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Research Paper

First report on Guanshan Biota (Cambrian Stage 4) at the stratotype area of Wulongqing Formation in Malong County, Eastern Yunnan, China

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ABSTRACT

Exceptionally preserved fossils, such as those from Cambrian Burgess Shale-type fossil-Lagerstätten are critical because of their unique contributions to knowledge of the phylogenetic radiation and palaeoecological expansion of metazoans during the Cambrian explosion. Critically, these deposits provide information that is usually unobtainable from shelly and skeletonized fossils alone. The Guanshan Biota (Cambrian Series 2, Stage 4) in the Yunnan Province of South China, has produced abundant and diverse, exquisitely preserved fossils that often retain soft tissues and organs. To date, most fossils from the Guanshan Biota have been collected from localities such as Gaoloufang and Gangtoucun, which have become inaccessible due to new urban expansions and constructions of residential buildings. Here we present the first report of soft bodied fossils from a new section at Kanfuqing, close to the Wulongqing village in Malong County, approximately 3 km east of the Wulongqing Formation stratotype section. Fossils retain soft morphology, and include brachiopods with delicate marginal setae, priapulids with well-preserved sclerites and vetulicolians with entire sections of body. In addition, this fauna includes rare occurrences of trilobites preserved with soft tissues replicated as pyrite pseudomorphs after weathering. This discovery represents an important palaeogeographical extension of soft-bodied fossils of the Guanshan fauna to the east of the Xiaojiang Fault (related to Tsinning tectonic movements ca. 700 Ma). The fauna from the new Kanfuqing section is similar to that reported from the Wulongqing Formation west of the Xiaojiang Fault, and thus has significant implications for early Cambrian palaeogeography, faunal successions and palaeoenvironments of eastern Yunnan.

1. Introduction

Fossils from Cambrian Konservat-Lagerstätten have captured both scientific interest and the curiosity of the public due to their capability to elucidate usually unobtainable aspects of the anatomy, behaviour, ecology and evolution of ancient organisms (e.g. Hou et al., 2017). The Cambrian Stage 4 Guanshan Biota (temporally equivalent to the late Tsanglangpuan in China, or Botomian in Siberia, and correlated to the trilobite *Palaeolenus-Megapalaeolenus* assemblage) is particularly noteworthy because of its exquisite preservation of a rich diversity of fossils that distinguish it from the older Chengjiang Biota (Hou et al., 2017), Xiaoshiba Biota (Yang et al., 2013, 2014; Zeng et al., 2014) and Malong Fauna (Stage 3) (Luo et al., 2008; Hu et al., 2010b) in eastern Yunnan Province and younger Kaili Biota (Stage 5) in Guizhou Province (Zhao et al., 2005). Pioneer studies of the Guanshan Biota were made by Luo et al. (1999), who found faunal elements of the Chengjiang Biota, such as the enigmatic deuterostome *Vetulicola*, in the muddy siltstone of the Wulongqing Formation (formerly Wulongqing Member of Canglangpu Formation) in the Kunming area. Subsequently, comprehensive investigations of the fossil taxa, diversity and palaeogeography of the faunal assemblages have been conducted (Fig. 1) (Luo et al., 2008; Hu et al., 2013). Recent intensive excavations of the Guanshan Konservat-Lagerstätte from Kunming revealed that the faunal assemblages are numerically dominated by brachiopods (commonly aggregated as high-density concentrations of shell valves on the same bedding planes), followed by a rich assemblage of trilobites, and an assortment of non-mineralised soft-bodied organisms, including the earliest-known eocrinoids

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(Hu et al., 2007a, 2010a, b, 2013). A wide variety of metazoan fossil groups are now known from the Guanshan Biota including sponges, chancelloriids, cnidarians, ctenophores, priapulids, lobopodians, arthropods, anomalocaridids, hyoliths, molluscs, brachiopods, echinoderms and vetulicolians, in addition to problematic soft bodied fossils and abundant trace fossils (Hu et al., 2010a, b).

The Chengjiang (Yu'anshan Formation and its equivalents), Malong (upper Hongjingshao Formation) and Guanshan (Wulongqing Formation) biotas from the lower Cambrian of Yunnan permit the unique opportunity for spatial and temporal comparisons of key lower Cambrian fossil deposits. Strong discrepancies between the faunas are clearly seen in the brachiopod and trilobite assemblages (Table 1), and in the presence of non-mineralized animals such as priapulids (Hu et al., 2012, 2013). Instances of faunal overturn in these deposits suggest that sessile benthic members of the assemblages were affected by the same factors that affected mobile trilobites (Luo et al., 2008).

Recent geological surveys of the Cambrian in eastern Yunnan have led to the discovery of additional occurrences of Guanshan Biota in the Wulongqing Formation west of the Xiaojiang Fault (Hu et al., 2010b, 2013; Liu et al., 2012, 2016). However, most are characterized by relatively low-diversity fossil assemblages (Liu et al., 2012, 2016). Since these discoveries, the classic Gaoloufang and Gangtoucun sections that contain Guanshan Biota have been covered by urban landscaping and construction, making further collection impossible.

Here, we report the discovery of soft-bodied Guanshan Biota from a new section through the Wulongqing Formation close to Kanfuqing Village, ca. 20 km west of Malong County. The silty mudstone and muddy siltstone of the Wulongqing Formation is well-developed and widely exposed around the Kunming-Wuding and Malong-Yiliang areas of eastern Yunnan Province. This study is the first to document the soft-bodied components of the Guanshan Biota from the region near the stratotype section of the Wulongqing Formation in eastern Yunnan, east of the Xiaojiang Fault (Fig. 1). Fossils from the new section include brachiopods with setae, trilobites with gut remains, articulated soft-bodies of priapulids and abundant vetulicolians, as well as anomalocaridid appendages. These new discoveries of a soft-bodied assemblage from the Kanfuqing section have increased the number of Guanshan faunal assemblages known from the east side of the Xiaojiang Fault, and demonstrate that similar faunas were deposited on both sides of the Xiaojiang Fault after the transgression of the eastern Yunnan sea during the Cambrian Tsanglangpuan Stage (Stage 4).

Table 1
Comparison of the Chengjiang, Malong and Guanshan biotas from the Kunming-Wuding (west) and Malong-Yiliang (east) areas (Luo et al., 1994, 1999, 2008; Hu, et al., 2005, 2013; Shu, 2005; Liu et al., 2012; Wang et al., 2012; Yang et al., 2013, 2014; Zhang and Holmer, 2013; Zeng et al., 2014; Zhang and Shu, 2014; Papov et al., 2015; Zhang et al., 2015; Hou et al., 2016, 2017). Similar genera or fossil groups from both sides of Xiaojiang Fault are indicated in blue. Fossils from the Kanfuqing section are underlined.

					Kunming-Wuding (west)				Malong-Yiliang (east)			
					Trilobites	Brachiopods	Soft-body animals	Exoskeletons	Trilobites	Brachiopods	Soft-body animals	Exoskeletons
Cambrian	Stage 4	Tsanglangpuan	Wulongqing Fm.	Guanshan Biota	*Redlichia*	*Eoobolus*	Cnidaria	Chancelloriids	*Redlichia*	*Eoobolus*	×	×
					Palaeolenus	*Neobolus*	Ctenophora	Brachiopoda	*Palaeolenus*	*Neobolus*	×	Brachiopoda
					Megapalaeolenus	*Schizopholis*	Spongia	Hyolitha	×	*Schizopholis*	Spongia	Hyolitha
					Breviredlichia	*Acanthotretella*	Priapulida	Mollusca	×	×	Priapulida	×
					Yuehsienszella	*Palaeobolus*	Lobopodians	Arthropoda	*Yuehsienszella*	*Palaeobolus*	×	Arthropoda
					Kootenia	*Kutorgina*	Vetulicolia	Anomalocaridids	×	×	Vetulicolia	Anomalocaridids
						Nisusia		Echinodermata		*Nisusia*		Echinodermata
	Stage 3		Hongjingshao Fm.	Malong Fauna	×	×	×	×	*Malungia*	*Palaeobolus*	Vetulicolia	Brachiopoda
					×	×		×	*Yiliangella*	*Westonia*		Hyolitha
					×			×	*Drepanopyge*			Arthropoda
					×			×	*Drepanuroides*			Anomalocaridids
					×				*Paramalungia*			
					×				*Yiliangellina*			
					×				*Parayiliangella*			
					×				*Mayiella*			
					×				*Longduia*			
					×				*Hongjunshaoia*			
					×				*Yinites*			
					×				*Syndianella*			
					×				*Yunnanaspis*			
					×				*Yunnanaspidella*			
					×				*Neomalungia*			
					×				*Kanfuqingia*			
		Chiungchussuan	Yu'anshan Fm.	Xiaoshiba Biota / Chengjiang Biota	*Hongshiyanaspis*	×	Cnidaria	Chancelloriids	×	*Kuangshanotreta*	Cnidaria	×
					Yunnanocephalus	*Diandongia*	Ctenophora	Brachiopoda	×	*Diandongia*	×	Brachiopoda
					Malongocephalus	*Eoglossa*	Spongia	Hyolitha	×	×	Spongia	Hyolitha
					Fuminaspis	*Lingulellotreta*	Annelida	Mollusca	×	×	×	×
					Zhangshania	*Heliomedusa*	Chaetognatha	Arthropoda	×	*Heliomedusa*	×	Arthropoda
					Eoredlichia	*Alisina*	Priapulida	Anomalocaridids	×	×	Priapulida	Anomalocaridids
					Kuanyangia	*Kutorgina*	Lobopodians		×	×	Lobopodians	
					Chengjiangaspis	*Longtancunella*	Phoronida		×	×	×	
					Wutingaspis	*Xianshanella*	Sipuncula		*Wutingaspis*	×	×	
					×	*Yuganotheca*	Wiwaxia		*Malungia*	×	×	
							Hemichordata				×	
							Vetulicolia				×	

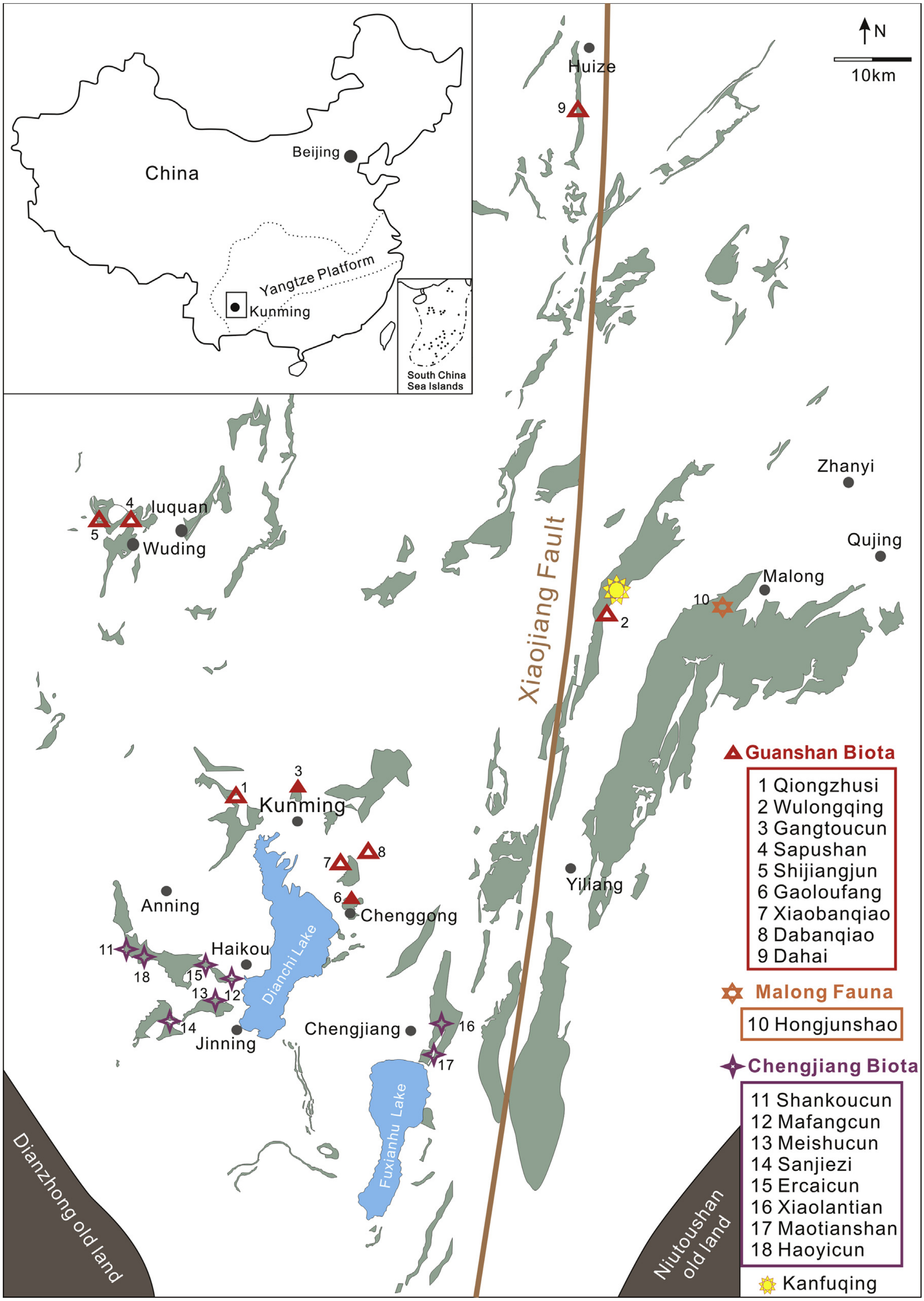

Figure 1. Distribution of early Cambrian outcrops in eastern Yunnan, South China showing fossil localities, chronologically numbered by the year of discovery. The new fossil locality (Kanfuqing section) is marked by a yellow star. Red triangles (solid) represent main fossil localities of Guanshan Biota (Nos. 1–9). Main fossil locality of Malong Fauna is the Hongjunshao section near Malong County (No. 10). Fossil localities of the Chengjiang Biota (Nos. 11–18) are mainly distributed around the Haikou, Chengjiang, Jinning and Anning areas.

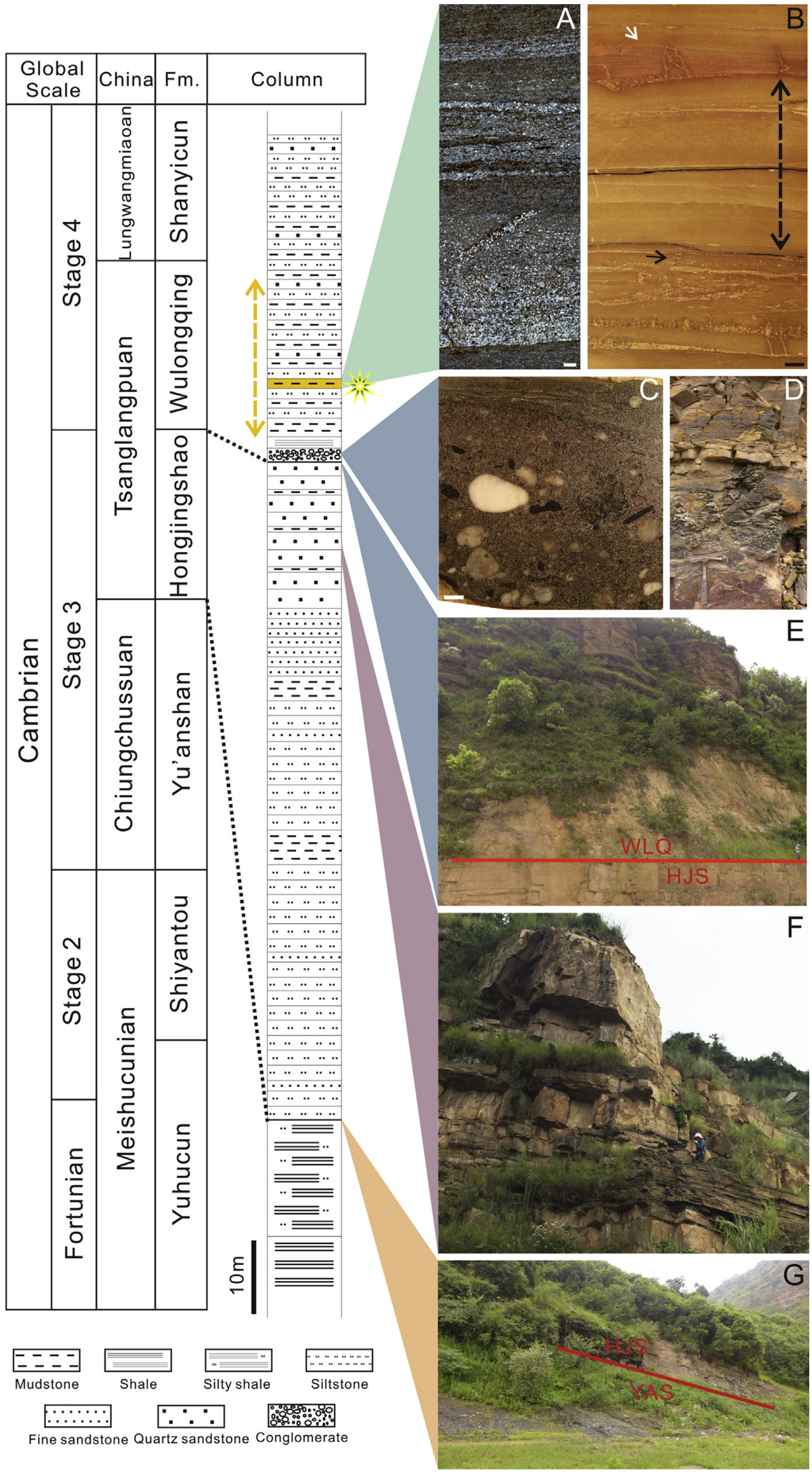

Figure 2. Kanfuqing section, Malong County, South China. Position of the 1 m-thick interbed yielding soft-tissue fossils is indicated in the column with a yellow star. All specimens were collected from the lower part of the Wulongqing Formation which is marked by the yellow dotted line. (A) Thin section within the 1 m-thick interbed shows bioturbation and several normally graded beds; (B) polished slab within the 1 m-thick interbed, noting relatively thicker mud deposits where soft-tissue fossils were preserved (black dotted line), graded bedding (white arrow) and bioturbation (black arrow); (C) polished slab of the conglomerate from the base of Wulongqing Formation; (D) close up field photo shows the boundary between Hongjingshao and Wulongqing formations, thick bedded sandstone is overlain by 3 layers of conglomerate; (E) field photo shows boundary between Hongjingshao Formation and Wulongqing Formation; (F) outcrop of thick-bedded sandstone in the upper Hongjingshao Formation from Kanfuqing section; (G) outcrop of boundary between Yu'anshan and Hongjingshao formations. Scale bars: A, 2 mm; B and C, 1 cm.

2. Material and methods

Fossils documented herein were collected from the Kanfuqing section, approximately 3 km east of the stratotype section of the Wulongqing Formation, and about 20 km west of Malong County (Fig. 1). In total, over 3000 fossils have been recovered from muddy siltstone and silty mudstone in the lower Wulongqing Formation (Fig. 2). Nearly all the fossils with soft morphology are derived from a 1 m-thick succession of silty mudstone, 6–7 m above the conglomerates of the Wulongqing Formation in the Kanfuqing section (Fig. 2A, B).

All the specimens are deposited in the Northwest University Early Life Institute, Xi'an, China (ELI). Fossils were examined under a Zeiss Stemi 305 microscope and photographed with the Zeiss Smart Zoom 5 Stereomicrographic system. Uncoated specimens were analysed with a Backscatter Scanning Electron Microscope (BSEM) Quanta FEG 450, with attached Energy Dispersive X-ray spectrometry (EDS) system, with 20.0 kV, 60 Pa and WD 11.4 mm at the State Key Laboratory of Continental Dynamics, Northwest University, Xi'an, China. Polished slabs and thin sections were made in Shaanxi Key laboratory of Early Life and Environments before they were photographed under a Nikon stereoscopic microscope. Some fossils were photographed using a fluorescence stereoscopic microscope to improve the contrast of soft parts to the matrix.

3. The Kanfuqing assemblage and their soft-part preservation

Over 3000 fossils have been recovered so far from the Kanfuqing section, spanning six major animal groups (arthropods, anomalocaridids, brachiopods, priapulids, vetulicolians and hyoliths), and ichnotaxa, all of which are also found in the classic Gaoloufang Quarry of Guanshan fauna in the Kunming area (Table 1). Fossils are oriented parallel, or sub-parallel to the bedding planes, and normally appear as reddish-brown or grayish-white stains on the surface, which contrasts with the surrounding yellowish-green matrix. Arthropods (*Redlichia*, *Palaeolenus*, *Isoxys*, *Tuzoia*) and brachiopods (*Eoobolus*, *Neobolus*, *Schizopholis*, *Palaeobolus* and *Nisusia*) are the most diverse components of the fauna (Table 1, Fig. 3), however, brachiopods vastly outnumber any other group in these benthic communities (Fig. 3). Notable taxa include the bivalved arthropods *Isoxys* and *Tuzoia*, two diagnostic fossils of the lower Cambrian worldwide. In addition to anomalocaridids, palaeoscolecidans, vetulicolians and hyoliths occur with soft morphology.

3.1. Brachiopods

Brachiopods are both highly diverse and abundant at the Kanfuqing section, including at least five genera, e.g. *Eoobolus*, *Neobolus*, *Schizopholis*, *Palaeobolus* and *Nisusia* (Table 1). A large proportion of the brachiopods are preserved with conjoined valves, and are oriented parallel or sub-parallel to the bedding planes. *Neobolus* sp. commonly includes soft interior morphology (Fig. 5). Aside from the imprints of the visceral area of brachiopods, the mantle canals including the proximal parts of the *vascula lateria*, and the middle ridge are also imprinted as dark remains in the postmedian valves (Fig. 5A, B). Preservation of setal fringes is the most striking aspect of the preservation in the brachiopods. The setae are clearly spiny and rigid, with a maximum length up to 1.3 mm, and radiated outward from the shell margin (Fig. 4A–G). Setae from the left posterior parts of the shell have different sizes and display variable distribution on the shell margin (Fig. 4E). Three types of setae may be distinguished, each with different width and length (Fig. 4D, E). The smallest (ca. 8 μm in diameter) and intermediate size setae (ca. 15 μm in diameter) are distributed between the largest setae (ca. 25 μm in diameter) and may reflect different stages of setae growth. Occasionally the setae appear to be preserved with some relief, as rod or spine-like pseudomorphs of pyrite (Fig. 4J). In contrast, some parts of the setae have been replaced as reddish-brown stains (Fig. 4G). When observed under fluorescence, the setae appear as darkish, spine-like lineations with significant contrast to the host brachiopod shells and surrounding rock (Fig. 4C).

In most cases, the shell valves are slightly displaced or distorted, with a dark visceral area (Fig. 5B, C) due to pyrite framboidal pseudomorphs or euhedral crystals (Fig. 5D–F), similar to the brachiopods from Kunming area (Forchielli et al., 2014).

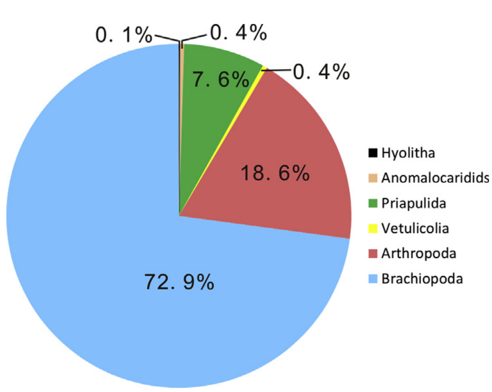

Figure 3. Relative abundance of the major taxonomic groups from Kanfuqing section, Malong County. Brachiopods dominated the assemblage, followed by arthropods (trilobites, *Isoxys*, *Tuzoia*), priapulids, vetulicolians, anomalocaridids and hyoliths.

3.2. Palaeoscolecidans (Cycloneuralia)

In the bedding planes dominated by brachiopods, there are occasionally flattened impressions of palaeoscolecidans that crosscut some sedimentary layers. In total, more than seven hand specimens often containing several individuals or parts of individuals have been collected. The palaeoscolecidans occur either individually or as aggregations of several gently convoluted individuals overlapping one another (Fig. 6A–F). The palaeoscolecidans have a maximum length of 56 mm and are 4.9 mm in width. No specimens in the current collections show any indications of an introvert (proboscis) and a caudal region. Most individuals are strongly compressed, with reddish-brown or darkish-brown tints and weakly expressed annulations (Fig. 6A, C, E). SEM reveals either exterior or interior cuticles of the original cylindrical body, with the ornamented sclerites either as pronounced pustules or negative, pitted structures (Fig. 6I–M).

A well preserved coiled specimen (ELI-KFQ-P-003) is densely annulated along its whole length (about 3–6.5 annulations per millimeter) (Fig. 6G, H), and is covered in rows of circular sclerites (Fig. 6E) parallel to the annulations, that have characteristic *Hadimopanella*-type morphology (Fig. 6I–M, O, P). Each annulation usually bears two transverse rows of large circular sclerites (Fig. 6G, H). Most sclerites bear 4–7 nodes, with no central nodes (Fig. 6I–M, O), though rarely sclerites may bear up to nine nodes with 1–2 central nodes (Fig. 6O, P). Sclerite sizes can reach up to 75 μm in diameter. Platelets and microplates are absent in all specimens. Thus, the worms are confidently referred to the palaeoscolecidan genus of *Wronascolex* (Ivantsov and Wrona, 2004; García-Bellido et al., 2013).

In several specimens, dark lineations along the body are interpreted as partial relics of digestive tracts (Fig. 6A, C). Elemental mapping of two specimens shows that the sclerites and trunk bearing brown and red staining have elevated concentrations of iron (Fig. 7A–D, F, I). Oxygen is in high abundance and is evenly distributed across the specimen and the matrix, including areas

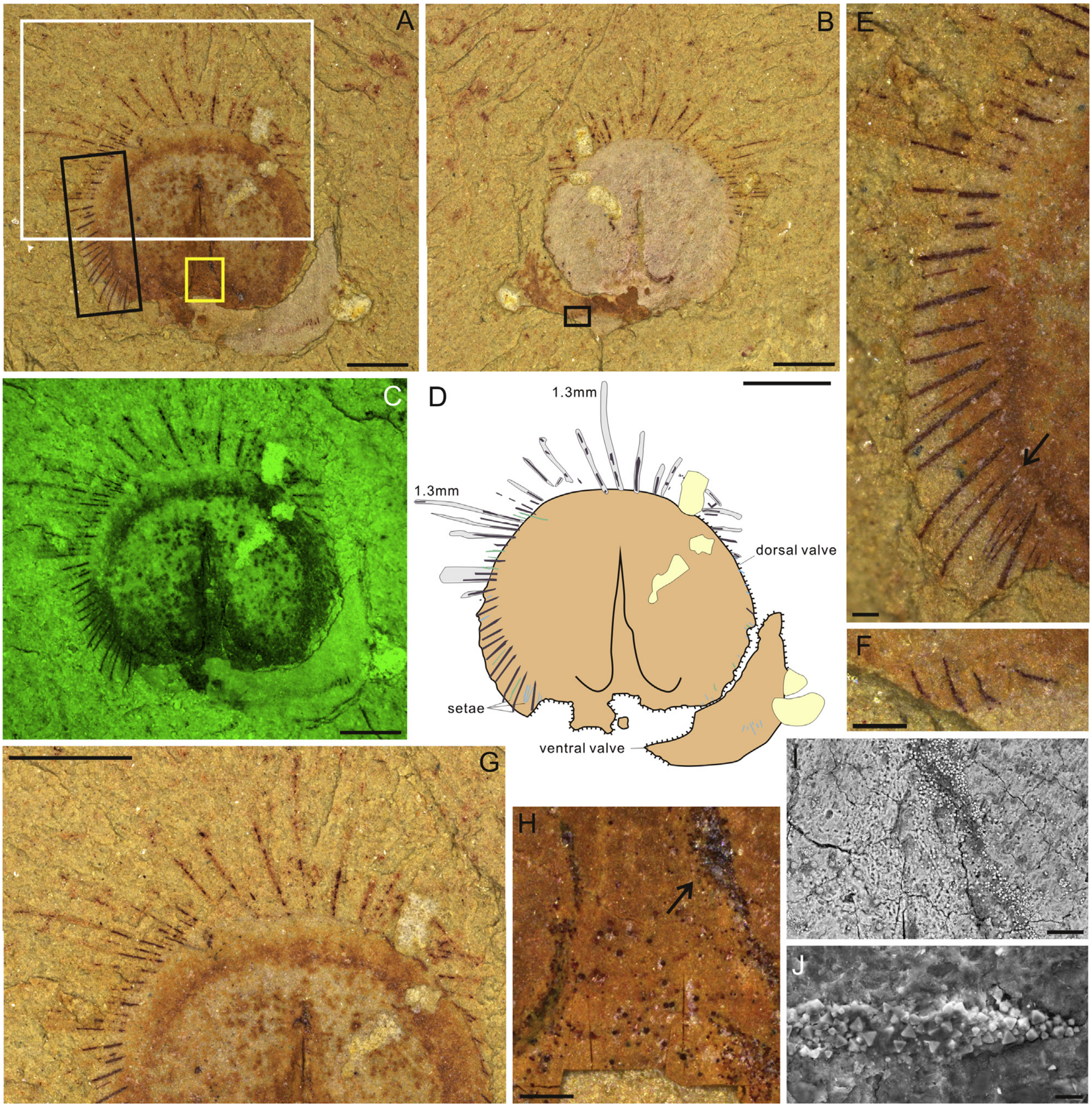

Figure 4. *Neobolus* sp. collected from the lower part of the Wulongqing Formation at Kanfuqing section, Malong (ELI-KFQ-B-189AB). (A, B) Part and counterpart of *Neobolus* sp. with setal fringes; (C) fluorescence image showing the different composition between shells, setal fringes and sediments in A (dark colour indicates higher Fe content); (D) interpretative drawings of A, noting the ventral and dorsal valves with setae; (E) enlargement of setae in A (black box); (F) enlargement of setae in B (black box) showing the setae on the ventral valve; (G) enlargement of setae in A (white box), showing frontal setae replaced as reddish-brown stains; (H) enlargement of yellow box in A, showing reddish spherulites; (I) SEM image showing the euhedral pyrite crystals from H (black arrow); (J) SEM image showing euhedral pyrite crystals on setae in E (black arrow). Scale bars: A–D, G, 1 mm; E, F, H, 100 μm; I, 50 μm; J, 10 μm.

where Fe is concentrated (Fig. 7E, H). This indicates that the red staining is composed of iron oxides. Enlarged photos under SEM further shows pseudomorphs of pyrite framboids (Fig. 6N). In addition, there is a higher concentration of P on the sclerites, and C on the trunk respectively which indicate the phosphatization and carbon impression (Fig. 7G, J).

3.3. Vetulicolians (Deuterostomia)

Vetulicolians in China are mainly known from the Chengjiang Biota (Stage 3), where eight species have been recorded (Shu, 2005; Li et al., 2015). Until now only three species have been recorded from the Guanshan Biota including *Vetulicola gangtoucunensis* (Luo et al., 2005), *Vetulicola longbaoshanensis* (Yang et al., 2010; Li et al., 2017) and *Vetulicola* sp. (Li et al., 2015). New discoveries of *Vetulicolia* from east of the Xiaojiang Fault expands the biogeographic distribution of this genus.

Specimen 2 in ELI-KFQ-V-001 (Fig. 8A, B) is laterally compressed, with a clearly distinguishable anterior body (AB) and posterior body (PB). The AB is 52.8 mm long and 32.8 mm wide, and has a sub-rectangular outline, with no discernable oral opening. The dorsal edge of the AB is slightly convex, with a triangular fin (Fig. 8B, C). The ventral posterior edge is wide and has bulges (Fig. 8B, black arrow on the bottom), with a small but distinct

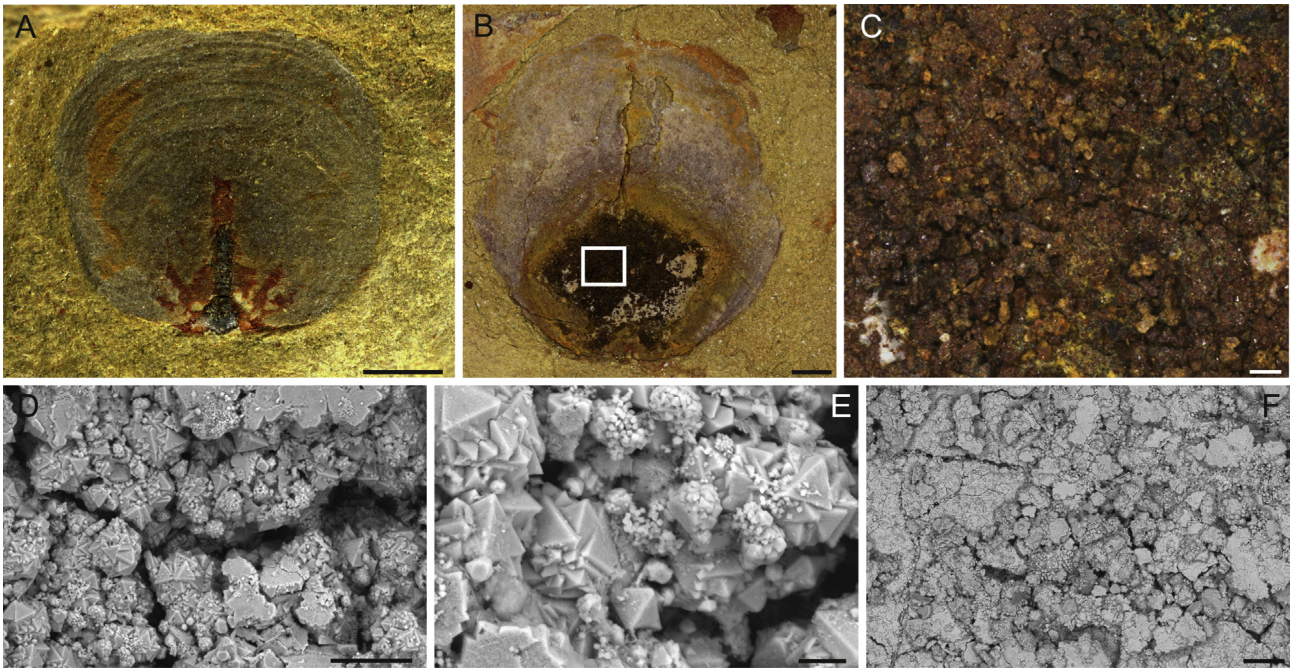

Figure 5. *Neobolus* sp. from the Kanfuqing section showing soft-tissue preservation. (A) *Neobolus* sp. with well-preserved middle ridge and *vascula lateria* (ELI-KFQ-B-044); (B) dorsal valve of *Neobolus* sp. preserved with dark cavity (ELI-KFQ-B-227B); (C) enlargement of white box in B; (D) SEM image of iron oxide pseudomorphs of pyrite crystals in cavity of *Neobolus* ELI-KFQ-B-187B; (E) SEM image of iron oxide pseudomorphs of pyrite crystals in cavity of *Neobolus* ELI-KFQ-B-184A; (F) SEM image of iron oxide pseudomorphs of pyrite crystals in C. Scale bars: A, B, 1 mm; C, F, 100 μm; D, 50 μm; E, 10 μm.

projection at the posteroventral corner (Fig. 8E). While the PB is nearly complete, seven segments can be confidently recognized. The compressed anterior three segments are similar in length, around 4.5–5.5 mm. The last four segments are wider and have a flabellate outline. The fourth segment width increases towards the posterior, reaching 15.4 mm, which is maintained in the fifth and sixth segments, while the seventh is slightly narrower. There are also articulating flanges between each segment in the posterior body, especially between the last four segments (Fig. 8B, C).

Specimen 4 in ELI-KFQ-V-001 (Fig. 8A, B) is also laterally compressed, with the PB folded towards the anterior. The AB is 50 mm long and 32 mm high, with a broken posterior margin. The anterior edge is slightly concave, and the ventral margin is slightly convex. The AB is divided into the dorsal and ventral parts by a lateral groove, along which are five rhomboid-gills (Fig. 8B, F, G). The lateral groove nearly reaches the posterior edge of the anterior body, and the ventral part is weakly segmented (Fig. 8D). There is a triangular fin at the position between the third and the fourth gills (Fig. 8B). The PB is nearly complete, consisting of seven segments (Fig. 8D) that reach 41.9 mm in length. The anterior-most three segments appear to have been cylindrical and show variable lengths due to the PB folding towards the anterior (Fig. 8D). The width of fourth to seventh segment increases towards the posterior from 9.6 to 13.6 mm, which is maintained in the fifth and sixth segments.

Vetulicola gangtoucunensis is characterized by a straight dorsal margin, with a prominent triangular, fin-like structure positioned at the most posterior part of the AB on the dorsal surface, smooth posterior margin and elliptical PB in lateral view. The two specimens described herein do not share these features with *V. gangtoucunensis*. Specimen 4 (Fig. 8B) exhibits gross morphology that is similar to *V. longbaoshanensis*, sharing several diagnostic features such as the position of the dorsal fin, and the shape of the PB. However, the posteroventral part of the AB is broken, precluding comparison of this part of the anatomy. Specimen 2 (Fig. 8B) has a wide lower posterior margin and a small projection at the posteroventral corner. In comparison, the posteroventral projection in the AB of *V. longbaoshanensis* is large and prominent. Hence, we assign this individual (Specimen 2 in Fig. 8B, C) to *Vetulicola* sp. (Li et al., 2015).

3.4. Trilobites

After brachiopods, trilobites are the most abundant fossils in the Guanshan Biota. More than one hundred individuals of *Redlichia* and *Palaeolenus* have been collected from the Wulongqing Formation in the Kanfuqing section. Most trilobite specimens from the new locality are partially articulated or disarticulated, without librigenae, and hypostomes are rare. Some cranidia are overlain by burrows. The original calcareous cuticle was lost during diagenesis, but surface ornamentation has been retained via fine impressions. Trilobites with digestive glands have been previously reported from the Guanshan Biota in the classic Gaoloufang section (Hopkins et al., 2017). However, while digestive glands in the trilobites from the Guanshan deposits in the Malong area are present, they are rare.

Internal structures have been described in trilobites from the Wulongqing Formation near Kunming (Fig. 9A, B) (Hopkins et al., 2017), though some of these specimens have incurred secondary loss of sulphur during weathering, leaving a cavity lined with spherical, yellowish iron-oxide aggregates (Fig. 9A, B). Digestive glands or alimentary canals in the trilobites from the Guanshan Biota in the Malong area are rare and are generally not as well preserved as in the specimens from the Kunming area. The crop described herein from the Malong area is contained within the glabella of a *Palaeolenus* specimen, and is elliptical in shape, narrowing at the posterior (Fig. 9D). The anterior part of the glabella is enlarged and characterized by dark brown or black staining (Fig. 9C). Elemental mapping of the areas with brown and red staining have high concentrations of iron (Fig. 9H, I). Oxygen is also

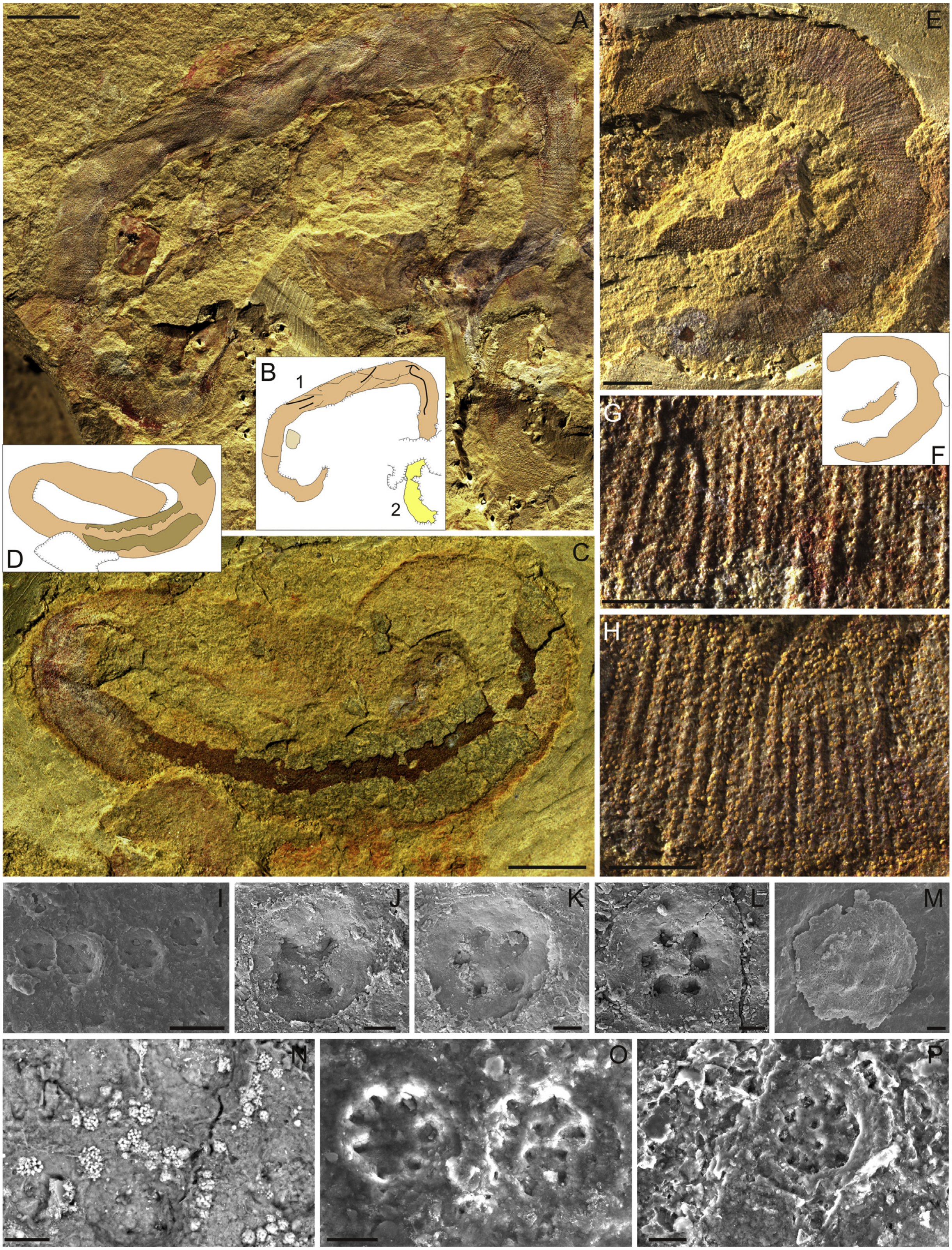

Figure 6. Palaeoscolecidans (Cycloneuralia) from Kanfuqing section. (A, B) Palaeoscolecidan (No. 1) preserved with other partial individual (No. 2) punctuated with brachiopods (ELI-KFQ-P-001); (C, D) colied individual, brown coloured area shows partially weathered body fossil without detailed structures (ELI-KFQ-P-002); (E, F) another palaeoscolicidan (with partial individual) shows annulations on the trunk (ELI-KFQ-P-003); (G, H) well-preserved surface annulations on specimen in E; (I–M) SEM images of plates from specimen in C; (N) SEM image of palaeoscolecidan cuticle preserved with pyrite framboids (ELI-KFQ-P-005); (O) SEM image of plates from specimen in A; (P) SEM image of plates (ELI-KFQ-P-004). Scale bars: A, 5 mm; C, 3 mm; E, 2 mm; G, H, 1 mm; I, 50 μm; J–M, 10 μm; N–P, 20 μm.

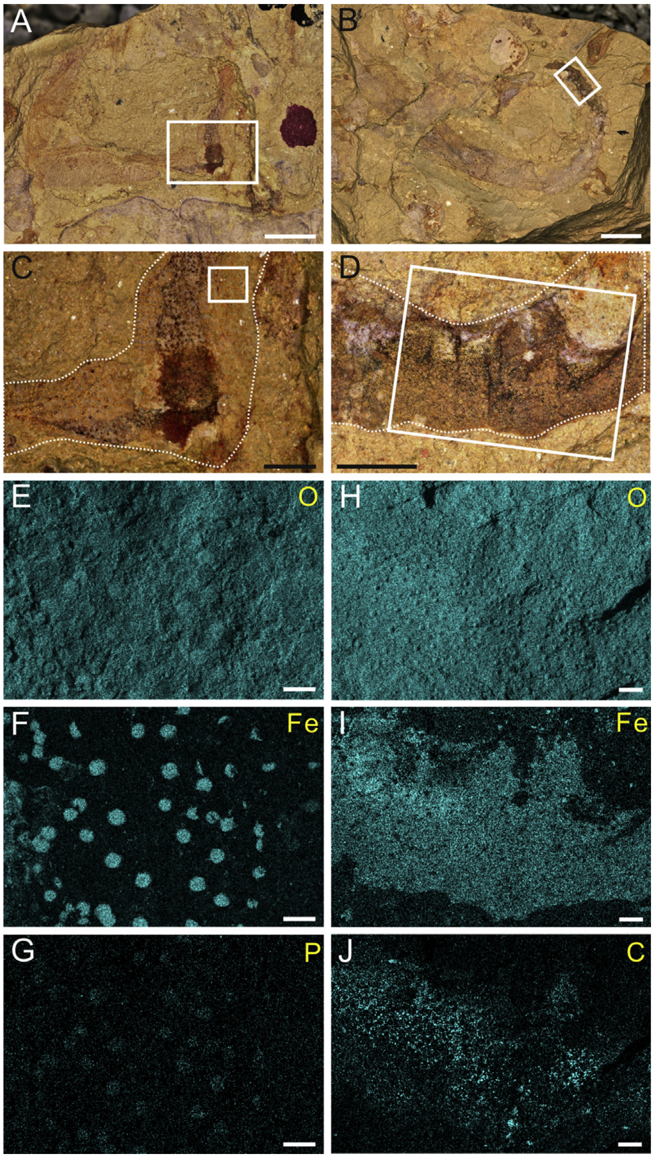

Figure 7. Palaeoscolecidans (Cycloneuralia) from Kanfuqing section. (A) a C-shape palaeoscolecidan (ELI-KFQ-P-005); (C) enlargement of white box in A; (E–G) elemental mapping of the white box in C, showing elevated concentration of Fe and P on plates and O evenly distributed across the specimen and the matrix; (B) another curved palaeoscolecidan (ELI-KFQ-P-004); (D) enlargement of white box in B; (H–J) elemental mapping of the white box in D, showing higher concentration of Fe and C on trunk and O evenly distributed across the specimen and the matrix. Scale bars: A, B, 2 mm; C, D, 1 mm; E–G, 100 μm; H–J, 200 μm.

in high abundance and evenly distributed across the specimen and the matrix, including areas where Fe is concentrated, indicating that the red staining is composed of iron oxides. Si, Al, and K are usually in high abundance and are evenly distributed across the matrix and the impression of the exoskeleton, but are frequently absent where Fe is concentrated. Iron oxide is also concentrated along the cephalic margin, the thorax and the thoracic pleural spines which may have been more resistant to decay due to the presence of the doublure (Fig. 9J). Euhedral pyrite crystal aggregates are found in the crop (Fig. 9F). These aggregates are in the same size range as those reported from other Guanshan fossils (Forchielli et al., 2014).

A trilobite pygidium with dark brown staining also shows evidence of high abundance of Fe presumably due to the marginal doublure of exoskeletons (Fig. 9E). Abundant cubic pyrite crystals are distributed in the middle-upper part of specimen (Fig. 9G). Cubic pyrite crystals are between 4 μm and 7 μm in size, with an average size of 5.27 μm ($n = 126$).

4. Discussion

4.1. Preservation

The main fossil preservation modes in Burgess Shale-type fossil Lagerstätten worldwide include carbonaceous compressions (Butterfield, 1995; Brett et al., 2009; Lin and Briggs, 2010), pyritization (Gabbott et al., 2004; Hu, 2005; Lin and Briggs, 2010; Gaines et al., 2012), phosphatization (Zhu et al., 2005; Lin and Briggs, 2010) and replacement by clay minerals (Zhu et al., 2005) which all occur in the Guanshan Biota from Malong. In the Kanfuqing section, some non-mineralized parts (trilobite crops and pygidia, brachiopod vascula media, visceral cavities and setal fringes) are either completely or partially defined by mineral coatings. These coatings may be framboidal, tabular, cubic, octahedral crystals or spherical aggregates, with enriched Fe and O in weathered samples (Figs. 4I, J, 5D–F, 6N and 9F–J).

Priapulids from the Kanfuqing section play an important role in understanding the preservation of carbonaceous compressions and phosphatization of fossils at this locality. Two specimens show higher content of phosphorus on the plates, and carbon on the trunk respectively (Fig. 7G, J) when compared with sediments. The concentration of Fe and absence of S on both trunk and plates (Fig. 7F, I) indicate extensive weathering, possibly due to progressive loss of carbon and subsequent coating of Fe-oxide derived from the oxidation of pyrite in the enclosing mudstones (Zhu et al., 2005; Forchielli et al., 2014). Other specimens such as priapulids with cuticular sclerites, brachiopod shells and hyoliths were preserved by Fe-rich clay mineral replacement (Fig. 10).

4.2. Fidelity of preservation

Remarkable preservation of soft morphology in both brachiopods and trilobites demonstrates that the fossils from the Kanfuqing section are comparable with material from Lagerstätten such as the Chengjiang Biota, and previously established localities for the Guanshan Biota. For example, up until now fossil records of brachiopod setae have come primarily from the Chengjiang Biota (Zhang et al., 2004a, 2006, 2007a, c, 2008, 2009, 2011a, b) and the Burgess Shale (Topper et al., 2015) with few reports from the Guanshan Biota (Hu et al., 2010a). Herein, we report the setal fringes of *Neobolus* sp. from the Guanshan Biota for the first time (Fig. 4A, B), expanding the range of soft tissue types preserved in the Guanshan Biota. In addition, the Guanshan Biota at the Kanfuqing section also includes trilobites with well-preserved digestive system, similar to the oldest known trilobite digestive systems from the Wulongqing Formation, Kunming (Hopkins et al., 2017).

Palaeoscolecidans (Cycloneuralia) are an important component of many Lower Palaeozoic soft-bodied marine assemblages, with notable occurrences in several Burgess Shale-type Fossil-Lagerstätten (Conway Morris, 1997; Hu, 2005; Huang, 2005; Han et al., 2007b; Hu et al., 2008; García-Bellido et al., 2013; Smith, 2015). While isolated plates are common in shelly fossil assemblages, preservation of plates, platelets, and microplates - key taxonomic characteristics - are rare in siliciclastic settings (Conway Morris, 1997; Botting et al., 2012; García-Bellido et al., 2013; Martin et al., 2016). However, the plates of palaeoscolecidans from Malong County have strong three dimensionality and display a wide morphological variability of the plate nodes from four to nine, and occasionally with one or two central nodes. And this variability on a single sample has also been mentioned in acid retrieved specimens

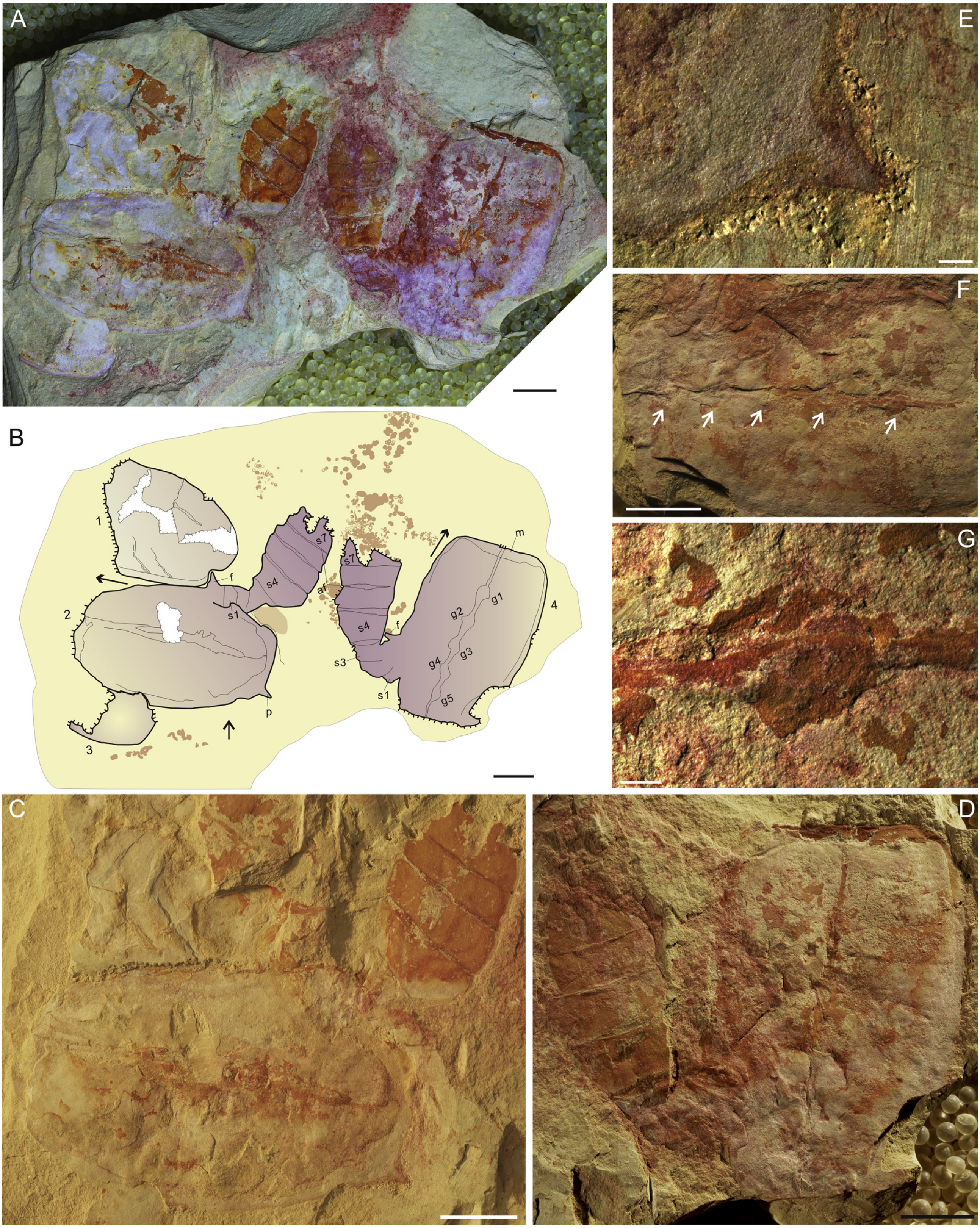

Figure 8. Vetulicolians from the Kanfuqing section. (A) Four individuals (specimens 1–4) preserved in the same bedding plane (ELI-KFQ-V-001); (B) interpretative drawings of A. Abbreviations: g1–g5 = gill 1–gill 5; m = mouth; s1–s7 = segment 1–segment 7; f = fin; af = articulating flanges; p = projection; (C) enlargement of specimen 2 in B; (D) enlargement of specimen 4 in B; (E) enlargement of projection in specimen 2; (F) enlargement of gills in specimen 4; (G) enlargement of g1 in specimen 4. Scale bars: A–D, F, 1 cm; E, G, 1 mm.

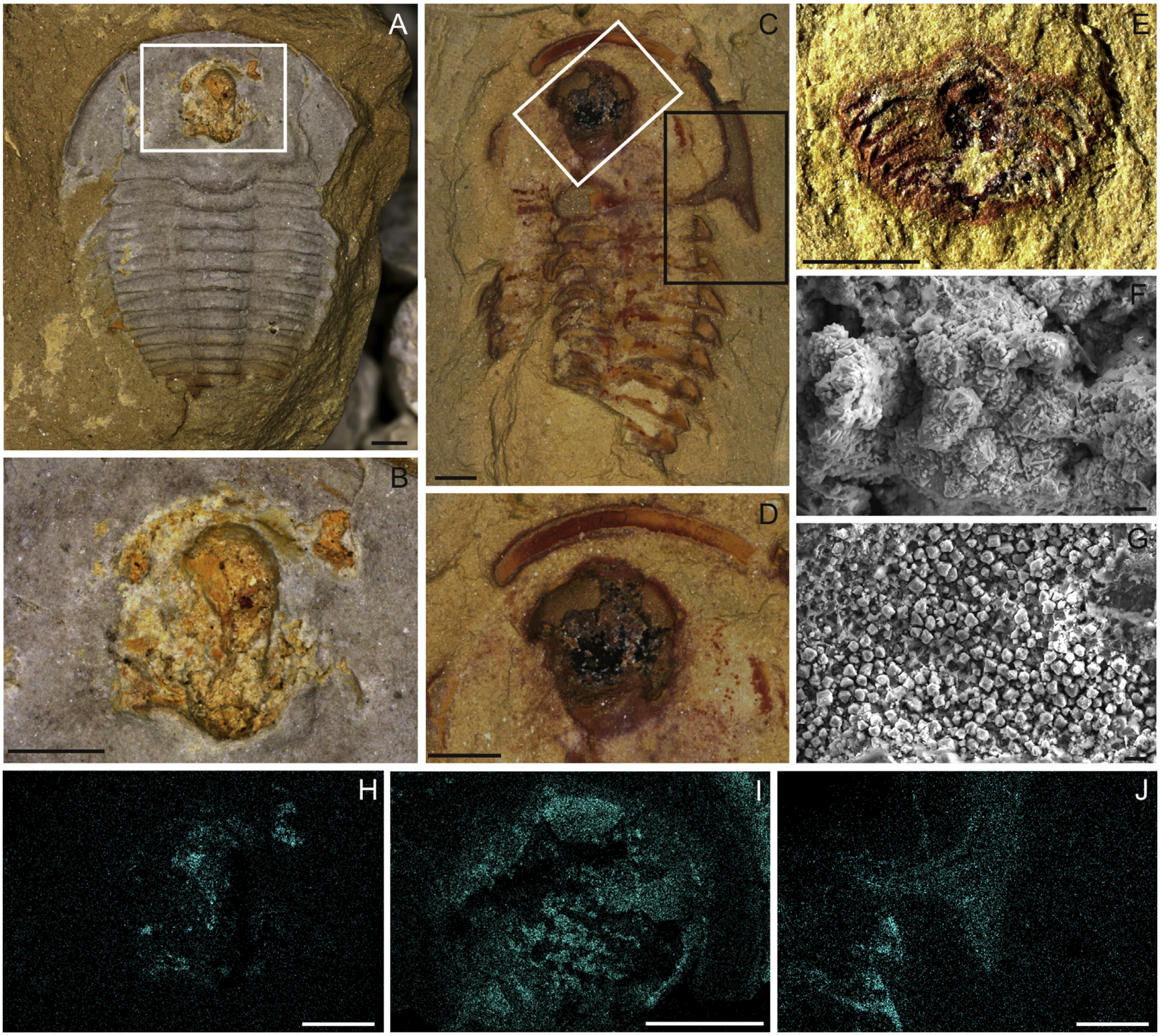

Figure 9. Trilobites with soft tissue within the Wulongqing Formation from Kunming and Malong areas. (A) *Palaeolenus* sp. with yellowish crop from Guanshan Biota, Gaoloufang section, Kunming (ELI-GLF-T-270); (B) enlargement of crop (white box) in A; (C) *Palaeolenus* sp. with reddish crop from Kanfuqing section in Malong (ELI-KFQ-T-068); (D) enlargement of crop (white box) in C; (E) trilobite pygidium from Kanfuqing section in Malong (ELI-KFQ-T-009A); (F) SEM image showing euhedral pyrite crystal aggregates from the crop in D; (G) SEM image showing euhedral pyrite crystals in pygidium in E; (H) elemental map showing the higher concentration of Fe in the crop area; (I and J) elemental maps show high concentration of Fe in crop (white box in C), part of cranidium and pleural spines (black box in C). Scale bars: A–E, 1 mm; F, G, 10 μm; H–J, 1 mm.

from South Australia (Topper et al., 2010). In the preservation of sclerites, the Kanfuqing locality shows much higher fidelities than the other Guanshan fossil localities of Biota west to the Xiaojiang Fault. All specimens from the new section display remarkably clear *Hadimopanella*-type plate morphologies which are comparable with isolated plates recovered by acid leaching methodologies (Gedik, 1989; Wrona, 2004). Well preserved specimens provide scope for future taxonomic work, and elucidation of the relationship between soft and mineralized anatomy in a single taxon (Streng et al., 2017).

4.3. Stratigraphy, lithology and palaeoenvironment

Terminal Proterozoic and lower Cambrian stratigraphic successions are well-developed and well exposed around Kunming, Yunnan Province, South China. The traditional “Early Cambrian” chronostratigraphic units officially adopted in China have been established at stratotype sections located around the Kunming, Jinning and Malong areas, in ascending order, the Meishucunian, Chiungchussuan (informally Qiongzhusian), Tsanglangpuan (Canglangpuan) and Lungwangmiaoan (Longwangmiaoan) (Figs. 1 and 2; Luo et al., 1994).

The soft-bodied Chengjiang Biota mainly occurs in the mudstones of the Yu’anshan Formation in the areas around Haikou, Chengjiang, Jinning and Anning west of the fault (Fig. 1). However, east of the fault, depositional regimes were relatively high energy, with extensive bioturbation (Hu, 2005). As a result, Chengjiang-type fossil occurrences are rare in the Malong-Yiliang area (Table 1). Faunal disparities between eastern and western sides of the Xiaojiang Fault have been previously documented (Table 1). For example, the Kunming-Wuding area west of the fault yields abundant trilobites including *Eoredlichia intermedia*, *Yunnanocephalus yunnanensis*, whereas the Malong-Yiliang area contains *Wutingaspis malungensis* and *Malungia laevigata* (Luo et al., 1994; Hu, 2005).

Conformably overlying the Yu'anshan Formation, the Hongjingshao Formation represents a post-Chiungchussuan regression event. Hu et al. (2010b) interpreted the Hongjingshao Formation as delta front and delta plain environments deposited during a regressive marine system. Fossil deposits in the coarse siliciclastics of the upper Hongjingshao Formation include about 0.7–1 m thick intervals of *Palaeobolus* sp. shell-beds and abundant trilobites such as *Yiliangellina* and *Drepanuroides*, herein called the "Malong Fauna" (Table 1) (Luo et al., 2008). In the Malong-Yilang area, the lower Hongjingshao Formation consists of occasionally bioturbated, interbedded fine sandstones and reddish-purple mudstones. These deposits are gradually replaced upward by thickly bedded, cross-bedded quartz sandstones interbedded with thin (often purple coloured) shales (Figs. 2 and 13). In the Kunming-Wuding area, the Hongjingshao Formation is characterized by thickly bedded sandstones and a lower proportion of mudstones, with few fossils so far recovered (Fig. 13).

The Xiaoshiba Biota has been documented from the shales intercalated in the thick-bedded sandstones of the lower Hongjingshao Formation in the eastern suburb of Kunming (Yang et al., 2013, 2015, 2016; Zeng et al., 2014; Hou et al., 2016). The Xiaoshiba Biota is temporally equivalent to the Xiazhuang assemblage in Chenggong, Kunming, China (Zeng et al., 2014) and includes soft-bodied fossils, such as euarthropod fuxianhuiids (Yang et al., 2013), articulated *Wiwaxia* (Yang et al., 2014) and armoured lobopodians (Yang et al., 2015, 2016), as well as abundant trilobites that demonstrate a Chiungchussuan age (Yang et al., 2014; Zeng et al., 2014). Therefore, the Hongjingshao Formation in Kunming area most likely spans the late Chiungchussuan to Tsanglangpuan age (Zeng et al., 2014), and the Malong Fauna discovered at the base of the Hongjingshao Formation belongs to the Chiungchussuan (Fig. 13, Table 1).

The boundary between the Hongjingshao Formation and the overlying Wulongqing Formation appears conformable (Fig. 2D) (Luo et al., 1994). Blocky sandstones at the top of the Hongjingshao Formation are overlain by dark green micaceous shales (up to ~2 m thick) intercalated with 3 layers of conglomerate (up to 30 cm thick). These shales contain *Eoobolus malongensis* and are interpreted as representing the basal deposits in the Wulongqing Formation as they exhibit similar lithology to the upper parts of the

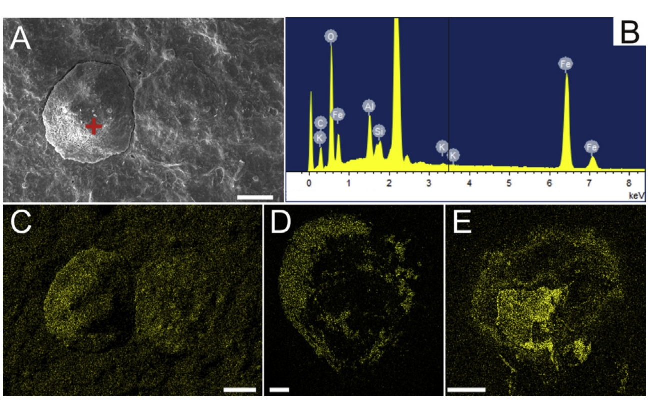

Figure 10. Elemental mapping shows the coating of Fe-rich clay minerals on fossils from the Wulongqing Formation in Malong. (A, C) Enlargement of plates from palaeoscolecidans, and elemental map showing the concentration of Fe in plates (ELI-KFQ-P-004); (B) energy dispersive X-ray spectrograph of area indicated in A showing high concentration of Fe and O; (D) elemental mapping showing the concentration of Fe in *Eoobolus* sp. (ELI-KFQ-B-805); (E) elemental map showing the concentration of Fe in a hyolith operculum (ELI-KFQ-H-001). Scale bars: A, C, 20 μm; D, E, 500 μm.

unit (Fig. 2C, D, F) (Luo et al., 1994; Hu et al., 2010b). The conglomerates are polymict, with medium-sorted clasts (ranging from 0.2 cm to about 4 cm in diameter) composed of mostly quartz and other lithic clasts distributed throughout the greenish mudstone matrix. Clasts are sub-rounded, tabular, equant or irregular in shape (Fig. 2C), indicating that the palaeoenvironment was influenced by frequent high energy events where terrestrially-derived material was rapidly deposited on the shelf. These conglomerates are traceable over all of eastern Yunnan, and indicate a major change in depositional regime from a regressive (Hongjingshao Formation) to transgressive system (Wulongqing Formation) during the mid-late Tsanglangpuan (Fig. 2E) (Luo et al., 2008; Hu et al., 2010b).

Characteristic facies in the Wulongqing Formation around the Malong area consist of micaceous mudstone and siltstone with multiple couplets of graded silty and muddy laminae (Fig. 11B, C). This is similar to the lithology of the Wulongqing Formation in areas west of the Xiaojiang Fault (Hu et al., 2010b). The siltstone layers range from 0.4 to 2.5 cm in thickness, fine upward, and normally show sharp, erosive bases. Brachiopods in shell beds at the base of graded beds are usually oriented parallel or slightly oblique to bedding (Fig. 11A, D, E). Sole marks are common at the base of the siltstones, as well as abundant vertical and horizontal burrows (Fig. 11A). A wide variety of well-preserved trace fossils are present in the middle–upper part of the Wulongqing Formation (Fig. 12B). These include diminutive traces, *Planolites*, *Palaeophycus*, *Guanshanichnus glockerichnoides* (Fig. 12C, D), *Merostomichnites* (Fig. 12F), *Thalassinoides* (Fig. 12G) and *Psammichnites* (Fig. 12H) (Hu et al., 2013). Ripple marks (Fig. 12A) in various directions and shell beds (Fig. 12E) are also very common in the middle-upper part of the Wulongqing Formation in the Kanfuqing section.

In the Malong area, sedimentary structures such as wave bedding and lenticular bedding, in addition to occasional hummocky cross stratification occur in the same interval as the exceptionally preserved Guanshan fossils (Fig. 11A–C). Hummocky cross stratification may be evidence for shallow water storm deposits (Kreisa, 1981; Dumas and Arnott, 2006), and graded bedding and sole marks indicate the influence of currents during deposition. The trace fossil assemblage from Malong is similar to that documented from the Kunming area which indicates a shallow water environment (Hu et al., 2013). Hence, it is likely that the Guanshan Biota from the Wulongqing Formation in the Malong area was deposited above storm wave-base, in a relatively shallow marine setting (shoreface to foreshore) under the influence of currents and submarine flows.

Many Cambrian Lagerstätten such as the Sinsk deposit in Russia (Ivantsov et al., 2005), Sirius Passet in Greenland (Peel and Ineson, 2011), Burgess Shale in Canada (Collom et al., 2009) and Kaili Biota in China (Zhao et al., 2005) are associated with distal offshore environments, and Konservat Lagerstätten deposited in relatively shallow environments are much rarer. However, sites where exceptional preservation is associated with shallow water or proximal facies include the Ordovician Fezouata in Morocco, which was deposited in shoreface sediments (Martin et al., 2016), and perhaps also the Emu Bay Shale Lagerstätte in South Australia (Gehling et al., 2011; Paterson et al., 2016). Lithologically, the Guanshan deposits are more closely comparable with these Lagerstätten, and the exceptional preservation in the Wulongqing Formation is therefore attributed to rapid burial, and the protective action of microbial mat communities within Wulongqing sediments (Hu et al., 2010b, 2013).

4.4. Influence of regional tectonics

In Yunnan, successions spanning the Shiyantou, Yu'anshan, Hongjingshao and Wulongqing formations have been measured in

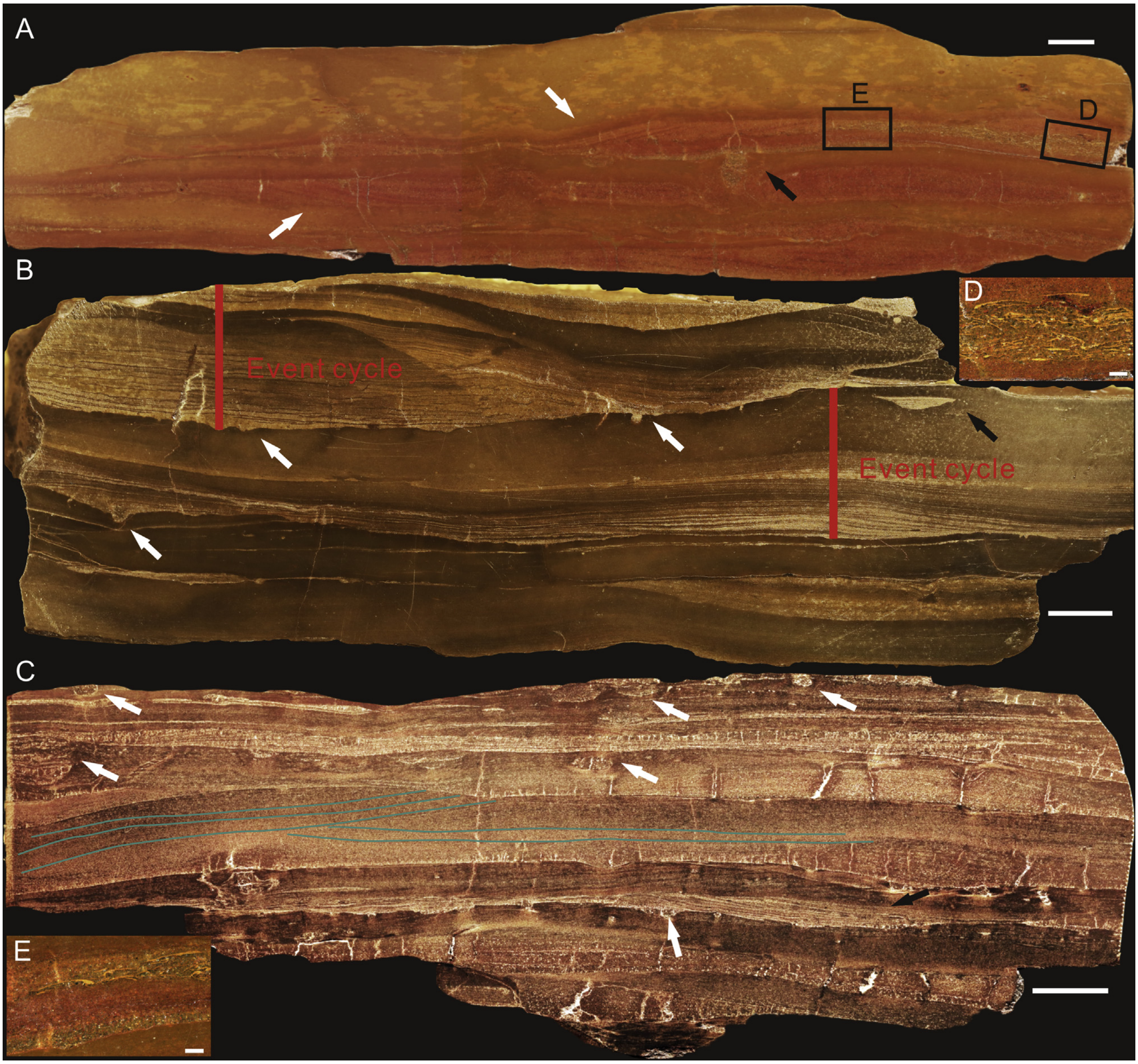

Figure 11. Polished slabs from the lower part of Wulongqing Formation in Kanfuqing section, Malong County, indicating sedimentary structures and brachiopod shell beds. (A, D, E) Shell beds at the base of graded beds (enlargements in D and E), cross bedding (white arrow) and burrows (black arrow); (B) several graded beds representing event cycles. Sole marks (white arrows) are clear at the base of graded beds. Small scale lenticular bed occurs in the upper right corner (black arrow); (C) slab shows multiple horizontal trace fossils (white arrows), cross beds (black arrow) and hummocky cross stratification (green lines). Scale bars: A–C, 1 cm; D, E, 1 mm.

the Wuding (Luo et al., 2008; Zhao et al., 2012), Kunming (Luo et al., 1994; Zeng et al., 2014; Hou et al., 2016) and Malong areas (Luo et al., 1994; Zhao et al., 2012) (Figs. 1 and 13). West of the Xiaojiang Fault, the Yu'anshan Formation has a high mud content which increases the preservation potential of soft tissues. By comparison, in the Malong-Yiliang area east of the fault, the Yu'anshan Formation contains a higher proportion of silt which reflects a relatively unstable palaeoenvironment, and fossils are generally rare in this interval (Table 1) (Hu, 2005).

The Hongjingshao Formation on the western side of the fault in Wuding area is characterized by thick siliceous sandstones with large-scale inclined bedding, cross-bedding and wave-bedding, and fossils are rare. By comparison, a wide variety of fossils including brachiopods and trilobites (Malong Fauna) are preserved in the siltstone and muddy interlayers under thick sandstones in the Hongjingshao Formation east of the fault (Table 1) (Luo et al., 1994, 2008). A widespread transgression influenced deposition throughout eastern Yunnan from the mid-Tsanglangpuan (Luo et al., 2008; Hu et al., 2013). In the Kanfuqing section, there are 1–3 layers of conglomerate at the base of the Wulongqing Formation (Fig. 2D), indicating several pulses of deposition related to sea level rise.

In contrast with the lithological differences observed between the Yu'anshan and Hongjingshao formations on either side of the Xiaojiang Fault, there are strong similarities between the sequences of the Wulongqing Formation deposited on both sides of the Xiaojiang Fault. Despite variations in thickness, lithologically the Wulongqing Formation is consistent in the Wuding, Kunming and Malong areas where bioturbated, thinly-bedded, siltstones and mudstones crop out. Fossil deposits in the Wulongqing Formation are also similar on both sides of the fault (Table 1). For example, thick *Neobolus* shell beds are developed in both the Kunming and

Figure 12. Field photos show sedimentary structures and abundant trace fossils of Wulongqing Formation in middle-upper part of Kanfuqing section. (A) Ripples with various directions on different bedding planes; (B) abundant horizontal and vertical trace fossils; (C, D) *Guanshanichnus glockerichnoides* Weber, Hu et Steiner, 2012; (E) shell beds dominated by brachiopod and trilobite fragments; (F) *Merostomichnites* Packard, 1900; (G) *Thalassinoides* Ehrenberg, 1944; (H) *Psammichnites* Torell, 1870. Scale bars: A, 40 cm; B, D, 5 cm; C, 2 cm; E–H, 1 cm.

Malong areas. Overall, the Guanshan Biota recovered from the Wulongqing Formation in localities on both sides of the Xiaojiang Fault share strong similarities, with most groups common to both areas (Table 1).

The Xiaojiang Fault was caused by the Tsinning tectonic movement ca. 700 Ma (Luo et al., 1994). Periodic activation of the fault likely impacted depositional regimes across the basin which may have imposed important environmental constraints on the palaeoecology and composition of Cambrian marine communities on east and west sides of the fault (Luo et al., 1994, 2008). By contrast, comparable lithologies and faunal assemblages in the Wulongqing Formation in eastern and western localities suggest that this depositional system was less affected by dramatic episodes of fault reactivation during the mid-late Tsanglangpuan, and the palaeoenvironment remained stable across a wider area.

4.5. Changing community composition

Lower Cambrian successions in Yunnan provide a unique opportunity to map changes in early Cambrian ecological communities both temporally and spatially. In the Kunming-Wuding and Malong-Yiliang areas, exceptionally preserved fossils occur at three major stratigraphic intervals spanning Cambrian Series 2, stages 3–4 (Table 1). Faunal composition in these three key assemblages has been influenced by taphonomic factors, palaeoenvironmental conditions (a product of dynamic regional tectonic regimes, discussed above) and stratigraphic ranges of taxa.

4.5.1. Temporal changes

Generally, the Chengjiang, Malong and Guanshan assemblages share similar types of skeletonized taxa, however the main trilobite and brachiopod assemblages from each of these deposits are unique. The Chengjiang Biota (mid-Stage 3) is characterized by a highly diverse assemblage that contains exceptionally preserved, soft-bodied fossils and skeletonized taxa. Statistical analyses revealed that arthropods (particularly trilobites) are the most abundant group in the Chengjiang Biota (Zhao et al., 2012). Common brachiopod taxa from the Chengjiang Biota include *Diandongia*, *Eoglossa* and *Lingulellotreta* (Table 1).

By contrast, the Malong Fauna in the Hongjingshao Formation (upper Stage 3) contains almost exclusively skeletonized taxa (vetulicolians are the only non-mineralized forms), including trilobites and brachiopods, in addition to anomalocaridids, hyoliths and arthropods such as *Branchiocaris* (Table 1) (Luo et al., 1994, 2008). The lingulid brachiopod *Palaeobolus* occurs in densely-packed shell beds, and trilobites such as *Yiliangella* and *Drepanuroides* are also common

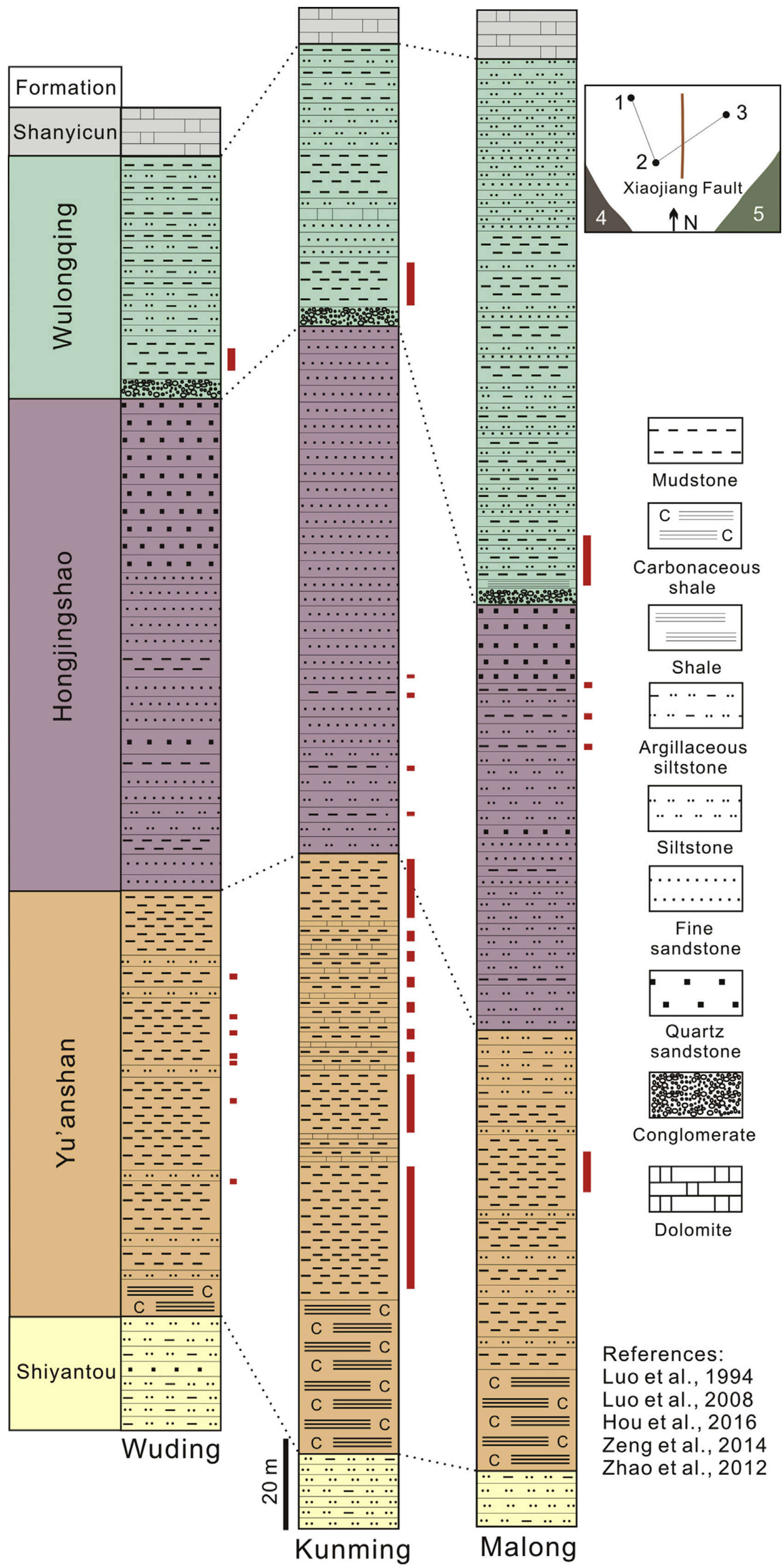

Figure 13. Stratigraphic sections through the Shiyantou, Yu'anshan, Hongjingshao and Wulongqing formations in the Wuding, Kunming and Malong areas. Red bars mark the main intervals yielding fossils. The small map at the top-right corner shows the relative position of Wuding (1), Kunming (2), Malong (3), Dianzhong old land (4) and Niutoushan old land (5).

(Table 1). Limited soft-bodied preservation in the Malong deposits may be attributed to a high energy depositional environment and the relatively coarse, siliciclastic facies in which the fossils occur.

The younger Guanshan Biota is dominated by skeletonized forms, however soft-bodied taxa also occur in the Wulongqing Formation, east and west of the Xiaojiang Fault (Table 1). *Eoobolus* and *Neobolus* are the most abundant brachiopods in the Guanshan Biota, which shares no brachiopod taxa with either the Malong or Chengjiang assemblages. Similarly, while the Malong Fauna contains a diverse trilobite assemblage, none of these taxa are found in the Guanshan Biota which is dominated by *Palaeolenus* and *Megapalaeolenus*. Vetulicolians are the only group (genus-level) common to all three assemblages, which suggests that they were long-ranging and capable of withstanding a broad spectrum of palaeoenvironments. Faunal overturn between the Chengjiang, Malong and Guanshan biotas suggest that sessile benthic members of the assemblages were affected by the same factors that affected mobile trilobites (Luo et al., 2008).

4.5.2. Spatial variation

The Chengjiang deposits west of the fault are dominated by soft-bodied forms, whereas less soft bodied taxa occur in deposits east of the fault (Table 1). In the west, Chiungchussuan communities were periodically smothered by distal tempestites (Zhu et al., 2001b; Zhao et al., 2012; Yang et al., 2013). Reduced instances of soft-bodied preservation in the Yu'anshan Formation east of the Xiaojiang Fault suggest that the taphonomic processes that allowed the preservation of highly detailed soft anatomy in the western localities did not occur to the same degree in the eastern deposits.

In the Hongjingshao Formation, the relatively high degrees of bioturbation and hydrodynamic disturbance are likely responsible for the substantial decrease in the quality of preservation and reduced number of soft-bodied species present in the Malong Fauna (Zhao et al., 2012). Elevated occurrences of skeletonized taxa in the Malong Fauna may be attributed to the development of communities consisting of taxa that were capable of withstanding relatively high energy conditions, or a taphonomic bias toward the preservation of a robust, mineralized anatomy. The Malong fauna only occurs in the mid-upper Hongjingshao Formation east of the Xiaojiang Fault around the Malong-Yiliang area and is characterized by abundant skeletonized taxa especially trilobites and brachiopods. Lack of fossils in the mid-upper Hongjingshao Formation west of the Xiaojiang Fault is likely due to the shallower, higher energy palaeoenvironment, which precluded the preservation of any fossils (Table 1) (Luo et al., 1994, 2008; Zhao et al., 2012; Hu et al., 2013).

The Wulongqing Formation has a similar lithology and fauna in the regions east and west of the Xiaojiang Fault. Trilobites such as *Palaeolenus*, *Redlichia* and *Yuehsienszella* are found on both sides of the fault, and the brachiopod faunas are similar, with *Eoobolus* and *Neobolus* shell beds present in both areas. Soft bodied taxa such as priapulids and vetulicolians also occur in the Wulongqing Formation in both the Kunming-Wuding and Malong-Yiliang areas. Similar community structures in areas east and west of the Xiaojiang Fault are likely related to a stable palaeoenvironment and stable depositional regime occurring in both regions.

5. Conclusion

This is the first report of a new locality for the Guanshan Biota at Kanfuqing, near Malong, Yunnan. This locality is of critical importance as many of the classic Guanshan fossil localities around Kunming have been destroyed or covered. A total of seven fossil groups are reported herein from the Kanfuqing section. The fossils are preserved by carbonaceous compressions, pyritization, phosphatization and clay mineral replacement, and display high fidelity preservation of soft tissues, similar to that seen in the Chengjiang and other Guanshan Biota localities west of the Xiaojiang Fault. New discoveries of soft-bodied assemblage from the Kanfuqing section on the eastern side of the Xiaojiang Fault has increased the occurrences of the Guanshan Biota, and suggest that similar faunal assemblages were deposited across the basin after the transgression of the eastern Yunnan Sea.

The palaeoenvironment of the Guanshan deposits in the Malong region was generally shallower than most other Burgess Shale-type Lagerstätten, and therefore shares more similarities with Konservat-Lagerstätte such as the Fezouata in Morocco, and perhaps also the Emu Bay Shale in South Australia. The occurrence of the Guanshan Biota in shallow water facies demonstrates that a wide variety of sedimentary environments may preserve Burgess Shale-type fossil Lagerstätten, from nearshore (e.g. Fezouata) to more offshore settings (e.g. Burgess Shale).

Exceptionally preserved fossils from stratigraphically and geographically discrete deposits in Yunnan allow the unique opportunity to map temporal changes and spatial variations in key early Cambrian fossil deposits in China. While the Guanshan Biota is similar on both sides of Xiaojiang Fault, the community composition of the older Chengjiang Biota and Malong Fauna on either side of the Xiaojiang Fault is quite different. It is likely that the Xiaojiang Fault affected basinal depositional dynamics and played an important role in controlling palaeogeography and palaeoenvironments during the Chiungchussuan and early Tsanglangpuan in eastern Yunnan. This tectonic activity imposed important palaeoenvironmental constraints on the ecology and composition of marine communities in eastern Yunnan as the depositional facies changes are taken into consideration. This new occurrence of the Guanshan Biota provides fresh insights into the taphonomy, biodiversity and depositional dynamics of a critical lower Cambrian fossil deposit in Yunnan.

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