Middle Telychian (Llandovery, Silurian) graptolite and chitinozoan faunas and biostratigraphy of the upper part of the Xiushan Formation in the Xiushan area, southwestern China

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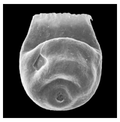

The middle Telychian (Llandovery, Silurian) Xiushan Fauna (characterized by abundant benthic brachiopods, cephalopods and trilobites) from South China is important in understanding the re-radiation of the Early Palaeozoic Evolutionary Fauna after the Late Ordovician Mass Extinction. Although previous integrated studies based on graptolites, conodonts and chitinozoans have resulted in the erection of a biostratigraphical framework for the Xiushan Fauna, the precise biostratigraphical correlation has long been debated, due to the sporadic occurrence of biozonal index fossils, *e.g.* only a few graptolites in carbonate clasts and siliciclastic rocks. Here, we report a moderately well-preserved graptolite fauna from the interbedded shaly layers of the Xiushan Formation in Chongqing Municipality, southwestern China. The graptolites and chitinozoans from the Xiushan Formation at the Hujiadongkan section suggest a middle Telychian (Llandovery, Silurian) age for the upper part of the Xiushan Formation, possibly corresponding to the upper part of the *Monoclimacis crenulata* to the lower *Oktavites spiralis* biozones, for the graptolite assemblages, and the *Angochitina longicollis* chitinozoan Biozone. This age identification, based on the co-occurrences of graptolites and chitinozoans at the Hujiadongkan section, agrees with earlier biostratigraphical studies based on other fossil groups, *e.g.* conodonts for the Xiushan Fauna recovered from the upper part of the Xiushan Formation. The graptolitic shales in the upper part of the Xiushan Formation may provide new evidence for high sea-levels in the middle Telychian, as have been reported worldwide. • Key words: early Silurian, Chongqing Municipality, Xiushan Formation, graptolite, chitinozoan, biostratigraphy.

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Telychian rocks have been much studied in South China in recent decades based on integrated biostratigraphy (Holland & Bassett 2002, Rong *et al*. 2019, Wang *et al*. 2020). In the Upper Yangtze region, Telychian strata are largely represented by the Xiushan Formation (Ge *et al*. 1979, Chen & Rong 1996, Chen *et al*. 2002), named after the Rongxi section in Xiushan County, Chongqing Municipality. It is widely developed in southeast Chongqing Municipality, northeast Guizhou, northwest Hunan, and southwest Hubei provinces (Nanjing Institute of Geology and Palaeontology 1974). It is divided into two parts based on lithology and fossil assemblages (Ge *et al*. 1979). The upper part is characterized by fine-grained siliciclastic rocks and carbonates yielding various invertebrate fossils. It is from this part that the famous Xiushan Fauna is recorded. The definition of the Xiushan Fauna originated from the finding by Ge *et al*. (1979) of an association of a short-ranging, widely distributed, mixed fauna, *i.e.* the *Coronocephalus–Salopinella–Sichuanoceras–Stomatograptus* assemblage, however, Ge *et al*. (1979) did not introduce the name "the Xiushan Fauna". This was first used as a formal name in Rong *et al.* (1990). The fauna suggests a mid–late Telychian age (Chen & Rong 1996, Rong *et al*. 2019, Chen 2023).

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Understanding the mid–late Telychian Xiushan Fauna is of great importance, because, on the one hand, most regions in South China lack strata younger than of late Telychian age (*e.g.* Rong *et al.* 2019), making the upper Telychian contain the highest strata providing fossil evidence to study the re-radiation after the Late Ordovician Mass Extinction. On the other hand, although previous integrated studies based on graptolites, conodonts, brachiopods and chitinozoans have resulted in the erection of a biostratigraphical framework for the Xiushan Fauna, the biostratigraphical correlation is of low resolution, *e.g.* the *Sichuanoceras* cephalopod fauna which is typical of the Xiushan Fauna ranges through several graptolite biozones (*Monoclimacis griestoniensis* Biozone to *Stomatograptus grandis* Biozone) (Chen & Rong 1996, Rong *et al.* 2012). Moreover, the precise age of the Xiushan Fauna and its biostratigraphical correlation with graptolite and chitinozoan biostratigraphy have long been debated, partially due to the facies.

As most Telychian strata in the Yangtze Region are dominated by shelly fossils, conodont workers were the pioneers for biostratigraphical work. Conodont studies established that the upper part of the Xiushan Formation is of middle Telychian age, lying almost exclusively within the *Pterospathodus eopennatus* superbiozone (topmost strata have been assigned to the *Pterospathodus celloni* superbiozone) (Wang & Aldridge 2010, Wang *et al.* 2010, Chen *et al.* 2016, Yan *et al.* 2018). Brachiopods are abundant in the Xiushan Fauna (Rong *et al.* 1990, Huang *et al.* 2017). A recent investigation of Telychian brachiopods in South China has led to the recognition of the *Nalivkinia magna–Striispirifer–Xinanospirifer–Aegiria* assemblage, typical of the Xiushan Fauna (Chen 2023). Contrastingly, only sporadic occurrences of graptolites have been reported in intermittent mudstone layers within the shelly facies. Discontinuities or even missing sequences of graptolite biozones have been recorded in the Telychian Stage in China, making it difficult for stratigraphical correlations within the dominantly shelly facies of the Yangtze Region. From well-studied Telychian reference sections in the Yangtze Region, only occasional occurrences of low diversity graptolite assemblages have been recorded (Rickards & Chen 2002, Wang *et al.* 2020).

Chitinozoans, which may also provide important biostratigraphical information for the Xiushan Fauna, have also been investigated in previous works. Early studies on the Telychian chitinozoan succession in South China resulted in the first recognition of the *Angochitina longicollis* Biozone by Geng & Cai (1988), later widely recognized in the Yangtze Region (Geng *et al.* 1997, Geng & Downie 2002). However, the age of the base of the *Angochitina longicollis* chitinozoan Biozone conflicts between different faunas. Based on the integrated biostratigraphy of conodonts and chitinozoans from the Zigui area, Hubei Province, the *Angochitina longicollis* Biozone is suggested as equivalent to the *Pterospathodus eopennatus* conodont Biozone (Wang & Zhang 2010), considered by them to be roughly equivalent to the middle and upper part of the *Spirograptus turriculatus* graptolite Biozone, of early Telychian age. This age is much older than that indicated by integrated biostratigraphical studies with graptolites, which suggest the *Monoclimacis crenulata* Biozone for the *Angochitina longicollis* chitinozoan Biozone, as in other regions of South China (Geng & Downie 2002). This conflict is due to the fact that, although the Telychian *Angochitina longicollis* Biozone is a globally distributed and well recognized unit (Verniers *et al.* 1995), a consensus has not been reached regarding the base of the biozone worldwide; apparent inconsistencies can exist between different groups (*e.g.* Loydell *et al.* 2007). More detailed integrated chitinozoan and graptolite biostratigraphical studies on the Telychian of South China will help to answer this question.

Our recent findings of the moderately well-preserved graptolite and chitinozoan faunas from the basal part of the upper Xiushan Formation at the Hujiadongkan section, Chongqing Municipality, have enabled a close examination of these two faunas in the Xiushan Fauna. This work thus provides new biostratigraphical insights for the intervals yielding the Xiushan Fauna from South China.

Materials and methods

Both the graptolite specimens and samples for extracting chitinozoans were collected from the Hujiadongkan section in Xiushan County, Chongqing Municipality, South China, *ca* 8 km west of Hong'an Town, Chongqing Municipality, and close to the borders of the Hunan and Guizhou provinces (Fig. 1). This study is confined to the upper part of the Xiushan Formation (Telychian, Llandovery) exposed in the Hujiadongkan road-cut section. The Hujiadongkan section has a thickness of more than 44 m, with the interval of the Xiushan Formation dominated by dark grey to light grey limestones, intercalated with several thin interbeds of argillaceous limestone and mudstone. Abundant cephalopods, trilobites and brachiopods are found in the limestones, indicating the presence of the Xiushan Fauna in the strata. Graptolites were collected from three mudstone intervals: 12–15 m, 15–18 m and 21 m in the lithological column (Fig. 2). Chitinozoans were collected every 3 m except for the 12–18 m interval (Fig. 2).

Most graptolite specimens from the lowermost horizon (Fig. 2; 12–15 m) are preserved as flattened carbon films, while a few are pyritized. Graptolites from the other

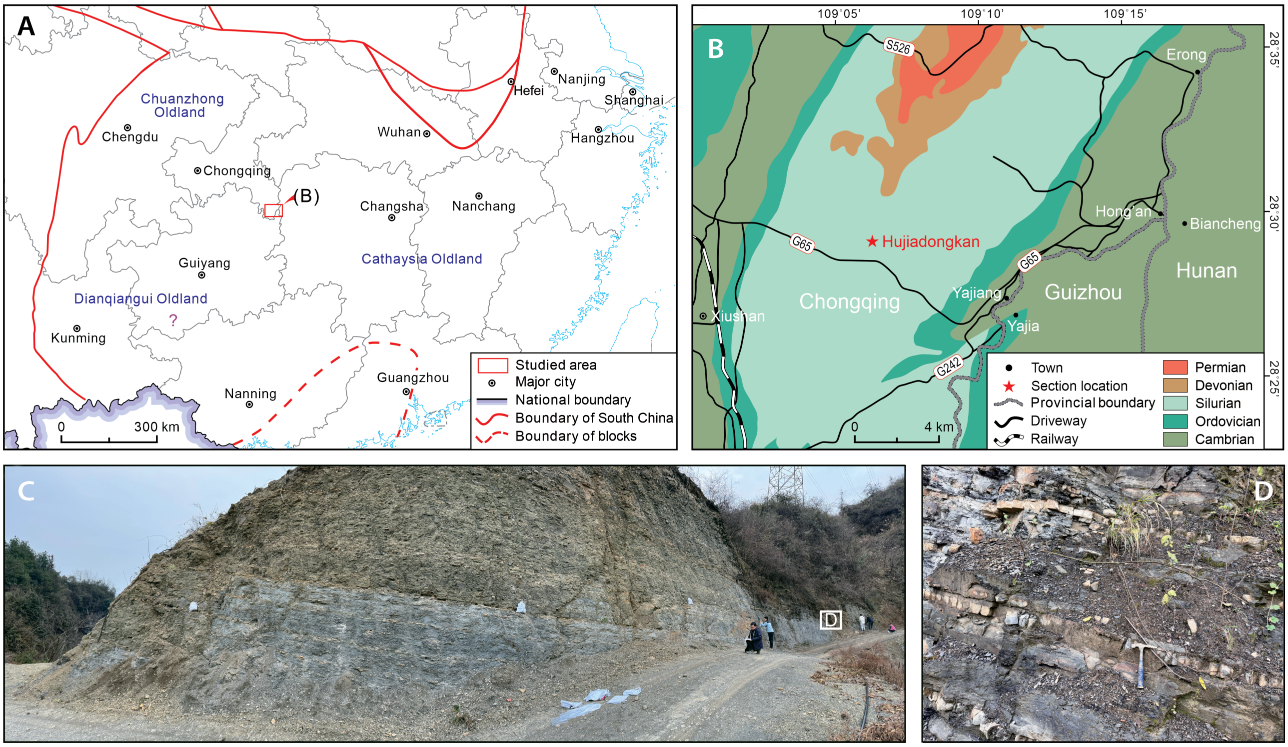


Figure 1. Locality map of the Hujiadongkan section, Xiushan County, Chongqing Municipality, South China. • A – studied area, at the junction of three provinces in South China (modified from Chen 2023). • B – close-up of the studied area indicated in (A), showing the location and stratigraphical setting of the Hujiadongkan section. • C – photograph of the Hujiadongkan section. • D – close-up of the graptolite bearing layers in the Hujiadongkan section.

two horizons (Fig. 2; 15–18 m and 21 m) are preserved as diagenetically flattened original periderm, which has flaked off to a variable extent, resulting in a combination of original periderm and low relief external mould. Pyritized graptolites were photographed under alcohol to increase the contrast of the pyrite with the surrounding rocks.

In total, thirteen samples were collected from the Hujiadongkan section for chitinozoans. All samples were processed in acid following the standard process (Paris 1981). The weight of each sample was around 50 g. The taxonomic classification scheme of Paris *et al.* (1999) has been adopted. The measurements of chitinozoans are abbreviated as: L – length of the vesicle; Dc – maximum diameter of the chamber; Dco – diameter of the aperture. Three values for each measurement are provided in the following order: minimum, mean and maximum values. Most specimens in this study were flattened, and biometric measurements for flattened specimens are provided in their raw form. Due to the erosion of the basal processes or spongy ornamentations, many chitinozoan specimens recovered could be assigned only to generic level and left in open nomenclature. The abundance and measurements of each species are provided in Appendix Table 1 and Appendix Table 2.

All of the graptolite and chitinozoan specimens are housed at the School of Earth Sciences and Info-physics, Central South University, and the graptolites have been assigned sample and specimen numbers accordingly (CSU 10291–10297, 10301–10311).

Results and biostratigraphical discussion

Notes on the graptolite fauna

The lowermost horizon of the Hujiadongkan section (Fig. 2; 12–15 m) contains a rich but low-diversity graptolite assemblage, which includes abundant *Monograptus priodon* (Bronn, 1835) (Fig. 3A, C), *Monograptus parapriodon* (Bouček, 1931), *Stimulograptus splendens* (Štorch, 1998) (Fig. 3B) and *Pristiograptus* sp. In the horizon of 15–18 m, abundant broken specimens of *Monoclimacis* sp. indet. (Fig. 3D), *Monograptus parapriodon* and *Monograptus priodon* are recorded. In the uppermost horizon at 21 m, abundant specimens belonging to *Monoclimacis* sp. indet. (Fig. 4B–L) were collected, in association with *Streptograptus* sp. indet. (Fig. 4A), *Stimulograptus* sp., *Monograptus priodon*, *Monograptus parapriodon* (Fig. 3F–I) and *Pristiograptus* sp. (Fig. 3E).

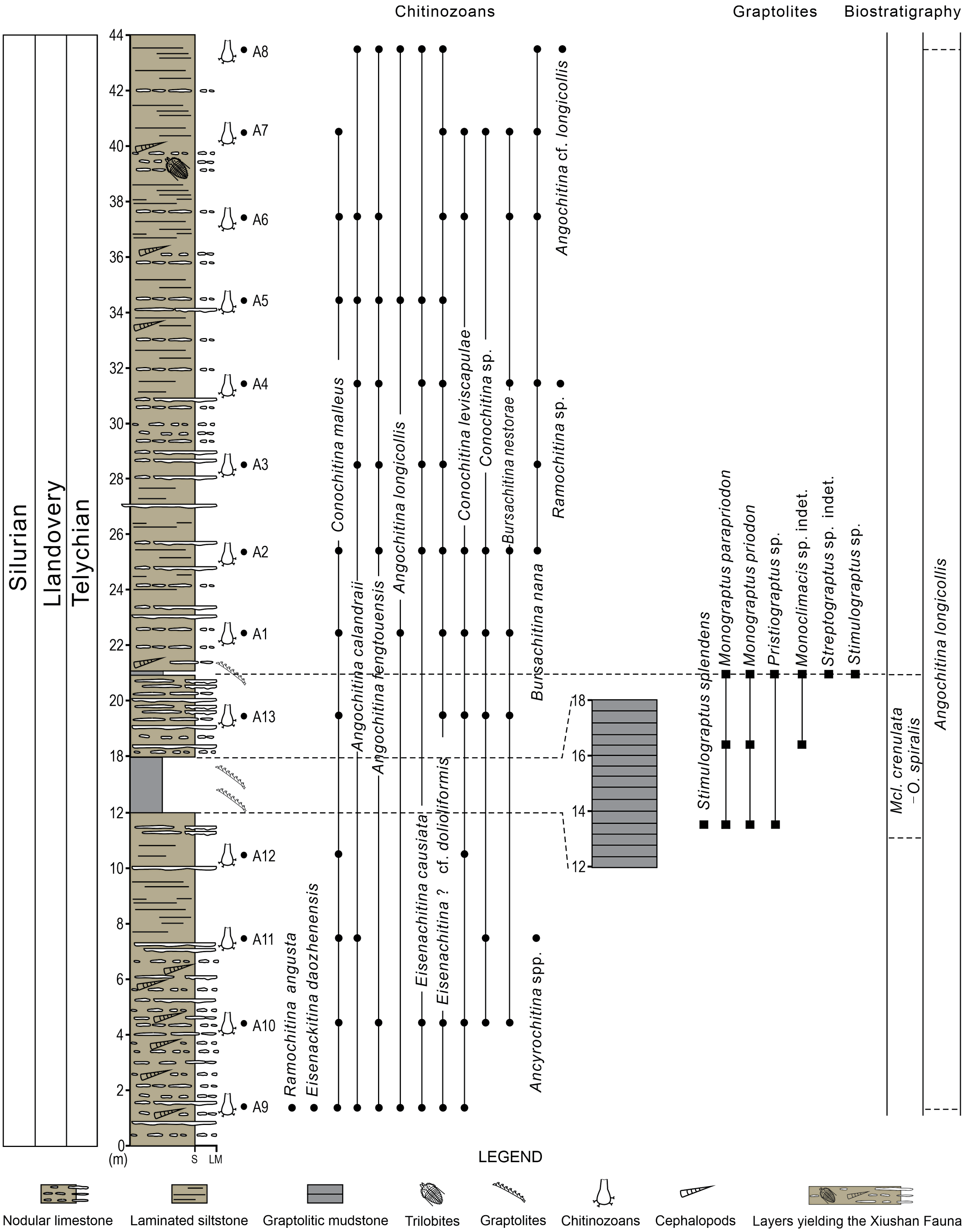


Figure 2. Range chart of graptolites and chitinozoans recovered from the Hujiadongkan section. Abbreviations: S – silty mudstone; LM – lime mudstone.

Two species of *Monograptus* are present, *M. parapriodon* (Fig. 3F–I) and the long-ranging *M. priodon* (Fig. 3A, C), from all three graptolitic horizons. Both species are distributed world-wide and possess hooked thecae, but the tubarium (an alternative term for rhabdosome) of the former species is more slender. *Monograptus priodon* is a long-ranging Telychian to Wenlock species. It has been recovered low in the Telychian within the *Spirograptus turriculatus* Biozone (*e.g.* Walasek *et al.* 2018), throughout the many succeeding Telychian graptolite biozones, and its highest occurrence may be the lower Sheinwoodian (Wenlock) *Cyrtograptus murchisoni* or *Monograptus riccartonensis* Biozone (*e.g.* Lenz 1974, Zalasiewicz 1994, Loydell *et al.* 2003, Loydell & Jeppsson 2006, Loydell *et al.* 2010, Lopez & Kaufmann 2023, Štorch 2023) or higher. *Monograptus parapriodon* has been reported from the lower part of the Cuijiagou Formation at Xuanhe, Guangyuan, northern Sichuan (Chen 1984), from the *Oktavites spiralis–Stomatograptus grandis* Biozone. It has been recorded doubtfully in the upper part of the *Spirograptus turriculatus* and *Streptograptus crispus* biozones in China, *e.g.* from the *Spirograptus turriculatus* and *Streptograptus exiguus* biozones in the Nanjiang Formation in Sichuan (Chen 1984). In Guizhou, *Monograptus parapriodon* is the only species reported in the Telychian Wenghsiang Formation (Chen & Rong 1996, Tang *et al.* 2010). In Europe, *Monograptus parapriodon* is indicative of the *Monoclimacis crenulata* Biozone and lower *Oktavites spiralis* Biozone from which the type material of Bouček (1931) originated. It possibly already occurred in the *Monoclimacis griestoniensis* Biozone, and then became a common species of the *Monoclimacis crenulata* Biozone in the British Isles (Rickards & Chen 2002).

Stimulograptus is a genus typical of middle Telychian assemblages. In the Hujiadongkan section only one identifiable species, *Stimulograptus splendens* (Fig. 3B), was found. *Stimulograptus splendens* was first described from the Badenas Formation in Spain (Štorch 1998). This species is widespread and common in the upper *Torquigraptus tullbergi* Biozone (a biozone equivalent to the *Monoclimacis crenulata* Biozone) and lower *Oktavites spiralis* Biozone in Spain. Recently, it was also described from the *Oktavites spiralis* Biozone in the Co To Formation in northeastern Vietnam (Saparin *et al.* 2020).

Monoclimacis is one of the most common taxa in the Hujiadongkan section, often preserved as long, straight fragments. *Monoclimacis* can be recognized to genus level even in fragmentary material because of the semi-circular thecal apertures and apertural hoods (Figs 3D, 4B–L). *Monoclimacis crenulata* is a critical index fossil for the eponymous Telychian biozone in Britain (Zalasiewicz *et al.* 2009, Loydell 2012). In previous work on the Telychian in South China, no *Monoclimacis crenulata* was found in the Yangtze Region (Rickards & Chen 2002), and the middle–upper Telychian was represented by the *Oktavites spiralis–Stomatograptus grandis* Biozone (Rickards and & Chen 2002, *e.g.* figs 9, 58). However, on another

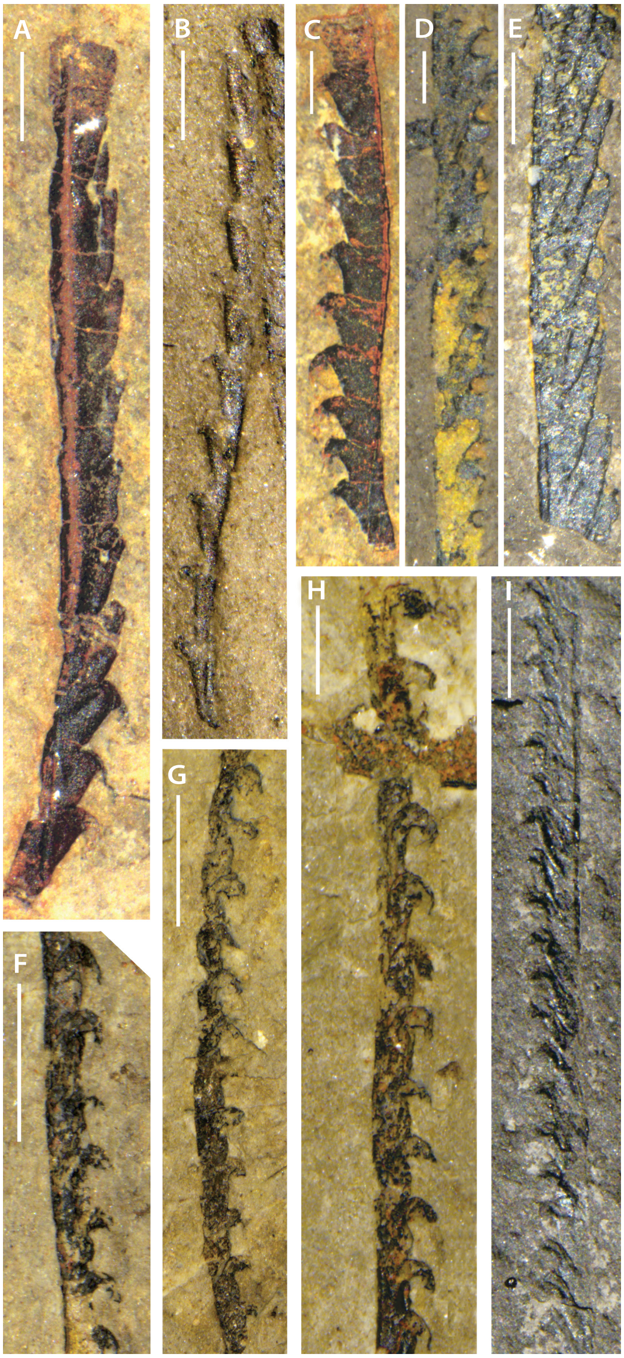


Figure 3. Graptolites from the Xiushan Formation at the Hujiadongkan section, South China. • A, C – *Monograptus priodon* (Bronn, 1835), 12–15 m, CSU-10291, CSU-10292. • B – *Stimulograptus splendens* (Štorch, 1998), 12–15 m, CSU-10293. D – *Monoclimacis* sp., 15–18 m, CSU-10294. • E – *Pristiograptus* sp., distal fragment, 21 m, CSU-10295. • F–I – *Monograptus parapriodon* (Bouček, 1931), 21 m, CSU-10296. Scale bars represent 1 mm.

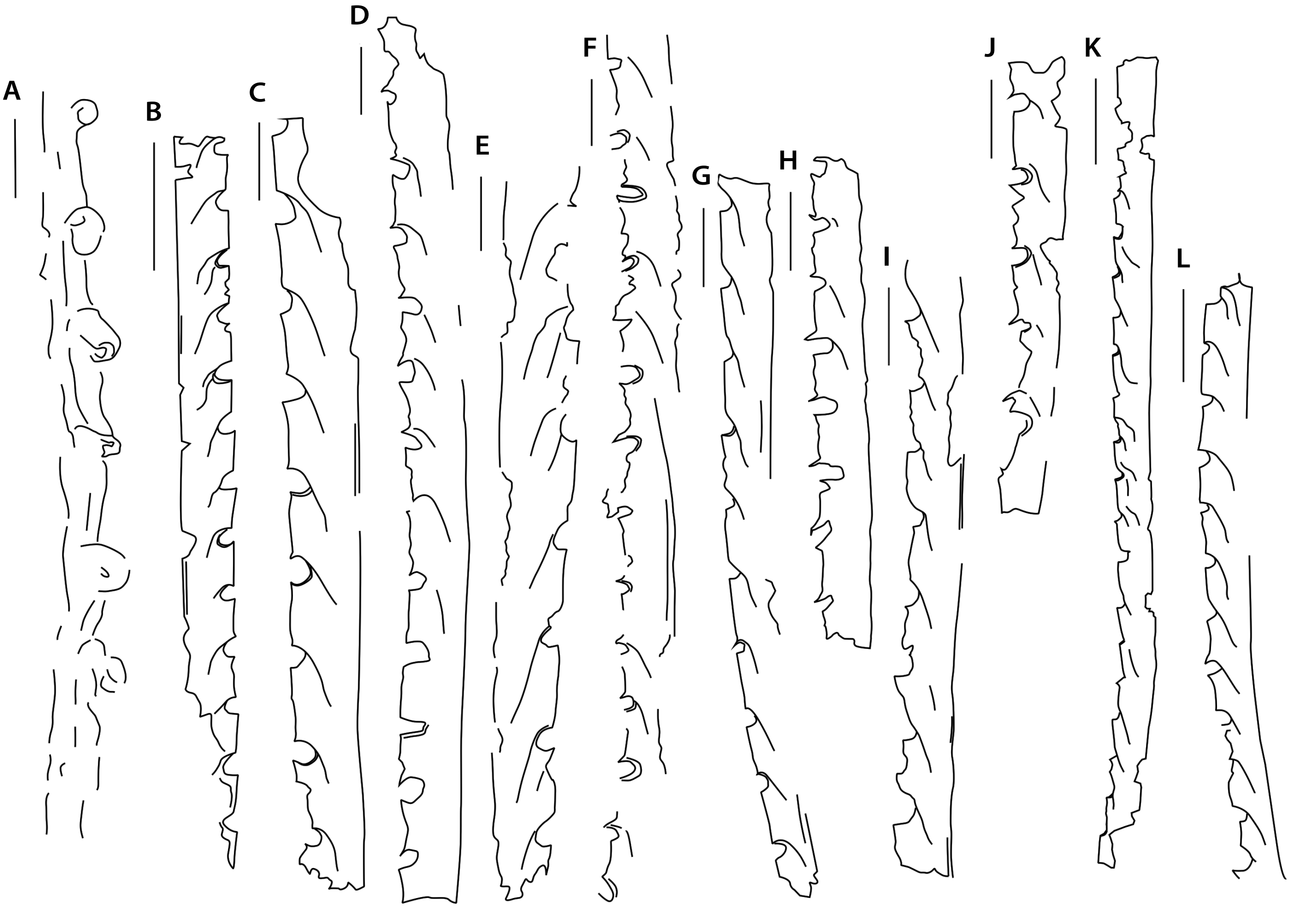


Figure 4. Camera lucida drawings of graptolites from the upper part of the Xiushan Formation at the Hujiadongkan section, South China. • A – *Streptograptus* sp. indet., 21 m, CSU-10297. • B–L – *Monoclimacis* sp(p). indet., 21 m, CSU-10301–CSU-10311. Scale bars represent 1 mm.

palaeoplate in China, it has been recorded in the Manbo Formation of Yunnan Province, southwestern China (Wang & Zhang 2010). In the Hujiadongkan section, the fragments (which lack proximal ends) can be identified only as *Monoclimacis* sp. indet.

Among the most challenging uniserial Telychian graptolites for identification are those belonging to *Streptograptus* because the tubaria of many taxa in the genus are slender (less than 1 mm in dorsal-ventral width, DVW) (Loydell & Maletz 2004), and the complex thecal details are often obscured by diagenetic flattening. As a result, all of the fragmented tubaria bearing streptograptid thecae (*e.g.* Fig. 4A) are left in open nomenclature due to the difficulty of identifying fragmentary specimens to specific level.

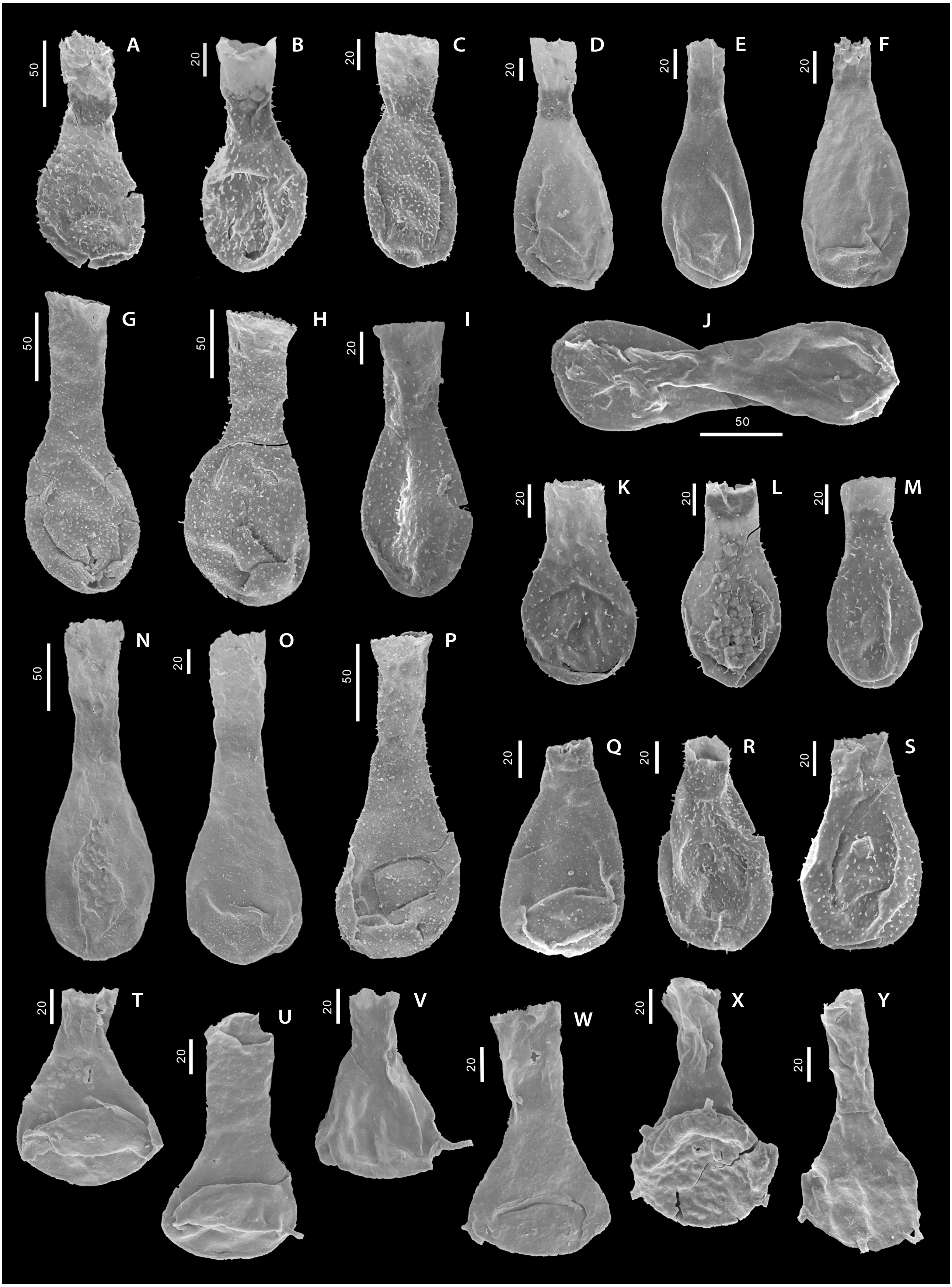
The *Pristiograptus* specimens occur in the uppermost graptolite bed (21 m). The specimens are identified as *Pristiograptus* sp. (Fig. 3E), showing the characteristic simple tubular thecae with a thickened apertural rim.

Notes on the chitinozoan fauna

Fifteen species of chitinozoans were identified from the Telychian Xiushan Formation at the studied Hujiadongkan section (Fig. 2).

Angochitina longicollis Eisenack, 1959 (Fig. 5J, N–P) is the most characteristic species, with high abundance and common occurrences throughout the Hujiadongkan section. The presence of *A. longicollis* indicates the

Figure 5. Silurian chitinozoans from the Xiushan Formation at the Hujiadongkan section, South China. • A–C, K–M – *Angochitina fentouensis* (Li & Geng, 1985). A – A2–7; B – A5–48; C – A5–32; K – A8–50; L – A8–30; M – A8–52. • D–I – *Angochitina* cf. *longicollis* Eisenack, 1959. D – A8–12; E – A8–74; F – A8–106; G – A9–50; H – A9–16; I – A4–20. • J, N–P – *Angochitina longicollis* Eisenack, 1959. J – A8–96; N – A8–123; O – A8–119; P – A9–3. • Q–S – *Angochitina calandraii* (Cramer, 1966). Q – A8–15; R – A5–51; S – A5–49. • T–Y – *Ancyrochitina* spp. T –A11–31; U – A11–16; V – A11–34; W – A11–21; X – A11–24; Y – A11–33. The unit of the scale bars is μm.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eponymous Telychian biozone, which is distributed world-wide (Verniers *et al*. 1995, Geng *et al*. 1997, Nestor 2012, Melchin *et al*. 2020, Klock *et al.* 2024). *Angochitina longicollis* is, however, a long-ranging species, reported from the Telychian *Spirograptus turriculatus* graptolite Biozone to the middle Sheinwoodian *Monograptus riccartonensis* graptolite Biozone.

In the topmost sample, *Angochitina longicollis* is accompanied by *A.* cf. *longicollis* (Fig. 5D–I). The former species differs from the latter in having a longer neck/chamber ratio. *Angochitina* cf. *longicollis* has been frequently identified as either *A. longicollis* (Li & Geng 1985, pl. 2, figs 4, 5), or *A.* sp. (Li *et al*. 2021) in previous works from South China. The other two *Angochitina* species from the Hujiadongkan section are *A. fentouensis* (Li & Geng, 1985) (Fig. 5A–C, K–M), and *A. calandraii* (Cramer, 1966) (Figs 5Q–S; 7A, B). These species are smaller than the biozonal index and *A.* cf. *longicollis*. *Angochitina fentouensis* was first found within the *A. longicollis* Biozone of the Fentou Formation in Nanjing, Lower Yangtze Region (Li & Geng 1985), and it also appears in the higher layers of the Aeronian–Telychian Shamao Formation in the Middle Yangtze Region (Li *et al*. 2021). The specimens identified as *Angochitina longicollis* in Latvia (Loydell *et al*. 2003, fig. 16x; Loydell & Nestor 2005, fig. 4d) are short-necked ones, possibly *A. fentouensis*. The specimen from Anticosti Island, Canada identified as *A.* sp. A (fig. 6e, f *in* Klock *et al*. 2024) which has a similar prominent flexure is suggested to be *A. fentouensis*. *Angochitina calandraii* (Figs 5Q–S; 7A, B) is a short-necked species and was first reported from Spain (Cramer 1966), and also reported from the *Plectochitina pseudoagglutinans* to *Eisenackitina dolioliformis* biozones in South China (Chen *et al*. 2018), and in the *A. longicollis* Biozone (as *A.* cf. *calandraii*) of the Fentou Formation in the Nanjing area (Li & Geng 1985).

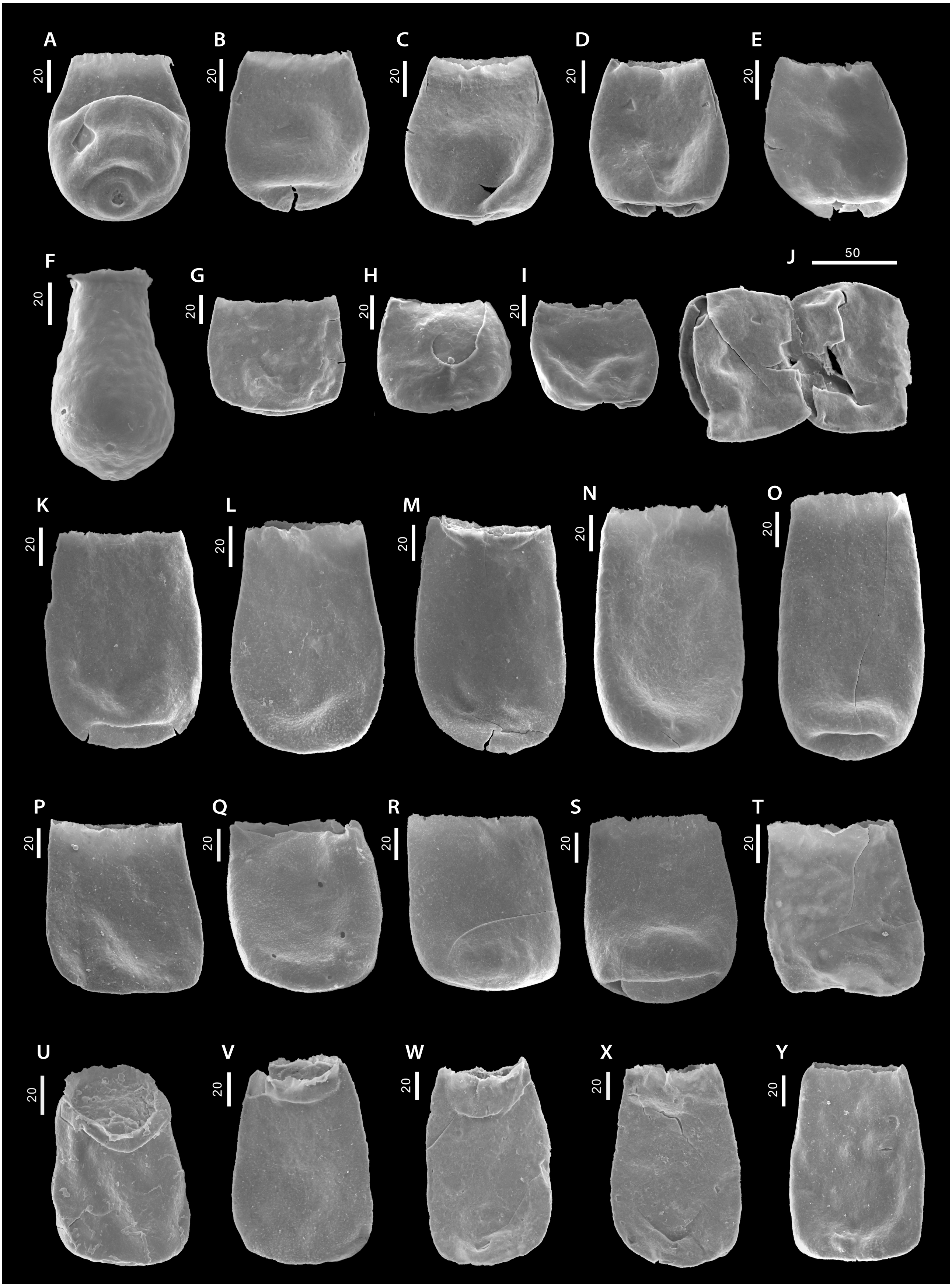
Ancyrochitina spp. (Figs 5T–Y, 7P–S) may represent a mixture of many species of the genus. They are, thus, of very limited biostratigraphical significance. In some specimens, the basal remnants of the processes can be observed, and thus the number of processes can be deduced (Fig. 5X). One specimen has a short neck but tiny spines on the bottom of the chamber (Fig. 7Q). Some have a longer neck (Fig. 7S).

Eisenackitina? cf. *dolioliformis* (Umnova, 1976) (Fig. 6A–E) and *E. causiata* (Verniers, 1999) (Fig. 6P–T) are the most abundant species from the section. Specimens with the overall shape of *E. dolioliformis*, but lacking spines are referred to *E.*? cf. *dolioliformis*. *Eisenackitina dolioliformis* is the eponymous Telychian biozonal index species in Baltica for the biozone just below the *A. longicollis* Biozone (Loydell & Nestor 2005). *Eisenackitina causiata* (Fig. 6P–T), another possible indicator of the upper Telychian, is characterized by the ornamentation of tiny spines mostly near the base of the vesicle (Verniers, 1999). It is reported from the *A. longicollis* Biozone to the *Conochitina proboscifera* Biozone in Gotland, Sweden (Nestor & Nestor 2002), Belgium (Verniers *et al*. 2002), Scotland (Vandenbroucke *et al*. 2002), Estonia (Nestor 2005, Rubel *et al*. 2007) and Latvia (Loydell & Nestor 2005, Loydell *et al*. 2010). In the Yichang area of South China, the *E. causiata* Biozone was correlated with the *Oktavites spiralis* graptolite Biozone (Chen *et al*. 2018), indicating that the occurrence is of similar age to that in the present study.

In the Hujiadongkan section, some small, wide subcylindrical or subconical chitinozoans have a length less than 100 μm, and a copula at the bottom. These are identified as *Bursachitina nana* (Nestor, 1994) (Fig. 6G–J), and are morphologically quite close to *B.* cf. *nana* from Sweden (Männik *et al*. 2015, fig. 6ac). *Bursachitina nana* occurs with *Angochitina longicollis* in the Häädemeeste section in the Baltica region (Nestor 1994). It can range into the *Conochitina acuminata* Biozone (Nestor 2012), and the *Margachitina margaritana* Biozone and overlying Interzone (Loydell *et al*. 2003, 2010; Nestor 2005). *Bursachitina nestorae* (Mullins & Loydell, 2001) (Fig. 6F, K–O) is also quite common at the Hujiadongkan section, and the specimens are morphologically similar to the types of the species from Wales, UK. However, some of our specimens lack the typical granules of the species. The species is characterized by the presence of a mucron. It was first reported from the *Monoclimacis crenulata* Biozone or lower *Oktavites spiralis* Biozone to the *Cyrtograptus lapworthi* Biozone in Wales (Mullins & Loydell 2001). It has also been reported from Latvia (Loydell & Nestor 2005, Loydell *et al*. 2010), and from the *A. longicollis* Biozone to the *Margachitina margaritana* Biozone in Sweden (Männik *et al*. 2015).

Species of *Conochitina* are also quite common from the Hujiadongkan section. *Conochitina malleus* (Van Grootel, 1990) (Figs 6U–Y, 7K–N) has a rounded base

Figure 6. Silurian chitinozoans from the Xiushan Formation at the Hujiadongkan section, South China. • A–E – *Eisenackitina*? cf. *dolioliformis* Umnova, 1976. A – A3–31; B – A3–13; C – A3–34; D – A3–14; E – A4–12. • G–J –*Bursachitina nana* (Nestor, 1994*)*. G – A8–5; H – A4–26; I – A4–25; J – A3–44. • F, K–O – *Bursachitina nestorae* Mullins & Loydell, 2001. F – A4–24; K – A5–40; L – A8–93; M – A8–40; N – A7–15; O – A5–43. • P–T – *Eisenackitina causiata* Verniers, 1999. P – A8–101; Q – A7–32; R – A8–68; S – A7–38; T – A8–66. • U–Y – *Conochitina malleus* (Van Grootel, 1990). U – A8–95; V – A5–31; W – A2–17; X – A2–32; Y – A6–25. The unit of the scale bars is μm.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and coarse surface. It is the index fossil for the nominative biozone of the Shamao Formation in Hubei (Chen *et al*. 2018, Li *et al*. 2021), which can be correlated with the upper Aeronian *Stimulograptus sedgwickii* graptolite Biozone. It was also reported from the *Conochitina alargada* and *Eisenackitina dolioliformis* biozones in Latvia (Loydell *et al*. 2010, Nestor 2012). *Conochitina leviscapulae* (Mullins & Loydell, 2001) (Fig. 7F–J) has an unobvious neck. It coexists with *A. longicollis* in the upper part of the *Conochitina proboscifera* Biozone in Sweden (Männik *et al*. 2015). *Conochitina* sp. (Fig. 7D–E) is abundant in the Hujiadongkan section. This genus has been reported, as *Conochitina* spp., in the higher Xiaoxi Formation (formerly known as the Xiaoxiyu Formation) in Zhangjiajie (Wang *et al*. 1988), and in the higher *Angochitina longicollis* fauna from Guangyuan, northern Sichuan, in association with graptolites indicative of the *Oktavites spiralis–Stomatograptus grandis* Biozone (Chen *et al*. 1991).

The lower part of the section yields two chitinozoan specimens, which are identified as *Eisenackchitina daozhenensis* (Geng, 1986) (Fig. 7C). The thick wall and simple morphology and structure of *E. daozhenensis* is characteristic. However, it is low in abundance and confined to the lowest sample in the Hujiadongkan section. In South China, the *E. daozhenensis* Biozone (originally the *Plectochitina brevicollis* Biozone for the equivalent interval) was correlated with the lower part of the Telychian *Spirograptus guerichi* graptolite Biozone (Tang *et al*. 2010, Li *et al*. 2021). The occurrence of *E. daozhenensis* immediately below the *Monoclimacis crenulata* Biozone in the Hujiadongkan section suggests a higher horizon for the species, in the middle Telychian *A. longicollis* Biozone.

Ramochitina angusta (Nestor, 1982) (Fig. 7T, U), which is characterized by bi-rooted and multirooted spines as ornamentation on the vesicle surface, is also found in the present collection. However, other ornamentations are weathered in the recovered specimens. *Ramochitina angusta* is typically common in the *A. longicollis* Biozone to the *M. margaritana* Biozone in Latvia (Loydell *et al*. 2003). *Ramochitina* sp. (Fig. 7O) is characterized by its pronounced longitudinal rows of spines on the vesicle wall. However, only one specimen was found in the present collection, and thus it is left in open nomenclature.

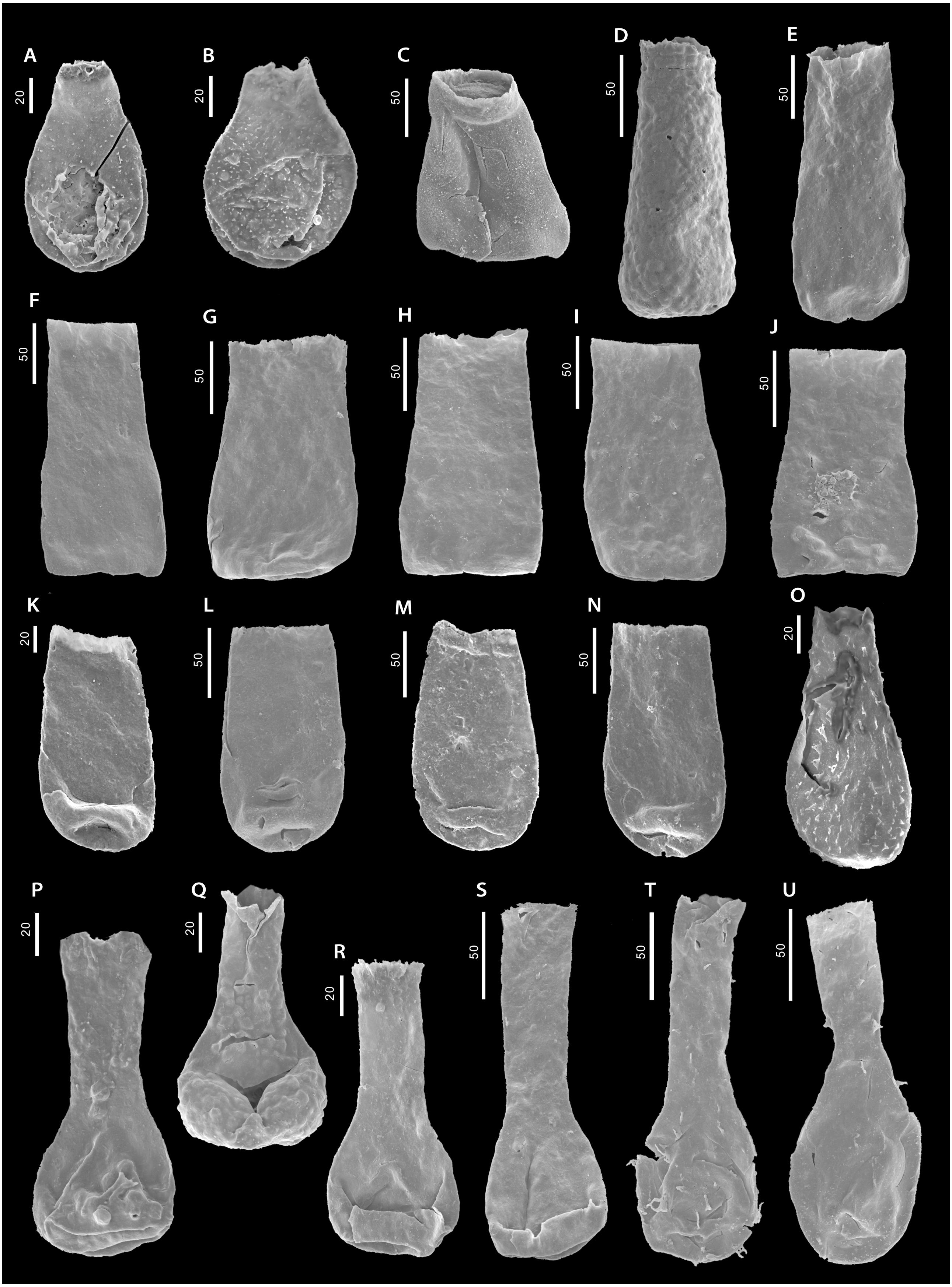
Discussion

Age of the graptolite and chitinozoan assemblages

Rickards & Chen (2002) listed the stratigraphical ranges of Telychian graptolites based on examination of the precise records from Hunan, Guizhou, Chongqing, Sichuan and Shaanxi provinces in China (Ni 1978, Chen 1984, Fu & Song 1986, Ge 1990). When compared to those found in the British Isles, Rickards & Chen (2002) found a low degree of commonality of graptolite species between the Yangtze Platform (Region) of South China and the British Isles. Unlike the graptolite associations of the *Monoclimacis crenulata* Biozone in the British Isles and its equivalent level elsewhere, *Monoclimacis crenulata* is very seldom reported from South China; so far only from Ziyang County, southern Shaanxi Province (Fu *et al*. 2005), and from Yunnan Province, southwestern China (Wang & Zhang 2010); in South China there is the *Oktavites spiralis–Stomatograptus grandis* Biozone. Rickards & Chen (2002) then appraised the Telychian graptolite assemblage biozones of South China as *Spirograptus guerichi*, *Spirograptus turriculatus*, *Streptograptus crispus*, *Monoclimacis griestoniensis*, and *Oktavites spiralis–Stomatograptus grandis* biozones (the last is correlatable with equivalent biozone levels, *e.g*. the *Oktavites spiralis* and *Cyrtograptus lapworthi* biozones, elsewhere around the world).

In the present study, although abundant broken pieces of *Monoclimacis* are found at the Hujiadongkan section, no definite *M. crenulata* can be identified, and no *Stomatograptus grandis* and *Stomatograptus sinensis* which are typical of the *Oktavites spiralis–Stomatograptus grandis* Biozone, have been found in the present collection. Based on biostratigraphically diagnostic taxa such as *Monograptus parapriodon*, which has a stratigraphical range within the *Oktavites spiralis* Biozone in the British Isles (Zalasiewicz *et al*. 2009) and the Prague Synform, Czechia (Štorch 2023), combined with the presence of *Stimulograptus splendens*, which is described from the uppermost *Torquigraptus tullbergi* Biozone (equivalent to the *Monoclimacis crenulata* Biozone) in Spain (Štorch 1998), a level within the upper *Monoclimacis crenulata* Biozone or the lower *Oktavites spiralis* Biozone is possible for the present

Figure 7. Silurian chitinozoans from the Xiushan Formation at the Hujiadongkan section, South China. • A, B – *Angochitina calandraii* (Cramer, 1966). A – A8–71; B – A5–55. • C – *Eisenackitina daozhenensis* (Geng, 1986), A9–47. • D, E – *Conochitina* sp. D – A10–10; E – A10–44. • F–J – *Conochitina leviscapulae* (Mullins & Loydell, 2001). F – A10–50; G – A11–13; H – A10–45; I – A10–32; J – A10–41. • K–N – *Conochitina malleus* (Van Grootel, 1990). K – A10–50; L – A13–9; M – A1–37; N – A1–60. • O – *Ramochitina* sp., pronounced longitudinal rows of spines on the vesicle wall, A4–19. • P–S – *Ancyrochitina* spp. P – A11–37; Q – A11–5; R – A11–4; S – A11–29. • T–U – *Ramochitina angusta* (Nestor, 1982). T – A9–49; U – A9–43. The unit of the scale bars is μm.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graptolite assemblages, suggesting a middle–late Telychian age for the faunas from the Hujiadongkan section (Fig. 8).

The graptolitic beds have also been correlated with the chitinozoan biostratigraphical framework (Figs 2, 8). The chitinozoan biostratigraphical data obtained from the upper part of the Xiushan Formation at the Hujiadongkan section enables the recognition of the *Angochitina longicollis* Biozone, of middle Telychian age.

The age of the base of the *Angochitina longicollis* chitinozoan Biozone in terms of the graptolite biozonation differs between different regions. The *A. longicollis* Biozone is correlated with the *Oktavites spiralis* and *Cyrtograptus insectus* graptolite biozones of the middle

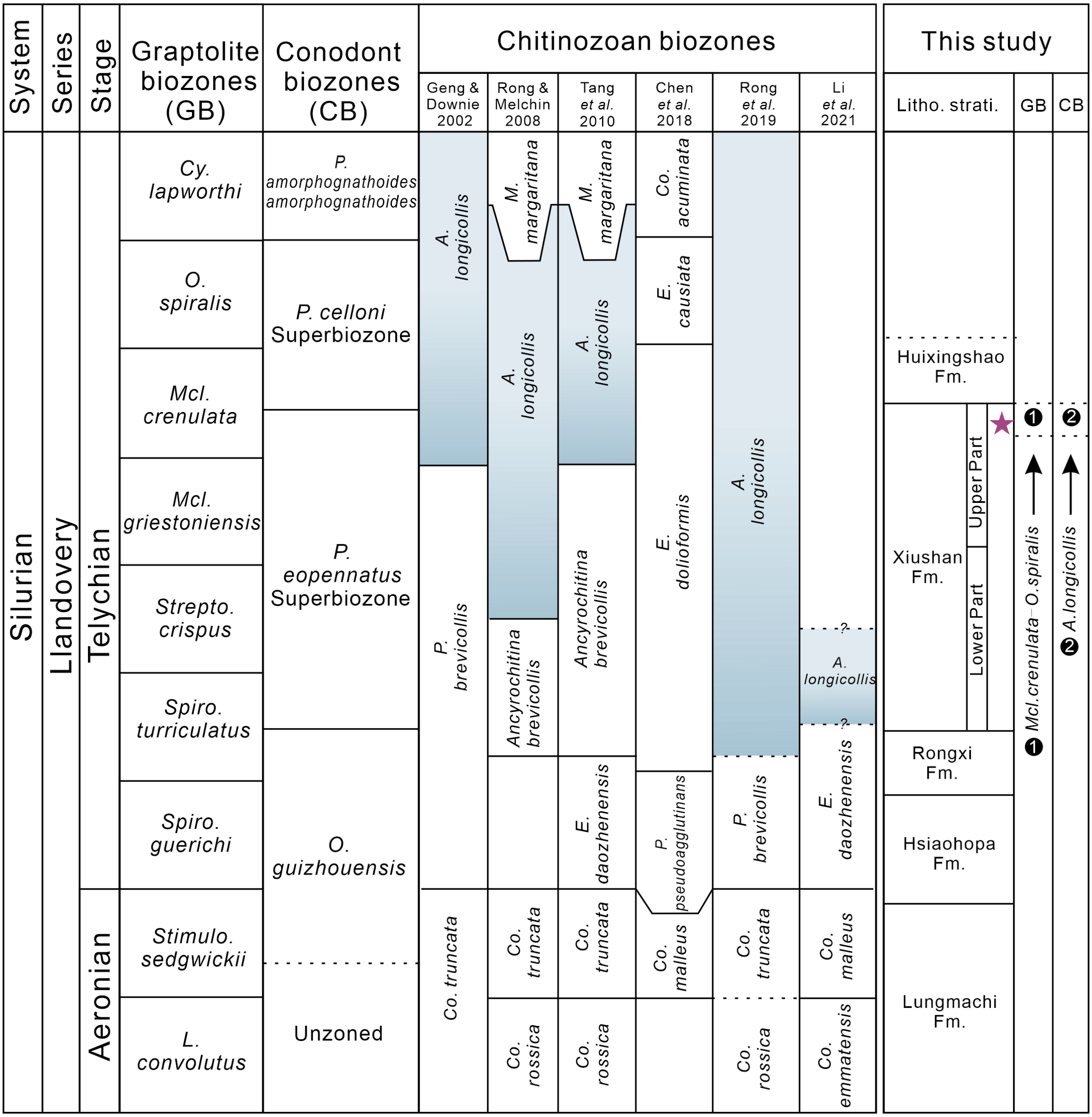

Figure 8. Correlation of the Llandovery strata of the Hujiadongkan section under the framework of graptolite, chitinozoan and conodont biozones. The star represents the horizon of the present section. Abbreviation: Fm – Formation. Data sources of graptolite biozones (GB) and conodont biozones (CB) are from Melchin *et al.* (2020) and Wang & Aldridge (2010). Note that due to the constraint by conodont stratigraphy, the chitinozoan biostratigraphy is correlated only to the lower *M. crenulata* graptolite Biozone.

to upper Telychian in the global Silurian chitinozoan biozonation framework (Verniers *et al*. 1995). However, in later studies, it is considered diachronous (Mullins & Loydell 2001, 2002). In the Yangtze region, the *Angochitina longicollis* Biozone was subdivided into two informal units, a lower *Angochitina longicollis–Plectochitina brevicollis* fauna (typified by the co-occurrence of *A. longicollis* and *P. brevicollis*), and a higher *Angochitina longicollis* fauna (typified by the index fossil and absence of *P. brevicollis*) (Geng & Downie 2002). The lower assemblage of the *A. longicollis* Biozone is suggested to correlate with the *Monoclimacis griestoniensis* graptolite Biozone while the higher assemblage of the *Angochitina longicollis* Biozone is associated with graptolites indicative of the *Oktavites spiralis–Stomatograptus grandis* Biozone (Geng *et al*. 1997). In our collection, no specimens of *Plectochitina brevicollis* were found, but the association of chitinozoans (*A. longicollis*, *Bursachitina nana*, *B. nestorae* and *Conochitina malleus*) is comparable to the higher *A. longicollis* fauna in the Yangtze Region (Geng & Downie 2002, Tang *et al*. 2010) (Fig. 8).

A correlation of the *Angochitina longicollis* Biozone with the upper part of *Monoclimacis crenulata* or lower part of the *O. spiralis* graptolite biozone in the Xiushan Formation at the Hujiadongkan section is thus suggested based on our analysis (Fig. 8). It is essential to know that in this study, both the upper and lower boundaries of graptolite and chitinozoan biozones drawn herein are tentative (dotted line in Fig. 2), as the graptolites were collected only from the interbedded shales and thus the sampling is not sufficient for the precise placement of the basal or top boundaries of the biozones. The results of our studies suggest a middle Telychian age for the Xiushan Fauna from the upper part of the Xiushan Formation, which agrees with the previous conodont biostratigraphy of the Xiushan Formation (Chen *et al*. 2016, Wang & Wang 2016, Yan *et al*. 2018), and results of brachiopod and chitinozoan biostratigraphy (Huang *et al*. 2017) as well.

Graptolitic mudstones and sea-level change fluctuations

Significant Silurian global eustastic sea-level fluctuations are recorded (Loydell 1998, Haq & Schutter 2008, Simmons *et al*. 2020), indicative of an extremely turbulent palaeogeography-ocean-climate system during the Silurian (Munnecke *et al*. 2010, Trotter *et al*. 2016, Yan *et al*. 2025).

Loydell (1998, and refs therein) suggested that the highest sea-levels of the Silurian were during the Telychian upper *Streptograptus crispus*–lower *Monoclimacis griestoniensis* and *Oktavites spiralis*–lower *Cyrtograptus lapworthi* biozones, based primarily on the identification of well-dated graptolitic shales within bioturbated non-graptolitic sequences of Eastern Avalonia, Baltica and other localities in the Silurian world. However, due to the low degree of commonality of graptolite species between the Yangtze Platform (Region) and elsewhere in the world (Rickards & Chen 2002), the eustatic fluctuations during the Telychian in South China are not so easily compared to those recognized elsewhere in previous works (*e.g.* Loydell 1998).

In the Yangtze Region, there is some discrepancy in Telychian lithofacies, attributable to their location in the Yangtze Sea. In the Ningqiang Formation, which is distributed mainly near the north border of the Yangtze Region, *e.g.* in southern Shaanxi, Lin (1989) described the presence of interbedded limestones which contain diverse benthic fauna and graptolitic shales. In the Middle Yangtze Region, the Telychian is preserved as the Shamao Formation. The upper part of the Shamao Formation is distinguished by its fine-grained sandstones. The uppermost layer of the Shamao Formation (*s.s.*), which consists of a bed of greenish-yellow soft shale, is also a good example of sea-level rise during the Telychian. This bed has recently been assigned to the Telychian *A. longicollis* Biozone (Li *et al*. 2021, fig. 11). In Guizhou Province, which is in the centre of the Telychian Yangtze Sea, the upper part of the Upper Wengxiang Formation comprises grey-green shales and silty shales, with a small number of limestone lenticles. The included faunas indicate that this part is comparable to the Xiushan Fauna (Tang *et al*. 2010). The Xiushan Formation, which lies in-between the two red beds in Southwestern China (Rong *et al*. 2012), records well the sea-level fluctuations. The upper part of the Xiushan Formation in Xiushan, Chongqing Municipality (near the centre of the Yangtze Region/Sea) is represented by the shales and siltstones intercalated with limestone lenses (Chen *et al*. 1996). In the present Hujiadongkan section, the 6 m thick graptolitic mudstone within the dominantly limestone sequence in the upper part of the Xiushan Formation, as shown in Figure 2, is a good example representing a high sea-level comparable to that in the *Oktavites spiralis* Biozone which is recognized elsewhere in previous works (Loydell 1998, Simmons *et al*. 2020). Our work thus provides further evidence for the occurrence of high sea-level during the middle Telychian dated by graptolites and chitinozoans.

Conclusions

This study reported the chitinozoan and graptolite faunas and biostratigraphy of the upper part of the Telychian Xiushan Formation at the Hujiadongkan section in Xiushan County, Chongqing Municipality, South China.

The graptolite assemblage includes occurrences of the biostratigraphically diagnostic taxa *Stimulograptus splendens* and *Monograptus parapriodon*, indicating an interval equivalent to the upper *Monoclimacis crenulata* to the lower *Oktavites spiralis* biozones, suggesting a middle–late Telychian age for the fauna of the Hujiadongkan section. The age is strongly supported by the associated chitinozoan assemblages typical of the *Angochitina longicollis* Biozone of middle Telychian age. This study sheds new light on the assemblages of the Xiushan Fauna from both macroplankton fossils (graptolites) and microfossils (chitinozoans). Moreover, the recognition of graptolitic mudstones is related to the high sea-level of the Telychian *Oktavites* s*piralis* Biozone.

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Supplementary Electronic Material

Appendix 1. Absolute abundance for chitinozoans recovered from the Hujiadongkan section.
Appendix 2. Measurements of chitinozoans recovered from the Hujiadongkan section.