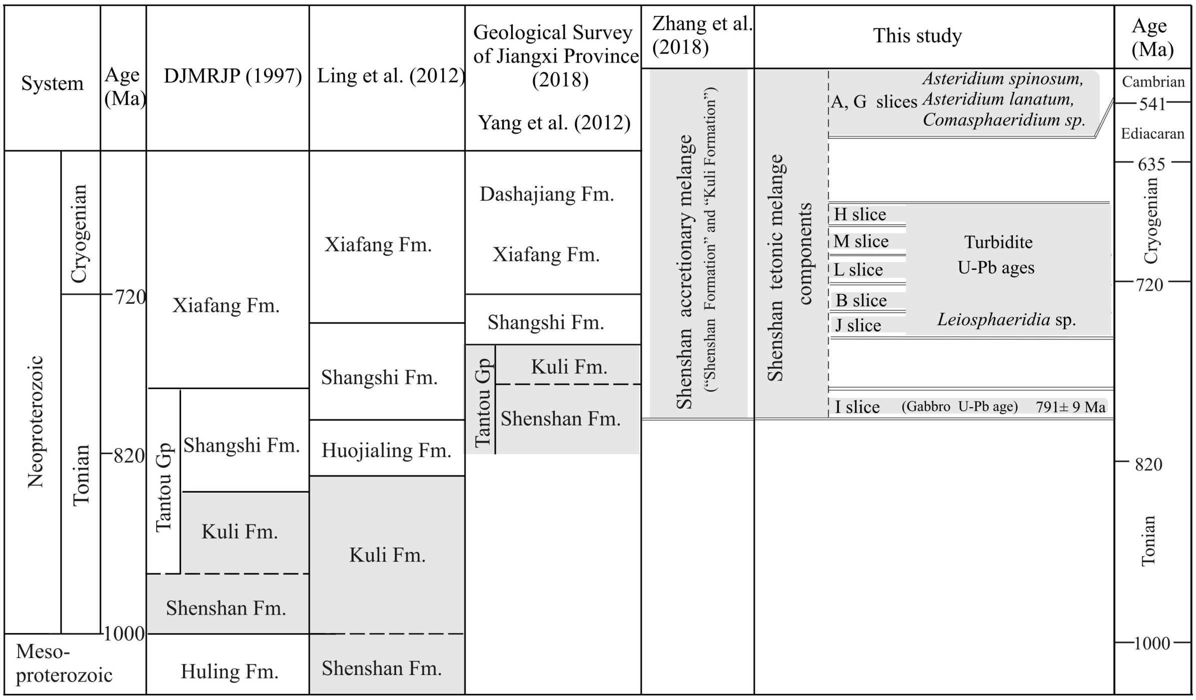

Fig. 2. The division and age correlation of the "Shenshan Formation" and the "Kuli Formation" in the Shenshan area, Jiangxi Province, South China.

where the Shenshan and Kuli formations were established by Jiangxi Geological Survey in 1964 (DGMRJP, 1997). The Late Neoproterozoic Shangshi and Xiafang formations, mainly exposed in the southern part of the study area, is composed of meta-quartz sandstone, garnet-bearing mica schist and quartzite with intercalated BIF in the upper part (DGMRJP, 1997), suggesting a much higher metamorphic grade (higher greenschist facies to lower amphibolite). Some Silurian granite plutons intruded into the Shangshi and Xiafang formations (Fig. 3). The lacustrine facies Eocene sequences are in fault contact with older strata, and Quaternary sedimentary rocks overlie all the other strata.

The previously defined Shenshan and Kuli formations are mainly composed of gray-green tuffaceous phyllite, grayish sericite phyllite, dark gray carbonaceous phyllite, tuff, tuffaceous silty phyllite and tuffaceous metasandstone (DJMRJP, 1997; Ling et al., 2004), interpreted to be intruded by several bodies of ultramafic and mafic rocks (Yang et al., 2012, 2019). The originally defined Shenshan Formation is characterized by dark gray phyllite, especially the carbonaceous phyllite, while the Kuli Formation mainly contains tuff and tuffaceous phyllite (Fig. 3).

More recently, Pan et al. (2016) and Zhang et al. (2016) proposed that the "Shenshan and Kuli formations" in the study area are not continuous strata but an accretionary mélange (the Shenshan mélange), and the ultramafic to mafic rocks are not intrusions but blocks embedded in the sedimentary matrix of the mélange.

Our field work shows that rocks in the "Shenshan and Kuli formations" or the "Shenshan mélange" include different lithological units separated by faults. For convenience of description, we divide them into 16 tectonic slices in the geological cross-section, labelled as A to P from north to south (Fig. 3a, b). The A and G slices are dominated by the carbonaceous phyllite (Fig. 4). The C, D, F, H and K slices mainly consist of ultramafic to mafic rocks, such as olivine pyroxenolite, pyroxenolite, gabbro and diabase. A red mudstone dominates the N slice. The other slices mainly contain tuffaceous phyllite, tuffaceous silty phyllite, meta-siltstone and meta-sandstone, referred to as the turbidite below and in Fig. 3

The different rock slices are fragmented and mixed, resulting in a block-in-matrix structure. The ultramafic and mafic rocks occur as blocks embedded in the metasedimentary rocks. The sedimentary rocks are highly deformed and develop strong foliation and tight folds. Primary sedimentary structures such as the Bouma sequence, parallel bedding, current bedding and horizontal laminae are locally preserved in low-strain zones (see Wang et al., 2020).

3 Samples and Methods

Acritarchs are the most common organic-walled microfossils during the Neoproterozoic to early Paleozoic (Evitt, 1963). Although their phylogenetic affinities and classifications are still to be solved, they have a great potential for dating late Neoprozerozoic to Early Paleozoic sedimentary rocks (Moldowan and Talyzina, 1998; Talyzina and Moczydlowska, 2000; Servais et al., 2004; Nowak et al., 2015; Yin, 1995), including low-grade clastic meta-sedimentary sequences (Montenari et al., 2000; Bian et al., 2001; Beccaletto et al., 2005). Organic-walled microfossils have previously been noted in the "Shenshan and Kuli formations" in the study area (DJMRJP, 1997; Ling et al., 2004; Guo et al., 2018), but

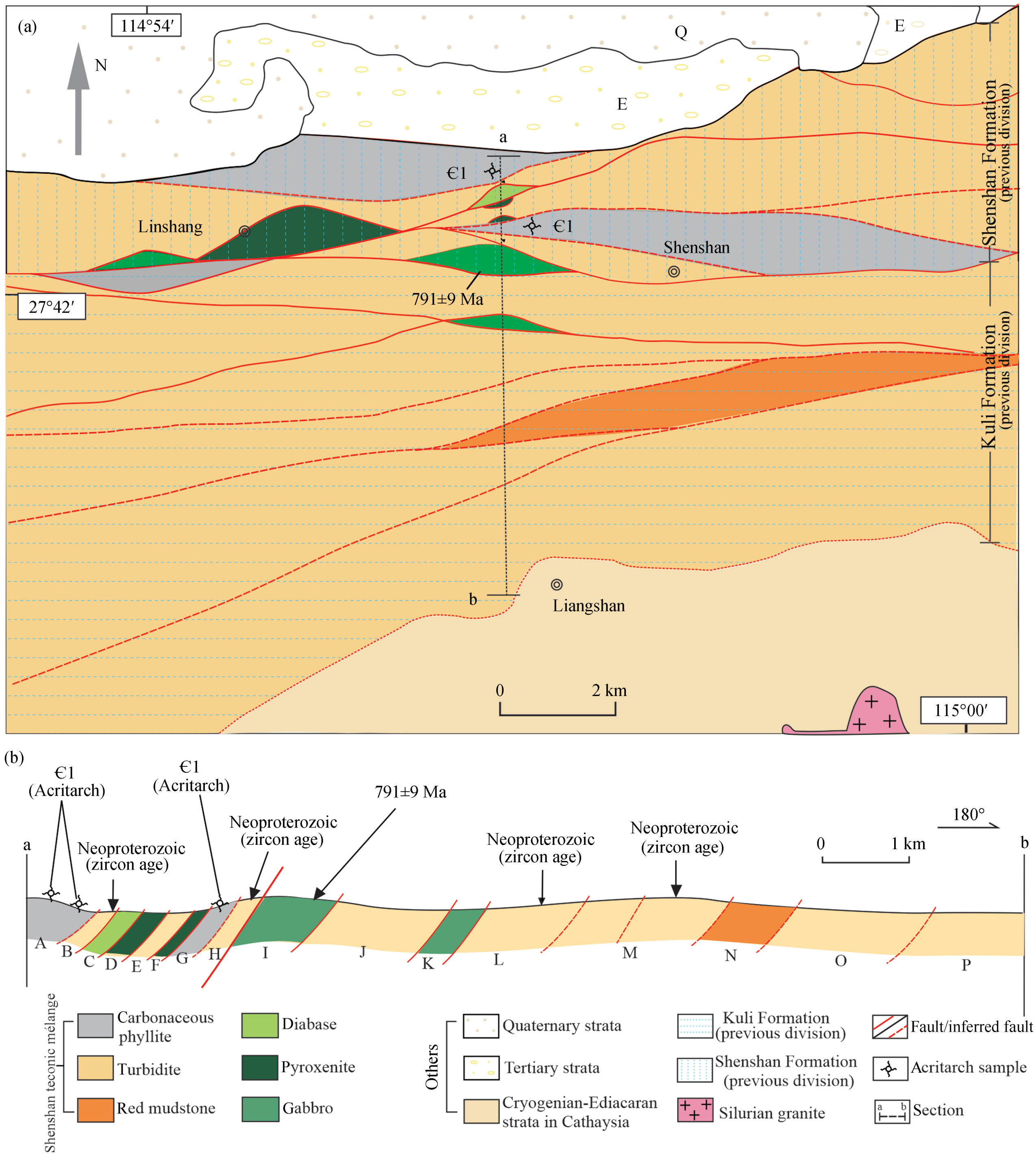

Fig. 3. (a) Simplified geological map of the Shenshan area, Jiangxi Province (modified from the geological map of Yichun City (1:250,000), Geological Survey Institute of Jiangxi Province, 2013). (b) A cross-section (location indicated in a) showing the structural relationships among the different litho-structural units in the study area and the sample locations. A to P indicate structural slices.

no description has been provided.

A palynological sampling program was carried out in the different tectonic slices in the study area. The positions of the palynologically investigated samples containing organic-walled microfossils are indicated in the cross section (Fig. 3b). A total of 48 samples were collected for palynological processing. Most of the investigated samples come from the carbonaceous phyllite in the A and G slices; other samples were investigated from the turbidite in the J, L and M slices.

The samples were processed using the standard palynological preparation procedures. Because the sedimentary rocks are deformed and metamorphosed, special care was taken to extract the extremely poorlypreserved organic-walled microfossils. Samples of fresh rock are carefully washed and pre-treated in concentrated hydrochloric acid (HCl) and then crushed into "Mung bean size". Generally 30–50 g of the fresh rock makes up a standard sample. Samples were treated with HCl to remove carbonates. The organic material was then isolated by dissolving the silicates with 45% hydrofluoric acid. After the acid was neutralized, filtration of the organic residue was carried out by hand using filters with an 8 μm mesh. The use of an ultrasonic separator was avoided, as experiences on this type of material have shown that the microfossils are commonly damaged and broken by these procedures. The material was mounted on glass slides using a micropipette. We repeated the processing for some of the samples from which acritarchs were found, to verify the results.

We also used the laser Raman spectrum analysis to rule out the possibility of modern pollution; the Raman spectra of these acritarchs were acquired by using a Horiba Jobin Yvon-LabRAM HR 800 Microprobe Laser Raman Spectrometer. A wavelength of 532 nm and a laser power of < 15 mW were set up.

The material investigated and discussed herein is permanently housed in the collections of the Institute of Geological Survey, China University of Geosicences, Wuhan.

4 Results

4.1 Palynology result

Of the 48 processed samples, only seven provided palynomorph assemblages. These seven samples have been obtained from the A, G slices in the northern part of the section (Fig. 3b). The preservation of the material recovered from the seven samples is much poorer compared to palynomorphs from non-metamorphic rocks. The acritarchs were all carbonized and are fuscous–black in colour and nearly opaque under transmitted light microscope; and not all distinctive characteristics are available. The limited number of specimens does not allow understanding the variability of the recovered morphotypes and the systematic paleontology of most taxa. Most determinations in this study are therefore tentative and generally at the generic level. The acritarch taxa from the carbonaceous phyllite in the A and G slices are characterized with acanthomorphic forms and are described in detail below. The acritarchs from the turbidite in the J slice are dominated with spheromorphic form (*Leiosphaeridia*) and some fragments of benthic algae, which significantly differ from those in the carbonaceous phyllite

Five out of the thirty processed rock samples from the carbonaceous phyllite in the A and G slices yielded a small amount of acritarchs (Figs. 5–6) accompanied by organic fragments. The most frequent are smooth and undiagnostic spheromorphs attributed to *Leiasphaeridia* sp., while the diagnostically ornamented acritarch taxa exhibiting processes and spines are less numerous. The *Asteridium spinosum*, *Asteridium lanatum* and *Comasphaeridium* sp. (Figs. 5–6) are three featured taxa in the A and G slices.

Asteridium are organic-walled microfossils with small vesicle, including species that possess solid processes separated from the interior of the vesicle and clearly the smooth nature of the surface. Length of the processes is usually smaller than diameter of central body. *Asteridium* differs from *Comasphaeridium* Staplin (Jansonius and Pocock, 1965) by the definitely smaller dimensions of the vesicle and the morphology of the processes.

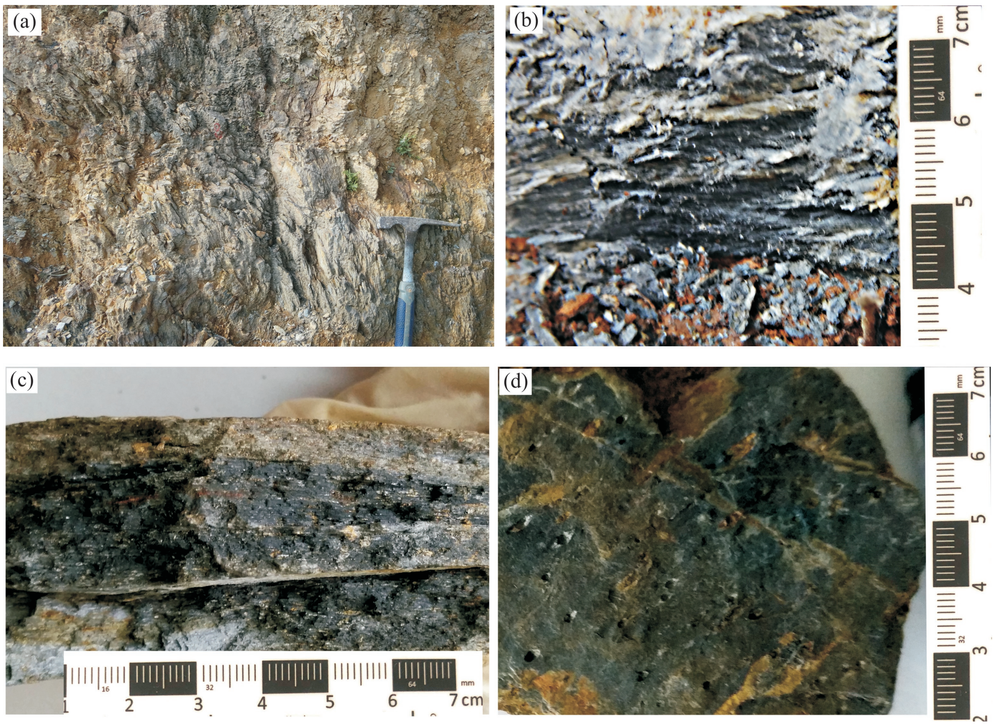

Fig. 4. Photographs for the carbonaceous phyllite in the Shenshan area, Jiangxi Province, South China. (a), (b) are from A slice; (c), (d) are from G slice.

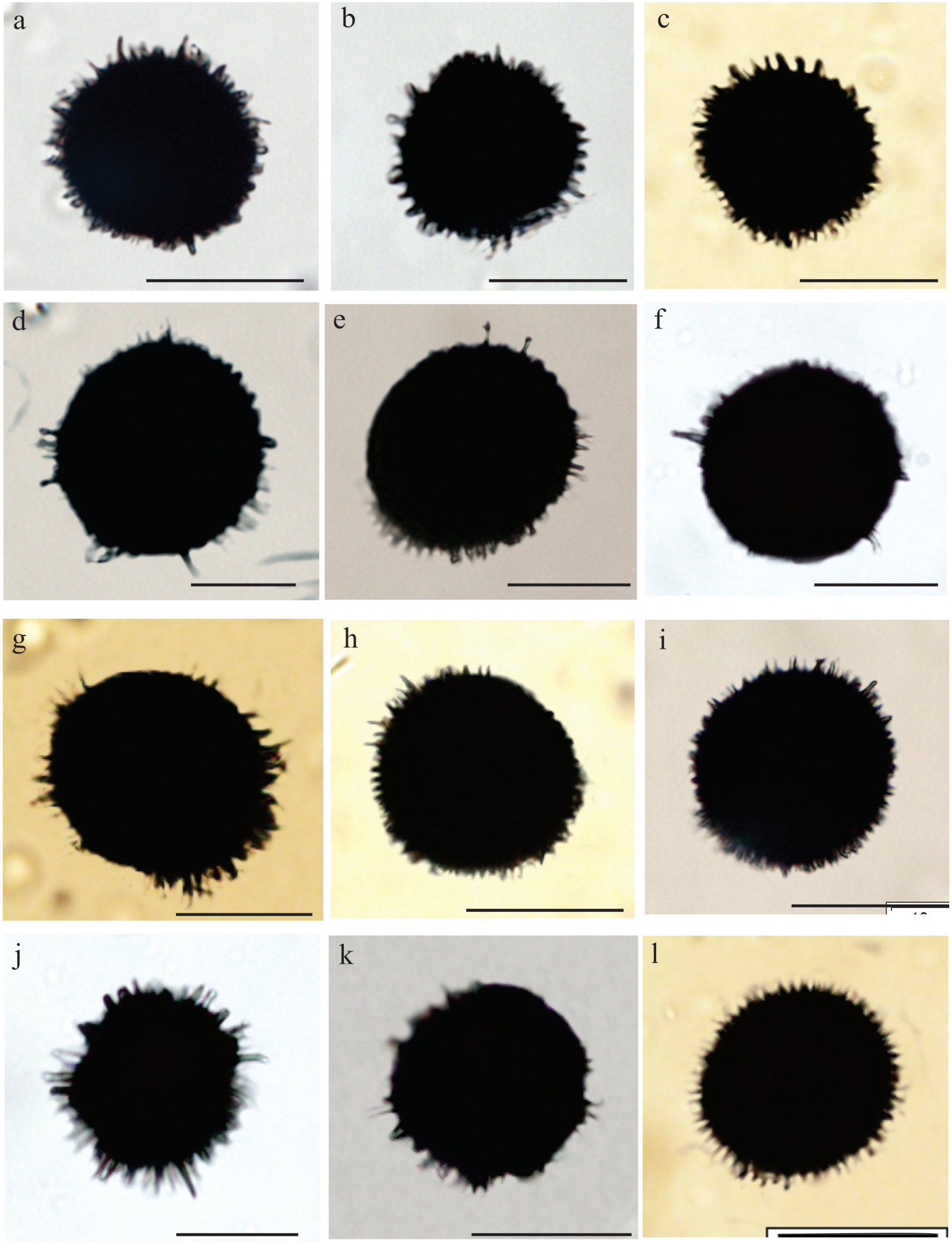

Fig. 5. Acritarchs found from the carbonaceous phyllite in the B and G slices in the study area.
(a–c) *Asteridium lanatum*; (d–f) *Asteridium spinosum*; (g–l) *Asteridium* sp. All scale bars are 10 μm. a, b, d, e, f, i, j and k are from A slices; c, g, h and l are from G slice.

Asteridium spinosum in our samples (Fig. 5d–f) is characterized by small, spherical to oval central vesicle. Numerous processes are evenly distributed on the surface of the central body. These solid simple processes are in the shape of long spines. The bases of the processes are slightly widened, and the tips are sharp; tips of some longer processes are blunt or swollen.

Asteridium lanatum (Fig. 5a–c) in our sample has a larger vesicle and more processes compared with *Asteridium spinosum*. Processes are solid, without communication with the interior of the central body. The processes are uniform, slender and hair-like, and the tips of the processes taper to distal portions. Excystment is not observed in these two taxa.

Comasphaeridium (Fig. 6a–c) identified in our samples has circular to oval vesicles, surface covered by abundant, short, and very closely arranged processes. The processes are simple, slender, and almost equal length. The tips of the processes are acuminate and flexible. The processes are slightly widened.

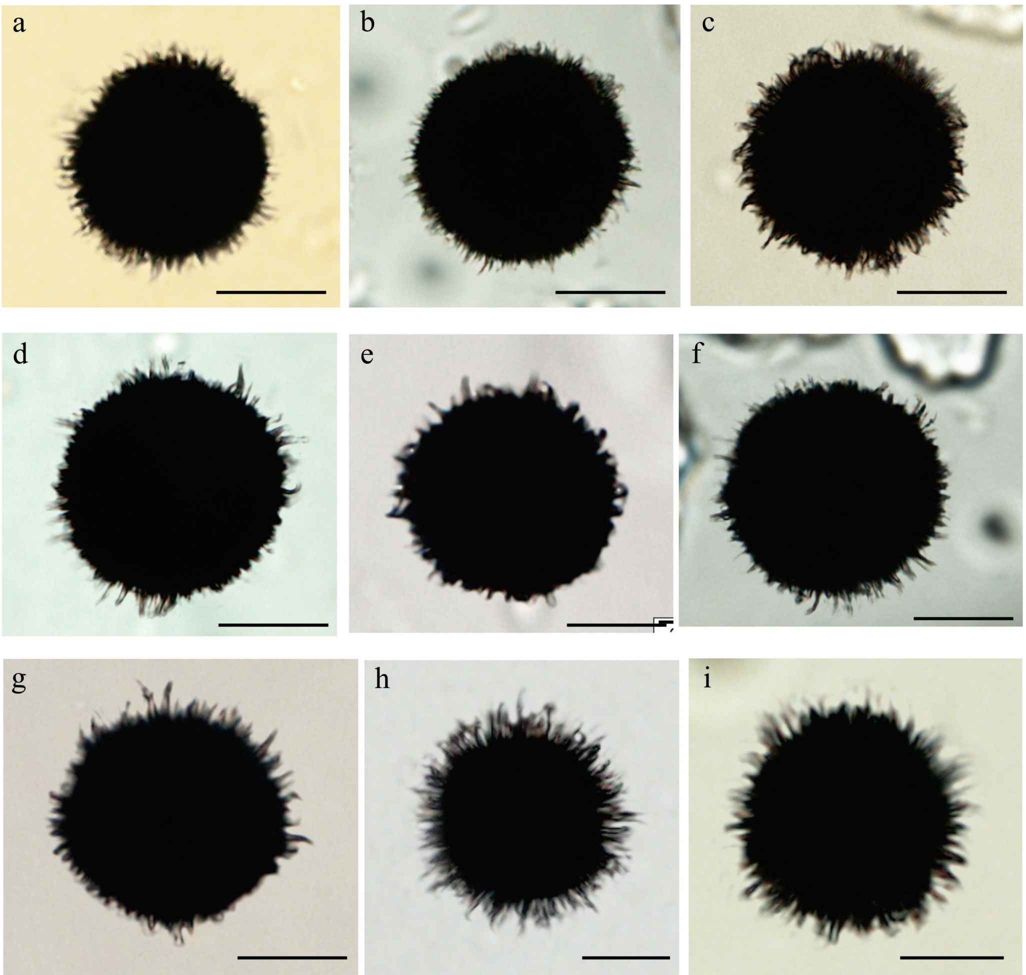

Fig. 6. Acritarchs from the carbonaceous phyllite found in the A and G slices in the study area.
(a–c) and (g–i) *Comasphaeridium* sp; (d–f) *Asteridium* sp. All scale bars are 10 μm. a and c are from G slice; b, d, e and f are from G slice.

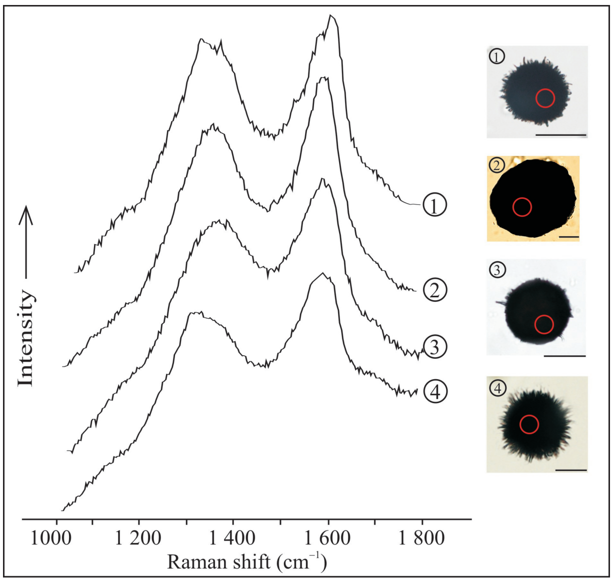

Fig. 7. Raman spectra and corresponding transmitted light photomicrograph of the acritarches in this study. The red circles indicate the analysed spots.

4.2 Laser Raman microprobe result

Four acritarchs were analyzed using Raman spectroscopy. Analyzed taxa include two specimens of *Asteridium lanatums*, and each specimen of *Comasphaeridium* and *Leiosphaeridia*.

Raman spectra of acritarchs from the carbonaceous phyllite unit show two peaks diagnostic of disordered carbon, a distinct peak at ~1600 cm^{-1} and a broad, less intense band from 1300 to 1450 cm^{-1}, centered at ~1360 cm^{-1} (Fig. 8). The major peak at 1600 cm^{-1} is attributed to ordered C = C stretching (Be´ny-Bassez and Rouzaud, 1985) from in-plane vibrations of graphite-like layers whilst the less intense peak at ~1360 cm^{-1} is attributed to minimal vibrations from disordered structures (Tuinstra and Koenig, 1970).

Raman spectra of carbonaceous material in meta-sediments exhibit a systematic change with metamorphic grade (e.g. Aoya et al., 2010; Beyssac et al., 2002; Kouketsu et al., 2014). From these Raman spectra, previous workers evaluated the metamorphic grade using spectral features such as intensity (i.e. height) ratio, area (i.e. integrated intensity) ratio, and width (i.e. full width at half maximum; FWHM) between several different peaks.

	Age (Ma)	Tarim	Yangtze Block	Lesser Himalaya	This Study
		Xiaoerblaq Fm./ Xidasha Fm.	Niutitang Fm./ Shuijingtuo Fm./ Yu'anshan Fm.	Lower Tal Fm.	
Lower Cambrian		Yurtus Fm./ Xishanblaq Fm.	Taozichong Fm./ Tianzhushan Mbr/ Zhujiaqing Fm.	Chert–phosphorite Mbr	Carbonaceous phyllite
	541	(*AHC*) *Asteridium-* *Heliosphaeridium-* *Comasphaeridium*	(*AHC*) *Asteridium-* *Heliosphaeridium-* *Comasphaeridium* reassigned from *Micrhystridium-like Acritarches*	(*AHC*) *Asteridium tornatum,* *Heliosphaeridium, ampliatum,* *Comasphaeridium annulare* reassigned from *Micrhystridium-like Acritarches*	(*AC*) *Asteridium spinosum* *Asteridium lanatum* *Asteridium* sp. *Comasphaeridium* sp.
Ediacaran		Qigeblaq Fm./ Hankalchough Fm.	Dengying Fm.	Krol C-E	

Fig. 8. Comparison of the stratigraphic occurrences of the acritarches from the carbonaceous phyllite in this study with the *Asteridium-Heliosphaeridium-Comasphaeridium* (*AHC*) acritarch assemblage in the basal Cambrian in Tarim (Yao et al., 2005), Yangtze Block (Taozichong Formation: Wang, 1985; Zhujiaqing Formation: Yin, 1990; Tianzhushan Member: Yin, 1995) and the Lesser Himalaya (Tiwari, 1999).

Comparison of our acritarch results to the previously defined spectral trend suggests that the acritarch in the carbonaceous phyllite experienced metamorphism with apparent peak metamorphic temperatures between 280°C to 400°C (Aoya et al., 2010; Kouketsu et al., 2014). This result corresponds well to the over-mature feature of our samples and the regional metamorphic grade.

5 Dicussion

5.1 Acritarch ages and comparison of the assemblages

As described above, the carbonaceous phyllite in the A and G slices contains *Micrhystridium*-like acritarch microfossils characterized by the *Asteridium-Comasphaeridium* assemblage.

Many Cambrian palynofloras and acritarch zonations have been studied and defined worldwide, which contributed to comprehensive biostratigraphical correlations and paleoecological interpretations (Zhu et al., 2001; Babcock et al., 2005; Babcock and Ahlberg, 2014). The *Micrhystridium*-like acritarchs are widely distributed in basal Cambrian in South China, Tarim, and Lesser Himalaya (Fig. 8) (Yin and Gao 1995; Yin, 1990; Yao et al., 2005; Yin et al., 2009)). They were recognized as the *Micrhystridium-Paracymatiosphaera-Megathrix* assemblage and correlated to the lowermost Meishucunian small shelly fossil assemblage (Yin, 1995;) in the Yangtze Block. This assemblage also occurs in the chert phosphorite of the lower Zhongyicun Member of the Zhujiaqing Formation in west Yunan Province (Yin, 1990), and in the lower Yangjiaping Formation in northwest Hunan Province (Wang 1985; Ding and Chen 1992).

Yang et al. (2005) revised the taxonomy of the basal Cambrian *Micrhystridium*-like acritarchs from the Yangtze Block using the morphological criteria established by Moczydłowska (1991, 1998). The taxonomic revision was not motivated by presumed stratigraphic correlation, but compelled by morphological similarities. *Micrhystridium*-like acritarchs in the Yangtze Block were reassigned to two genera, *Asteridium* Moczydłowska, 1991 and *Heliosphaeridium* Moczydłowska, 1991. Yao et al. (2005) also reported results from the basal Cambrian Yurtus and Xishanblaq formations in Tarim, characterized by three genera: *Asteridium* Moczydłowska, *Heliosphaeridium* Moczydłowska and *Comasphaeridium* Staplin, Jansonius and Pocock. This assemblage is named the *Asteridium-Heliosphaeridium-Comasphaeridium* (*AHC*) acritarch assemblage (Fig. 8).

The *AHC* assemblage is also present in the Chert-Phosphorite Member of the Lower Tal Formation, Lesser Himalaya. Tiwari (1999) reported *Micrhystridium tornatum*, *M. lanceolatum* and *Paracymatiosphaera irregularis* from this member. These acritarch taxa were also reassigned to *Asteridium tornatum*, *Heliosphaeridium ampliatum* and *Comasphaeridium annulare* according to the morphological criteria established by Moczydłowska (1991, 1998).

Thus, these biostratigraphic data suggest that the *AHC* acritarch assemblage is restricted to the lower Meishucunian Stage in South China and Tarim.

The above *AHC* acritarch assemblage taxa are all found in cherts. Records in clastic rocks have been widely reported in other areas of the world, e.g., in Poland, East European Platform, Scotland, Sweden, Ireland, Baltiea, and Siberia (Downie, 1982; Moczydłowska, 1991). The acritarchs characteristic of the *Asteridium tornatum–Comasphaeridium velvetum* zone are found in shale beds of the Chulaktau Formation of the East European Platform (Moczydłowska 1991, 1998). As reviewed by Moczydłowska and Yin (2012), the *Asteridium tornatum–Comasphaeridium velvetum* acritarch zone, one of the four lower Cambrian microfossil zones that occur between 541 and 510 Ma, represents the base of the Fortunian Stage.

The *AHC* acritarch assemblage in South China, Tarim, and this study is most similar to the *Asteridium tornatum–Comasphaeridium velvetum* zone in the East European Platform.

Based on the above analysis, we conclude that the acritarch assemblage found in the carbonaceous phyllite from the study area is early Cambrian in age. Thus, the sedimentary age of the A and G slices, which are dominated by the carbonaceous phyllite, is reliably defined as the early Cambrian.

5.2 Confirmation of the Shenshan tectonic mélange

As mentioned above, the volcano-sedimentary rocks in the Shenshan area were previously defined as the Shenshan and Kuli formations. The two formations were included in the early Neoproterozoic strata by DJMRJP (1997), whereas Yang et al. (2012) and Geological Survey of Jiangxi Province (2018) put them in the middle Neoproterozoic strata (Fig. 2). Yang et al. (2012) also correlated these supracrustal rocks with the Banxi and Dengshan groups in the Nanhua Rift Basin. These authors considered the ultramafic and mafic intrusive rocks in the area as intrusions in the Shenshan and Kuli formations.

Recent U-Pb dating results support the previous interpretation that the turbidite in the "Shenshan and Kuli formations" is Neoproterozoic in age. Wang et al. (2020) obtained four U-Pb ages from the tuffaceous metasedimentary rocks in the study area (from the B, H, L and M slices, respectively; (Fig. 3) and they range from ca. 790 Ma to ca. 770 Ma, based on the youngest peak ages. Guo et al. (2018) reported U-Pb zircon ages of 773 ± 13 Ma and 767 ± 12 Ma from a turbidite in the Xiangshan area, about 10 km east of the study area (see also Yu et al., 2018). It should be noted that the youngest zircon ages obtained by Wang et al. (2020) are ca. 669 Ma, 649 Ma, 689 Ma and 707 Ma in the B, H, L, and M slices, respectively. However, these single zircon data strongly deviate from the predominant Neoproterozoic population and show lower concordance; their younger apparent ages are most likely due to lead loss.

A gabbro from the I slice of the ultramafic and mafic rocks in the study area has yielded a U-Pb zircon age of 791 ± 9 Ma (Wang et al., 2019).

The age of the carbonaceous phyllite in the "Shenshan and Kuli formations" was previously unknown. The arcritarch assemblage from the phyllite reported here constrains the depositional age to early Cambrian.

The data summarized above and the field relationships (Fig. 3) indicate that the rocks in the Shenshan area include fault-bounded slices of vastly different ages: the turbidites in the B, H, L, and M slices have zircon ages from ca. 790 Ma to ca. 770 Ma; the carbonaceous phyllite in the A and G slices is early Cambrian in age; and the gabbro from the I slice has an age of ca. 791 ± 9 Ma. Therefore, the volcano-sedimentary rocks in the Shenshan area cannot be a continuous Neoproterozoic stratigraphic sequence. Available data support the idea of Pan et al. (2016) and Zhang et al. (2016) that the "Shenshan and Kuli formations" and the ultramafic and mafic rocks in the study area are parts of a tectonic mélange.

The early Cambrian acritarches in the Shenshan tectonic mélange constrain the timing of the mélange formation to the early Cambrian or later. The mélange is near the JSP Fault, the boundary between the Yangtze and Cathaysia blocks, and Zhang et al. (2018) suggested that this mélange is an early Paleozoic subduction-accretionary mélange related to the closure of the Nanhua Ocean. Additional work is needed to test this interpretation.

6 Conclusions

The organic-walled microfossils (acritarchs) from the carbonaceous phyllite in the Shenshan area are characterized by the *Asteridium-Comasphaeridium* assemblage. This assemblage can be correlated with the *Asteridium-Heliosphaeridium-Comasphaeridium* (*AHC*) acritarch assemblage which is distributed in basal Cambrian in South China, Tarim and the Lesser Himalaya. This result proves that the carbonaceous phyllite was originally deposited during the early Cambrian. As the turbidite in the Shenshan area is known to be Neoproterozoic in age, the new result indicates that the different rock units in the area have different ages. They cannot be parts of a continuous stratigraphic sequence (the "Shenshan and Kuli formations") and are most likely parts of a tectonic mélange that formed in or after the early Cambrian.

Acknowledgements

This research is funded by the National Natural Science Foundation (No. 41772107 and No. 41472166), the Geological Survey Program (No. DD20190370 and No. DD20190811) of the People's Republic of China, the 13th Five-year Plan of the Ministry of Science and Technology of China (2016ZX05034-002-003) and the Natural Sciences and Engineering Research Council of Canada. We thank Xiaohu Kou, Chengwei Yao, Zhiyuan Liu and Yang Li for assistance during field work. The manuscript was completed while the first author was a visiting PhD student at the University of Waterloo, which was supported by the Fundamental Research Funds for National Universities, China University of Geosciences (Wuhan).

Manuscript received Apr. 5, 2020
accepted Jun. 5, 2020
associate EIC: DING Xiaozhong
edited by FEI Hongcai

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