Cretaceous Research 78 (2017) 196–205

Contents lists available at ScienceDirect

Cretaceous Research

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

Clam shrimp genus *Ordosestheria* from the Lower Cretaceous Dalazi Formation in Jilin Province, north-eastern China

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ARTICLE INFO

Article history:
Received 15 March 2017
Received in revised form
8 June 2017
Accepted in revised form 11 June 2017
Available online 17 June 2017

Keywords:
Clam shrimp taxonomy
Ordosestheria
Yanjiestheria fauna
Lower Cretaceous
Dalazi Formation
China

ABSTRACT

Ordosestheria Wang, 1984 was originally described from the lower Aptian Jingchuan Formation (previously the sixth member of the Zhidan Group) in north-western China. It was recovered from the lower Barremian Bouhedma Formation in southern Tunisia. However, we identified species of *Ordosestheria* from the upper Albian Dalazi Formation in north-eastern China, which were previously identified as orthestheriids. This means that the distribution area of *Ordosestheria* is wider than we thought before. Through the SEM examination of specimens of *Or. multicostata* (Chen in Zhang et al., 1976), new features have been discerned: 1) small-sized polygonal reticulation occurs on growth bands near the umbo; 2) reticulation changes into evenly distributed puncta; 3) then widely spaced radial lirae with intercalated fine puncta; 4) puncta are disappeared on middle and lower part of the carapace, leaving an undulating upper part and a row of small pits along the lower margin of each growth band; 5) growth lines are serrated in their lower margins. As a result, *Ordosestheria* is also a principal component of the *Yanjiestheria* clam shrimp fauna, and can be an index genus for the subdivision of non-marine sequences in China.

1. Introduction

Clam shrimps, Order Spinicaudata, are large bivalved branchiopod crustaceans with a hinged chitinous (Webb, 1979; Li et al., 2010, 2015) or complex chitin-mineral (Astrop and Hegna, 2015) carapace, which are often fossilized as calcium phosphate in the fossil records (Stigall et al., 2008). The earliest record of the spinicaudatans was recovered in the Devonian Period (Raymond, 1946; Tasch, 1969; Chen and Shen, 1985), and they were extremely prosperous during the Mesozoic, especially in Asia (Li and Matsuoka, 2012, 2013; Teng et al., 2016). But during the Cenozoic, they gradually declined (Kobayashi, 1982; Chen et al., 2007), consequently, there are only 16 genera in three families remained today (Martin and Boyce, 2004; Brendonck et al., 2008; Rogers et al., 2012, 2016; Timms and Schwentner, 2012). Fossil spinicaudatans are commonly abundant and widely distributed in fine lacustrine deposits that accumulated in quiet, freshwater environments (Li, 2005; Wang and Li, 2008; Li et al., 2009a, b,c, 2014a, 2016a). As a result, they are useful for biostratigraphic subdivision and correlation of non-marine successions (Novojilov, 1963; Defretin-Lefranc, 1967; Kobayashi, 1973; Cui, 1987; Chen and Hudson, 1991; Shen et al., 2002b; Niu et al., 2003; Vannier et al., 2003; Pramparo et al., 2005; Rohn et al., 2005; Gallego and Martins-Neto, 2006; Gallego et al., 2013; Wang, 2014; Boukhalfa et al., 2015; Li and Matsuoka, 2015; Scholze and Schneider, 2015; Li et al., 2016c, 2017; Schneider and Scholze, 2016; Zhang et al., 2017).

The *Yanjiestheria* fauna occurs widely in the non-marine Lower Cretaceous rocks of East Asia and is principally composed of *Neodiestheria*, *Orthestheria*, *Orthestheriopsis* and *Yanjiestheria* (Li, 1993; Chen, 1996, 2012). The nominated genus *Yanjiestheria* Chen in Zhang et al., 1976 was erected basing on specimens collected from the upper Albian Dalazi Formation in the Yanji Basin, Jilin Province, north-eastern China (Li et al., 2007a) (Fig. 1), and has been reported subsequently from the Lower Cretaceous in the south-eastern China, north-western China, Korea and south-western Japan. In south-eastern China, the *Yanjiestheria* fauna can be subdivided into

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http://dx.doi.org/10.1016/j.cretres.2017.06.011
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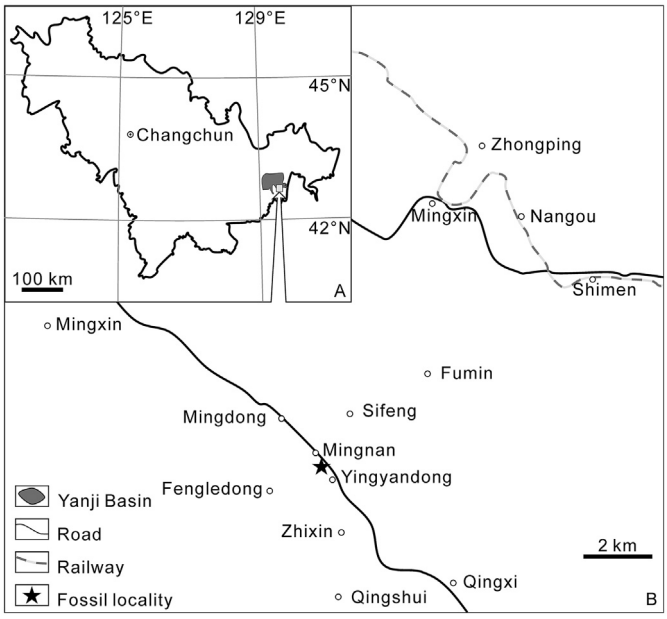

Fig. 1. A, Sketch map of Jilin Province, showing the locality of the Yanji Basin. B, Sketch map of the southern Yanji basin, showing the fossil locality.

two assemblages, i.e. the lower *Yanjiestheria*–*Migransia* assemblage and the upper *Cratostracus*–*Orthestheria*–*Orthestheriopsis* assemblage (Chen, 2012).

A vast amount of work has been done on the *Yanjiestheria* fauna during the last four decades. In addition to extensive taxonomic work there is also some research on phylogeny and biostratigraphy (Wang, 1976; Zhang et al., 1976; Chen and Shen, 1982; Shen et al., 1982; Wang et al., 1984; Liu, 1988; Chen et al., 1998; Li et al., 2016b, 2017). Most previous studies on the taxonomy of spinicaudatans have been relied on examination of specimens under optical microscopes, this means that some characters of potential taxonomic value are difficult to be seen clearly and easily to be overlooked (Li et al., 2006, 2007b, 2014b). As an important component of the *Yanjiestheria* fauna, the genus *Orthestheria* Chen in Zhang et al., 1976 is worthy of further taxonomic study. In fact, it is easy to identify a species of other genera as a species of *Orthestheria*, such as the species *Qinghaiestheria hongshuikouensis* (Chang, 1957) (Wang, 1983) has been assigned to *Orthestheria* (Zhang et al., 1976). Specimens for the present paper were collected from the upper Albian Dalazi Formation at Mingnan, Longjing County, Jilin Province by the second author (Fig. 1). An examination of these specimens under a scanning electron microscope (SEM) has revealed important morphological features, which were not previously seen. As a result, we herein synonymize a few species of *Orthestheria* and assign them to *Ordosestheria* Wang, 1984, an important component of the *Yanjiestheria* fauna.

2. Geological setting

The Dalazi Formation crops out in both Longjing County and Wangqing County (Fig. 1). Li et al. (2016b) logged the type section of the formation and exposures of both the Longjing and Dalazi formations along a road cut, and an idealized columnar section of both formations had been given by them.

The Longjing Formation exhibits a marked upward-fining and bed-thinning cycle. The lower thick-bedded breccias are capped by alternating beds of conglomerate and red siltstone. The breccias in the lower part are mostly composed of matrix-supported debris-flow and trough-cross-stratified, traction-current deposits. The upper part of the formation consists of lenses of conglomerate and coarse sandstone within red mudstone and siltstone. The red mudstone-siltstone facies occasionally contain traces of rootlets and calcrete nodules.

The Dalazi Formation overlies the Longjing Formation unconformably. The basal part of the Dalazi Formation is deposited in a conglomeratic facies, which fines upward rapidly to a mudstone-dominated facies with a few hundreds of metres thickness. The basal conglomerates have a large-scale cross-stratified bedding geometry. The beds are internally massive but locally inverse grading is discernible. The bulk of the formation above is composed of dark grey mudstone that is rich in the spinicaudatans, ostracods, bivalves and gastropods, especially in the lower and middle units (in Fig. 2, unit 5 yielding *Neodiestheria dalaziensis* Chen in Zhang et al., 1976, emend. Li et al., 2016b; unit 6 yielding *Ordosestheria multicostata* (Chen in Zhang et al., 1976)). Units 8 and 9 are now buried under soil. The uppermost part of the Dalazi Formation (unit 10 in Fig. 2, yielding *Yanjiestheria bellula* Chen in Zhang et al., 1976; Li et al., 2007a) is composed of finely laminated rhythmites with turbiditic sandstone intercalations.

3. Material and methods

The here examined well-preserved spinicaudatans are fossilized carapaces, which were collected by the second author from the middle part of the Dalazi Formation (unit 6 in Fig. 2) exposed at Mingnan, Longjing County (Fig. 1). The figured specimens are deposited in the collection of the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPCAS). The authors have relied on examination of specimens using an LEO 1530 VP SEM. Nowadays, SEMs become widely available and have played more and more important roles in the taxonomy of fossil clam shrimps (Li et al., 2016b,c).

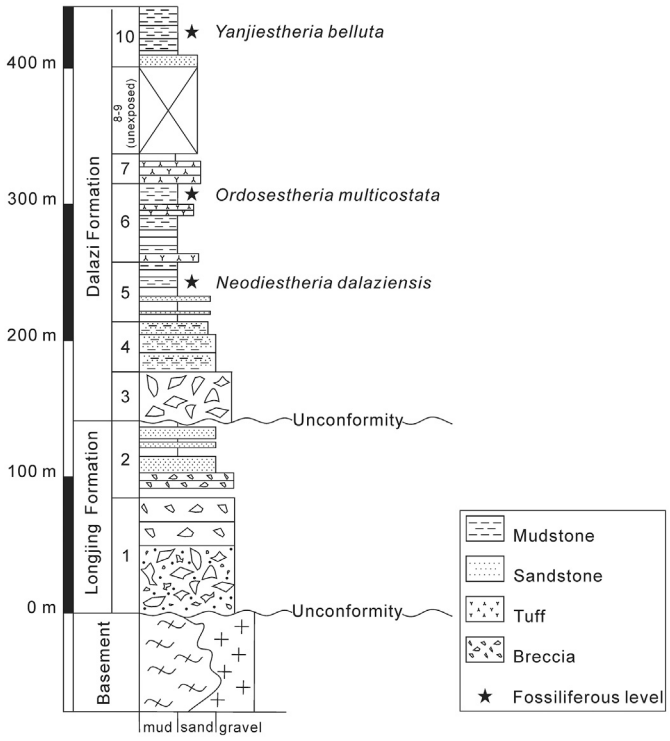

Fig. 2. Column section of the Longjing and Dalazi formations in the Yanji Basin showing the fossil clam shrimp horizons (after Li et al., 2016b).

4. Stratigraphic implications

Ordosestheria was originally described from the lower Aptian Jingchuan Formation in Inner Mongolia. It was recovered in the lower Barremian Bouhedma Formation in southern Tunisia (Li et al., 2017). Now, we identify a species *Ordosestheria multicostata* (Chen in Zhang et al., 1976) from the upper Albian Dalazi Formation in north-eastern China. This probably means that ordosestheriids first originated in North Africa, then in the early Aptian they spread to the Ordos Basin of southern Inner Mongolia, and finally in the late Albian they dispersed further eastward to the Yanji Basin of eastern Jilin. Thus, *Ordosestheria* became a principal member of the widely distributed *Yanjiestheria* fauna in East Asia.

The *Yanjiestheria* fauna is widely distributed in the Lower Cretaceous deposits in China. In south-eastern China, it can be subdivided into two assemblages. The early *Yanjiestheria* fauna was named *Yanjestheria–Migransia* Assemblage. *Neodiestheria*, *Orthestheria*, *Orthestheria* (*Migransia*) and *Orthestheriopsis* are four principal components of this assemblage. The late *Yanjiestheria* fauna was previously named as a *Cratostracus* fauna (Chen and Shen, 1982) or *Cratostracus–Orthestheria–Orthestheriopsis* assemblage (Chen, 2003, 2012), which is dominated by *Cratostracus*, with additional subordinate members, including *Orthestheria*, *Orthestheriopsis*, *Ellipsograpta*, *Aglestheria* and *Orthestheria* (*Migransia*). It is extremely different from the late *Yanjiestheria* fauna in the Dalazi Formation in north-eastern China, where *Yanjiestheria* and *Neodiestheria* are still the dominant members (Chen, 2012; Li et al., 2016b).

The *Yanjiestheria* fauna, recorded from the Lower Cretaceous rocks in north-western China, is dominated by species of *Yanjiestheria*, with additional subordinate members, including *Neodiestheria*, *Orthestheriopsis* and *Ordosestheria*. In Xinjiang, species of *Cratostracus*, *Orthestheriopsis* and *Yanjiestheria* have been recorded from the Tugulu Group (Wang, 1985; Chen, 2012). In Gansu Province, species of *Yanjiestheria*, *Neodiestheria* and *Orthestheriopsis* have been reported from the Xinminpu Group (Shen, 1981). In Inner Mongolia, *Yanjiestheria*, *Ordosestheria* and *Neodiestheria* have been recorded from the Zhidan Group (Wang, 1984; Liu, 1988; Li, 2017).

5. Systematic palaeontology

The classification scheme of recent spinicaudatans of Martin and Davis (2001) is followed here. Because *Cyclestheria* Sars, 1887 has been removed from the suborder Spinicaudata Linder, 1945 and is now placed in the suborder Cyclestherida Sars, 1899, which is on an equal footing with the remaining Spinicaudata and Cladocera Latreille, 1829, the Conchostraca Sars, 1867 as a monophyletic unit has been abandoned.

Class Branchiopoda Latreille, 1817
Subclass Phyllopoda Preuss, 1951
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 *Ordosestheria* Wang, 1984, emend. Li, 2017
Type species: *Ordosestheria wujiamiaoensis* Wang, 1984; lower Aptian Jingchuan Formation of the Zhidan Group, Inner Mongolia, north-west China.

Revised diagnosis. Carapace of small size, gently convex, oval, obliquely rounded or elliptical in outline; growth bands near umbo ornamented with fine reticulations; growth bands in the ventral part of the carapace ornamented with a row of pits along the lower margin of each growth band, between the pits are short lirae; growth lines are serrated in the lower margins (Li, 2017).
Discussion. Wang (1984) erected the genus *Ordosestheria* and assigned it to Afrograptidae Novojilov, 1957 basing on the occurrence of a row of tubercles along the lower margin of each growth band. Because the original description was based on external moulds, thus, the described tubercles should indicate a row of pits along the lower margin of each growth bands. A recent SEM examination discerned that the growth lines in the type species *O. wujiamiaoensis* are serrated in the lower margins (Li, 2017). Although the growth line serration has been regarded as a important criterion for the family Afrograptidae in previous literatures (Chen and Shen, 1977, 1982, 1985; Shen and Chen, 1982), this feature has been found in different recent families (Shen, 2003). Thus, the growth line serration could be of taxonomic value only for generic or subgeneric level, not for higher ranks (Shen et al., 2002a; Li et al., 2004, 2009d; Li, 2004, 2017; Li and Batten, 2004a,b, 2005). For this reason, *Ordosestheria* was attributed to Fushunograptidae.

Ordosestheria is similar to *Cratostracus* Huang in Chen and Shen, 1977 emend. Li and Batten, 2004b in having serrated growth lines, fine reticulation on growth bands near the umbo (Li and Batten, 2004a) and short radial lirae on the lower part of each growth band in the lower part of the carapace. But the former differs by having puncta on growth bands in the dorsal part of the carapace, and a row of small pits between the short radial lirae on growth bands in the ventral part of the carapace.

Ordosestheria multicostata (Chen in Zhang et al., 1976), emend. Figs. 3–6

1976 *Orthestheria intermedia* (Chi), Zhang et al., p. 185–186, pl. 69, figs. 10–12.
1976 *Orthestheria minuta* Chen in Zhang et al., p. 185, pl. 68, figs. 7–9.
1976 *Orthestheria multicostata* Chen in Zhang et al., p. 185, pl. 68, figs. 4–6.
1976 *Orthestheria reniformis* Chen in Zhang et al., p. 184–185, pl. 70, figs. 3–6.

Figured specimens. A right valve (male?), NIGPCAS 165341; a right valve (female?), NIGPCAS 165342; a right valve (male?), NIGPCAS 165343; a left valve (female?), NIGPCAS 165344; a left valve (male?), NIGPCAS 165345.
Dimensions of figured specimens. In order: specimen no. (prefixed NIGPCAS), number of growth lines, length (mm), height (mm), height/length ratio: 165341, 31, 3.0, 2.0, 0.69; 165342, 29, 3.3, 2.4, 0.73; 165343, 49, 3.9, 2.7, 0.69; 165344, >33, 3.3, 2.4, 0.74; 165345, >30, 4.4, 3.0, 0.69.
Emended diagnosis. Carapace thick, convex, of small size, sub-oval (male?) or sub-quadrate (female?) in outline; growth lines wide, prominent, with serrated lower margins; growth bands wide in the dorsal part, narrow and dense in the ventral part of the carapace; growth bands near the umbo ornamented with fine reticulations; growth bands in upper-middle part of the carapace, reticulations change to evenly distributed puncta; growth bands in the lower-middle part of carapace ornamented with widely spaced radial lirae with intercalated fine puncta; the lower part of carapace with a row of small pits to form a row of pronounced short radial lirae in the lower part of each growth band, leaving the upper part of each growth band undulated.
Description. Carapace thick, small, sub-oval (male?) in outline with slightly higher anterior height and narrow posterior margin, or sub-quadrate (female?) with widely rounded anterior and posterior margins; dorsal margin straight and short, at its middle part located the small narrow umbo; growth lines 29–49 in number,

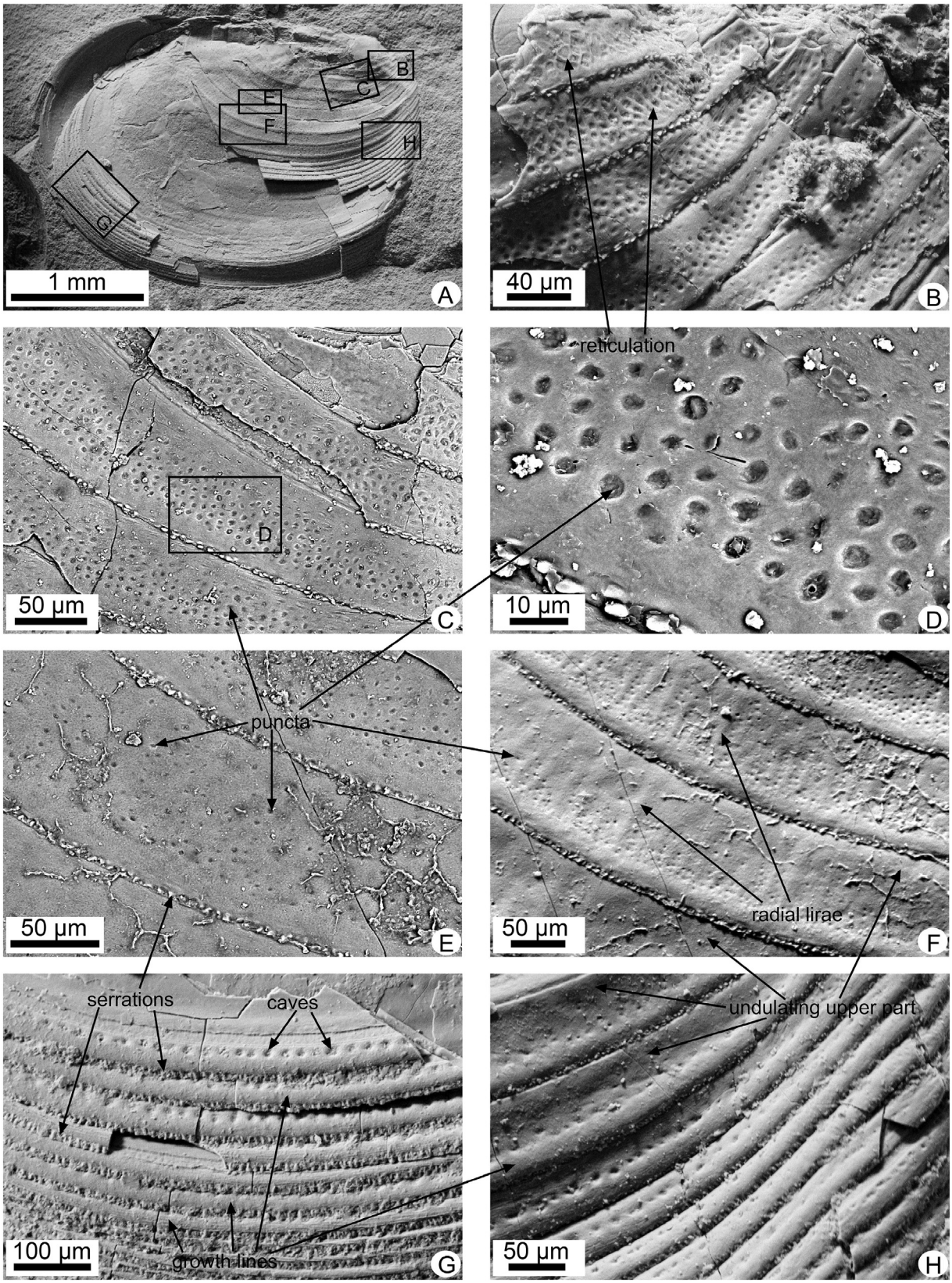

Fig. 3. *Ordosestheria multicostata* (Chen in Zhang et al., 1976), emend. SEM images of the specimen NIGPCAS 165341 from the Lower Cretaceous, upper Albian Dalazi Formation. A, A right valve (male?), a half part of the carapace has disappeared. B, Small-sized polygonal reticulations on the upper two growth bands (near the umbo). C, D, Evenly distributed puncta in the upper part of the carapace, growth lines are serrated in the lower margins. E, Scattered puncta on growth band in the middle part of the carapace, the size of punctum is smaller than those in Fig. 3C. F, Widely spaced radial lirae with intercalated puncta on growth bands in the lower upper part of the carapace. G, Ornamentation on growth bands in the postero-ventral part of the carapace, showing crowded growth lines with serrated lower margins, and a row of small pits along the lower margin of each growth band. H, Ornamentation on growth bands near the anterior margin of the carapace, showing crowded growth lines with serrated lower margins, a row of small pits along the lower margin of each growth band.

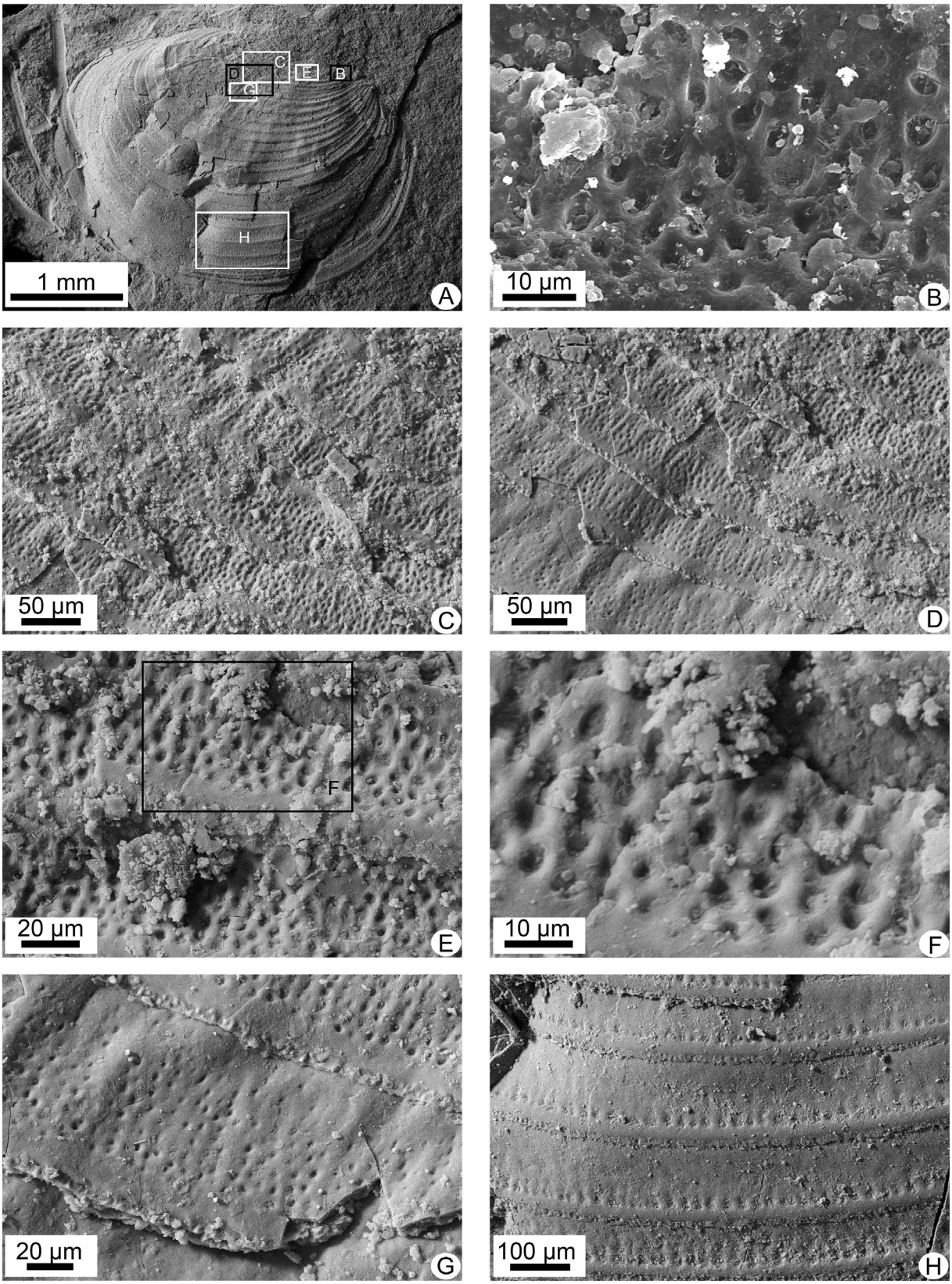

Fig. 4. *Ordosestheria multicostata* (Chen in Zhang et al., 1976), emend. SEM images of the specimen NIGPCAS 165342 from the Lower Cretaceous, upper Albian Dalazi Formation. A, A right valve (female?). B, Dense puncta on growth band in antero-dorsal part of the carapace. C, Ornament on growth bands in dorsal part of the carapace, showing reticulation on the upper bands changes into puncta in the lower bands. D, Puncta intercalated between widely spaced radial lirae in the upper-middle part of the carapace. E, F, puncta in growth bands in the upper part of the carapace. G, Puncta with decreased size on growth bands in the middle part of the carapace. H, Ornamentation on growth bands near the ventral margin of the carapace, showing a row of small pits along the lower margin and the undulating upper part of each growth band, and serrated growth lines.

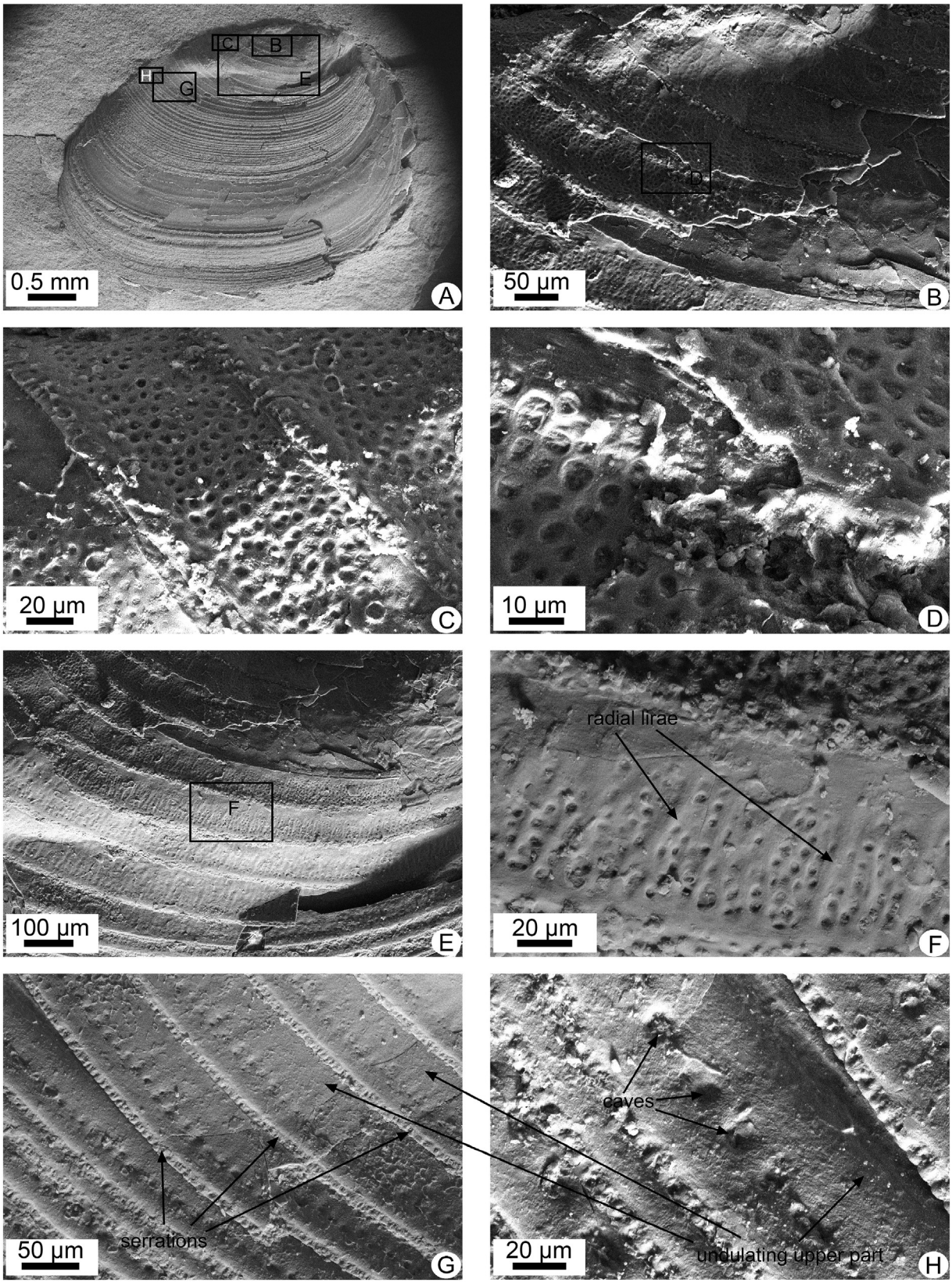

Fig. 5. *Ordosestheria multicostata* (Chen in Zhang et al., 1976), emend. SEM images of the specimen NIGPCAS 165343 from the Lower Cretaceous, upper Albian Dalazi Formation. A, A right valve (male?). B, Ornament on growth bands in the dorsal part of the carapace, showing small-sized reticulation on the upper two growth bands, which changes into puncta on the lower growth bands, widely spaced radial lirae are also developed. C, D, Puncta on growth bands in the dorsal part of the carapace. E, F, Ornamentations on growth bands in the dorsal part of the carapace, showing radial lirae with intercalated puncta. G, H, Ornamentation on growth bands in the postero-middle part of the carapace, showing a row of pits along the lower margin of each growth band, undulating upper part of each growth band, and serrated lower margins of growth lines.

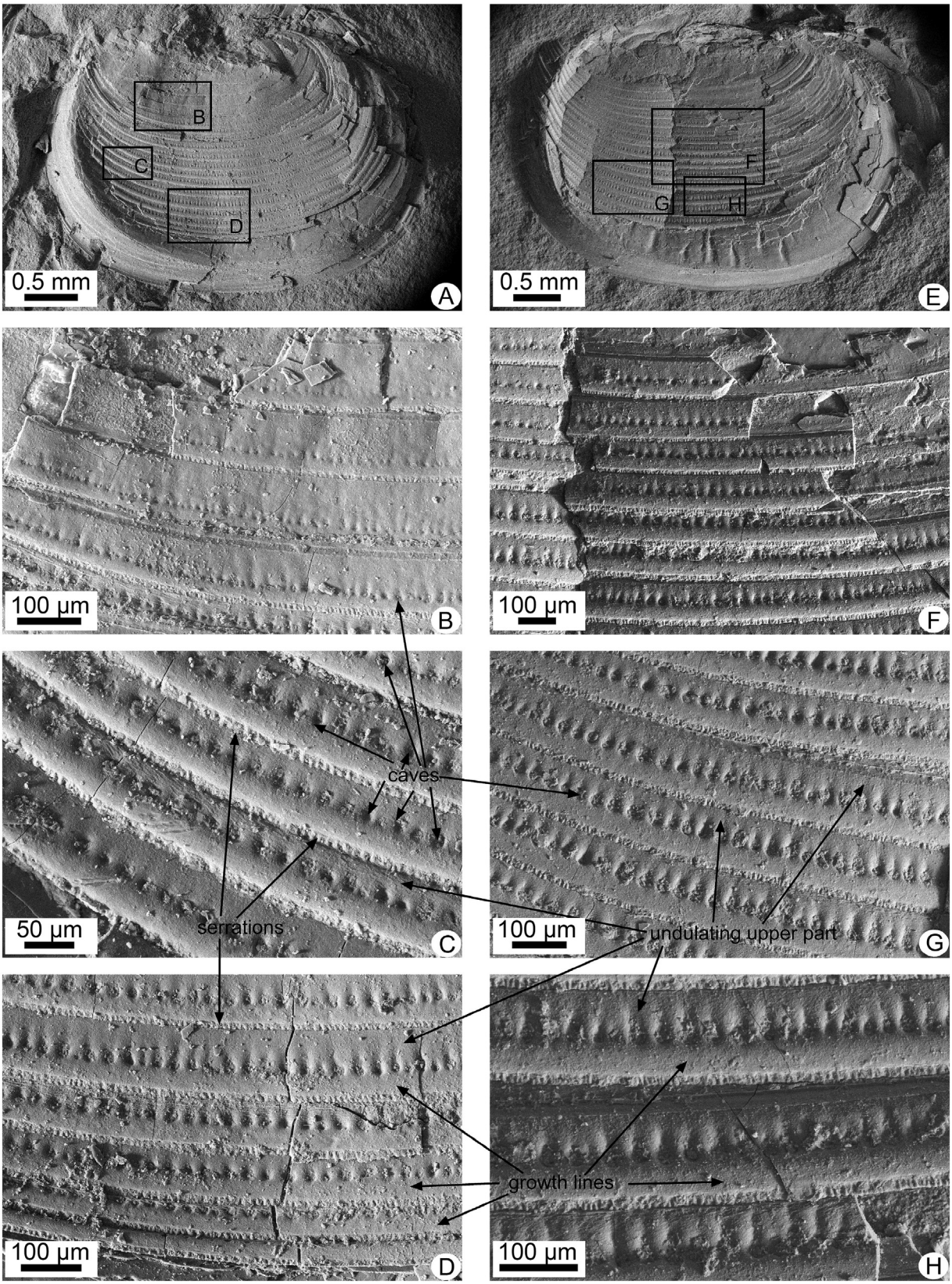

Fig. 6. *Ordosestheria multicostata* (Chen in Zhang et al., 1976), emend. SEM images of specimens from the Lower Cretaceous, upper Albian Dalazi Formation. A–D, Specimen NIGPCAS 165344; A, A left valve (female?); B, Ornamentation in the dorsal part of the carapace, showing a row of pits along the lower margin and undulating upper part of each growth band, growth lines are serrated along the lower margins; C, Ornamentation in the antero-ventral part of the carapace; D, Ornamentation on growth bands near the ventral margin. E–H, Specimen NIGPCAS 165345; E, A left valve (male?); F, Ornamentation on the growth bands in the middle part of the carapace, showing a row of pits along the lower margin of each growth band, whose upper part is undulated; G, Ornamentation in the antero-ventral part of the carapace; H, Ornamentation on growth bands in the lower part of the carapace.

wide, prominent, with serrated lower margins; growth bands in the umbonal area narrow, relatively wider below (Fig. 4A), and become narrower again (Fig. 6A), or extremely narrow and crowded (Figs. 3A, 5A) in the lower part of the carapace; growth bands near the umbo ornamented with polygonal fine reticulations, mesh wall thin, mesh diameter about 6–10 μm (Figs. 3B, 5B); then on subsequently lower growth bands reticulate ornament changes to evenly distributed puncta, which are about 3–5 μm in diameter (Figs. 3B–3D, 4B, 5C, 5D); further below on the upper part of the carapace, puncta become smaller, irregularly distributed on growth bands (Fig. 3E), which are intercalated between widely spaced radial lirae on the growth band further lower (Figs. 3F, 4D, 4G, 5E, 5F); finally each growth band in the middle and lower part of the carapace are undulated in its upper part (Figs. 3H, 5G, 6B), with a row of small pits along its lower margin to form a row of pronounced short radial lirae on the lower part of each growth band (Figs. 3G, 4H, 6D, 6F–6H).

Discussion. Chen in Zhang et al. (1976) erected the genus *Orthestheria* and described it as being ornamented with regular radial lirae on the growth bands. He had also described four species from the Dalazi Formation, they are *Orthestheria intermedia* (Chi, 1931), *O. minuta* Chen in Zhang et al., 1976, *O. multicostata* Chen in Zhang et al., 1976 and *O. reniformis* Chen in Zhang et al., 1976. These species were discriminated in carapace size and outline, and growth band density. *O. intermedia* is of sub-quadrate outline. *O. minuta*, *O. multicostata* and *O. reniformis* are oval in outline, but the former is smaller than other species in size. We examined the type specimens of these species under an SEM, and found that they have not only radial lirae on growth bands, but also with puncta between the radial lirae, and a row of pits on growth bands in the ventral part of the carapace, thus they could be assigned to *Ordosestheria*. Because they have similar ornamentation, we think that *O. minuta* is probably a junior synonym of *O. reniformis*. And considering the sexual dimorphism, we regard *Orthestheria intermedia* and *O. reniformis* as synonyms of *Ordosestheria multicostata*.

Ordosestheria multicostata is very similar to the type species *Ordosestheria wujiamiaoensis* in outline. But they differ in that the latter has less number of growth bands, and a row of pores in growth lines. Because of the poor preservation in the dorsal part of the carapace in *Or. wujiamiaoensis*, a new collection is needed to check if the fine reticulate and punctate ornamentation could be found on the growth bands near the umbo in *Or. wujiamiaoensis*.

Orthestheria intermedia described from the Lower Cretaceous Shouchang Formation at the Dongcun village of Zhejiang (Chi, 1931; Zhang et al., 1976; Chen and Shen, 1982) are quite different from *Ordosestheria multicostata* (including previously *Orthestheria intermedia* described from the Dalazi Formation) in that the former is only ornamented by stout and neat radial lirae on growth bands.

Occurrence. Upper Albian Dalazi Formation of Yanji, Jilin Province, north-eastern China.

6. Conclusions

We have identified an *Ordosestheria* species from the upper Albian Dalazi Formation, north-eastern China relying on examination of specimens under an SEM, which were previously described as species of *Orthestheria*. As a result, we confirmed that the distribution of *Ordosestheria* species is wider than we thought before, and this genus can be an index genus for the subdivision of non-marine sequences in China. According to previous studies we tentatively propose that the ordosestheriids first originated from northern Africa in the early Barremian, during the early Aptian transgression they escaped from northern Africa and dispersed to the Ordos Basin of eastern Asia, then they further dispersed eastward to the western palaeo-Pacific coastal area and colonized in the Yanji Basin in late Albian.

Acknowledgements

This study was supported by National Natural Science Foundation of China (41572006, 91514302, 41688103) and the Strategic Priority Pre-Research Program (B) of the Chinese Academy of Sciences (XDPB05). The SEM micrographs were taken through the courtesy of the LEO 1530 VP facility, State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing. Many thanks go to Mr. F. Scholze (TU Bergakademie Freiberg & Kazan Federal University, Russia) and an anonymous reviewer for their constructive comments to improve the manuscript.

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