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Tremadocian (Ordovician) reclined graptolites from Baishan, North China

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ABSTRACT

The Erdaopuzi section in the Baishan area of Jilin Province, northeast China, contains abundant late Tremadoc graptolites. However, there are some taxonomic controversies regarding the characters of the hand specimens that are difficult to identify. In this paper, we present our restudy of isolated graptolites from acid residue and discuss the taxonomic problems of the subgenus *Clonograptus* (*Neoclonograptus*) Zhao and Zhang. Four genera and six species were identified, including *Adelograptus tenellus* (Linnarsson), *Ancoragraptus gracilis* (Zhao and Zhang), *Dictyonema* sp., *Psigraptus jacksoni* Rickards and Stait, *Psigraptus lenzi* Jackson, *Psigraptus arcticus* Jackson. According to the significant evolution of morphological characters, two graptolite zones (from bottom to top) can be identified in ascending order in the study area, i.e. *Adelograptus* Zone and the *Psigraptus* Zone.

Introduction

The Baishan area (formerly the Hunjiang area) of Jilin Province, North China, is a classical research area of the Cambrian–Ordovician system, tectonically belonging to the Sino-Korean Craton. The Xiaoyangqiao section of Dayangcha in this area (Fig. 1A, B) is an ASSP section of the Cambrian–Ordovician boundary horizon (Wang et al. 2019). In the nearby Erdaopuzi section, abundant late Tremadoc graptolites have been collected from the Yehli Formation, making it an ideal section for studying late Tremadoc shallow-water graptolites.

The Erdaopuzi section was originally studied by Zhao and Zhang (1985). According to the morphological difference of the reclined graptolites, they had successively established four new genera and one new subgenus, which include *Muenzhigraptus*, *Diphygraptus*, *Hunjianggraptus*, *Holpsigraptus* and *Neoclonograptus* (Zhao and Zhang 1985, 1986; Zhao et al. 1988). Most scholars believe that the above five (sub-)genera and *Yukongraptus* Lin, 1981 are all synonymous with *Psigraptus* (Wang and Erdtmann 1986; Rickards et al. 1991; Maletz 1992; Wang et al. 1996; Zhang and Erdtmann 2004), while others have also classified a group of morphologically similar graptolites as the subgenus *Clonograptus* (*Neoclonograptus*) Zhao and Zhang, 1985 into the genus *Ancoragraptus* (Cho et al. 2009).

Due to the morphological features of graptolites that are difficult to recognize on hand specimens, the taxonomy of reclined graptolites remains controversial. We recollected graptolite specimens from the Erdaopuzi section and obtained a number of isolated fossils by acid hydrolysis. All the isolated graptolites clearly show morphological features, thus providing some new evidence for taxonomy. The electronic documentation of the study on fossils and strata is deposited in the China Geological Survey Stratigraphy and Palaeontology Database http://8.140.107.20:8080/navigator/index.aspx.

Materials and biostratigraphy

The Erdaopuzi section only includes the upper part of the Yehli Formation of the Lower Ordovician with a thickness of 31.9 m. Graptolites occur in the lower part of the section with a thickness of about 10.9 m, they are mainly preserved in shale or

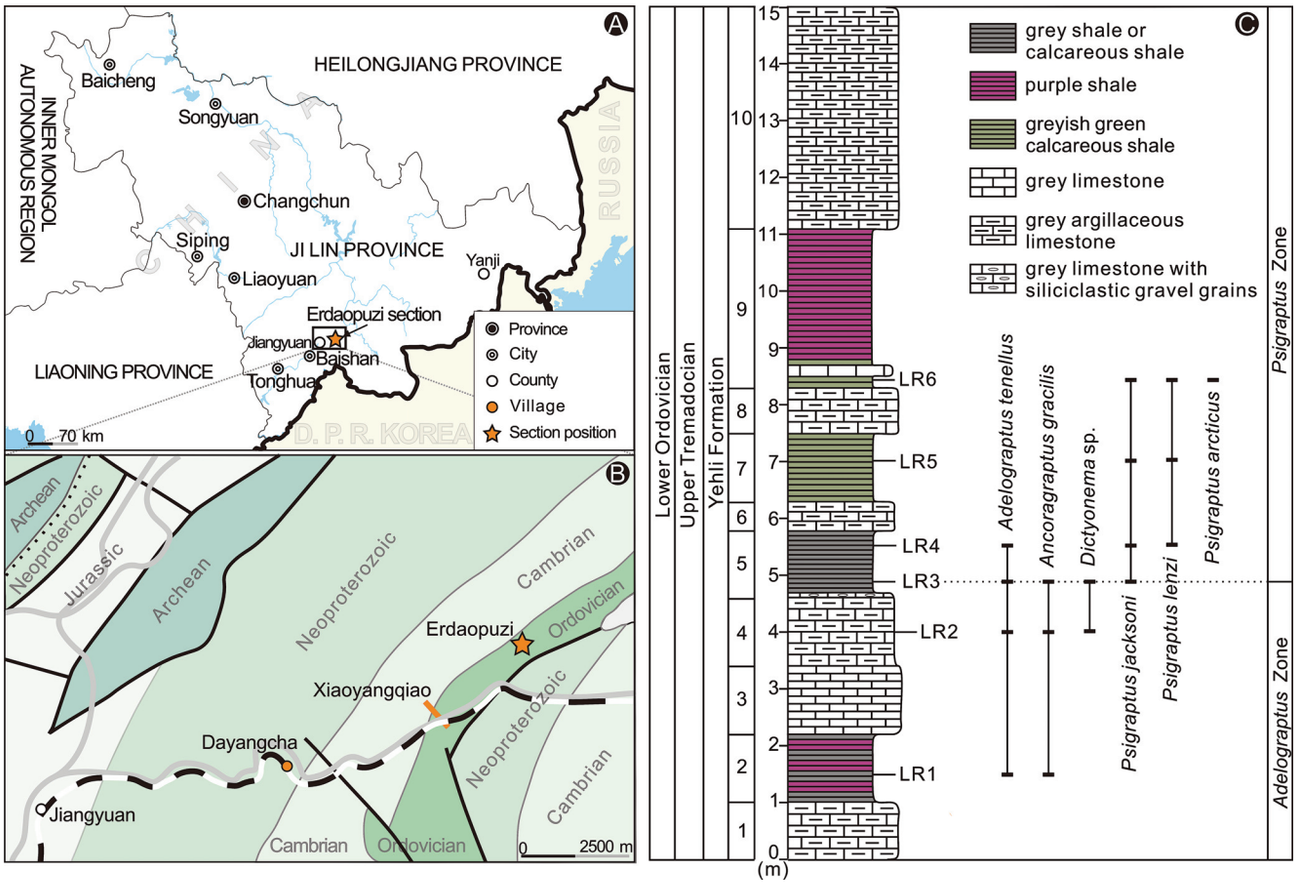


Fig. 1. **A** – location map of the study area; **B** – geological map of the study area, with the location of the Erdaopuzi section northeast of the village of Dayangcha, Baishan, Jilin Province, Northeast China; **C** – biostratigraphy and lithostratigraphy of the Erdaopuzi section, colours used in the legend correspond to the colours of the fresh rock surfaces; **LR1–LR6** – number of the sampled graptolite-rich horizons.

calcareous shale, partly preserved in argillaceous limestone (Fig. 1C). A number of graptolite specimens were collected from six layers (LR1–LR6), and all the isolated graptolites were recovered from shale or calcareous shale (including LR1, LR3, LR5 and LR6).

The base of the section is characterized by argillaceous limestone with a thickness of about 1 m. It is overlain by grey and purple interbedded shale with a thickness of 1.2 m, and the former yields the graptolites *Adelograptus tenellus* (Linnarsson) and *Ancoragraptus gracilis* (Zhao and Zhang).

The overlying strata of LR1 are a medium thin layer of gravel limestone with a thickness of 1.2 m. It is overlain by grey argillaceous limestone (LR2) about 1 m thick, which contains the graptolites *Dictyonema* sp., *Adelograptus tenellus* (Linnarsson) and *Ancoragraptus gracilis* (Zhao and Zhang).

The strata overlying LR2 comprise grey calcareous shale, which are characterized by a layer of limestone with siliciclastic gravel grains at the base. The lower part of calcareous shale (LR3) contains the graptolites *Dictyonema* sp., *Adelograptus tennellus* (Linnarsson), *Ancoragraptus gracilis* (Zhao and Zhang) and *Psigraptus jacksoni* Rickards and Stait. The upper part of the calcareous shale (LR4) contains the graptolites *Psigraptus jacksoni* Rickards and Stait and *Psigraptus lenzi* Jackson.

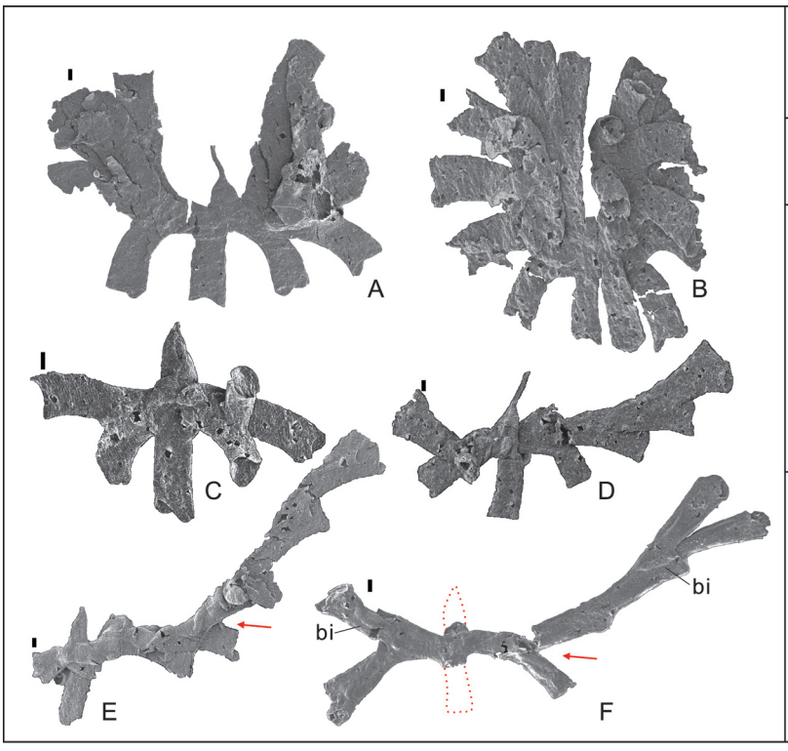
The calcareous shale is overlain by argillaceous limestone with a thickness of about 0.5 m, succeeded by greyish green calcareous shale with a thickness of 1.2 m (LR5), containing the graptolites *Psigraptus jacksoni* Rickards and Stait and *Psigraptus lenzi* Jackson.

The overlying strata of LR5 are grey argillaceous limestone with a thickness of 0.8 m. The strata are dominated by purple shale overlying the grey limestone with a thickness of 2.8 m. The bottom of this interval is greyish green calcareous shale intercalated with a thin layer of limestone, this part of the strata has a thickness of about 30 cm and contains graptolites (LR6) *Psigraptus jacksoni* Rickards and Stait, *Psigraptus lenzi* Jackson and *Psigraptus arcticus* Jackson.

The subsequent strata consist of limestone and shale, the latter commonly with purple shale and grey shale interlayers. The strata are about 21 m thick and contain no graptolites. Figure 1C shows only the basal part of this strata.

Results and discussion

The study area and Yeongwol of Korea are both located in the Sino-Korean Craton, therefore the graptolite fauna is very similar in both areas (Kim et al. 2006; Cho and Kim 2007; Cho et al. 2009), except for the typical *Psigraptus lenzi* and *Psigraptus arcticus*, which are quite common in Baishan but not yet found in Korea. The study interval includes a variety of characteristic reclined graptolite species, which are important biostratigraphic markers (Fig. 2).



Dayangcha (this paper)	Yukon (Jackson and Lenz 2003)	Australia (Rickards et al. 1991; Cooper 1999)	Korea (Cho and Kim 2007)
Aorograptus victoriae Zone	*Adelograptus antiquus* Zone	*Aorograptus victoriae* Zone	*Callograptus* spp. Zone
Psigraptus Zone	*Adelograptus* cf. *tenellus* Zone	*Psigraptus*/*Adelograptus* Zone	*Adelograptus* cf. *tenellus* Zone
Adelograptus Zone			

Fig. 2. Photos of isolated Tremadoc graptolites from the Erdaopuzi section of the Baishan area, and correlation of the late Tremadoc graptolite zones in Baishan with those in other parts of the world. **A** – *Psigraptus lenzi* Jackson, specimen LR5-1-5; **B** – *Psigraptus arcticus* Jackson, specimen LR6-1-5; **C**–**D** – *Psigraptus jacksoni* Rickards and Stait, specimens LR3-44 and LR3-3-2; **E**–**F** – *Ancoragraptus gracilis* (Zhao and Zhang), specimens LR1-1 and LR1-15. Scale bar: 100 μm. The red arrows point at the first branch position on the stipe, the red dotted line indicates the inferred morphology of sicula. Abbreviation: bi – bitheca.

The base of the Upper Tremadocian is identified by the first appearance of *Adelograptus tenellus* (Linnarsson), associated with *Ancoragraptus gracilis* (Zhao and Zhang). *Ancoragraptus gracilis* was originally defined by Zhao and Zhang (1985) as *Clonograptus* (*Neoclonograptus*) *gracilis*, but subsequently considered the synonym of *Psigraptus jacksoni* Richkards and Stait (Wang and Erdtmann 1986; Rickards et al. 1991; Maletz 1992; Wang et al. 1996; Jackson and Lenz 2003; Zhang and Erdtmann 2004). Based on the reclined rhabdosome with free metasicula and non-free metathecae, Cho et al. (2009) assigned the subgenus *Neoclonograptus* to the genus *Ancoragraptus* Jackson and Lenz. In the studied section, '*Neoclonograptus*' is very different from *Psigraptus jacksoni* (Fig. 2), in the former the theca on the stipe usually buds from the metatheca (Fig. 2E), whereas in the latter it buds from the protheca, resulting there in a higher thecal overlap (Fig. 2D). Notably, '*Neoclonograptus*' has a distinct bitheca on the stipes (Fig. 2F) and an obviously isolated metasicula, suggesting an *Ancoragraptus* affinity.

From the first occurrence of the reclined *Psigraptus* in layer LR3, the stipes of *Psigraptus* begin to recline upwards (Fig. 2D), up to layer LR6 they are nearly parallel (Fig. 2B). From layer LR1 to layer LR6, the direction of extension of graptolite stipes gradually evolved from declined or horizontal to reclined and nearly parallel, and the isolation degree of thecal aperture gradually enhanced. The trigger remains unknown until more work is conducted, but it is speculated that the morphological evolution could have been caused by sea-level fluctuations. The lowest fossiliferous layer LR1–LR2 yields the declined to slightly reclined graptolites *Adelograptus* and *Ancoragraptus*, also the apparently reclined *Psigraptus* occurs from layer LR3 onwards. In the studied section, the characters such as free metathecae, budding from prothecae and distinct reclined stipes first appear in layer LR3. It is suggested that the *Adelograptus tennellus* Zone can be subdivided into the *Adelograptus* Zone and the *Psigraptus* Zone in the study area.

Conclusions

The reclined graptolites reported here come from the upper Tremadoc in the Erdaopuzi section. The isolated graptolites show that the subgenus *Clonograptus* (*Neoclonograptus*) Zhao and Zhang, 1985 with free metasicula and smaller overlap of the thecae is significantly different from *Psigraptus* and shows close similarity to *Ancoragraptus* Jackson et Lenz, 2003. The significant morphological changes of graptolites are probably related to the local sea-level changes. Based on the remarkable morphological evolution, two graptolite zones, the *Adelograptus* Zone and the *Psigraptus* Zone, have been identified in the studied section, in ascending order. These two graptolite zones could be correlated with the *Adelograptus* cf. *tenellus* Zone in South Korea (Cho and Kim 2007), the *Psigraptus*/*Adelograptus* Zone in Australia (Rickards et al. 1991; Cooper 1999) and the *Adelograptus* cf. *tenellus* Zone in the Yukon region (Jackson and Lenz 2003) (Fig. 2).

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