

Short communication

Morphological restudy of the type species of *Xibeiestheria* (Spinicaudata) from the lower Aptian, northwestern China

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ABSTRACT

The fossil clam shrimp genus *Xibeiestheria* Wang in Shen et al., 1982, a component of the well-known Early Cretaceous *Yanjiestheria* fauna, was originally described from the lower Aptian Jingchuan Formation of Yanchi County, Ningxia Hui Autonomous Region of northwestern China. The morphological re-examination under an SEM of the holotype of the type species *Xibeiestheria pora* Wang in Shen et al., 1982 has revealed new taxonomic features not previously recognized. These include: (1) growth lines with serrated lower margins, having a row of small pores; (2) widely spaced radial lirae intercalated cross bars on growth bands in the dorsal part of the carapace; (3) fine reticulum occurring within coarse reticulation on growth bands in the middle part of the carapace; (4) puncta radially aligned along the widely spaced radial lirae on growth bands in the lower part of the carapace.

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1. Introduction

Spinicaudatans (clam shrimps, “conchostracans”) are large branchiopod crustaceans with a bivalved, chitinous (Li et al., 2010, 2015) or complex chitin-mineral (Astrop and Hegna, 2015) carapace, which were normally fossilized as calcium phosphate in the fossil records (Stigall and Hartman, 2008). Extant clam shrimps normally inhabit small, temporary water bodies (Webb, 1979; Li et al., 2014a, b), in which physical and chemical conditions fluctuate seasonally to offer favourable conditions for the hatching of resting eggs (Guériaux et al., 2016). Their life cycles are relatively short, such as in the recent species *Eulimnadia stoningtonensis* Berry, 1926, death occurs about 23 days after an individual hatches from the egg (Chen and Shen, 1985). These ecological characteristics indicate that spinicaudatans can experience a whole life cycle when a wet season can keep favourable water conditions for an enough long duration. Although there are only 16 extant genera in three families (Brtek, 1997), spinicaudatans were much more prosperous during the Mesozoic (Raymond, 1946; Novojilov, 1963; Defretin-Lefranc, 1967; Tasch, 1969; Zhang et al., 1976;

Gallego, 2010; Li and Matsuoka, 2015; Scholze and Schneider, 2015; Teng et al., 2016; Li et al., 2016a; Zhang et al., 2017). They are commonly abundant and widely distributed in freshwater lacustrine deposits (Chen et al., 2007; Li and Matsuoka, 2012). Consequently, they are useful for biostratigraphic subdivision and correlation of Mesozoic non-marine successions (Wang, 1981, 1987; Li, 1993; Shen, 1994; Wang et al., 2004; Niu et al., 2005; Rohn et al., 2005; Li et al., 2007b, 2017b; Wang and Li, 2008; Chen, 2012; Gallego et al., 2013; Schneider and Scholze, 2016), and further for the palaeoenvironmental reconstruction of the continental ecosystem (Vannier et al., 2003; Ando et al., 2011; Ohta et al., 2011; Boukhalfa et al., 2015; Li et al., 2017a).

Xibeiestheria Wang in Shen et al., 1982 is a small- or medium-sized spinicaudatan component of the *Yanjiestheria* fauna (Liu, 1988; Chen, 2003b), which was first described from the lower Aptian Jingchuan Formation of the Lower Cretaceous Zhidan Group in Yanchi, Ningxia Hui Autonomous Region, northwestern China (Fig. 1). Because the original description of the genus *Xibeiestheria* was based on examination of specimens under a light microscope, some taxonomic features have not been clearly illustrated and described. An SEM morphological re-examination of the type specimen has revealed important taxonomic features not previously seen, as are shown in this paper.

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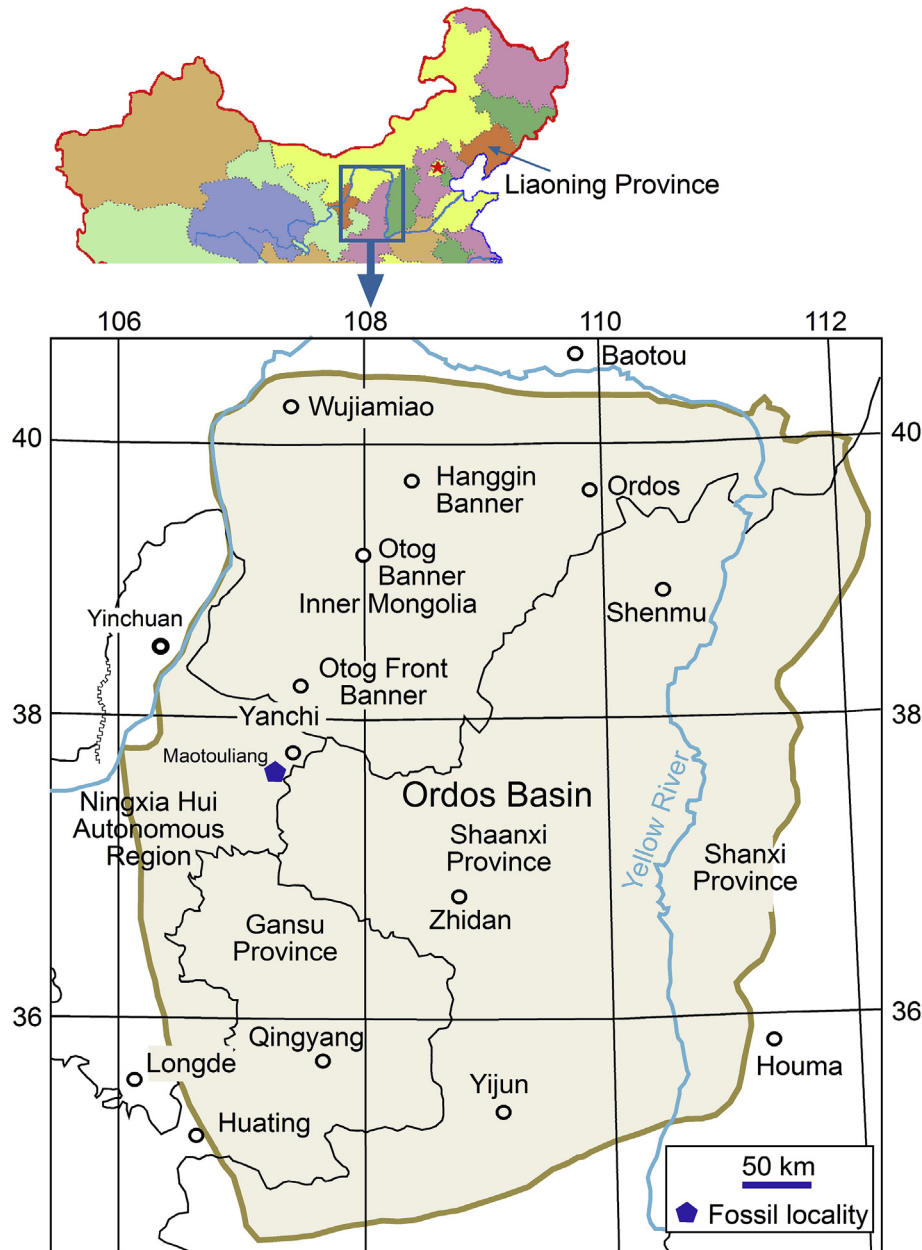


Fig. 1. Schematic map showing the fossil locality hosting *Xibeiotheria pora* in the Ordos basin of mid-west mainland China (after Li, 2017).

2. Geological setting

The Ordos basin is well-known for energy resources of coal, gas and oil in the mid-west of mainland China. The Lower Cretaceous sequence of the Ordos basin is represented by the Zhidan Group (BGMRNHAR, 1996; BGMR, 1998; Chen, 2003a, b). Its lower part includes the Yijun, Luohe, and Huanhe (combined with the Huachi Formation) formations, yielding a middle Jehol biota, and is roughly correlatable with the Barremian Yixian Formation of western Liaoning Province (Chen, 1988; Li, 2017). The middle part of the Zhidan Group, equivalent to the lower Aptian Jiufotang Formation of western Liaoning, includes the Luohandong and Jingchuan formations, yielding a late Jehol biota (Chen, 1988; Li, 2017). The upper part of the Zhidan Group includes the Fengshan Formation in the south (Qi et al., 1988) and the Lamawan Formation in the north-eastern margin of the basin (Chen, 2003b), which are equivalent to

the upper Aptian Shaihai Formation of western Liaoning (Chen, 1988; Li, 2017).

The herein examined material was collected from the Jingchuan Formation, which is widely distributed in the Ordos basin, and mainly composed of greyish green breccias and conglomerate, yellowish green calcareous sandstones and variegated mudstones with intercalated oolitic limestone and marls (IGCAGS, 1980). The formation contains an abundant *Yanjiestheria* clam shrimp fauna (Liu, 1988; Chen, 2003b), including *Ordosestheria wujiamiaoensis* Wang, 1984 emend. Li, 2017, *Xibeiotheria ovata* Wang in Shen et al., 1982, *X. pora* Wang in Shen et al., 1982, *X. yanchiensis* Wang in Shen et al., 1982, *Yanjiestheria* cf. *sinensis* (Chi, 1931) and *Y. cf. yumenensis* (Chang and Chen in IGPCAS, 1963). *Ordosestheria* is a widely distributed genus, which was first described from the lower Aptian Jingchuan Formation at Wujiamiao of Hanggin Banner, Ordos, Inner Mongolia (Fig. 1). It has been recently discovered in the lower

Barremian in North Africa (Li et al., 2017a) and in the Albian Dalazi Formation in northeastern China (Teng and Li, 2017). *Xibeioestheria* has a relatively limited distribution. It was first recovered from the Jingchuan Formation in Yanchi of Ningxia Hui Autonomous Region (Fig. 1), but further field investigation in the type area by the author has failed to find any further fossil material. Then some specimens, tentatively assigned to the genus, have been reported from the Lower Cretaceous in eastern Gansu Province (Shen et al., 1982). *Yanjiestheria* is a widely distributed clam shrimp genus in the Early Cretaceous in eastern Asia (Li et al., 2007a). *Y. yumenensis* was originally described from the Lower Cretaceous Xinminpu Group at Hanxia, Yumen of Gansu, and it was later recovered in the Lower Cretaceous Heishidu Formation at Xiaotian of Shucheng, Anhui (Chen and Shen, 1982), and in the Lower Cretaceous Laiyang Group of eastern Shandong (Shen, 1981). *Y. sinensis* is widely distributed in the Lower Cretaceous of southeastern China, such as in the Laiyang Group of eastern Shandong, in the Shouchang Formation of Zhejiang, in the Bantou Formation of Fujian, in the Yantang Formation of southern Anhui (Chen and Shen, 1982; Chen, 1994).

3. Material and methods

The examined specimen was originally collected from the lower Aptian Jingchuan Formation near the Maotouliang village of Yanchi County, Ningxia Hui Autonomous Region (Fig. 1) (Shen et al., 1982).

Most of the previous studies on the taxonomy of fossil clam shrimps have relied on examination of specimens under a light microscope. This led to that some delicate carapace ornamentation of potential taxonomic value were difficult to see clearly (Li, 2004, 2005; Li et al., 2009a, b, c, d). Here the author has examined the holotype by using an SEM, a LEO 1530 VP, and a Zeiss V20 light microscope. By the way the author has used the invert function of the software Adobe Photoshop to reverse SEM images taken from the external mould, as if they were taken directly of the carapace, so that the detailed ornamentation on the carapace could be clearly illustrated (Li et al., 2006; Li and Matsuoka, 2013; Li et al., 2016b, c).

4. Systematic palaeontology

The classification scheme of recent spinicaudatans by Martin and Davis (2001) is followed here. Use of Conchostraca Sars, 1867 as a taxonomic unit has been abandoned because *Cyclestheria* Sars, 1887, having a unique direct development of the brood, has been removed by Martin and Davis (2001) from the suborder Spinicaudata Linder, 1945 and placed in the suborder Cyclestherida Sars, 1899, which is of equal taxonomic rank as the remaining Spinicaudata and Cladocera Latreille, 1829. The classification schemes of fossil clam shrimp of Zhang et al. (1976) and Chen and Shen (1985) are followed here, which include a phylogenetic hypothesis of relationships between fossil and living groups based on stratigraphic occurrence and morphological features of the carapaces. The scientific value and validity of the Chinese classification schemes have recently been reviewed by Astrop and Hegna (2015).

The studied material is deposited in the Institute of Geology, Chinese Academy of Geological Sciences (IGCAGS). The carapace size is normally described as small when its length less than 5 mm; medium with a carapace length between 5 and 15 mm; and large when the carapace length longer than 15 mm (Chen and Shen, 1985).

Terminological note. Radial lirae are raised, longitudinal linear markings on a growth band (Li and Batten, 2004b, p. 920, fig. 1C), which have been described as longitudinal striae in the previous contributions (Tasch, 1969, p. R151, fig. 50(6c); Chen and Shen, 1982; Li and Batten, 2004a, p. 580). However, striae have been

regarded as grooves between ridges (or lirae) as in palynomorphs (Li and Batten, 2004b).

Order Diplostraca Gerstaecker, 1866

Suborder Spinicaudata Linder, 1945

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

Family Fushunograptidae Wang in Hong et al., 1974

Genus *Xibeioestheria* Wang in Shen et al., 1982 emend.

1982 *Xibeioestheria* Wang in Shen et al., p. 69.

1985 *Xibeioestheria* Wang; Chen and Shen, p. 149.

Type species. *Xibeioestheria pora* Wang in Shen et al., 1982; lower Aptian Jingchuan Formation of the Lower Cretaceous Zhidan Group of Yanchi County, Ningxia Hui Autonomous Region, China.

Emended diagnosis. Carapace elliptical or ovate in outline, small or medium in size; umbo small; growth lines with serrated lower margins, having a row of small pores. Growth bands in the dorsal part of the carapace ornamented with widely spaced radial lirae intercalated with cross bars; in the middle part of the carapace growth bands ornamented with polygonal reticulation (mesh diameter between 25 and 50 μm), more finer reticulation also occurring within the mesh. In the ventral and postero-ventral parts of the carapace, each growth band is ornamented with widely spaced radial lirae, along which puncta radially aligned. The radial lirae ornamentation is limited to the lower two-thirds and leaving the upper part of the growth band smooth.

Discussion. *Xibeioestheria* was originally assigned to the family Afrograptidae Novojilov, 1957 owing to the occurrence of a row of small pores or pits along the lower margin of each growth band (Wang in Shen et al., 1982, p. 69) and the additional feature of the serrated lower margins of growth lines (Chen and Shen, 1985, p. 149). A feature of serrated lower margins of growth lines has been considered as a characteristic feature for identifying an afrograptid (Chen and Shen, 1977, 1982, 1985; Shen and Chen, 1982). However, recent studies (Shen et al., 2002; Shen, 2003) have clarified that the serrated lower margin of growth lines is only of taxonomic significance at generic and subgeneric levels, not for the family rank (Li et al., 2004; Li and Batten, 2004a, b, 2005). Hence, the growth line serration cannot be used as a distinct character for the family rank of the Afrograptidae. As a result, Shen (2003) has moved *Migransia* Chen and Shen, 1977 out of the family Afrograptidae and incorporated it as a subgenus into *Ortheastheria* Chen in Zhang et al., 1976. According to the originally described carapace features, he concluded that *Xibeioestheria* was a junior synonym of *Ortheastheria* (*Migransia*), and assigned it to the family Fushunograptidae Wang in Hong et al., 1974. The SEM examination of the holotype of the type species *X. pora* demonstrates that polygonal reticulations (mesh diameter 25–50 μm) in the middle part of the carapace transition to radial lirae in the ventral part of the carapace. Thus, herein *Xibeioestheria* is kept as a valid genus.

Xibeioestheria pora Wang in Shen et al., 1982 emend.

Fig. 2A–H

1982 *Xibeioestheria pora* Wang in Shen et al., p. 69, pl. 29, figs. 1–2.

Material examined. Holotype, IGCAGS 0216, external mould of a left valve, lower Aptian Jingchuan Formation of the Lower Cretaceous Zhidan Group at Maotouliang, Yanchi County, Ningxia Hui Autonomous Region, northwestern China.

Emended diagnosis. Carapace elongated elliptical, medium in size; ornamentation as in the emended genus diagnosis.

Description. Carapace elongated elliptical in outline, anterior margin straight, posterior margin rounded, ventral margin widely arched; holotype specimen 5.9 mm long, 3.8 mm high; umbo small, located at the anterior part of the long and straight dorsal margin;

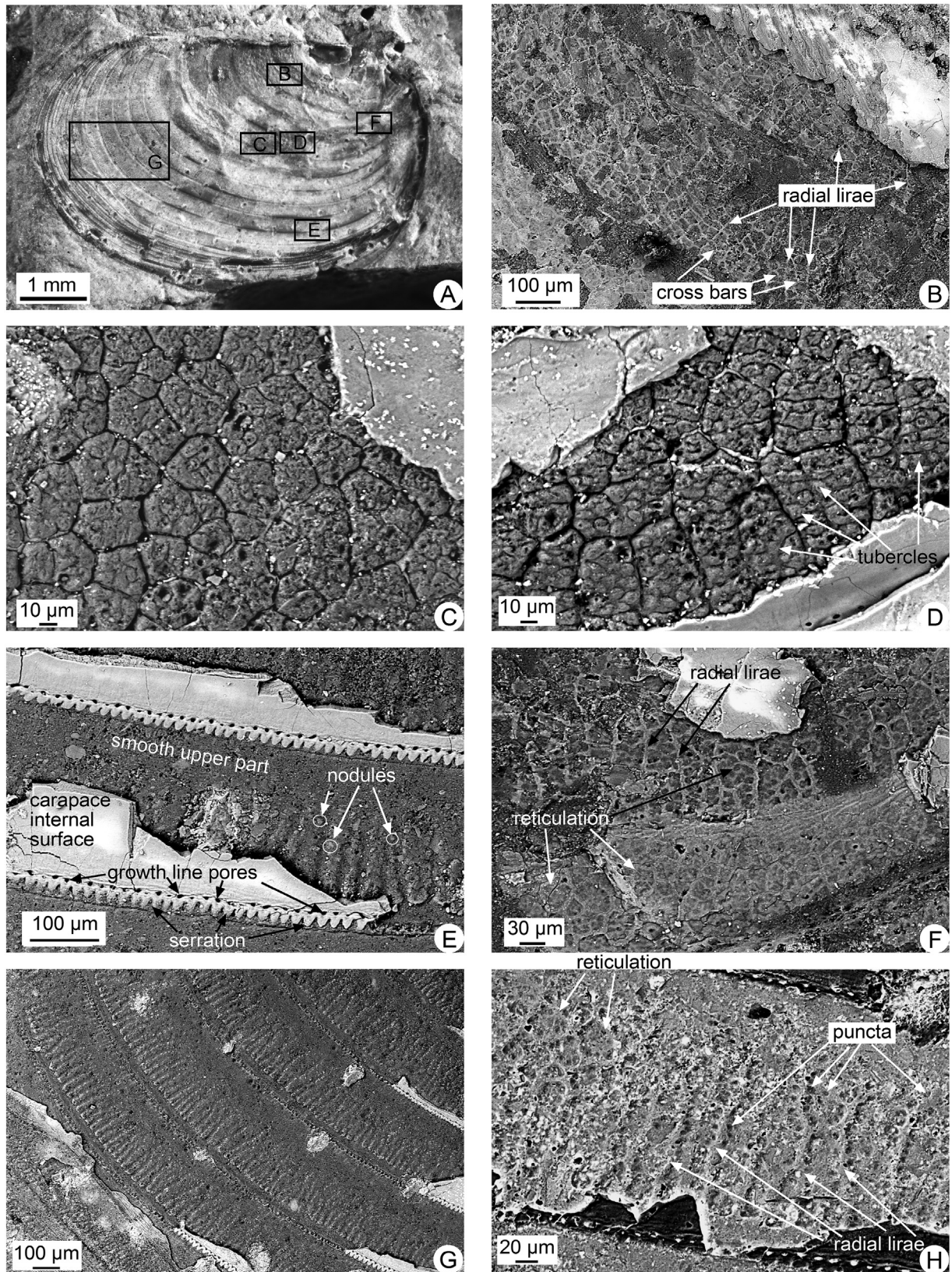


Fig. 2. *Xibeistheria pora* Wang in Shen et al., 1982 emend. All are SEM images, except for A, which is a light microscopy image. A, External mould of a left valve, holotype, IGCAGS 0216. B, Widely spaced radial lirae with intercalated cross bars on growth bands near the umbo. C, D, External mould of reticulations on growth bands in the middle part of the carapace, appearing as polygonal protuberance (platform) with small tubercles. E, External mould of radial lirae, limited to the lower part of each growth band in the ventral part of the carapace, showing nodules (appearing as puncta along radial lirae on growth bands), serrated lower margins of growth lines and a row of small pores in each growth line. F, Ornamentation on growth bands near the anterior margin of the carapace, showing widely spaced radial lirae with intercalated reticulation, which changes downward into polygonal reticulation. G, External mould of radial lirae on growth bands in the posterior part of the carapace, radial lirae are limited to the lower two-thirds of each growth band; growth lines are serrated in the lower margins. H, Reverse contrast image, showing the transition of the ornament from reticulation to widely spaced radial lirae in the ventral part of the carapace; puncta occur along the radial lirae or within the reticulation.

the first seven growth bands near the umbo are wide (0.36 mm wide), the following five growth bands in the middle part of the carapace become a little narrower (0.24 mm wide), and the last eight growth bands are extremely narrow, indicating the adult stage.

Growth lines with serrated (festoon- or garland-like) lower margins (Fig. 2E, G); one row of small pores occurs in each growth line (Fig. 2E). Growth bands in the dorsal part of the carapace are ornamented by widely spaced radial lirae intercalated with cross bars (Fig. 2B) or fine reticulation (Fig. 2F). In the middle part of the carapace growth bands are ornamented with polygonal reticulation (diameter between 25 and 50 μm), within which finer reticulation also occur. On the external mould, reticulation become polygonal protuberances (polygonal platform) consisting of finer tubercles (Fig. 2C, 2D); growth bands in the ventral and postero-ventral parts of the carapace are ornamented with widely spaced, fine radial lirae, which distributed in the lower two-thirds of each band (Fig. 2G), with radially aligned puncta along radial lirae (Fig. 2H); on the external mould the puncta appearing as small nodules (Fig. 2E).

Discussion. A row of small pores along the lower margin of each growth band was originally described in *X. pora* Wang in Shen et al., 1982. Through the re-examination of the holotype under an SEM it is found that a row of pores occurs in each growth line (Fig. 2E). The similar growth line pores were also described in *Martinesstheria codoensis* (Cardoso, 1962) comb. Gallego et al., 2013 from the Lower Cretaceous Santana Formation of Brazil. This kind of pore structure was also described in *Ordosestheria* Wang, 1984 (Li, 2017, fig. 3G; Li et al., 2017a, figs. 7E, 7G, 7H). The growth line pores in *M. codoensis* were interpreted as setae attachment sites. Thus, the similar function is herein interpreted for the here described growth line pores in *X. pora*. Fossil records have shown traces of setae preserved along the tips of the serrations (or beads) in *Cratostracus? tunisiaensis* Boukhalfa et al., 2015 (figs. 4F and 5F). While the growth line nodules (or tubercles), observed in fossil genera (such as *Sinoestheria* Chang, 1957, *Monilestheria* Shen and Chen, 1984, *Sen-testheria* Wang, 1981, *Ganestheria* Bi and Xie in Chen and Shen, 1982), have been interpreted as rivets to strengthen the conjunction of neighbouring growth bands (Wang, 1989; Shen, 2003).

There are three other species assigned to this genus, they are *X. yanchiensis* Wang in Shen et al., 1982, *X. ovata* Wang in Shen et al., 1982 and *X? beishanensis* Shen and Chen in Shen et al., 1982. The former two species were collected from the same horizon as the type species, but differ by having ovate carapace outline. *X? beishanensis* was collected from the Lower Cretaceous of Gansu Province, its umbo located in the centre of the short dorsal margin, while *X. pora* differs by having a longer dorsal margin with a narrow umbo located in its anterior part. The detailed SEM morphological re-examination of these three species will be included in a successive study in the future.

Occurrence. Lower Aptian Jingchuan Formation of the Zhidan Group, Yanchi, Ningxia Hui Autonomous Region, northwestern China.

5. Conclusion

The Jingchuan Formation is characterized by a *Yanjiestheria* clam shrimp fauna, which is dominated by *Y. cf. sinensis*, and *Y. cf. yumenensis*, with subordinate *Ordosestheria wujiamiaoensis*, *Xibeistheria ovata*, *X. pora* and *X. yanchiensis*. The morphological re-examination under an SEM of the holotype of the type species

Xibeistheria pora has revealed important features not previously seen, such as a row of small pores in the growth lines, through which setae are attached; the growth lines are serrated in their lower margins; growth bands are ornamented with reticulation in the middle part of the carapace; then in the ventral and postero-ventral parts of the carapace growth bands are ornamented with widely distributed radial lirae, which are limited to the lower two-thirds of each growth band, and are surrounded by radially aligned puncta.

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