

New spinicaudatan species (Crustacea) of the Lower Cretaceous (Valanginian–Hauterivian) Jehol Biota from northern Hebei, China

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ABSTRACT

A well-preserved spinicaudatan species, *Yanjiestheria huajiyingensis* sp. nov., is here described from the Huajiying Formation in northern Hebei, northern China. The species is characterized by the transverse ridges in the postero-ventral part of the carapace. The preserved eggs in the new species aid in identifying sexual dimorphism in *Yanjiestheria*.

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1. Introduction

The well-known Early Cretaceous Jehol Biota was widely distributed in eastern Asia (Chen and Jin, 1999; Chang et al., 2003; Zhou et al., 2003). It is a spectacular fossil resource comprising representatives of almost all major clades of Early Cretaceous freshwater and terrestrial vertebrates, invertebrates and fossil plants. The Jehol Biota has been considered as having three developmental phases based on its fossil contents (Chen, 1988). The early Jehol Biota contains a *Nestoria*–*Keratetheria* clam shrimp fauna from the Valanginian–Hauterivian Dabeigou Formation, and coeval successions in northern Hebei, Inner Mongolia of China, and the Transbaikal region of eastern Russia (Wang, 1981; Chen, 1999). The upper Hauterivian–lower Aptian (Lower Cretaceous) middle Jehol Biota from the Yixian Formation and equivalent successions contains an *Eosestheria* clam shrimp fauna in northern China, which forms part of the *Eosestheria*–*Ephemeropsis trisetalis* (insect)–*Lycoptera* (fish) fauna (Li, 2017a).

In the last two decades, there have been continuous discoveries of spectacular key vertebrate taxa belonging to the early Jehol Biota from the Huajiying Formation in the Sichakou basin of northern

Hebei Province of northern China (Fig. 1) (Yang et al., 2020). These discoveries include the basalmost enantiornithine bird *Protopteryx fengningensis* Zhang and Zhou, 2000, the oldest ornithuromorph bird *Archaeornithura meemannae* Wang et al., 2015, the basalmost confuciusornithid bird *Eoconfuciusornis zhengi* Zhang et al., 2008, and the basal acipenseriform fish *Peipiaosteus fengningensis* Bai, 1983 (Yang et al., 2020). A clam shrimp fauna from the Huajiying Formation has been mentioned in the literature (Wang, 1986; Jin et al., 2008), but its detailed description is not yet reported. Here the author reports a new clam shrimp species from the Huajiying Formation of northern Hebei Province, China.

2. Material and methods

The figured specimens were collected from the Lower Cretaceous Huajiying Formation at the Jiacaigou village of Sichakou township, Fengning Manchu Autonomous County, northern Hebei Province, northern China (41° 38' N, 116° 21' E) (Figs. 1, 2). The Huajiying Formation (1629 m thick) was originally established in the Huajiying village (not far from Sichakou), and consists mainly of light grey, purple–grey, dark green, and black andesite lava breccia. The lower part is intercalated with fluvial and lacustrine deposits, consisting of light grey, greyish green sandstone, siltstone, shale, and greyish brown, black paper shale. Its base is a

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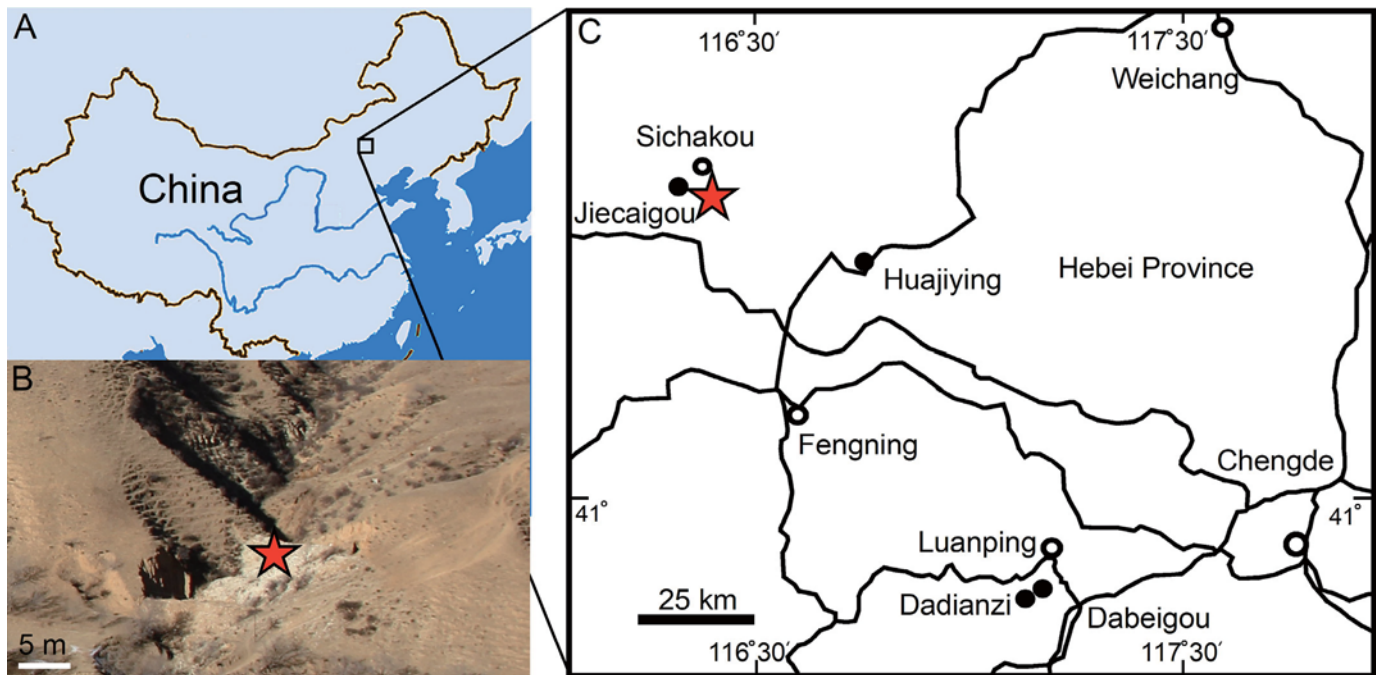


Fig. 1. Map showing the fossil clam shrimp locality (the star point). A, a map showing the study area in northern China. B, a field photograph showing the fossil horizon in the studied section in the Jiecaigou village. C, a map showing the location of the Jiecaigou fossil locality in the Sichakou township of Fengning Manchu Autonomous County, northern Hebei Province.

purple–grey, greyish green tuffaceous sandy conglomerate (Wang, 1986). The fossil clam shrimp *Eosestheria* cf. *lingyuanensis* Chen in Zhang et al., 1976, and *Fengninggrapta huajiyingensis* Wang, 1981 emend. Li et al., 2014 were reported from the lower lacustrine shale horizon, which was previously assigned to the Xiguayuan Formation (Wang, 1981), and later reassigned to the Huajiying Formation (Wang, 1986). The 90 m thick succession of the Huajiying Formation, exposed in the Jiecaigou village, consists mainly of greyish brown and pale shales intercalated with tuff and tuffaceous sandstone, with intrusive rocks in the base (Fig. 2). The well-preserved clam shrimp (together with eggs in some specimens) described herein were collected from the basal section, where the acipenseriform fish, *Peipiaosteus*, was recovered (Fig. 2).

The specimens were first prepared with needles in the laboratory with the help of a Zeiss V20 stereomicroscope, and then the carapace's delicate ornamentation was examined with a HITACHI SU3500 scanning electron microscope (SEM). Adobe Photoshop CC was used for focus stacking. Previous studies have shown that the delicate carapace microsculpture is of taxonomic value and cannot be observed under a light microscope, but can be clearly seen under the SEM (e.g. Li, 2017b, 2020a, 2020b, 2020c, 2022). The figured specimens are deposited in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPCAS).

The taxonomic act established in the present work has been registered in ZooBank LSID urn:lsid:zoobank.org:act:93ED1486-0B30-49E6-B6BB-47811F38ACBD.

3. Systematic palaeontology

The author follows the classification of diplostracan taxa by Martin and Davis (2001). The carapace size of the fossil clam shrimp was described as small (carapace length < 5 mm), medium (carapace length between 5 mm and 15 mm) or large (carapace

length > 15 mm) (Chen and Shen, 1985). Recently, Scholze and Schneider (2015, table 1) proposed another terminology to describe the size of clam shrimp. The author finds that the tripartite category of Chen and Shen (1985) is easy to follow for describing the carapace size.

Subphylum Crustacea Brünnich, 1772

Class Branchiopoda Lamarck, 1801 (Hegna and Olesen, 2020)

Subclass Phyllopoda Preuss, 1951

Order Diplostraca Gerstaecker, 1866

Suborder Spinicaudata Linder, 1945

Superfamily Eosestherioidea Zhang and Chen in Zhang et al., 1976

Diagnosis. The carapace valve small to large in size, of various shapes, such as cycliciform, cycladiform and telliniform. The umbo is small, located in the anterior or middle part of the dorsal margin. Growth bands in the dorsal part of the carapace are ornamented with polygonal reticulations, which can transform to various-sized reticulation, delicate puncta or radial lirae distally (Astrop and Hegna, 2015; Li, 2020b).

Family Eosestheriidae Zhang and Chen in Zhang et al., 1976

Diagnosis. The carapace size is medium to very large. The ornamentation transitions from polygonal reticulations in the dorsal and/or anteroventral part of the carapace to radial lirae in the ventral and/or postero-ventral part of the carapace. Polygonal cells small or large. Radial lirae fine or thick, sparse or dense, curving or branching, often intercalated with irregular short lines or oblique lines.

Genus *Yanjiestheria* Chen in Zhang et al., 1976

Type species. *Yanjiestheria bellula* Chen in Zhang et al., 1976, from the Lower Cretaceous Dalazi Formation, Yanji, Korean Autonomous Prefecture of Yanbian, Jilin Province, northeastern China.

Locality and horizon. Lower Cretaceous in China, Korea, Japan, Mongolia and eastern Transbaikal region of Russia.

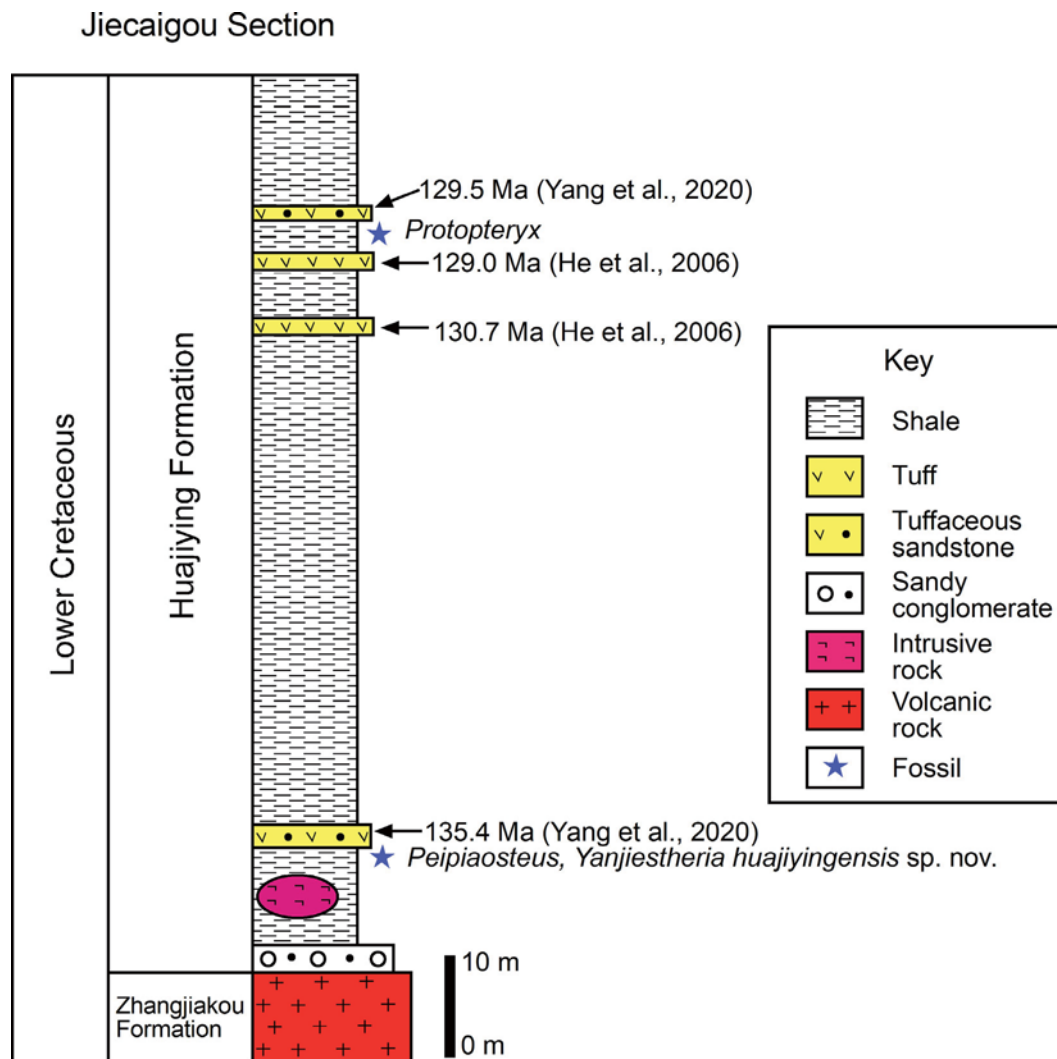


Fig. 2. Stratigraphy and geochronology of the Jiecaigou section in Sichakou, Fengning Manchu Autonomous County, Hebei Province, northern China (revised after Yang et al., 2020). Arrows indicate the radiometrically dated horizons. Stars indicate the fossil horizons.

***Yanjiestheria huajiyingensis* sp. nov.**
(Figs. 3–5).

Material. Holotype, NIGPCAS 180660, a left valve; paratype, female, NIGPCAS 180661, a left valve; paratype, NIGPCAS 180662, a left valve; paratype, NIGPCAS 180663a, a left valve; paratype, NIGPCAS 180663b, a right valve; paratype, NIGPCAS 180663c, a right valve; paratype, NIGPCAS 180663d, external mould of a left valve.

Etymology. The species name is after the Huajiying Formation, from which the material was collected.

Locality and horizon. Lower Cretaceous Huajiying Formation, in the Jiecaigou village, Sichakou township, Fengning Manchu Autonomous County, Hebei Province, northern China.

Diagnosis. The carapace is of moderate size, elongated elliptical (male?), ovate or subquadrate (female?) in outline. Small umbo located in the anterior part of the dorsal margin. Growth lines ornamented with short transverse ridges, more than 17 in number. Growth bands narrow near the umbo, ornamented with fine reticulations. Growth bands are widest in the middle part of the carapace, ornamented with fine reticulations. Growth bands are narrow near the ventral margin, which are ornamented with slender and dense radial lirae (about 70 per mm) in the anterior ventral part of the carapace, intercalated with cross-bars. Growth

band ornamentation transforms from radial lirae to transverse ridges in the ventral part of the carapace. Growth bands ornamented with transverse ridges in the postero-ventral part of the carapace.

Dimensions. In order of: specimen number, growth line number, carapace length (mm), carapace height (mm), ratio of height/length: NIGPCAS 180660, >19, 10.2, 6.9, 0.68; NIGPCAS 180661, >17, 7.5, 5.4, 0.72; NIGPCAS 180662, >24, 8.8, 5.5, 0.62; NIGPCAS 180663a, >18, 9.1, 6.9, 0.76; NIGPCAS 180663b, 22, 9.6, 6.1, 0.64; NIGPCAS 180663c, >15, 9.6, 6.1, 0.64; NIGPCAS 180663d, >19, 10.3, 7.2, 0.70.

Description. Carapace of moderate size, elongated elliptical (male?), ovate or subquadrate (female?) in outline. Small umbo located in the anterior part of the dorsal margin. Growth lines, ornamented with transverse ridges, 15 to 24, or more in number. Growth bands near the umbo narrow, and widening downwards, widest in the middle part, and narrow again near the ventral margin. Growth bands near the umbo ornamented with polygonal fine reticulations (polygonal cell diameter about 7–10 μm) (Fig. 3B). Growth bands in the anterior ventral part of the carapace ornamented with radial lirae, with intercalated cross-bars (Figs. 3E, G, 4G, H), about 70 within a width of 1 mm (Figs. 3E, G). Growth bands near the ventral

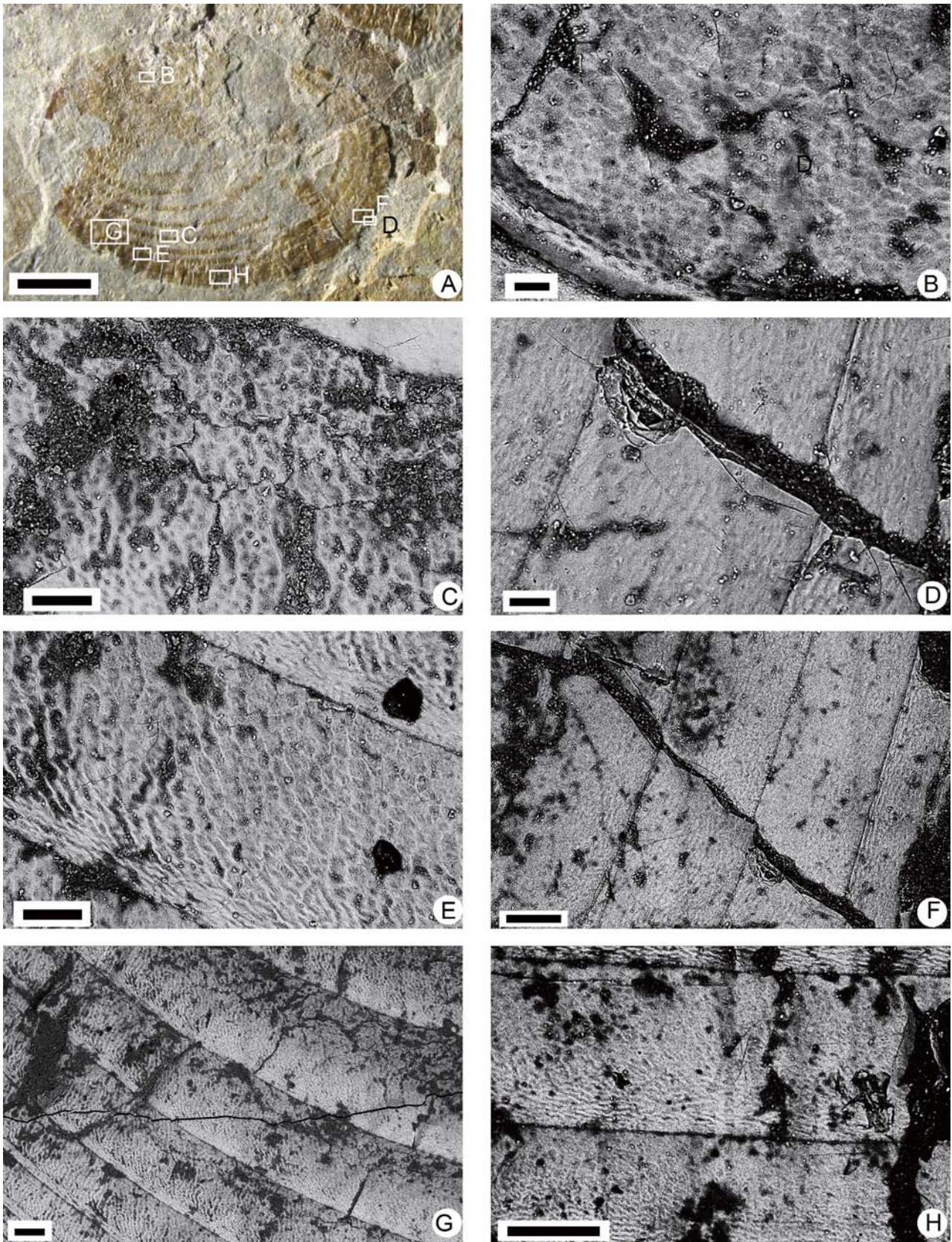


Fig. 3. *Yanjisestheria huajiyingensis* sp. nov. All are SEM images except A, which is a focus-stacked, light microscopy image. A, a left valve (female?), NIGPCAS 180660. B, fine reticulations on a growth band near the umbo. C, fine reticulations transitioning to radial lirae on a growth band in the ventral part of the carapace. D, F, transverse ridges (parallel to the growth lines) on growth bands in the postero-ventral part of the carapace. E, G, thin and dense radial lirae with multiple cross-bars on growth bands in the antero-ventral part of the carapace. H, radial lirae in the upper part change to transverse ridges in the lower part of growth bands in the ventral part of the carapace. Scale bars = 2 mm (A); 20 μ m (B, D); 50 μ m (C, E); 60 μ m (F); 100 μ m (G, H).

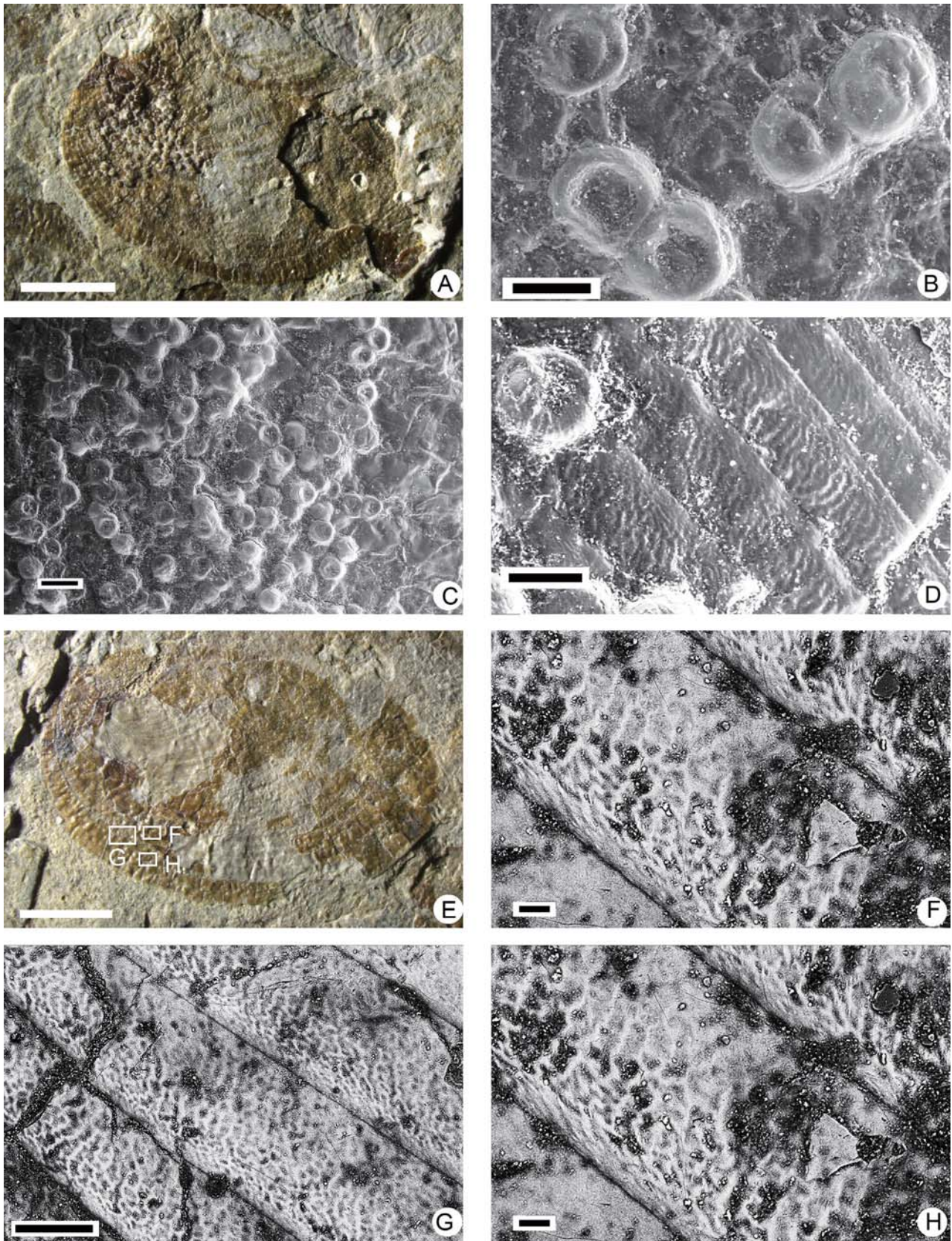


Fig. 4. *Yanjiestheria huajiyingensis* sp. nov. All are SEM images except A and E, which are focus-stacked, light microscopy images. A, a left valve, female, NIGPCAS 180661. B, C, eggs. D, a piece of left valve with an egg near the specimen in A, this image showing thin and dense radial lirae on growth bands in the antero-ventral part of a carapace. E, a left valve (male?), NIGPCAS 180662. F, fine reticulations on growth bands in the antero-ventral part of the carapace. G, H, fine reticulations and radial lirae with multiple cross-bars on growth bands in the antero-ventral part of the carapace. Scale bars = 2 mm (A, E); 20 μm (F, H); 100 μm (B, D, G); 200 μm (C).

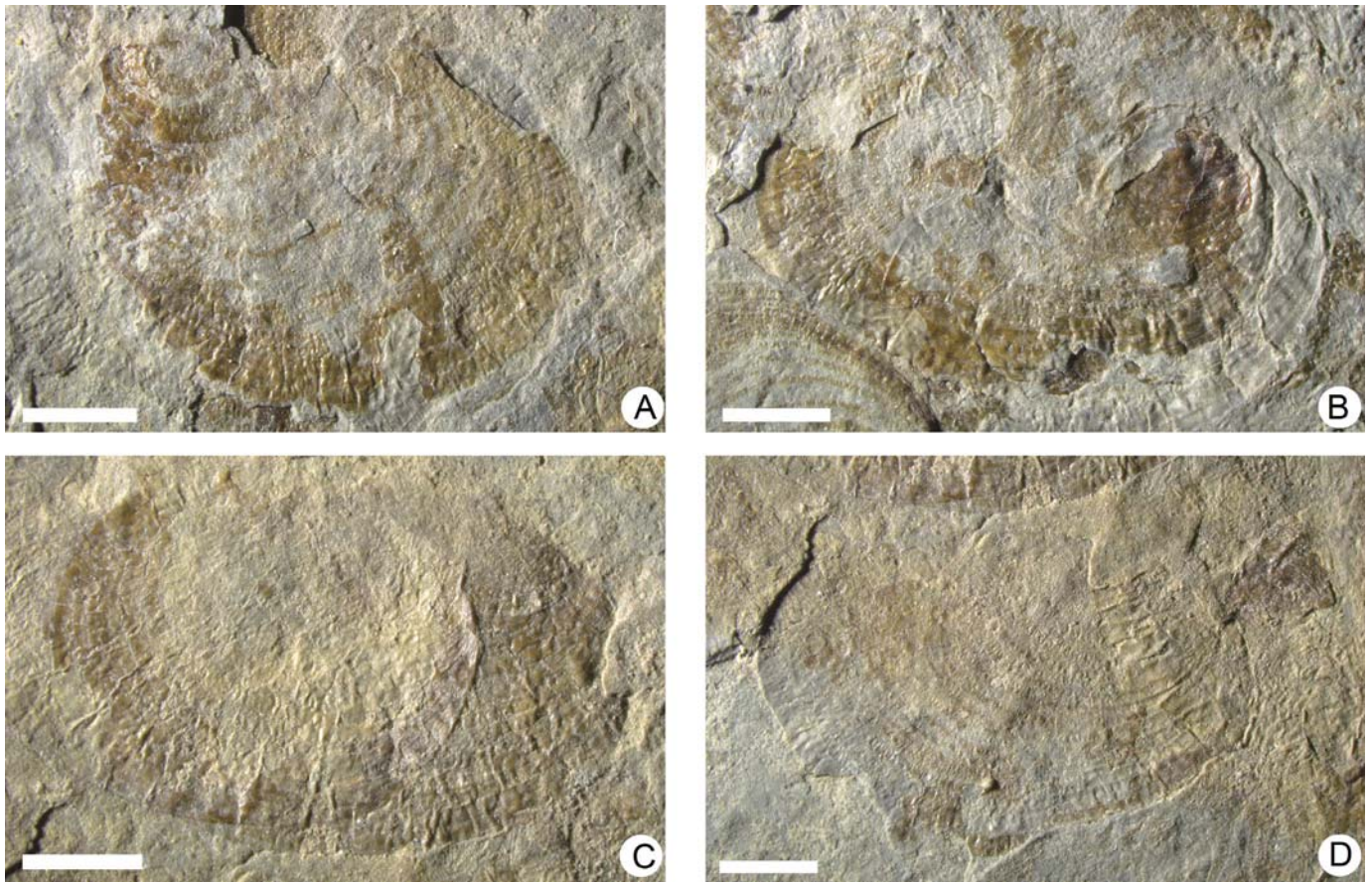


Fig. 5. *Yanjiestheria huajiyingensis* sp. nov. All are focus-stacked, light microscopy images. A, a left valve (female?), NIGPCAS 180663a. B, a right valve (male?), NIGPCAS 180663b. C, a right valve (male?), NIGPCAS 180663c. D, the external mould of a left valve (female?), NIGPCAS 180663d. All sclae bars = 2 mm.

margin ornamented with radial lirae in the upper part, and transverse fine ridges in the lower part of each band (Fig. 3H). Growth bands ornamented with transverse fine ridges in the postero-ventral part of the carapace (Figs. 3D, F). Eggs preserved in the anterior middle part of the female carapace (Fig. 4A), egg diameter about 136 μm (Fig. 4B). Some are well-rounded spheres (Fig. 4C), some show obvious indentations (Fig. 4B, C).

Remarks. The carapace outline of the new species differentiates into two forms: i.e. elongated elliptical (with a height/length ratio about 0.62–0.64), and ovate or subquadrate (with a height/length ratio between 0.68 and 0.76). The egg-bearing ovate carapace likely represent females (Fig. 4A), and the elliptical carapace likely represent males (Figs. 4E, 5B, C). Thus, this may indicate the first evidence of sexual dimorphism in *Yanjiestheria*. The elliptical (male?) specimen is similar to *Yanjiestheria yumenensis* (Chang and Chen, 1963) (Fig. 6A), and the ovate (female?) specimen is similar to *Yanjiestheria sinensis* (Chi, 1931) (Fig. 6C) or *Yanjiestheria chekiangensis* (Novozhilov, 1954) (Fig. 6F). But, the new species is readily differentiated from these three species by having transverse, thin ridges on the growth bands in the postero-ventral part of the carapace. The other three species do not have this kind of ornamentation in the postero-ventral part of the carapace (Fig. 6B, D, E, G).

4. Discussion

Clam shrimp are an important fossil group for the subdivision and correlation of the nonmarine strata (Chen et al., 2007; Li et al., 2009a, 2010; Gallego, 2010; Li and Matsuoka, 2012; Rohn et al., 2014; Gallego et al., 2020; Hegna, 2021). The Early Cretaceous

early Jehol Biota contains an abundant and high diversity *Nestoria*–*Keratestheria* clam shrimp fauna from the Valaginian–Hauterivian Dabeigou Formation, and coeval successions in northern Hebei, Inner Mongolia of China, and the Transbaikalian region of eastern Russia (Wang, 1981; Chen, 1999) (Fig. 7). This clam shrimp fauna contains three families with a total eight genera: Palaeolimnadiidae Tasch, 1956 (*Jibeilimnadia* Wang, 1981), Nestoriidae Shen and Chen, 1984 (*Keratestheria* Chernyshev, 1948; *Magumbonia* Wang, 1984 emend. Li et al., 2009b; *Nestoria* Krasinec, 1963; *Pseudograptia* Novozhilov, 1954; *Sentestheria* Wang, 1981), and Eosestheriidae Zhang and Chen, in Zhang et al., 1976 (*Abrestheria* Wang, 1981 emend. Li et al., 2006; *Yanjiestheria* Chen in Zhang et al., 1976) (Li et al., 2007). Most of these genera were extinct by the end of the deposition of the Dabeigou Formation. The exceptions to this were two eosestheriids, *Abrestheria* and *Yanjiestheria*, which, together with the first occurrence of *Eosestheria* Zhang and Chen in Zhang et al., 1976, formed the rudiments of the *Eosestheria* fauna of the middle Jehol Biota at the beginning of the deposition of the Dadianzi Formation in the Luanping basin (Fig. 7) (Li et al., 2007). The here described clam shrimp species, *Yanjiestheria huajiyingensis* sp. nov., has fine reticulations in the dorsal part of the carapace, and slender and dense radial lirae in the antero-ventral part of the carapace (about 70 within a width of 1 mm). In consideration the previous reports of *Abrestheria* (Jin et al., 2008), *Eosestheria* and *Fengninggrapta* (Wang, 1986), the clam shrimp fauna of the Huajiying Formation includes four genera, including the here reported *Yanjiestheria*. But, it does not contain the typical taxa, such as the boldly reticulated genera *Nestoria* and *Keratestheria*, which characterize the early Jehol Biota. According to the new precise radioisotopic SIMS U–Pb zircon ages (135.4 Ma to

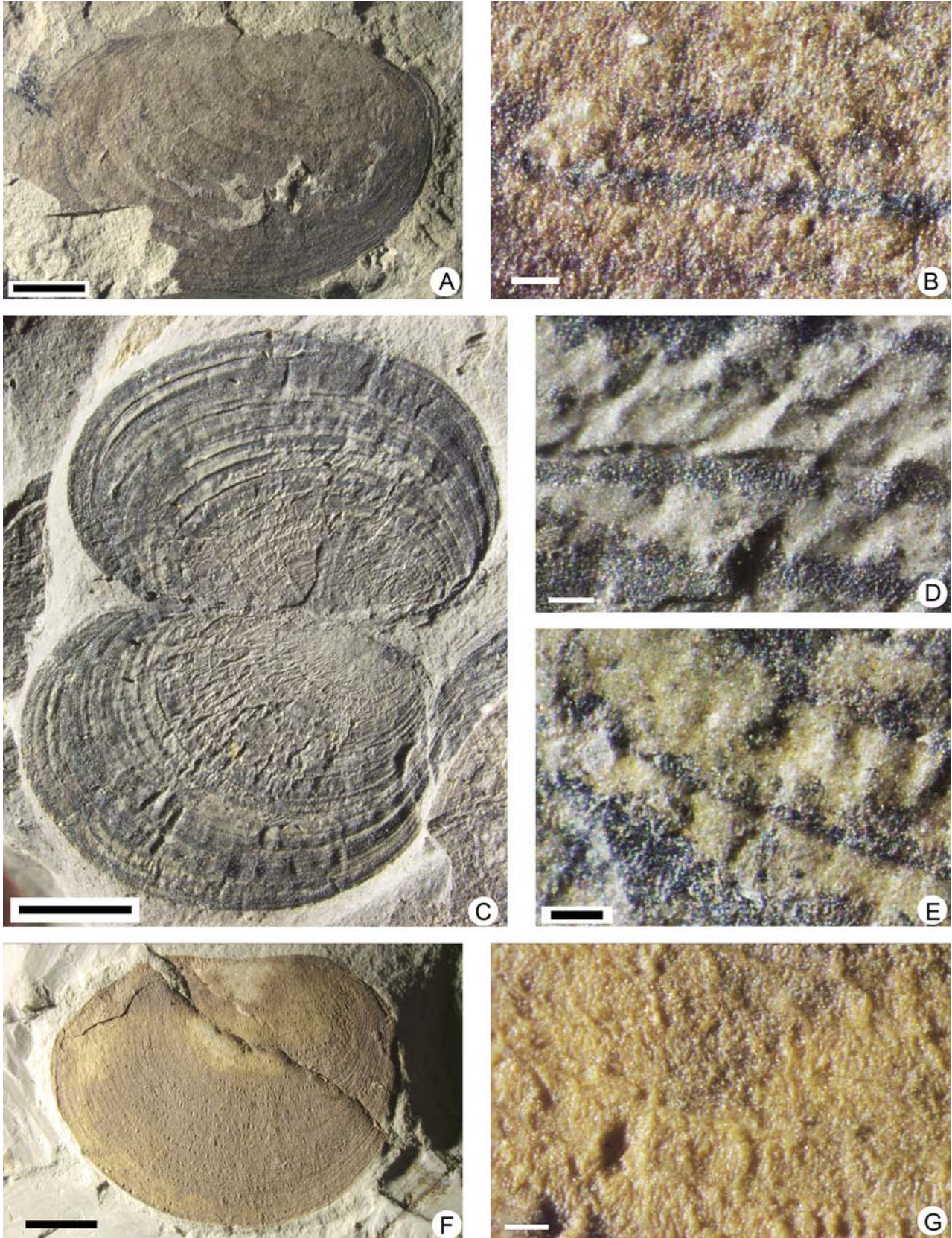


Fig. 6. All are focus-stacked light microscopy images. A, B, *Yanjiestheria yumenensis* (Chang and Chen, 1963) from the Lower Cretaceous of Yumen, northwestern China. A, holotype, NIGPCAS 29906, a left valve; B, radial lirae ornamentation of growth bands in the postero-ventral part of the carapace. C–E, *Yanjiestheria sinensis* (Chi, 1931) Chen in Zhang et al., 1976 from the Lower Cretaceous Bantou Formation of Fujian, southeastern China. C, holotype, NIGPCAS 3152, external mould of opened two valves. D, radial lirae ornamentation of growth bands in the postero-ventral part of the carapace of the upper specimen in C; E, radial lirae ornamentation of growth bands in the postero-ventral part of the carapace of the lower specimen in C. F, G, *Yanjiestheria chekiangensis* (Novozhilov, 1954) Chen in Zhang et al., 1976 from the Lower Cretaceous Shouchang Formation of Zhejiang, southeastern China. F, holotype, NIGPCAS 3165, external mould of a left valve; G, radial lirae ornamentation of growth bands in the postero-ventral part of the carapace. Scale bars = 2 mm (A, C, F); 100 μ m (B, D, E, G).

Series	Stage	Biota	Northern Hebei		Western Liaoning
			Luanping Basin	Sichakou Basin	
Lower Cretaceous	Barremian	Middle Jehol Biota	Dadianzi Fm <i>Eosestheria</i> Fauna	Huajiying Fm <i>Abrestheria</i> <i>Eosestheria</i> <i>Fengninggrapta</i> <i>Shouchangestheria</i> <i>Yanjiestheria</i> Assemblage	Yixian Fm <i>Eosestheria</i> Fauna
	Hauterivian	Early Jehol Biota	Dabeigou Fm <i>Nestoria–Keratestheria</i> Fauna		
	Valanginian		Zhangjiakou Fm	Zhangjiakou Fm	

Fig. 7. Stratigraphic correlation chart of the Lower Cretaceous successions in northern Hebei and western Liaoning provinces of northern China and the clam shrimp faunal assemblages. Abbreviation, Fm: Formation.

129 Ma) (He et al., 2006; Yang et al., 2020) (Fig. 2), the lower part of the succession of the Huajiying Formation in the Jiecaigou village could be correlated with the upper Zhangjiakou Formation according to the SHRIMP U–Pb zircon age of 135.4 Ma from the Luanping basin (Liu et al., 2003), and the upper part of the Jiecaigou succession could be correlated with the Dadianzi Formation (which bearing the middle Jehol Biota) in the Luanping basin (Yu et al., 2022). Thus, the Huajiying Formation should contain both early and middle Jehol Biota.

5. Conclusions

A new spinicaudatan species, *Yanjiestheria huajiyingensis* sp. nov., is taxonomically described from the Lower Cretaceous Huajiying Formation. The new species has distinct transverse ridges (parallel to growth lines) on growth bands in the postero-ventral part of the carapace. The recovery of eggs in *Y. huajiyingensis* sp. nov. aids in identifying sexual dimorphism in *Yanjiestheria*.

In consideration the previous reports of the genera *Abrestheria*, *Eosestheria* and *Fengninggrapta*, the clam shrimp fauna of the Huajiying Formation could represent the early middle Jehol Biota in the upper part of the succession at the Jiecaigou village. The 135.4 Ma radioisotopic SIMS U–Pb zircon age indicates the basal part of the succession should be correlated with the upper Zhangjiakou Formation of the Luanping basin. The SIMS U–Pb zircon age of 129 Ma for the upper section of the Huajiying Formation indicates its correlation with lower Dadianzi Formation (bearing early middle Jehol Biota) of the Luanping Basin. Thus, the Huajiying Formation should contain both early and middle Jehol Biota. However, no boldly reticulated spinicaudatan genera like *Nestoria* or *Keratestheria* have been discovered at the Jiecaigou section. This may indicate special palaeo-environmental conditions during the deposition of the Huajiying Formation in the Sichakou basin.

Data availability

Li, Gang (2022), "Fossil clam shrimp from Jiecaigou, Sichakou township, Fengning Man Autonomous County, northern Hebei Province, northern China", Mendeley Data, V1, <https://doi.org/10.17632/r8c2vd7kds.1>.

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