Cretaceous Research 75 (2017) 1–6

Contents lists available at ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

Short communication

SEM morphological study of the type species of *Ordosestheria* Wang, 1984 (Spinicaudata) from Ordos Basin of mid-west China

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ARTICLE INFO

Article history:
Received 8 January 2017
Received in revised form
26 February 2017
Accepted in revised form 8 March 2017
Available online 9 March 2017

Keywords:
Fossil clam shrimp
Ordosestheria
Lower Cretaceous Jingchuan Formation
Jehol Biota
Inner Mongolia
China

ABSTRACT

SEM morphological study of the type specimens of *Ordosestheria wujiamiaoensis* Wang, 1984 from the non-marine lower Aptian Jingchuan Formation in Inner Mongolia of the Ordos Basin in mid-west China has revealed taxonomic features not previously seen: 1) a row of small pits along the lower margin of each growth band in the lower part of the carapace; 2) growth lines are serrated in their lower margins; 3) a row of small pores on each growth line may indicate that through which a row of setae has developed. In consideration of the first occurrence of *Ordosestheria* from the lower Barremian of southern Tunisia, ordosestheriids may most likely have originated in North Africa and then dispersed to eastern Asia in early Aptian, and became a member of the well-known Jehol Biota.

1. Introduction

Clam shrimps are large branchiopod crustaceans with a chitinous bivalved carapace (Li et al., 2010, 2016a). They normally inhabit ephemeral alkaline fresh water pools, in which the water conditions fluctuate to offer recurrent favourable physical and chemical conditions for the hatching of resting eggs (Vannier et al., 2003; Li et al., 2014a,b; Guériau et al., 2016). Their life cycles are relatively short, such as in species *Eulimnadia texana* individuals disappeared 14–20 days after hatching, but the individuals of *Cyzicus cycladoides* in Tunisia had luckily lived for eight months before the living pool dried up (Chen and Shen, 1985). Thus, clam shrimps are an important components of ephemeral freshwater ecosystem (Guériau et al., 2016), and they can be a successful colonizer under a wet and dry alternating climate setting in the earth history, as abundant fossil clam shrimps have been recorded worldwide in the Mesozoic fine lacustrine deposits (Rohn et al., 2005; Chen et al., 2007; Stigall et al., 2008; Kozur and Weems, 2010; Li and Matsuoka, 2012; Gallego et al., 2013; Boukhalfa et al., 2015; Teng et al., 2016). They can be important biostratigraphic diagnostic markers and very useful for subdivision and correlation of non-marine successions when more detailed scanning electron microscope (SEM) based morphological study has been undertaken (Li et al., 2006, 2007a,b, 2009a,b,c).

Ordosestheria, a small spinicaudatan, was first described from the upper Lower Cretaceous of Inner Mongolia in the northwestern Ordos Basin in mid-west China (Wang, 1984) (Fig. 1). Recent discovery of *Ordosestheria* in southern Tunisia has widened their distribution area to the African continent (Li et al., 2017). Because the original description of the genus *Ordosestheria* was based on examination of type specimens under a light microscope, the taxonomic feature has not been clearly illustrated and described. Herein an SEM morphological re-examination of the type specimens has revealed important taxonomic features not previously seen, as shown in this paper.

2. Geological setting

There are two neighbouring basins important for energy resources of coal, gas and oil in mid-west mainland of China, i.e. the big Ordos Basin (also named Shaan-Gan-Ning Basin) in the east, and the small Liupanshan Basin in the west (Fig. 1). The Ordos Basin is covered by the well-known Loess Plateau in the south and deserts and grasslands in the north (Yang, 2002). The upper Lower

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http://dx.doi.org/10.1016/j.cretres.2017.03.006
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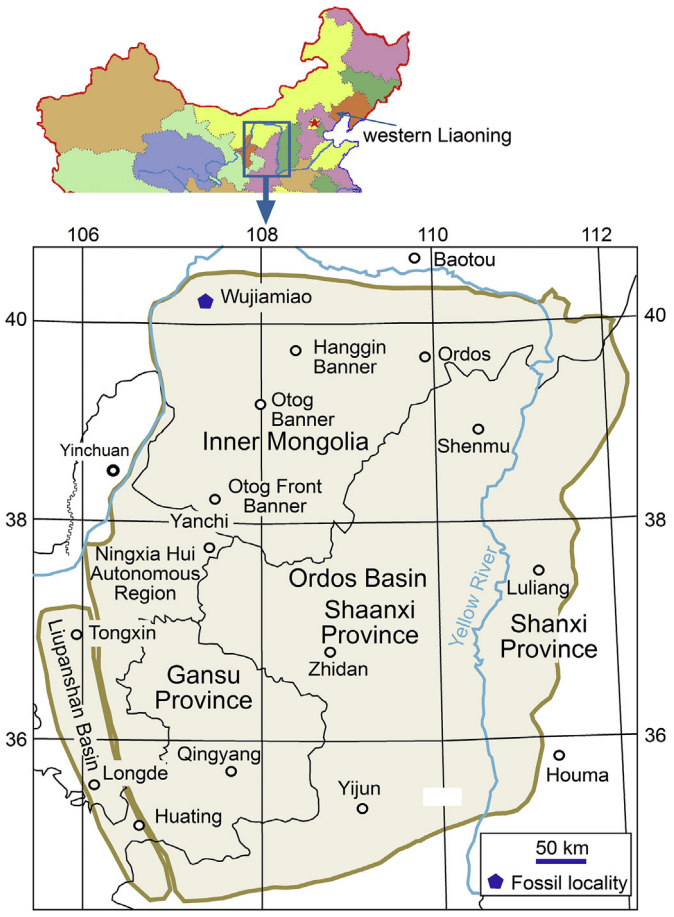

Fig. 1. Sketch map showing clam shrimp fossil locality and the position of Liupanshan and Ordos basins in mid-west China.

Cretaceous sequence of the Ordos basin is represented by the Zhidan Group, which is subdivided into seven formations, i.e. in ascending order, the Yijun, Luohe, Huanhe (combined with the Huachi Formation), Luohandong, Jingchuan, Fengshan/Lamawan formations (BGMRS, 1998; Chen, 2003a) (Fig. 2). The Fengshan Formation is limited to the south part of the basin (Qi et al., 1988) and the Lamawan Formation occurs only in the northeastern margin of the basin (Chen, 2003b). The Liupanshan Basin is a northwestern extending elongated narrow intermountain basin, located in the southeastern Ningxia Hui Autonomous Region, and in eastern Gansu and southwestern Shaanxi provinces (Fig. 1). The Lower Cretaceous sequence of the basin is named the Liupanshan Group, which is subdivided into five formations, i.e. in ascending order, the Sanqiao, Heshangpu, Liwaxia, Madongshan and Naijiahe formations (Fig. 2) (BGMRNHAR, 1996).

More precise age assignment is possible for the Zhidan and Liupanshan groups when they are correlated with the Jehol Group of western Liaoning basing on new radiometric and palaeontological data (Smith et al., 1995; Chen and Jin, 1999; Swisher et al., 1999; Chang et al., 2003; Zhou et al., 2003; He et al., 2004, 2006, 2008). Nowadays, a late Early Cretaceous age has been established for the Jehol Group, which is subdivided into four formations, i.e. in ascending order, the Yixian, Jiufotang, Shahai and Fuxin formations (Fig. 2) (Wan et al., 2013; Li and Matsuoka, 2015). The Yixian and Jiufotang formations contain a well-known Jehol Biota, the Shahai and Fuxin formations yield a Fuxin Biota.

The lower part of the Zhidan Group, being roughly correlatable with the Barremian Yixian Formation of western Liaoning (Chen, 1988; Wan et al., 2013), includes the Yijun, Luohe and Huanhe formations yielding a middle Jehol biota: plants *Cladophlebis* cf. *dunkeri*, *C.* cf. *browniana*; a *Yanjiestheria* clam shrimp fauna (Liu, 1988); insects *Mesolygaeus laiyangensis*, *Karadromeus xiangfanggouensis*, *Huaxiacinectus xinyaoensis* and *Huabeitendipes wuqiensis* (Hong, 1995); and fishes *Lycoptera woodwardi*, *Sinamia zdanskyi* (Liu et al., 1963a,b); pterosaur *Huanhepterus quingyangensis* (Dong, 1982). The middle part of the Zhidan Group, equivalent to the lower Aptian Jiufotang Formation of western Liaoning (Chen, 1988), includes the Luohandong and Jingchuan formations, yielding a late Jehol biota. The Luohandong Formation contains the plants *Cladophlebis* cf. *dunkeri*; ostracodes *Cypridea* (*Ulwellia*) *koskulensis*, *Darwinula simplus*, *Djungarica stolida*, *Lycopterocypris infantilis*, *Rhinocypris foveata* (IGCAGS, 1980; Ye and Li, 1988); fish *Sinamia*; dinosaur *Ikechosaurus sunailinae*, *Psittacosaurus* sp. (IGCAGS, 1980; Sigogneau-Russell, 1981). The overlying Jingchuan Formation is mainly composed of greyish green breccias and conglomerate, yellowish green calcareous sandstones and variegated mudstones with intercalated oolitic limestone and marls. The formation contains plants *Brachiphyllum obesum*; ostracodes *Cypridea* (*Bisulcocypridea*) *symmetrica*, *Cypridea* (*Ulwellia*) *koskulensis*, *C.* (*U.*) *subrectangular*, *Clinocypris scolia*, *Damonella celsa*, *D. jiandeensis*, *Djungarica stolida*, *Lycopterocypris circulata*, *L. multifera*, *Rhinocypris cirrita*, *Ziziphocypris* aff. *costata* (IGCAGS, 1980; Ye and Li, 1988); clam shrimps *Ordosestheria wujiamiaoensis*, *Xibeiestheria* spp., *Yanjiestheria* cf. *yumenensis*, *Y.* cf. *sinensis* (IGCAGS, 1980; Shen et al., 1982; Wang, 1984; Liu, 1988); bivalves *Nakamuranaia chingshanensis*, *Sphaerium jeholense*; gastropods *Valvata subturalis*; insects *Mesolygaeus rotundocephalus*; and fishes *Lycoptera lungteensis*, *L. woodwardi*, *Huashia tungi*, *Longdeichthys luojiaxiaensis* and *Sinamia* sp. (Liu, 1982; Ma, 1986; Jin et al., 1993); dinosaurs *Psittacosaurus youngi* (IGCAGS, 1980; Chen, 2003a,b). The upper part of the Zhidan Group is represented by the Lamawan Formation in the north and the Fengshan Formation in the south of the basin. The Lamawan Formation, equivalent to the upper Aptian Shahai Formation of western Liaoning (Chen, 1988), consists of grayish white and yellowish green massive feldspathic sandstone, and red and dark grey silty mudstone, with coal seams or coal intercalations in the upper part, yielding plants *Brachyphyllum* cf. *japanicum*, *Coniopteris onychioides*, *C.*? *nympharus*, *Elatocladus* cf. *manchuricus*, *Sphenolepidium* sp. (IGCAGS, 1980). The Fengshan Formation consists of brick-red silty mudstone, yielding a low diversity *Yanjiestheria* clam shrimp fauna (Liu, 1988).

In the Liupanshan Basin the Sanqiao Formation is composed of piedmont purple massive conglomerate with sandstone intercalation. The Heshangpu Formation, correlatable with the Jingchuan Formation, consists of fluvial-lacustrine purple sandstone, bluish grey mudstone and marls, yielding a late Jehol biota, including bivalves *Nakamuranaia qingshanensis*, *Sphaerium* sp.; gastropods *Galba pseudopalustris*, *G. obrutschewi*, *Bellamya* sp., *Pseudamnicola* sp.; fishes *Huashia tungi*, *Lycoptera kansuensis*, *L. lungteensis*, *Longdeichthys luojiaxiaensis* (Liu et al., 1963a; Liu, 1982; Ma, 1986). The Liwaxia Formation, correlatable with the upper Aptian Shahai and Lamawan formations (Chen, 1988), consists of fluvio-lacustrine variegated sandstone and mudstone, and yields a Fuxin biota, including plants *Araucarites* sp., *Brachyphyllum* cf. *obesum*, *Otozamites klipsteinii*; bivalve *Nipponaia sengokuensis*; clam shrimp *Orthestheriopsis liupanshanensis* (Shen et al., 1982); insect *Pseudofrenelopsis parceramosa*; fish *Kuntulunia longipterus* (Liu et al., 1985). The Albian Madongshan and Naijiahe formations consist of lacustrine bluish grey, grayish green and purplish red mudstone, shale and marls, yielding a diverse clam shrimp *Yanjiestheria* fauna; fishes *Kuntulunia longipterus*, *Tongxinichthys microdus* (Ma, 1980; Liu et al., 1985).

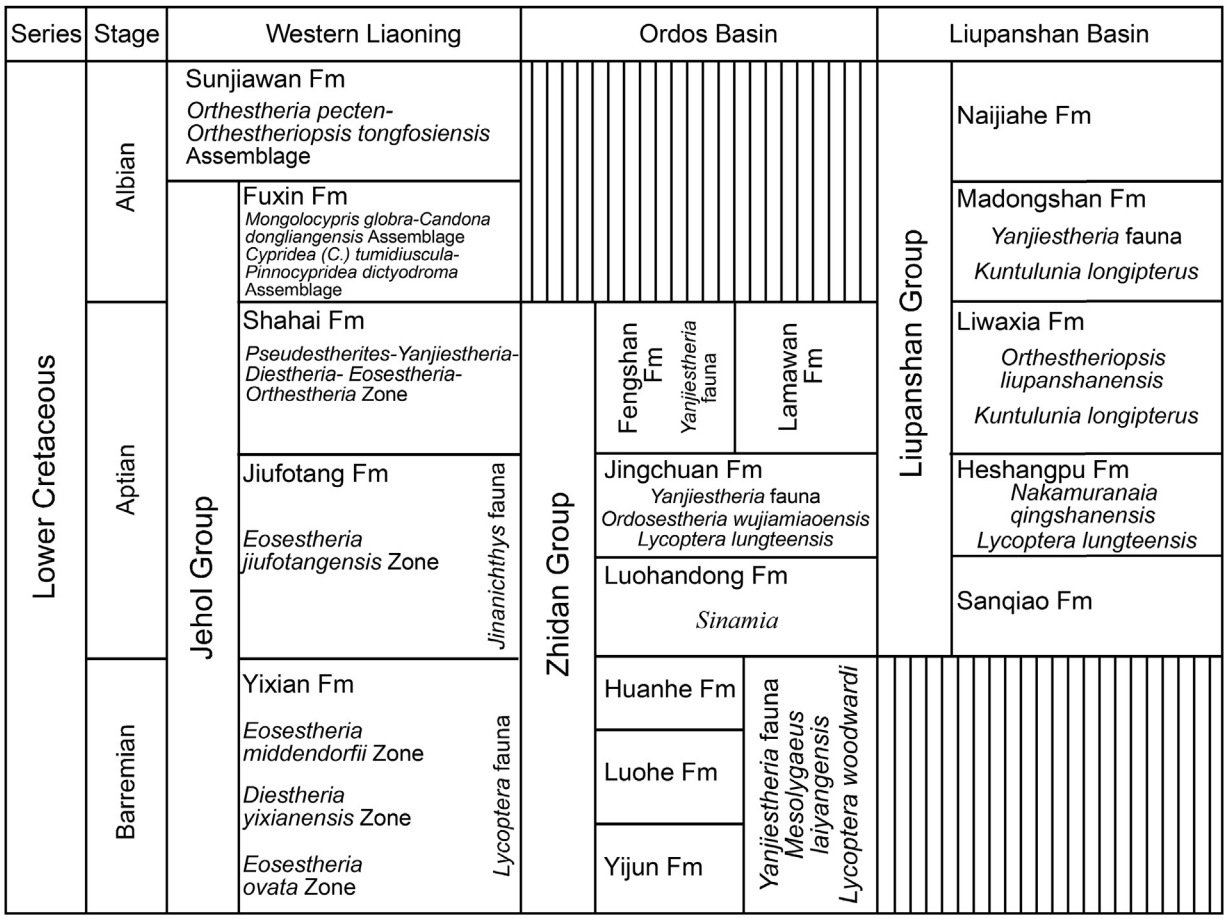

Fig. 2. Stratigraphic correlation chart among the Jehol, Zhidan and Liupanshan groups of northern China and the faunal assemblages. Abbreviation, Fm: Formation.

3. Material and method

The specimens examined are natural external moulds (with fragments of carapace), and were originally collected from the lower Aptian Jingchuan Formation at Wujiamiao, Hanggin Banner, Ordos, Inner Mongolia, mid-west China.

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 potential characters of taxonomic value were difficult to see clearly (Li et al., 2016a,b). Here the author has relied on examination of specimens using an SEM, a LEO 1530 VP, and a Zeiss V20 light microscopy. At the same time the author also uses the invert function of the software Adobe Photoshop to reverse images taken from external moulds of the specimens, as if they were taken directly of the carapace (Fig. 3E, H), so that the detailed ornamentation on the carapace could be clearly illustrated (Li and Matsuoka, 2013; Li et al., 2015).

4. Systematic palaeontology

The studied material is deposited in the Institute of Geology, Chinese Academy of Geological Sciences (IGCAGS). The classification schemes of Martin and Davis (2001) for recent spinicaudatans and Chen and Shen (1985) for fossil clam shrimps are followed according to the comments of Astrop and Hegna (2015).

Order Diplostraca Gerstaecker, 1866
Suborder Spinicaudata Linder, 1945
Superfamily Estheriteoidea Zhang and Chen, in Zhang, Chen and Shen, 1976
Family Fushunograptidae Wang, in Hong et al., 1974

Genus *Ordosestheria* Wang, 1984, emend.

1984 *Ordosestheria* Wang, p. 733.

Type species: *Ordosestheria wujiamiaoensis* Wang, 1984. Lower Cretaceous (lower Aptian) Jingchuan Formation, Inner Mongolia, mid-west China.

Emended diagnosis. Carapace small, ovate, obliquely circular or elliptical in outline. growth bands 10–30 in number; those near the umbo ornamented with small-sized reticulation; growth bands in the middle part of the carapace are smooth; a few of growth bands are ornamented with a row of small pits along the lower margin of each growth band in the ventral part of the carapace. Growth lines are serrated in their lower margins. A row of small pores is developed on growth lines.

Discussion. Wang (1984) originally described a row of tubercles along the lower margin of each growth band (Fig. 3B, D), and based on which he assigned *Ordosestheria* to Afrograptidae Novojilov, 1957. In fact, this description was based on external moulds. The described tubercles on external moulds should indicate a row of small pits on the carapace (Fig. 3E, H). And the additional characters, such as pores on growth lines (Fig. 3G) and the serrated lower margins of growth lines (Fig. 3D, G, H), have not been mentioned. As has been discussed in previous studies (Shen et al., 2002; Shen, 2003; Li, 2004; Li and Batten, 2004a,b, 2005; Li et al., 2004, 2009c) that serrated growth lines are only of taxonomic significance at

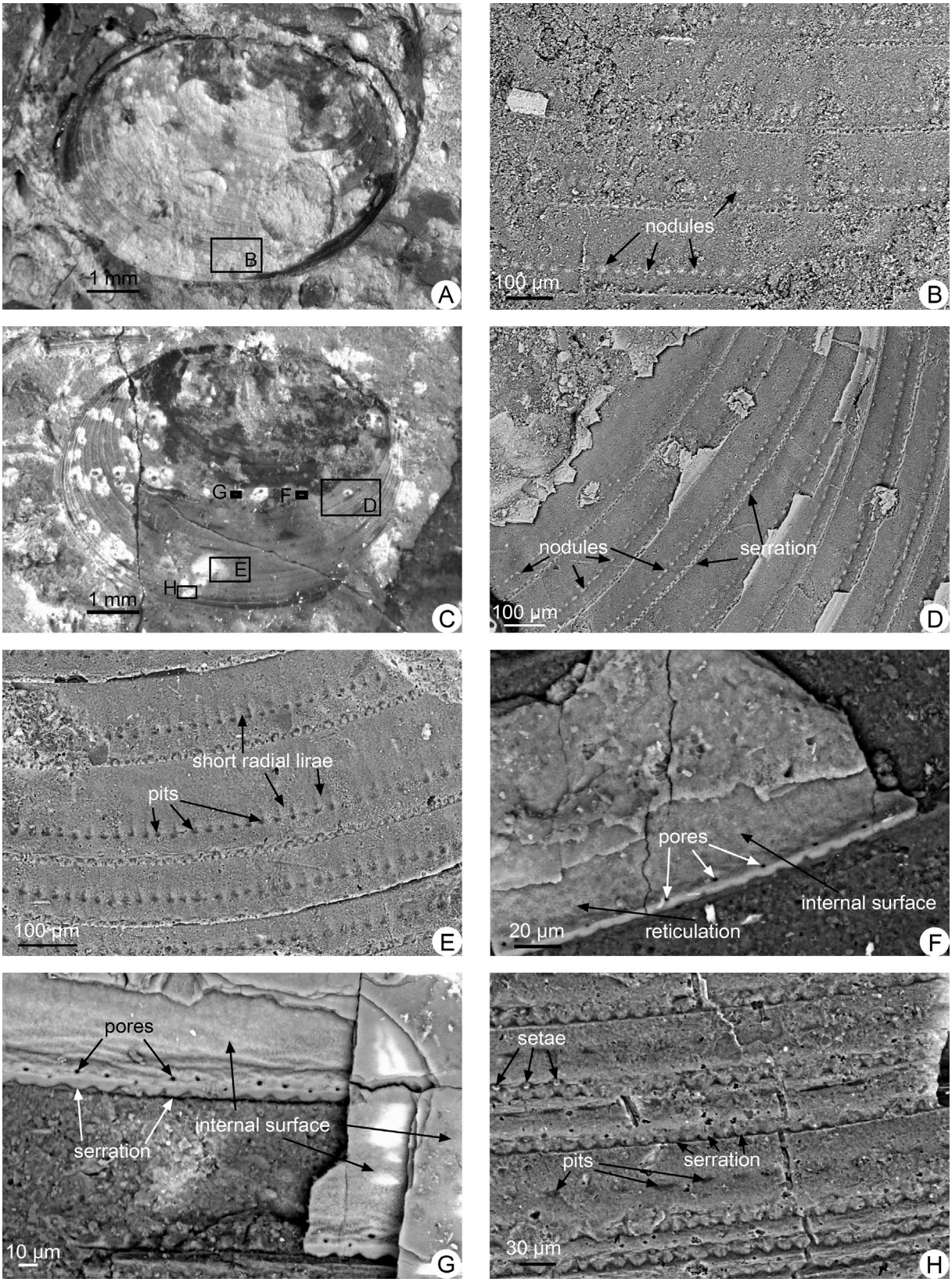

Fig. 3. *Ordosestheria wujiamiaoensis* Wang, 1984, emend. All figures, except for A and C (light microscopy images), are SEM images. A, External mould of a left valve, paratype, IGCAGS Or. 0023. B, Ornamentation on ventral part of the external mould of the specimen IGCAGS Or. 0023, showing serrated lower margins of growth lines, and a row of nodules on the lower margin of each growth band in the ventral part of the external mould. C, External mould of a left valve, holotype, IGCAGS Or. 0024. D, Ornamentation on growth bands in the antero-ventral part of the holotype specimen, showing serrated lower margins of growth lines, and a row of nodules along the lower margin of each growth band. E, Reversal image of the ornamentation on growth bands near the ventral margin of the holotype, showing short radial lirae on the lower part of each growth band, a row of pits along the lower margin of each growth band, and serrated lower margins of growth lines. F, A row of pores in the growth line, reticulation on internal surface of the growth band in the middle part of the holotype. G, Showing internal surface of growth bands of the holotype, a row of pores in growth line, which is serrated in the lower margin. H, Reversal image, showing growth bands in the ventral part of the holotype, serrated growth lines, a row of pits along the lower margin of each growth band, a row of setae along each growth line.

generic and subgeneric levels, not for a family rank. Thus, *Ordosestheria* is attributed to Fushunograptidae on the basis of short radial lirae on growth bands.

There are two species described within *Ordosestheria*. The type species has 26–30 growth bands, the Tunisian species *O. chottsensis* Li et al. (2017) has 10–14 growth bands. Small-sized reticulation has been observed in the latter on growth bands near the umbo. Thus, these features have been included in the emended diagnosis.

Ordosestheria wujiamiaoensis Wang, 1984 emend.
Fig. 3

1984 *Ordosestheria wujiamiaoensis* Wang, p. 734, pl. 2, figs. 9–12.

Material. External mould of a left valve with fragments showing internal surface of the carapace, holotype, IGCAGS Or. 0024; external mould of a left valve, paratype, IGCAGS Or. 0023.
Dimensions of figured specimens. In order: specimen no. (prefixed IGCAGS Or.), number of growth lines, length of carapace (mm), height of carapace (mm): 0024, 28, 4.4, 3.4; 0023, 26, 4.4, 3.2.
Emended diagnosis. Carapace small, ovate, obliquely circular or elliptical in outline. 26–30 growth bands, among which most are smooth, with a few of them in the ventral part of the carapace ornamented with closely spaced short radial lirae, occupying the lower part of each band; a row of small pits occur between neighbouring short and wide radial lirae along the lower margin of each growth band in the ventral part of the carapace. Growth lines are serrated in the lower margins. A row of small pores is developed on growth lines.
Description. Carapace small, ovate, obliquely circular or elliptical in outline. Dorsal margin short, slightly convex upwards, small umbo located near its middle part; postero-dorsal angle distinct. Anterior margin rounded, posterior margin widely rounded, ventral margin widely arched; anterior height less than posterior height. Growth bands 26–30 in number, which are wide in the dorsal and middle part of the carapace, and become narrower near the ventral margin; most of the growth bands are smooth, only the lower 10–15 growth bands in the ventral part of the carapace are ornamented with one row of small pits on the lower margin of each band (Fig. 3E, H). The pits extend upwards to form very narrow furrows, and mark the lower part of each growth band as ornamented with narrowly spaced short and thick radial lirae, which occupy the lower part of each band (Fig. 3E). The pits are slightly transversely elongated on the narrow growth bands near the ventral margin (3H). Growth lines are serrated in their lower margins (Fig. 3G, H), with a row of small pores on their internal surface (Fig. 3G). A piece of fragment in the middle part of the carapace show small-sized reticulation on internal surface of the growth band (Fig. 3F).
Discussion. Through the SEM imaging on specimens of the type species, the taxonomic feature has been clarified, i.e. the occurrence of a row of small pits along the lower margin of each growth band in the ventral part of the carapace. Additional important taxonomic features have been discerned, such as the serrated growth lines with a row of pores, through which setae may grow (Fig. 3H). Although the ornamentation on growth bands near the umb is not preserved in the type species, the thin-walled polygonal small-sized reticulation have been observed on the umbonal area of the carapace in the Tunisian species *O. chottsensis* Li et al. (2017). The two species differs in that the type species has denser growth bands (26–30 in number) than the Tunisian species (10–14 growth bands), although their carapace are of a similar size.
Occurrence. Lower Cretaceous (lower Aptian) Jingchuan Formation, Wujiamiao, Hanggin Banner, Ordos, Inner Mongolia, China.

5. Conclusion

Morphological re-examination under an SEM of the specimens of the type species *Ordosestheria wujiamiaoensis* has revealed important features not previously seen. Biostratigraphic data support the correlation of the Luohandong and Jingchuan formations of the middle Zhidan Group with the lower Aptian Jiufotang Formation in western Liaoning. The early Barremian occurrence of *Ordosestheria* in southern Tunisia indicates that ordosestheriids have most likely originated in North Africa and then dispersed to eastern Asia in the early Aptian.

Acknowledgements

This research is supported by National Natural Science Foundation of China (41572006, 91514302, 41688103, 41172010). Many thanks go to anonymous reviewers for their constructive comments to improve the manuscript.

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