

## A MIXED PERMIAN-TRIASSIC BOUNDARY BRACHIOPOD FAUNA FROM GUIZHOU PROVINCE, SOUTH CHINA

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*Abstract.* Although many studies have been concerned with Changhsingian brachiopod faunas in South China, brachiopod faunas of the mixed nearshore clastic-carbonate facies have not been studied in detail. In this paper, a brachiopod fauna collected from the Changhsingian Wangjiazhai Formation and the Griesbachian Yelang Formation at the Liuzhi section (Guizhou Province, South China) is described. The Liuzhi section represents mixed clastic-carbonate facies and yields 30 species of 16 genera of brachiopod. Among the described and illustrated species, new morphological features of genera *Peltichia*, *Prelissorbynchia* and *Spiriferellina* are provided. Because of limited materials, four undetermined species instead of new species from these three genera are proposed. The Liuzhi brachiopod fauna from lower part of the Wangjiazhai Formation shares most genera with fauna of carbonate facies in South China, and the fauna from the upper part is similar to that from the Zhongzhai and Zhongying sections, representative shallow-water clastic facies sections in Guizhou Province. Consistent with the lithological feature of the Wangjiazhai Formation at the Liuzhi section, the Liuzhi brachiopod fauna shows similar changing pattern with fauna from sections of shallow-water clastic and carbonate facies, and all present a sudden decline of diversity prior to the Permian-Triassic boundary.

### INTRODUCTION

As one of the most severely affected organisms in the end-Permian mass extinction (EPME) (Carlson 1991; Shen & Shi 2002), brachiopod plays a vital role in understanding the mechanism of this major crisis. South China yields numerous successive Permian-Triassic boundary sections deposited in varies of marine environmental settings (Feng et al. 1997). Over the past decades, there have been many studies published on brachiopods of the Permian-Triassic boundary interval in South China. So far, most studies are from the three typical depositional settings, namely the nearshore clastic

(Zhu 1990; Zhang et al. 2013, 2014a, 2015), the shallow-water carbonate (Huang 1932, 1933; Shen et al. 1992; Shen & Shi 2007; Chen et al. 2009a) and the deep-water siliciclastic facies (He et al. 2005, 2014; Chen et al. 2009b), and there are only two records from the mixed siliciclastic-carbonate facies (Shen & He 1994; Wu et al. 2018a). It was found that these brachiopod faunas from different sedimentary facies present different extinction patterns. Compared with the shallow-water environments (both carbonate platform and clastic-shelf), extinction occurred earlier and showed a two-episode pattern in the deep-water siliciclastic facies (He et al. 2015, 2016, 2019; Zhang et al. 2017; Shen et al. 2018). The difference of extinction pattern might identify the most likely trigger mechanism among the commonly recommended causes (e.g., global

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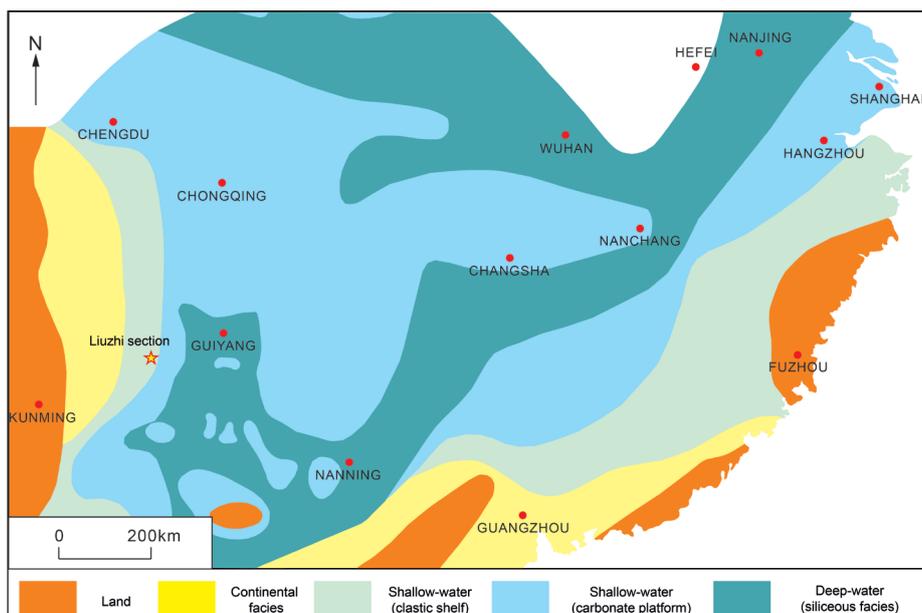


Fig. 1 - Palaeogeographical map of South China during Changhsingian (modified from Feng et al. 1997), and locality of Liuzhi section.

warming, anoxia, ocean acidification, Winguth & Winguth 2012; Brand et al. 2016; Silva-Tamayo et al. 2018). Therefore, studying brachiopod fauna from various sedimentary facies could provide vital information to fully understand the end-Permian mass extinction. However, no systematical work has been undertaken on the brachiopod fauna of the mixed nearshore clastic-carbonate facies by now, and the nature of the brachiopod fauna in such mixed facies and its extinction pattern still remain unclear.

In this paper, we describe a well-preserved brachiopod fauna of such mixed nearshore clastic-carbonate facies from the Liuzhi section, discuss the fauna changing pattern across the Permian-Triassic boundary and compare it with other contemporaneous fauna from different sedimentary facies in South China.

## GEOLOGICAL SETTING AND AGE

The Liuzhi section is located about 15 km southwestern to Liuzhi County, Guizhou Province, China. Palaeogeographically, the section is located in the junction area between shallow-water clastic and carbonate facies (Fig. 1). It spans the uppermost part of the Wangjiazhai Formation (Permian) and lowermost part of the Yelang Formation (Triassic). At the Liuzhi section, the Wangjiazhai Formation comprises siliceous and silty limestone and calcareous mudstone in the lower part, calcareous and silty mudstone in the upper part. Brachiopods yielded

in the lower part of Wangjiazhai Formation of the Liuzhi section, contains many relatively large and thick-shelled brachiopods, which is similar to brachiopods from the carbonate facies (Liao 1980b). Brachiopods from the upper part are very similar to that from the shallow-water clastic facies (Zhang et al. 2013, 2014a, 2015). Therefore, the palaeogeographical, lithological and biological evidences indicate that the Wangjiazhai Formation at the Liuzhi section represents a transitional sedimentary facies from shallow-water clastic facies to carbonate facies. At the Liuzhi section, the Yelang Formation conformably overlies the Wangjiazhai Formation, and comprises claystone in the basal part, calcareous mudstone and limestone in the upper part.

The Changhsingian age can be determined by the associated ammonoid *Pseudotirolites* in the Wangjiazhai Formation, which is a typical ammonoid genus for the late Changhsingian (Yang et al. 1987). The Permian-Triassic boundary (PTB) is temporarily located at the middle of bed 8 by lithological correlation with the very near Zhongzhai section and the occurrence of *Claraia wangi* in bed 10. Bed 6 at the Liuzhi section can be correlated to bed 27 at the Zhongzhai section by them both featured with calcareous mudstone and yielding extremely abundant *Fusichonetes* and *Neochonetes* (Fig. 2). The limestone in bed 7 and bed 8 at the Liuzhi section match the limestone of bed 28 and bed 30 at the Zhongzhai section. Thus, despite of no fossils found in beds 7-9, we temporarily locate the PTB of the Liuzhi section at the base of limestone of

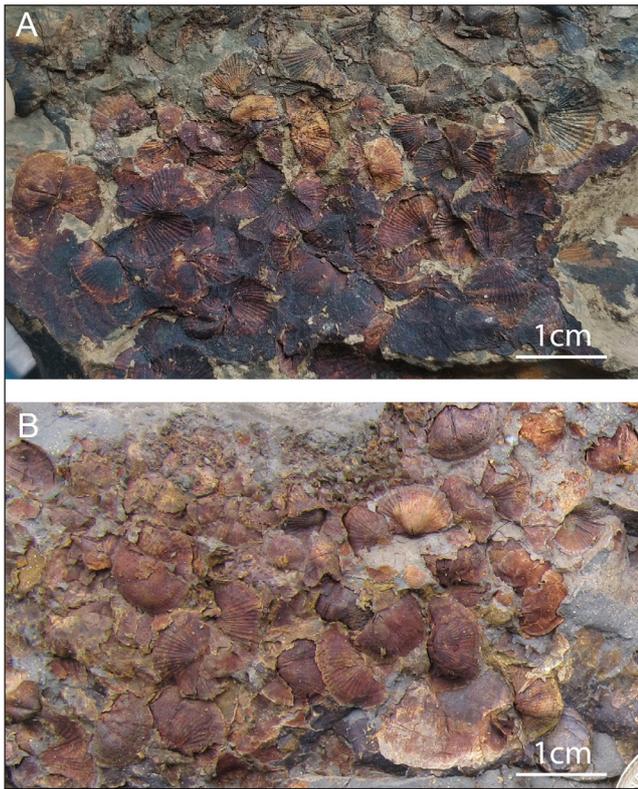


Fig. 2 - Brachiopod fauna of bed 6 at the Liuzhi section (A) and bed 27 at the Zhongzhai section (B) at outcrop.

bed 8 corresponding to the PTB at the base of bed 30 at the Zhongzhai section (Zhang et al. 2014b).

#### COMPARISON OF THE BRACHIOPOD FAUNA WITH OTHERS FROM DIFFERENT SEDIMENTARY FACIES IN SOUTH CHINA AND ITS EXTINCTION PATTERN

In the lower part of the Wangjiazhai Formation at the Liuzhi section, brachiopod fauna is mainly composed of *Peltichia*, *Spinomarginifera*, *Acosarina*, *Oldhamina* and *Araxathyris*. In the upper part of the Wangjiazhai Formation, it is mainly composed of *Fusichonetes*, *Neochonetes*, some *Orbicoelia* and *Acosarina*. In the lower part of Yelang Formation, only *Orbicoelia* and *Lingularia* remain in the earliest Triassic brachiopod fauna. Consistent with the mixed lithological feature of the Wangjiazhai Formation at the Liuzhi section, the Liuzhi fauna shows mixed feature of fauna from shallow-water carbonate and clastic facies. Based on exhaustive section-based investigation of Changhsingian brachiopod fauna in South China, Liao (1979) recommended that brachiopod

fauna from the carbonate platform environment is represented by *Peltichia zigzag*-*Spinomarginifera alpha* assemblage, and also mainly contains *Oldhamina*, *Araxathyris*, *Acosarina*, *Alphaneospirifer*, *Perigeyerella* and *Martinia*. Liao (1980a) and Zhang et al. (2017) reported brachiopod faunas from the Zhongzhai and Zhongying sections of the shallow-water clastic facies. Their data showed that the fauna from the shallow-water clastic facies contains abundant *Fusichonetes* and *Neochonetes*, some *Paryphella* and *Spinomarginifera* and a few other genera. Obviously, the Liuzhi fauna from lower part of the Wangjiazhai Formation resembles the brachiopod fauna from carbonate facies proposed by Liao, and fauna from upper part of the Wangjiazhai Formation is similar to that from the shallow-water clastic facies. The Liuzhi fauna is somewhat similar to that from the siliciclastic facies in sharing *Fusichonetes* as one of the dominant genera (Wu et al. 2018b). However, the other dominant genus in the siliciclastic facies is *Crurithyris* (at the Rencunping, Majiashan and Xinmin sections), and *Neochonetes* only sporadically distributes at these sections, which should be the essential difference between these two types of brachiopod fauna.

As is shown in the stratigraphic distribution of brachiopods (Fig. 3), there are two faunal changes existed in the Liuzhi fauna. The first change occurred in bed 5 is apparently attributed to the lithological change. The second one in bed 10 is the extinction level, marked by the decrease of abundance (from hundreds to only several specimens) and diversity (from 18 to two species). Above this level, two brachiopod species (*Orbicoelia speciosa* and *Lingularia* sp.) persist to the earliest Triassic with low abundance. According to He et al. (2015, 2016), there are five species at the Rencunping section (siliciclastic facies), seven species at the Majiashan (siliciclastic facies) and Daoduishan sections (siliciclastic-carbonate facies) persisted above the extinction horizon. There is no or only one articulated brachiopod species existed in the post extinction interval at Zhongzhai section (shallow-water clastic facies, Zhang et al. 2017) and Daijianggou section (shallow-water carbonate facies, Yuan et al. 2015). Therefore, consistent with the lithological feature, changing pattern of the Liuzhi brachiopod fauna is similar to that at the Zhongzhai section of shallow-water clastic facies and Daijiagou section of shallow-water carbonate facies, and presents a single-episode extinction pattern.

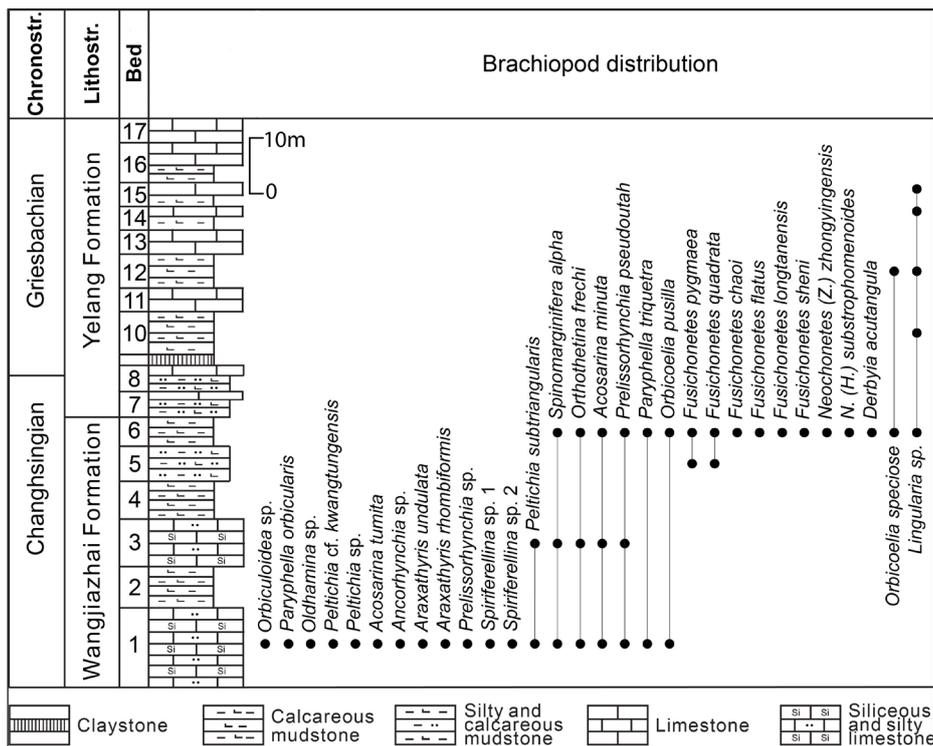


Fig. 3 - Distribution of brachiopods from the Wangjiazhai Formation to the basal Yelang Formation at the Liuzhi section.

## SYSTEMATIC PALAEOONTOLOGY

All the described and illustrated specimens were collected from the Liuzhi section, Guizhou province, South China. All specimens were deposited in School of Earth Sciences and Resources, China University of Geosciences, Beijing, China, numbered with prefixes LZ. The classification above genus level here follows Kaesler 1997, 2000a, b, 2002, 2006; Selden 2007.

Order **Lingulida** Waagen, 1885  
 Superfamily Linguloidea Menke, 1828  
 Family Lingulidae Menke, 1828  
 Genus *Lingularia* Biernat & Emig, 1993

### *Lingularia* sp.

Fig. 4A-C

**Material:** An external mould of a dorsal valve (LZ001003); two ventral valves (LZ001002, LZ001001).

**Brief description.** Shell small in size, elongate in outline; slightly biconvex in lateral profile, maximum convexity at umbonal region; lateral sides slightly divergent or parallel, anterior side rounded; maximum width at middle to anterior part of shell; external surface with numerous concentric striae.

**Discussion.** The specimen is similar to species of *Lingularia* in outline and lateral profile. Since our specimens have no internal structures preserved,

they were not assigned into any existed species.

**Occurrence.** Changhsingian (late Lopingian) to Griesbachian (earliest Triassic); South China.

Superfamily Discinoidea Gray, 1840  
 Family Discinidae Gray, 1840  
 Genus *Orbiculoidea* d'Orbigny, 1847

### *Orbiculoidea* sp.

Fig. 4D

**Material:** A ventral valve (LZ001111).

**Brief description.** Medium in size for the genus, rounded in outline. Ventral valve conical, apex located at posterior 1/3 of shell; pedicle track narrow and short; shell ornamented with concentric lines.

**Discussion.** The specimen can be assigned to genus *Orbiculoidea* based on its rounded outline and concentric line on shell.

**Occurrence.** Changhsingian (late Lopingian); South China.

Order **Productida** Sarytcheva & Sokolskaya, 1959  
 Suborder **Chonetidina** Muir-Wood, 1955  
 Superfamily Chonetoidea Bronn, 1862

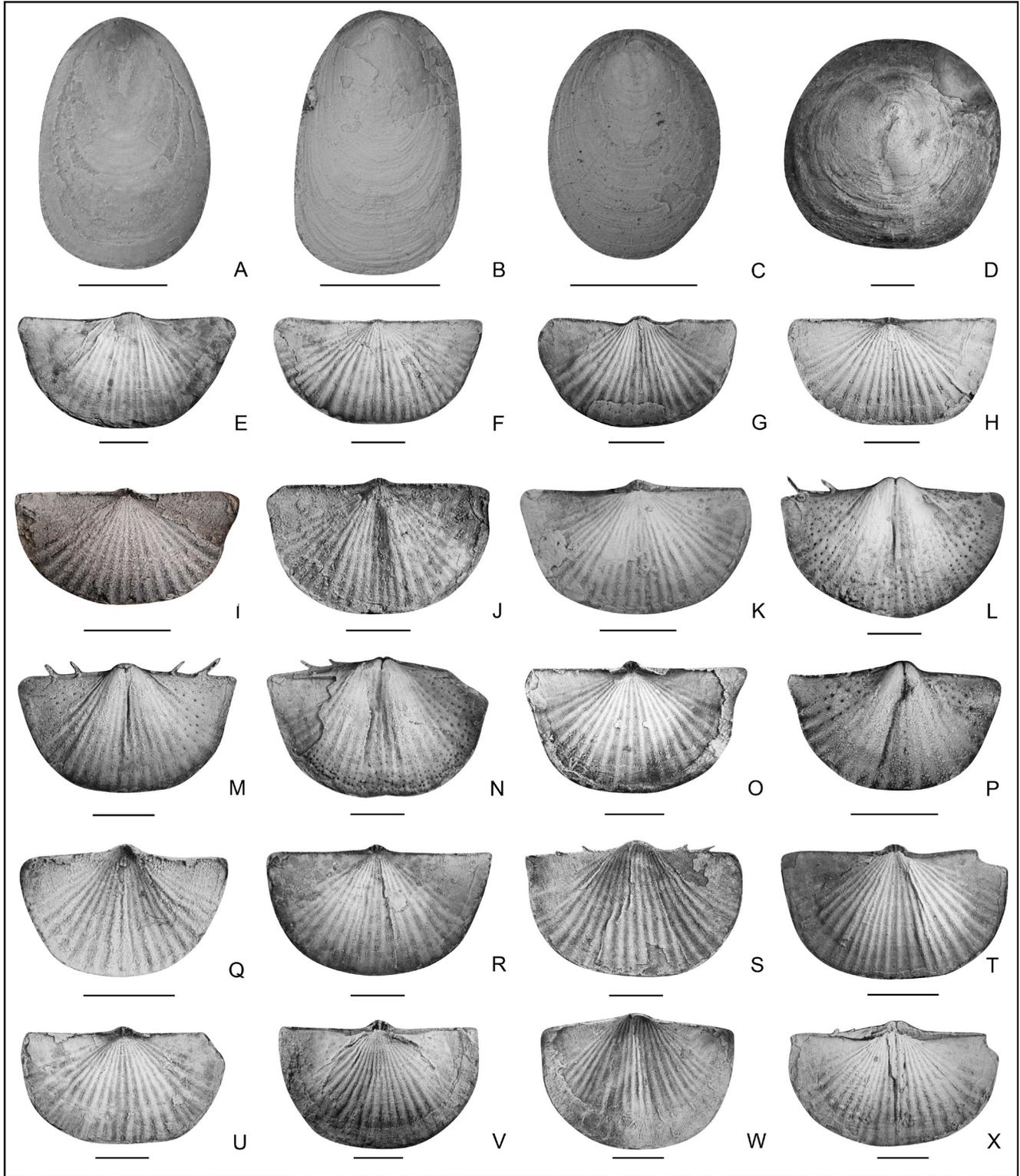


Fig. 4 - A-C - *Lingularia* sp., A) external mould of dorsal valve, LZ001003; B, C) ventral valves, LZ001002, LZ001001. D - *Orbiculoidea* sp., ventral valve, LZ001111. E-I - *Fusichonetes chaoi* (Chen et al., 2000), external moulds of dorsal valves, LZ006003, LZ006029, LZ006040, LZ006052, LZ006069. J-K - *Fusichonetes flatus* (Shen & Archbold, 2002), J) external mould of dorsal valve, LZ006039; K) external mould of dorsal valve with part of internal mould dorsal valve, LZ006063. L-N) *Fusichonetes longtanensis* (Liao, 1984), internal moulds of ventral valves, LZ006005, LZ006032, LZ006014. O-R - *Fusichonetes pygmaea* (Liao, 1980a), O, R) external moulds of dorsal valves, LZ006043, LZ006050; P) internal mould of ventral valve, LZ006074; Q), external mould of ventral valve, LZ006066. S-U - *Fusichonetes quadrata* (Zhan in Hou et al., 1979), S) external mould of ventral valve, LZ006006; T, U) external moulds of dorsal valves, LZ006009, LZ006062. V-X - *Fusichonetes sheni* (Zhang et al., 2013), V) external mould of dorsal valve, LZ006018; W) external mould of ventral valve, LZ006036; X) external mould of dorsal valve with part of internal mould of ventral valve, LZ006047. Scale bars are equal to 2 mm.

Family Rugosochonetidae Muir-Wood, 1962  
Genus *Fusichonetes* Liao in Zhao et al., 1981

***Fusichonetes chaoi*** (Chen et al., 2000)

Fig. 4E-I

1974 *Waagenites barusiensis* - Jin et al., p. 331, pl. 164, fig. 8.

2013 *Tethyochonetes chaoi* - Zhang et al., p. 227, fig. 5A.

2018a *Fusichonetes chaoi* - Wu et al., p. 347, figs 6E-G.

**Material:** Five external moulds of dorsal valves (LZ006003, LZ006029, LZ006040, LZ006052, LZ006069).

**Description.** Shell medium in size for the genus; transverse reverse trapezoid in outline, maximum width at hinge line; width approximately twice of length; moderately concavoconvex in profile; cardinal extremities normally obtuse; ears slightly inflated, smooth or partly costellate, well demarcated from visceral region; lateral sides slightly to moderately rounded, anterior side almost straight; external surface of visceral region with simple and coarse costellae, distinctly originating from umbo, occasionally intercalated and bifurcated; very small tubes irregularly distributed along costellae. Dorsal valve slightly to moderately concave; maximum convexity at the midlength part; umbonal region slightly swollen, not or slightly beyond hinge; fold slightly to moderately developed, originating from umbo anterior, widening anteriorly.

**Discussion.** The species can be differentiated from most of its counterparts by its larger width/length ratio, except for *Fusichonetes nayongensis* (Liao, 1980a) and *Fusichonetes soochowensis* (Chao, 1928). *F. nayongensis* differs from *F. chaoi* by its much more acute cardinal extremities, and stronger costellae. *F. soochowensis* is distinguished from the current species by its more acute cardinal extremities and more costellae.

**Occurrence.** Changhsingian (late Lopin-gian); South China.

***Fusichonetes flatus*** (Shen & Archbold, 2002)

Fig. 4J-K

2002 *Tethyochonetes flatus* Shen & Archbold, p. 342, fig. 6H-N.

2014 *Tethyochonetes flatus* - He et al., p. 919, fig. 6P.

**Material:** An external mould of a dorsal valve (LZ006039); an external mould of a dorsal valve with part of internal mould of a dorsal valve (LZ006063).

**Description.** Shell small to medium in size for the genus, reverse-trapezoidal in outline, maxi-

imum width at hinge line; cardinal extremities obtuse, cardinal angle almost 90°; ears flat, partly costellate, well demarcated from visceral region; lateral sides slightly rounded, anterior side straight to slightly rounded; external surface of visceral region with coarse and simple costellae, distinctly originating from umbo, occasionally bifurcated; thin and long micro tubes along costellae. Dorsal valve slightly concave; umbonal region slightly swollen, maximum convexity in middle part of shell; fold distinct, originating from umbonal region, widening anteriorly. Dorsal interior with quadrilobate cardinal process.

**Discussion.** It resembles *Fusichonetes pygmaea* (Liao, 1980a) and *Fusichonetes quadrata* (Zhan in Hou et al., 1979) in outline, but it has much flatter shell. It is somewhat similar to *F. cheni* in outline and profile, but the latter has no fold and sulcus.

**Occurrence.** Changhsingian (late Lopin-gian); South China.

***Fusichonetes longtanensis*** (Liao, 1984)

Fig. 4L-N

1984 *Waagenites longtanensis* Liao, p. 279, pl. 1, figs 8-9.

2013 *Tethyochonetes longtanensis* - Zhang et al., p. 229, fig. 5B-E.

2014 *Tethyochonetes longtanensis* - He et al., p. 915, fig. 4I-N.

**Material:** Three internal moulds of ventral valves (LZ006005, LZ006032, LZ006014).

**Description.** Shell medium in size for the genus, reverse-trapezoidal to triangular in outline; maximum width at hinge line; cardinal extremities obtuse, cardinal angle close to 90°; ears inflated, smooth, well demarcated from visceral region; lateral sides slightly rounded, anterior side slightly to moderately rounded; external surface ornamented with simple and coarse costellae, originating from umbo, distinctly shown in internal moulds; two pairs of spines at hinge, hinge spines projected convergently first and then posterolaterally. Ventral valve moderately convex, umbonal region swollen, overhanging hinge; maximum convexity in middle to umbonal part of the shell; sulcus distinct and deep, originating from umbo, widening anteriorly. Ventral interior surface with almost even-size papillae, radially and nearly evenly distributed in the interspace of costellae; medium septum short, occurred only in the umbonal part.

**Discussion.** The current species is similar to many species in the genus, like *F. pygmaea*, *F. quadrata*

and *F. flatus*, in outline and width/length ratio, but differs in its distinct and deep sulcus. It also resembles *Fusichonetes nayongensis* (Liao, 1980a) in its sometimes nearly triangular outline, but the latter has much larger width/length ratio.

**Occurrence.** Changhsingian (late Lopingian); South China.

***Fusichonetes pygmaea*** (Liao, 1980a)

Fig. 4O–R

- 1980a *Plicochonetes pygmaea* Liao, p. 257, pl. 4, figs 4–6.  
 1981 *Fusichonetes pygmaea* - Liao in Zhao et al., pl. 8, figs 7, 8.  
 1982 *Fusichonetes pygmaea* - Wang et al., p. 200, pl. 96, figs 8, 9.  
 1984 *Waagenites pygmaea* - Liao, p. 279, pl. 1, fig. 7.  
 2013 *Tethyochonetes pygmaea* - Zhang et al., p. 229, fig. 5F.  
 2014 *Tethyochonetes pygmaea* - He et al., p. 918, fig. 6A–D, H.  
 2018a *Fusichonetes pygmaea* - Wu et al., p. 348, fig. 6J–M.

**Material:** Two external moulds of dorsal valves (LZ006043, LZ006050); an internal mould of a ventral valve (LZ006074); an external mould of a ventral valve (LZ006066).

**Description.** Shell medium in size for the genus, reverse-trapezoidal in outline; moderately concavoconvex in profile; maximum width at hinge line; cardinal extremities acute; ears slightly inflated, smooth, well demarcated from visceral region; lateral sides straight to slightly rounded, anterior side slightly rounded to straight; external surface ornamented with coarse and simple costellae, originating from umbo and occasionally bifurcated, and micro tubes radially distributed on costellae; interior surface covered with radially and unevenly distributed papillae in the interspace of costellae. Ventral valve moderately convex; umbonal region swollen, overhanging hinge; maximum convexity in middle or posterior part of the shell; sulcus moderately developed; medium septum 1/5 to 4/5 of shell length. Dorsal valve moderately to slightly concave; umbonal slightly swollen; maximum convexity in middle part of shell; fold moderately to slightly developed; cardinal process quadrilobate.

**Discussion.** The most similar species in the genus to current species is *F. quadrata*. They both have no very differentiated features, and only have some moderate features, like width/length ratio about 1–2, moderately concavoconvex profile, moderately developed sulcus and fold. Herein we carefully check the original description and illustration of two species. According to the description in Liao (1980a), *F. pygmaea* has no distinctive features except the very large width/length ratio (about 2.5). How-

ever, according to the illustration in Liao (1980a), its width/length ratio is just about 1–2. As for *F. quadrata*, the author described many features which is very different to *Waagenites* (Zhan in Hou et al. 1979), but most of these features are common for *Fusichonetes*. After detailed comparison, we suggest that the only difference between the two species should be that *F. pygmaea* has a reverse-trapezoidal outline while *F. quadrata* has a quadrate to rectangular outline.

**Occurrence.** Changhsingian (late Lopingian); South China.

***Fusichonetes quadrata*** (Zhan in Hou et al., 1979)

Fig. 4S–U

- 1979 *Waagenites soochowensis quadrata* Zhan in Hou et al., p. 70, pl. 4, figs 16–19.  
 2000 *Tethyochonetes quadrata* - Chen et al., pp. 9–10, fig. 4A–D, G.  
 2002 *Tethyochonetes quadrata* - Shen & Archbold, pp. 339, 341, fig. 6B–C.  
 2013 *Tethyochonetes quadrata* - Zhang et al., p. 230, fig. 5K.  
 2014 *Tethyochonetes quadrata* - He et al., pp. 914, 915, fig. 4A–G.

**Material:** An external mould of a ventral valve (LZ006006); two external moulds of dorsal valves (LZ006009, LZ006062).

**Brief description.** Small to medium in size for the genus, subquadrate to subrectangular in outline; moderately concavoconvex to planoconvex in profile; ears slightly inflated, smooth; external surface ornamented with costellae, with a few intercalations; internal surface with radially distributed papillae; fold and sulcus weak to moderately developed.

**Discussion.** It is similar to *Fusichonetes rectangularis* (He et al., 2014) in its subrectangular outline, but the latter has much more transverse outline.

**Occurrence.** Changhsingian (late Lopingian); South China.

***Fusichonetes sheni*** (Zhang et al., 2013)

Fig. 4V–X

- 2013 *Tethyochonetes sheni* Zhang et al., p. 233, fig. 5U–Z.

**Material:** Two external moulds of dorsal valves (LZ006018, LZ006047); an external mould of a ventral valve (LZ006036).

**Description.** Medium in size, roundly reverse-trapezoidal in outline; moderately concavoconvex in profile; hinge slightly shorter than the greatest width; cardinal extremities obtuse, cardinal angle larger than 90°; ears slightly inflated, smooth, well demarcated from visceral region; lateral and anterior sides rounded; external surface ornamented with coarse

and simple costellae, occasionally bifurcated, micro tubes irregularly distributed along costellae. Ventral valve moderately concave; sulcus moderately developed; medium septum short. Dorsal valve slightly to moderately developed, fold slightly to moderately developed.

**Discussion.** It can be easily distinguished from other species in the genus by its rounded outline and hinge shorter than greatest width.

**Occurrence.** Changhsingian (late Lopingian); South China.

Genus *Neochonetes* Muir-Wood, 1962

Subgenus *Neochonetes* (*Huangichonetes*) Shen & Archbold, 2002

***Neochonetes* (*Huangichonetes*) *substrophomenoides***  
(Huang, 1932)

Fig. 5A-I

- 1932 *Chonetes substrophomenoides* Huang, pp. 3-5, pl. 1, figs 3-7.  
1964 *Chonetinella substrophomenoides* - Wang et al., pp. 243, 244, pl. 37, fig. 31.  
1977 *Neochonetes substrophomenoides* - Yang et al., p. 331, pl. 135, fig. 20.  
1978 *Chonetinella substrophomenoides* - Feng & Jiang, pp. 242, 243, pl. 88, fig. 1.  
1979 *Neochonetes sublatisinuata* Zhan in Hou et al., p. 70, pl. 11, figs 5, 6, 8.  
1980a *Neochonetes convexa* Liao, p. 257, pl. 5, fig. 18.  
1982 *Neochonetes substrophomenoides* - Wang et al., p. 200, pl. 96, figs 10, 11.  
1989 *Neochonetes* cf. *substrophomenoides* - Zhan in Li et al., pl. 25, fig. 16.  
2002 *Neochonetes* (*Huangichonetes*) *substrophomenoides* - Shen & Archbold, pp. 337, 338, fig. 5E-J, L, M.  
2013 *Neochonetes* (*Huangichonetes*) *substrophomenoides* - Zhang et al., pp. 235-239, fig. 9M-Z.

**Material:** Two external moulds of dorsal valves (LZ006019, LZ006064); seven internal moulds of ventral valves (LZ006007, LZ006008, LZ006013, LZ006017, LZ006038, LZ006042, LZ006058).

**Description.** Medium in size, reversely trapezoidal to subquadrate in outline ( $1.4 < \text{width/length} < 1.8$ ), maximum width at hinge line; cardinal extremities obtuse, cardinal angle  $60-90^\circ$ ; ears slightly inflated, smooth, well demarcated from visceral region; lateral and anterior sides slightly rounded to nearly straight; external surface ornamented with costellae with intercalation and bifurcation, distinctly originating from umbo, numbering about 30 at margin; hinge spine not well preserved, four pairs of spines at hinge, convergently projecting first and then posterolaterally projecting. Ventral valve moderately to strongly convex; umbonal region inflated, overhanging hinge; maximum convexity in middle

to posterior part of shell; sulcus slightly to moderately developed. Ventral internal surface with papillae radially distributed, inflated near marginal area and forming a distinct half-ring shape, and turning into very small size at marginal area; medium septum short, about  $1/5$  to  $1/3$  of shell length.

**Discussion.** The species is quite similar to *Neochonetes* (*Huangichonetes*) *meishanensis* (Li & Shen, 2008) in its reversely trapezoidal outline and moderately to strongly convex ventral valve. When Li & Shen (2008) proposed *Neochonetes* (*Huangichonetes*) *meishanensis*, it was suggested that the latter one differs in having weak to nearly no sulcus and smaller size. Actually, the current species also sometimes developed weak to nearly sulcus, as is shown in Shen & Archbold (2002). Thus, the only difference between the two species should be that *N.* (*H.*) *meishanensis* has much smaller size than the current species. It is also somewhat similar to *Neochonetes* (*Huangichonetes*) *costellata* (Cooper & Grant, 1975) in its outline and lateral profile, but the latter has much thinner and more costellae.

**Occurrence.** Capitanian (late Guadalupian) to Griesbachian (earliest Triassic); China, Japan and Malaysia.

Subgenus *Neochonetes* (*Zhongyingia*) Shen & Archbold, 2002

***Neochonetes* (*Zhongyingia*) *zhongyingensis*** Liao,  
1980a

Fig. 5J-M

- 1980a *Neochonetes zhongyingensis* Liao, p. 257, pl. 5, figs 10-13.  
2002 *Neochonetes* (*Zhongyingia*) *zhongyingensis* - Shen & Archbold, pp. 333, 334, fig. 4A-Q  
2013 *Neochonetes* (*Zhongyingia*) *zhongyingensis* - Zhang et al., pp. 243, 244, fig. 12W-AA.

**Material:** An internal mould of a dorsal valve (LZ006034); three external moulds of dorsal valves (LZ006061, LZ006070, LZ006073).

**Description.** Shell medium in size for the subgenus, reversely trapezoidal in outline; greatest width along hinge; cardinal extremities obtuse, cardinal angle about  $80^\circ$ ; ears flat, smooth, well demarcated from visceral region; lateral and anterior sides mostly straight; external surface ornamented with costellae, distinctly originating from umbo, with intercalation and bifurcation near anterior and lateral margin, numbering 28-46 at margin; micro tubes ra-

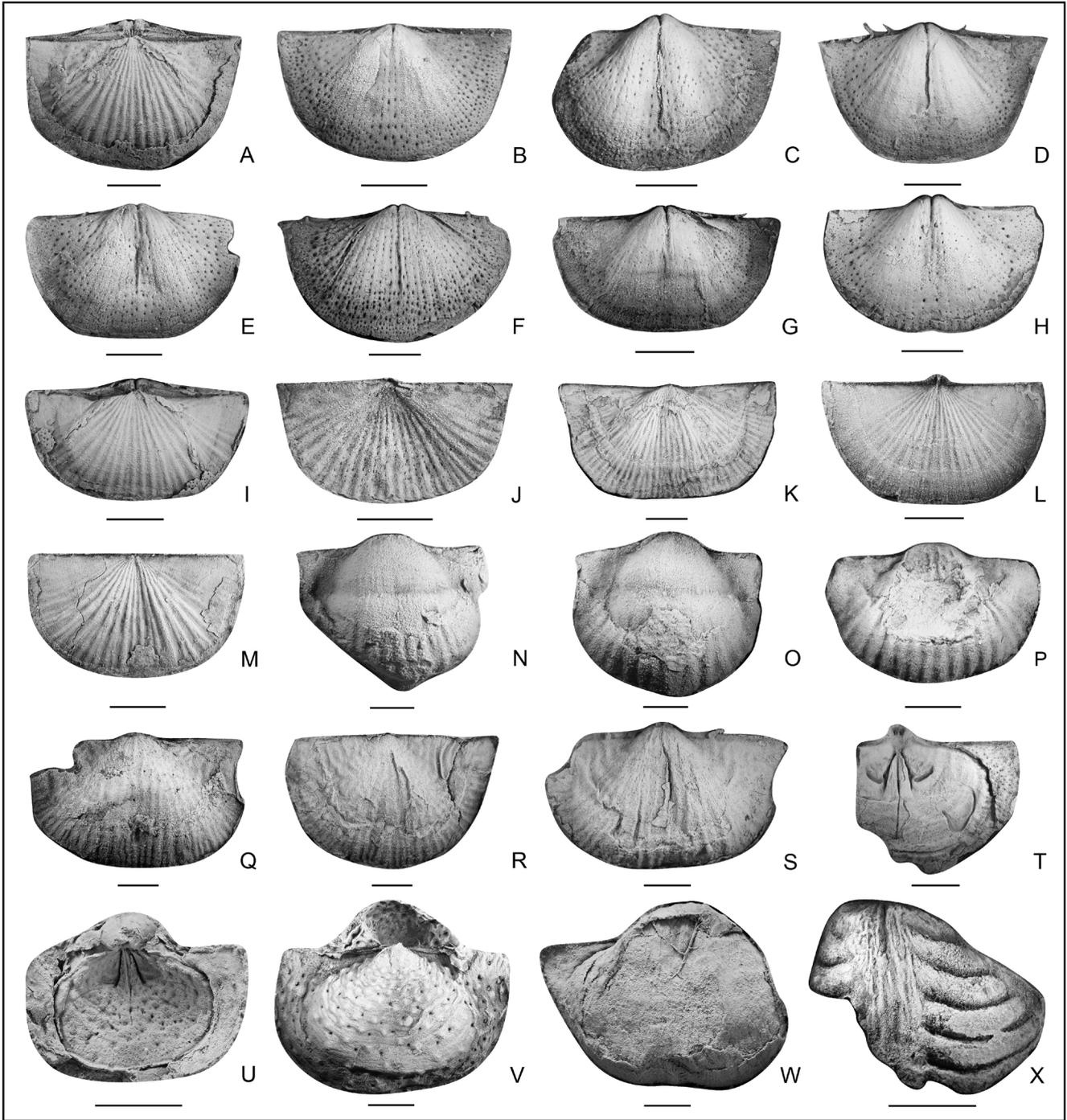


Fig. 5 - A-I - *Neobonetes (Huangichonetes) substrophomenoides* (Huang, 1932), A, I) external moulds of dorsal valves, LZ006019, LZ006064; B-H) internal moulds of ventral valves, LZ006007, LZ006008, LZ006013, LZ006017, LZ006038, LZ006042, LZ006058. J-M - *Neobonetes (Zhongyingia) zhongyingensis* Liao, 1980a, J) internal mould of dorsal valve, LZ006034; K, L, M) external moulds of dorsal valves, LZ006061, LZ006070, LZ006073. N-P - *Parypbella orbicularis* (Liao, 1980a), ventral valves, LZ006091, LZ006092, LZ006023. Q-S - *Parypbella triquetra* Liao in Zhao et al., 1981, S) ventral valve, LZ006093; Q, R) external moulds of dorsal valves, LZ006025, LZ006090. T-W - *Spinomarginifera alpha* (Huang, 1932), T, U) internal moulds of dorsal valves, LZ006128, LZ006125; V) external mould of dorsal valve, LZ001123; W) ventral valve, LZ001012. X - *Oldbamina* sp., internal mould of ventral valve, LZ001086. Scale bars are equal to 2 mm, except in T, U, W, X, scale bars are equal to 6 mm.

dially distributed on costellae. Dorsal valve slightly concave to almost flat; umbonal region slightly swollen; maximum convexity in posterior part of shell; fold moderately to slightly developed; papillae radi-

ally distributed, decreasing in size towards marginal area; socket elongate, inner socket ridges thin and paralleled with hinge and outer socket ridges divergent at an angle about 140°.

**Discussion.** It can be easily differentiated from species in other subgenus by its nearly flat dorsal valve and slightly convex ventral valve. It differs from *Neochonetes (Zhongyingia) transversa* Zhang et al., 2015 by the latter having larger width/length ratio.

**Occurrence.** Wuchiapingian (Lopingian) to Griesbachian (earliest Triassic); China and Japan.

Suborder **Productidina** Waagen, 1883

Superfamily Productoidea Gray, 1840

Family Productellidae Schuchert, 1929

Subfamily Productininae Muir-Wood & Cooper,  
1960

Genus *Paryphella* Liao in Zhao et al., 1981

***Paryphella orbicularis*** (Liao, 1980a)

Fig. 5N-P

1980a *Cathaysia orbicularis* Liao, p. 261, pl. 6, figs 8-10.

1980b *Paryphella orbicularia* - Liao, pl.1, figs 17, 18, pl. 2, figs 3.

1982 *Paryphella orbicularis* - Wang et al., p. 205, pl. 96, fig. 16.

1984 *Paryphella orbicularis* - Liao, pl. 2, fig. 19.

1994 *Cathaysia orbicularis* - Xu & Grant, p. 34, pl. 19, figs 1-6, 11-21.

2006 *Paryphella orbicularis* - Chen et al., pp. 312, 313, figs 6a-g.

2014 *Paryphella orbicularis* - He et al., pp. 933, 934, fig. 14B-H.

2015 *Paryphella orbicularis* - Zhang et al., p. 303, fig. 4P.

2018a *Paryphella orbicularis* - Wu et al., p. 349, fig. 6W-Y.

2019 *Paryphella orbicularis* - He et al., pp. 91-97, figs 9.16-18.

**Material:** Three ventral valves (LZ006091, LZ006092, LZ006023).

**Description.** Shell medium in size for the genus, subquadrate in outline; greatest width along hinge; cardinal extremities obtuse, cardinal angle about 90°; ears slightly inflated, small and smooth, well demarcated from visceral region by a groove; lateral sides nearly straight, anterior side rounded; external surface ornamented with coarse and simple costae, originating from middle part of shell. Ventral valve moderately convex; visceral region triangularly hummocky; maximum convexity in middle to posterior part of shell; sulcus nearly absent.

**Discussion.** *Paryphella corculum* (Liao, 1980a) and *Paryphella laobushanensis* Wang, 1982 are similar to the current species in their triangularly hummocky visceral region. *P. corculum* differs from the current species in its ornamented ears and acuter cardinal extremities. *P. laobushanensis* can be distinguished from the current species by its protruding and quadrate ears.

**Occurrence.** Wuchiapingian (Lopingian) to Griesbachian (earliest Triassic); China.

***Paryphella triquetra*** Liao in Zhao et al., 1981

Fig. 5P-S

1981 *Paryphella triquetra* Liao in Zhao et al., pp. 53, 54, pl. 8, figs 18-22.

1982 *Paryphella triquetra* - Wang et al., p. 205, pl. 96, figs 14, 15.

1984 *Cathaysia subpusilla* - Yang in Feng et al., pl. 32, fig. 1.

2014 *Paryphella triquetra* - He et al., p. 937, fig. 16A-I.

2015 *Paryphella triquetra* - Zhang et al., p. 304, fig. 4S-U.

**Material:** A ventral valve (LZ006093); two external moulds of dorsal valves (LZ006025, LZ006090).

**Description.** Shell medium in size for the genus, subquadrate to reverse-trapezoidal in outline; moderately concavoconvex in profile; greatest width along hinge; cardinal extremities obtuse, cardinal angle about 70-90°; ears slightly inflated, smooth or ornamented with concentric rugae, well demarcated from visceral region; lateral sides straight to rounded, anterior side slightly rounded; external surface ornamented with concentric rugae and costellae, numbering about 24-32 at margin, originating from umbonal region or middle part of shell; hinge spine not well preserved, two pairs of spines at hinge, posterolaterally projecting. Ventral valve moderately convex; umbonal region swollen, overhanging hinge; maximum convexity in middle or anterior part of the shell; sulcus moderately developed or nearly absent; inner surface with papillae. Dorsal valve slightly concave; umbonal region slightly swollen; fold slightly developed.

**Discussion.** It is similar to *Paryphella acutula* Zhang et al., 2015 and *Paryphella transversa* Liao in Wang et al., 1982 in its triangular visceral region and weak or no sulcus. *P. acutula* is distinguished from the current species by its acuter ears and distinct nasute in the middle of anterior margin. *P. transversa* differs from the current species by its larger width/length ratio.

**Occurrence.** Changhsingian (Lopingian) to Griesbachian (earliest Triassic); China.

Subfamily Marginiferinae Stehli, 1954

Genus *Spinomarginifera* Huang, 1932

***Spinomarginifera alpha*** (Huang, 1932)

Fig. 5T-W

1932 *Spinomarginifera kweichowensis* mut. α Huang, pp. 60, 61, pl. 5, figs 12, 13.

1960 *Spinomarginifera kweichowensis* alpha - Muir-Wood & Cooper, p. 215, pl. 65, fig. 23.

- 1964 *Spinomarginifera kueichowensis* mut.  $\alpha$  - Wang et al., pp. 316, 317, pl. 49, figs 31-33.  
 1974 *Spinomarginifera kueichowensis* mut.  $\alpha$  - Jin et al., p. 313, pl. 164, figs 11, 12.  
 1977 *Spinomarginifera kueichowensis* mut.  $\alpha$  - Yang et al., p. 349, pl. 139, fig. 9.  
 1979 *Spinomarginifera kueichowensis* mut.  $\alpha$  - Zhan in Hou et al., pp. 80, 81, pl. 11, figs 18, 19.  
 1980a *Spinomarginifera alpha* - Liao, p. 259, pl. 5, figs 44.  
 1980b *Spinomarginifera alpha* - Liao, pl. 2, figs 15-17  
 1981 *Spinomarginifera alpha* - Tian, p. 57, pl. 32, figs 11-14.  
 1982 *Spinomarginifera alpha* - Wang et al., p. 219, pl. 96, fig. 16.  
 1990 *Spinomarginifera alpha* - Zhu, p. 76, pl. 17, figs 21, 22.  
 2003 *Spinomarginifera alpha* - Shen et al., p. 231, pl. 1, figs 6-9.  
 2015 *Spinomarginifera alpha* - Zhang et al., p. 309, fig. 7L-Q.

**Material:** Two internal moulds of dorsal valves (LZ006128, LZ006125); an external mould of a dorsal valve (LZ001123); a ventral valve (LZ001012).

**Description.** Shell small to large in size, subquadrate to subpentagonal in outline; maximum width at hinge line. Ventral valve strongly convex, geniculated at anterior part; beak wide and arched, prominently overhanging hinge line; cardinal extremities acute, with cardinal angles about 60°; ears small and moderately convex, well demarcated from visceral region; sulcus slightly developed. Dorsal valve slightly to moderately concave; beak narrow and slightly over hinge line, umbonal region with an angle about 110°; ears small and triangular; marginal ridges wide in cardinal area; fold absent; external surface ornamented with concentric rugae which have irregularly distributed pits on it, and with evenly distributed spines; internal surface with evenly distributed papillae; medium septum thin and long, about half-length or extending to anterior part and close to marginal ridge; lateral septa thicker and short, diverging at an angle of 40°; brachial ridges prominent, hook-like, located at lateral part, near marginal ridges; a pair of triangular adductor scars on outer sides of both lateral septa; endospines in a row at midvalve.

**Discussion.** The current species can be easily differentiated from other species in the genus by its very long medium septum. It is similar to *Spinomarginifera pseudosintanensis* Huang, 1932 by its slightly concave dorsal valve, but the latter has dorsal valve geniculated to forming a trail and much smaller size.

**Occurrence.** Wordian (middle Guadalupian) to Griesbachian (earliest Triassic); China, Japan.

Suborder **Lyttoniida** Williams, Harper & Grant  
 in Williams et al., 2000  
 Superfamily Lyttonioidea Waagen, 1883  
 Family Lyttoniidae Waagen, 1883

Subfamily Lyttoniinae Waagen, 1883  
 Genus *Oldhamina* Waagen, 1883

***Oldhamina* sp.**

Fig. 5X

**Material:** An internal mould of a ventral valve (LZ001086).

**Brief description.** Shell medium in size, subtriangular in outline; hemispherical in profile; medium septum thin, with irregular grooves at both sides; lateral septa thin and oblique, at an angle about 70° to medium septum.

**Discussion.** Although the current specimen is not complete, the thin and oblique septa suggest that this species is assignable to *Oldhamina*.

**Occurrence.** Changhsingian (late Lopingian); South China.

Order **Orthotetida** Waagen, 1884  
 Suborder **Orthotetidina** Waagen, 1884  
 Superfamily Orthotetoidea Waagen, 1884  
 Family Derbyiidae Stehli, 1954  
 Genus *Derbyia* Waagen, 1884

***Derbyia acutangula* (Huang, 1933)**

Fig. 6A

- 1933 *Schellwienella acutangula* Huang, p. 24, pl. 3, figs 12-18.  
 1964 *Schellwienella acutangula* - Wang et al., p. 206, pl. 30, fig. 16.  
 1977 *Magniderbyia guangdongensis* Ni in Yang et al., p. 325, pl. 134, figs 7-8.  
 1978 *Derbyia acutangula* - Tong, p. 215, pl. 78, fig. 7.  
 1980a *Derbyia acutangula* - Liao, p. 255, pl. 2, fig. 25.  
 2007 *Derbyia acutangula* - Shen & Shi, p. 30, pl. 11, figs 1-26.

**Material:** An internal mould of a ventral valve (LZ006029).

**Brief description.** Shell large in size for the genus, roundly subtrapezoidal in outline; maximum width at hinge line. Ventral valve nearly flat, umbonal region slightly convex; lateral sides slightly concave, anterior side slightly convex; fold absent; shell ornamented with dense and thin costellae, which is shown in marginal area of internal mould; median septum strong and short, about 1/4 of shell length.

**Discussion.** The species is similar to *Derbyia regularis* Waagen, 1884 and *Derbyia dirata* Grant, 1993 in its flat ventral valve. *D. regularis* differs from the current species in having hinge shorter than greatest width. *D. dirata* differs in its much smaller size.

**Occurrence.** Lopingian; China.

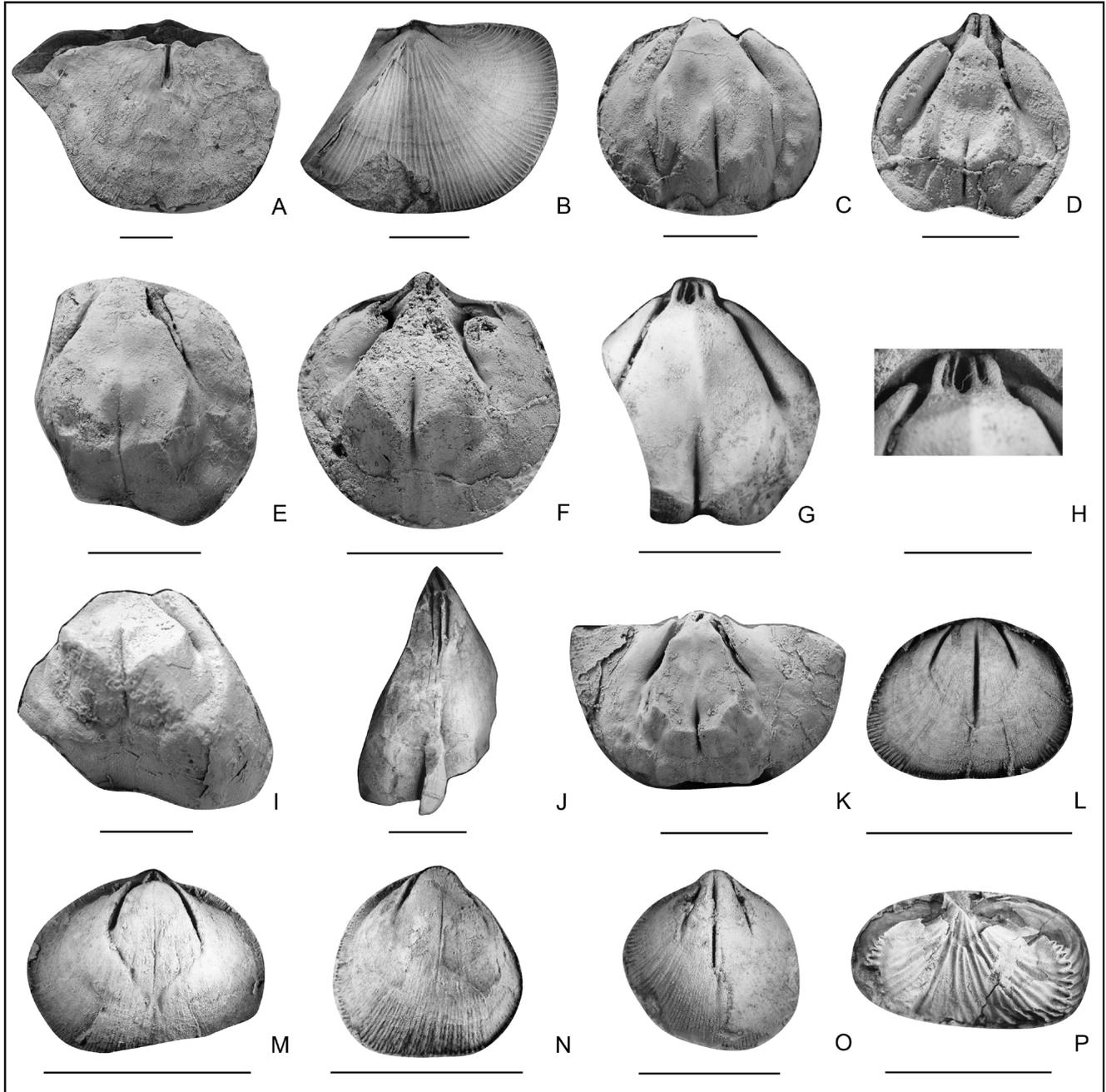


Fig. 6 - A - *Derbyia acutangula* (Huang, 1933), internal mould of ventral valve, LZ006029. B - *Orthothetina frechi* (Huang, 1933), internal mould of dorsal valve, LZ001087. C-H - *Peltichia* cf. *kwangtungensis* Zhan in Hou et al., 1979, C, D, E, F, G) internal moulds of dorsal valves, LZ001005, LZ001006, LZ001026, LZ001019, LZ001011; H) enlarged umbonal area in G. I-J - *Peltichia subtriangularis* Shen et al., 1999, I) internal mould of dorsal valve, LZ001009; J) internal mould of ventral valve, LZ001088. K) *Peltichia* sp., internal mould of dorsal valve, LZ001023. L-N - *Acosarina minuta* (Abich, 1878), L) internal mould of ventral valve, LZ001137; M, N) internal moulds of dorsal valves, LZ001140, LZ001149. O - *Acosarina tumita* Zeng et al., 1995, internal mould of ventral valve, LZ001134. P - *Ancorhynchia* sp., ventral view of a conjoined shell, LZ001118. Scale bars are equal to 1 cm, except in H, O, scale bars are equal to 5 mm.

Family Meekellidae Stehli, 1954  
Genus *Orthothetina* Schellwien, 1900

***Orthothetina frechi*** (Huang, 1933)

Fig. 6B

1933 *Schubertella frechi* Huang, pp. 21-23, pl. 3, figs 2-6.  
1978 *Orthothetina ruber* - Feng & Jiang, p. 238, pl. 87, fig. 9.

1980a *Orthothetina frechi* - Liao, pl. 2, fig. 12.  
2007 *Orthothetina frechi* - Shen & Shi, p. 24, pl. 7, figs 25-29.  
2014a *Orthothetina frechi* - Zhang et al., pp. 486, 487, fig. 7A-H.

**Material:** An internal mould of a dorsal valve (LZ001087).

**Brief description.** Medium in size for the genus, transversely semicircular in outline; maximum

width located in posterior part. Dorsal valve slightly convex; external surface ornament with costellae, distinctly originating from umbo, observable in internal mould; brachiophore plates short and strong, diverging at an angle about 110°.

**Discussion.** Species in this genus are differentiated from each other mainly by their ventral interior structures and outline. Although there is no ventral valve preserved, the current specimen can be assigned to *O. frechi* by its large size and transversely semicircular outline.

**Occurrence.** Roadian (early Guadalupian) to Changhsingian (late Lopingian); China, Japan.

Order **Orthida** Schuchert & Cooper, 1932

Suborder **Dalmanellidina** Moore, 1952

Superfamily Enteletoidea Waagen, 1884

Family Enteletidae Waagen, 1884

Genus *Peltichia* Jin & Liao in Jin & Sun, 1981

**Diagnosis:** Medium to large in size, biconvex, fold and sulcus variably developed; surface finely costellate, becoming tubular in adult specimens; ventral interior with a thin and long medium septum and two parallel dental plates; dorsal interior with scimitar-like to straight brachiophore plates, partly surrounding or extending through the adductor field; adductor platform elevated, bisected by a median ridge; cardinal process trilobated.

**Discussion.** The genus has been discussed in detail in Shen et al. (1999). According to our materials in this paper, we suggested to slightly expand several characteristics of the genus, mainly including sulcus development, dorsal valve convexity and cardinal process shape. Therefore, we provide an updated diagnosis of the genus herein.

*Peltichia* cf. *kwangtungensis* Zhan in Hou et al., 1979

Fig. 6C–H

**Material:** Five internal moulds of dorsal valves (LZ001005, LZ001006, LZ001026, LZ001019, LZ001011).

**Description.** Only dorsal valve preserved. Shell medium in size; subcircular to suboval in outline; slightly to moderately convex in profile; maximum width at middle or anterior part; umbonal moderately convex, maximum convexity at middle part; sulcus slightly developed or absent. Interior with strong brachiophore plates, round-bracket-

shaped or straight and fading anteriorly; muscular scars covered almost the whole middle to anterior part of valve; median ridge developed, originating from midlength, extending to anterior part of valve or to anterior margin; cardinal process trilobated.

**Discussion.** Among all Changhsingian species in the genus, *P. kwangtungensis* is the only one which has weak sulcus and fold, but our specimen has almost no sulcus and less convex dorsal valve. Since there is no ventral valve found and the dorsal interiors quite similar to that in Shen et al. (1999), we temporarily assigned these specimens to *P.* cf. *kwangtungensis*.

**Occurrence.** Changhsingian (late Lopingian); China.

*Peltichia subtriangularis* Shen et al., 1999

Fig. 6I–J

1999 *Peltichia subtriangularis* Shen et al., pp. 57, 58, figs 8.13–8.20.

**Material.** An internal mould of a dorsal valve (LZ001009); an internal mould of a ventral valve (LZ001088).

**Description.** Shell large in size for the genus, subtriangular in outline; maximum width anterior to midlength. Ventral valve moderately convex; beak long and thick; interior with distinct median septum, extending to midlength; dental plates parallel and shorter than median septum. Dorsal valve strongly convex, umbonal region wide and strongly swollen; valve sharply inclined ventrally from midvalve part; sulcus moderately wide and shallow, originating from midvalve; median septum long, originating from posterior part and extending to midlength; brachiophore plates curved, fading anteriorly and eventually convergent together at the end of median septum; adductor platform elevated.

**Discussion.** The species can be distinguished from its counterparts by its subtriangular outline, except for *Peltichia zigzag* (Huang, 1933), but the latter has a strongly W-shaped anterior commissure.

**Occurrence.** Lopingian; China.

*Peltichia* sp.

Fig. 6K

**Material.** An internal mould of a dorsal valve (LZ001023).

**Description.** Shell medium in size for the genus, transversely reverse-trapezoidal in outline; max-

imum width at hinge line; lateral sides slightly rounded, anterior side somewhat straight. Dorsal valve moderately convex, maximum convexity at middle or anterior part; beak slightly over hinge; sulcus absent; median septum short and strong, originating from midlength, extending anteriorly and about 1/3 of shell length; brachiophore plates strong and short, divergent at an angle about 60°, fading anteriorly and convergent at the end of median septum; adductor occupied most part of visceral region and elevated.

**Discussion.** Species in the genus are almost all subcircular to elliptical in outline, and most of them possess well-developed sulcus and fold. The current specimen is distinctly different from all species in the genus by its transverse outline and sulcus almost absent.

**Occurrence.** Changhsingian (late Lopingian); China.

Family Schizophoriidae Schuchert, 1929

Genus *Acosarina* Cooper & Grant, 1969

*Acosarina minuta* (Abich, 1878)

Fig. 6L-N

- 1878 *Streptorhynchus peregrinus* var. *minutus* Abich, p. 78, pl. 10, fig. 1.  
 1884 *Orthis indica* Waagen, pp. 568-570, pl. 56, figs 8, 14-16.  
 1911 *Dalmanella indica* - Frech, p. 120, pl. 18, fig. 1.  
 1922 *Dalmanella indica* - Hayasaka, p. 76, pl. 4, fig. 3.  
 1931 *Schizophoria indica* - Ozaki, pp. 167-169, pl. 15, fig. 13.  
 1962 *Orthis indica* - Zhan & Li, pp. 473, 474, pl. 1, figs 1-2.  
 1964 *Schizophoria indica* - Wang et al., pp. 134, 135, pl. 16, figs 24, 25, 28.  
 1969 *Acosarina dorsisulcata* Cooper & Grant, p. 2, pl. 5, figs 19-23.  
 1976 *Acosarina dorsisulcata* - Cooper & Grant, pp. 2621, 2662, pl. 667, figs 1-26.  
 1978 *Acosarina dorsisulcata* - Feng & Jiang, p. 235, pl. 85, fig. 10.  
 1978 *Orthis indica* - Tong, p. 211, pl. 27, fig. 3.  
 1979 *Acosarina indica* - Jin et al., p. 74, pl. 36, figs 6-9.  
 1982 *Acosarina indica* - Liu et al., pl. 125, fig. 7.  
 1982 *Acosarina indica* - Wang et al., p. 190, pl. 80, fig. 7.  
 1982 *Acosarina minuta* - Wang et al., p. 190, pl. 96, figs 4, 5, 27.  
 1984 *Acosarina indica* - Yang, pl. 29, fig. 10.  
 1988 *Acosarina* sp. - Yanagida, pl. 29, figs 1-12.  
 1990 *Acosarina indica* - Liang, pp. 354, 355, pl. 1, figs 6-10.  
 1990 *Acosarina indica* - Zhu, p. 62, pl. 9, figs 5-7.  
 1993 *Kotlaia capilosa* Grant, p. 5, figs 4.1-4.6.  
 1998 *Acosarina minuta* - Shi & Shen, pp. 506, 507, figs 3.5-3.11.  
 1999 *Acosarina kanmerai* Yanagida & Nakornsri, p. 111, pl. 26, figs 1-7.  
 2007 *Acosarina minuta* - Shen & Shi, pp. 39, 40, pl. 14, figs 27-38, pl. 15, figs 1-21.  
 2008 *Acosarina minuta* - Li & Shen, p. 318, fig. 6.27-6.32.  
 2014a *Acosarina minuta* - Zhang et al., pp. 488, 489, figs 7X-AC, 9A-D.  
 2018a *Acosarina minuta* - Wu et al., p. 354, fig. 8F-H.

**Material:** An internal mould of a ventral valve (LZ001137); two internal moulds of dorsal valves (LZ001140, LZ001149).

**Brief description.** Medium in size for the genus, slightly elongate subcircular to transverse subcircular in outline; shell width at or slightly anterior to midlength; nearly equally biconvex; external surface covered with dense costellae, distinctly originated from umbo; sulcus slightly developed or absent. Ventral interior with long medium septum, extending to half-length or nearly to anterior margin; dental plates short, divergent first and then almost parallel anteriorly. Dorsal valve interior with crenulated cardinal process; brachiophore plates short, about 1/4 to 1/3 of shell length.

**Discussion.** It is similar to *Acosarina regularis* Liao, 1980a in subcircular outline, but the latter has more developed sulcus and fold. It resembles *Acosarina circularis* Xu in Yang et al., 1987 in almost circular outline and undeveloped sulcus and fold, and differs in the latter possessing medium ridge and lateral ridges in dorsal interior.

**Occurrence.** Artinskian (late Cisuralian) to Changhsingian (late Lopingian); Armenia, Azerbaijan, China, Iran, Malaysia, Pakistan, Vietnam.

*Acosarina tumita* Zeng et al., 1995

Fig. 6O

**Material:** An internal mould of a ventral valve (LZ001134).

**Description.** Shell small in size for the genus, subcircular in outline; maximum width at midvalve. Ventral valve moderately convex, maximum convexity at umbonal region and turning gently convex anteriorly, lateral parts of valve on each side forming two laterally inclined slopes; umbonal region narrow and pointed; fold absent; external surface with dense and distinct costellae. Ventral interior with medium septum, extending to about half of shell length; dental plates short and straight, divergent at an angle about 50°.

**Discussion.** The current species can be easily distinguished from other species in the genus by its strongly convex umbonal region, inclined lateral parts of valve and pointed umbonal region.

**Occurrence.** Kungurian (late Cisuralian) to Changhsingian (late Lopingian); China.

Order **Rhynchonellida** Kuhn, 1949

Superfamily Wellerelloidea Licharew, 1956

Family Wellerellidae Licharew, 1956

Subfamily Uncinunellinae Savage, 1996  
Genus *Ancorhynchia* Jin & Ye in Jin et al., 1979

**Comment.** The genus has been misspelled as *Anchorhynchia* by previous researchers.

*Ancorhynchia* sp.

Fig. 6P

**Material:** A conjoined shell (LZ001118).

**Brief description.** Shell medium in size for the genus, transversely oval in outline; maximum width at about midlength. Ventral valve slightly convex; beak pointed and slightly convex; sulcus wide and inclined towards dorsal valve; costellae originating from beak, with bifurcation. Dorsal valve prominently geniculated towards ventral valve; ventral costellae and dorsal costellae interspace joined and resulting in anterior commissure undulate.

**Discussion.** It is similar to *Ancorhynchia grandis* Shen & He, 1994 and *Ancorhynchia ignobilis* Shen et al., 1992 in its transverse outline, but the former one differs from the current species in its denser and more costellae and the latter one differs in having larger angle of umbonal region.

**Occurrence.** Changhsingian (late Lopin-gian); China.

Family Pontisiidae Cooper & Grant, 1976  
Subfamily Pontisiinae Cooper & Grant, 1976  
Genus *Prelissorhynchia* Xu & Grant, 1994

*Prelissorhynchia pseudoutab* (Huang, 1933)

Fig. 7A-F

- 1933 *Pugnax pseudoutab* Huang, p. 64, pl. 10, figs 1-8.  
1955 *Pugnax pseudoutab* - Wang, p. 134, pl. 73, figs 13-16.  
1964 *Pugnax pseudoutab* - Wang et al., pp. 396, 397, pl. 66, figs 12-15.  
1974 *Pugnax pseudoutab* - Jin et al., p. 312, pl. 165, figs 7-9.  
1977 *Pugnax pseudoutab* - Yang et al., p. 381, pl. 151, figs 3a-c.  
1978 *Pugnax pseudoutab* - Feng & Jiang, p. 272, pl. 101, figs 3a-c.  
1978 *Pugnax pseudoutab* - Tong, pp. 241, 242, pl. 85, figs 11a-c.  
1979 *Pugnax pseudoutab* - Zhan in Hou et al., p. 95, pl. 13, figs 21-22.  
1979 *Neowellerella* cf. *pseudoutab* - Jin et al., p. 105, pl. 30, figs 6-9.  
1980a *Neowellerella pseudoutab* - Liao, pl. 7, figs 38, 39.  
1980b *Neowellerella pseudoutab* - Liao, pl. 1, figs 10, 11.  
1982 *Neowellerella pseudoutab* - Wang et al., p. 235, pl. 96, figs 18, 19.  
1986 *Neowellerella pseudoutab* - Liao & Meng, pl. 4, fig. 7.  
1987 *Lissorhynchia pseudoutab* - Xu in Yang et al., p. 229, pl. 13, figs 15, 16, pl. 14, figs 10, 12.  
1987 *Neowellerella pseudoutab* - Liao, pp. 108, 109, pl. 5, fig. 29, pl. 8, fig. 1.

- 1994 *Prelissorhynchia pseudoutab* - Xu & Grant, p. 38, fig. 22.28-22.48.  
1994 *Cryolexix antearcus* Xu & Grant, p. 39, fig. 26.1-26.20.  
1999 *Prelissorhynchia pseudoutab* - Chen & Shi, pp. 20, 22, 23, fig. 6A-F, H-J, L-R.  
1999 *Prelissorhynchia* sp. - Chen & Shi, p. 23, fig. 6G, K.  
1999 *Prelissorhynchia xui* Chen & Shi, pp. 23, 25, fig. 4.  
2007 *Prelissorhynchia pseudoutab* - Shen & Shi, pp. 53-55, pl. 20, figs 32-35, pl. 21, figs 1-4, 12-15, 20-23.  
2007 *Prelissorhynchia plena* Shen & Shi, pp. 55, 56, pl. 22, figs 1-23.  
2009 *Prelissorhynchia pseudoutab* - Chen et al., fig. 7T-U.  
2014a *Prelissorhynchia pseudoutab* - Zhang et al., pp. 490-493, fig. 9J-U.  
2018a *Prelissorhynchia pseudoutab* - Wu et al., pp. 354, 355, fig. 8J-T.

**Material:** Three internal moulds of ventral valves (LZ001107, LZ001106, LZ001108); a conjoined shell (LZ001202).

**Description.** Small to medium in size, suboval to subtriangular in outline, maximum width at or slightly anterior to midlength; anterior commissure uniplicate. Ventral valve gently convex; sulcus wide, variably developed, originating from umbonal region to only appeared at anterior part; costae originating from midvalve, two to three costae in sulcus and two to three pairs on lateral margins; interior with short dental plates, about 1/4 of shell length, divergent at an angle about 30-50°. Dorsal valve gently convex; fold originating from midvalve; four costae in fold and two pairs on lateral margins, concentric striae in middle part of valve; interior with denticulate socket, inner socket ridges thin, divergent at an angle about 120°.

**Discussion.** The species differs from most species in the genus by its less costae on lateral margins or in sulcus and fold.

**Occurrence.** Capitanian (late Guadalupian) to Griesbachian (earliest Triassic); Armenia, Azerbaijan, China, Iran, Italy, Malaysia, Thailand.

*Prelissorhynchia* sp.

Fig. 7G

**Material:** An internal mould of a ventral valve (LZ001104).

**Brief description.** Small in size for the genus, subtriangular in outline, maximum width near anterior margin. Ventral valve flat; sulcus absent; costae angular, originating from umbonal region, with intercalation and bifurcation; dental plates about 1/3 of shell length, divergent at an angle about 50°.

**Discussion.** The specimen can be easily distinguished from existed species by its flat shell, absence of sulcus and angular costae.

**Occurrence.** Changhsingian (late Lopin-gian); China.

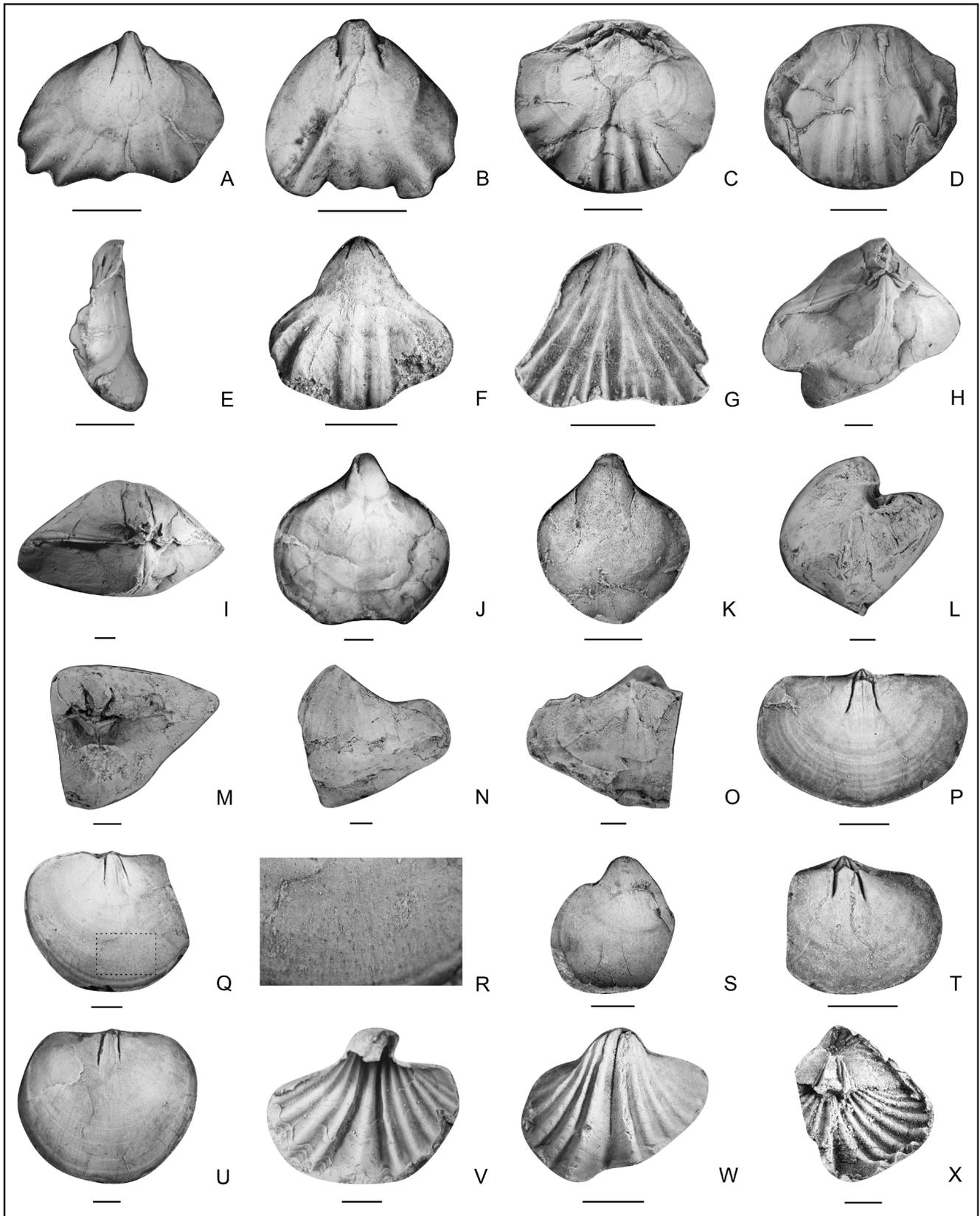


Fig. 7 - A-F - *Prelissorbynchia pseudoutab* (Huang, 1933), A, B, F) internal moulds of ventral valves, LZ001107, LZ001106, LZ001108; C, D, E) dorsal, ventral and lateral view of a conjoined shell, LZ001202. G - *Prelissorbynchia* sp., internal mould of ventral valve, LZ001104. H-J - *Araxathyris undulata* Shen et al., 1992, H, I) dorsal and lateral view of a conjoined shell, LZ001302; J) internal mould of ventral valve, LZ001081. K) *Araxathyris rhombiformis* Zeng et al., 1995, internal mould of ventral valve, LZ001082. L-P - *Orbicoelia pusilla* (Zhan in Hou et al., 1979), L, M, N, O) lateral, posterior and ventral view of a conjoined shell, LZ001301; P) internal mould of dorsal valve, LZ001122. Q-U - *Orbicoelia speciosa* (Wang, 1955), Q, T, U) internal moulds of dorsal valves, LZ006094, LZ006101, LZ006109; R) enlarged rectangular area in Q; S) internal mould of ventral valve, LZ006098. V-W - *Spiriferellina* sp. 1, V, external mould of ventral valve, LZ001133; W) internal mould of ventral valve, LZ001112. X - *Spiriferellina* sp. 2, external mould of a conjoined shell, LZ001115. Scale bars are equal to 2 mm.

Order **Athyridida** Boucot, Johnson & Staton, 1964

Suborder **Athyrididina** Boucot, Johnson & Staton, 1964

Superfamily Athyridoidea Davidson, 1881

Family Comelicanidae Merla, 1930

Subfamily Araxathyriinae Shen et al., 2004

Genus *Araxathyris* Grunt in Ruzhentsev & Sarytcheva, 1965

*Araxathyris undulata* Shen et al., 1992

Fig. 7H–J

**Material:** A conjoined shell (LZ001302); an internal mould of a ventral valve (LZ001081).

**Description.** Shell medium in size for the genus, subcircular in outline; maximum width at midlength. Ventral valve moderately convex, maximum convexity at middle to posterior part; sulcus originating from midvalve and shallow, deepening and widening anteriorly; lateral slopes slightly inclined; marginal area with concentric growth laminae, irregularly distributed. Ventral interior with dental plates converging and forming distinct spondylium; dorsal interior with divergent cardinal plates, a weak median septum about 1/4 of shell length.

**Discussion.** The species resembles *Araxathyris beipeiensis* Xu & Grant, 1994, and *Araxathyris tongluensis* Liang, 1990 in its outline. The latter two species differ from the current species in their more developed sulcus.

**Occurrence.** Kungurian (late Cisuralian) to Changhsingian (late Lopingian); China.

*Araxathyris rhombiformis* Zeng et al., 1995

Fig. 7K

**Material:** An internal mould of a ventral valve (LZ001082).

**Brief description.** Shell medium in size for the genus, subrhombic in outline; maximum width at midlength. Ventral valve moderately convex, maximum convexity at middle to posterior part; posterolateral and anterolateral sides slightly concave; sulcus originating from midvalve; dental plates converging and forming a quite large spondylium.

**Discussion.** It is similar to *Araxathyris glossexserta* Zeng et al., 1995 in its outline, but the latter one possesses more developed sulcus originating from umbo and strongly inclined dorsally.

**Occurrence.** Kungurian (late Cisuralian) to Changhsingian (late Lopingian); China.

Order **Spiriferida** Waagen, 1883

Suborder **Spiriferidina** Waagen, 1883

Superfamily Ambocoelioidea George, 1931

Family Ambocoeliidae George, 1931

Genus *Orbicoelia* Waterhouse & Piyasin, 1970

*Orbicoelia pusilla* (Zhan in Hou et al., 1979)

Fig. 7L–P

1979 *Crurithyris pusilla* Zhan in Hou et al., pp. 96, 97, pl. 13, figs 24–25.

1994 *Crurithyris pusilla* - Xu & Grant, pp. 43–45, figs 32, 34.1–34.47, 34.52.

**Material:** A conjoined shell (LZ001301); an internal mould of a dorsal valve (LZ001122).

**Description.** Shell large in size, transversely suboval in outline; maximum width at midlength; biconvex in lateral profile. Ventral valve strongly convex; beak high and incurved; cardinal extremities rounded; sulcus absent. Dorsal valve slightly to moderately convex, width to length ratio 1.7–2; beak slightly over hinge; cardinal extremities rounded, with cardinal angles about 140°; surface with concentric striae; interior with crural plates, diverging at an angle about 25°, extending about 1/3 of shell length; median ridge thin and weak, equal in length of crural plate; socket elongate, inner socket ridges short, diverging at an angle about 60°, outer socket ridges long and extending along hinge; cardinal process triangular.

**Discussion.** It can be easily differentiated from other species by its quite transverse outline.

**Occurrence.** Changhsingian (late Lopingian); China.

*Orbicoelia speciosa* (Wang, 1955)

Fig. 7Q–U

1955 *Crurithyris speciosa* Wang, p. 146, pl. 83, figs 1–4.

1956 *Crurithyris speciosa* - Wang, pp. 389, 390, pl. 6.1, figs 1–6.

1964 *Crurithyris speciosa* - Wang et al., p. 546, pl. 104, figs 13–16.

1978 *Crurithyris speciosa* - Tong, p. 254, pl. 89, fig. 6.

1978 *Crurithyris speciosa* - Feng & Jiang, p. 283, pl. 102, fig. 10.

1979 *Crurithyris speciosa* - Liao, pl. 1, fig. 21.

1980a *Crurithyris speciosa* - Liao, pl. 8, figs 16, 17.

1981 *Crurithyris speciosa* - Jin & Sun, pp. 156, 157, text-fig. 17

1994 *Crurithyris speciosa* - Xu & Grant, p. 45, figs 33, 34, 48–51.

2006 *Orbicoelia speciosa* - Chen et al., pp. 317–319, figs 9a–f, 10.

2014a *Orbicoelia speciosa* - Zhang et al., p. 498, fig. 10A–I.

**Material:** Three internal moulds of dorsal valves (LZ006094, LZ006101, LZ006109); an internal mould of a ventral valve (LZ006098).

**Description.** Medium in size, subcircular to suboval in outline; maximum width at posterior part. Ventral valve moderately convex; maximum convexity at midvalve; beak swollen and highly over hinge; sulcus absent. Dorsal valve flatly convex; fold absent; ornamented with concentric lines, and micro spines which are shown in internal mould; crural plates divergent at an angle about 15°-30°; median ridge absent to weakly developed; socket elongate, inner socket ridges thin and short, outer socket ridges long and extending along hinge; cardinal process elliptical.

**Discussion.** The species is similar to *Orbicoelia extima* (Grant, 1970) and *Orbicoelia tholiaphor* (Cooper & Grant, 1976) in its outline. *O. extima* differs from the current species by having more convex dorsal valve and shorter ventral beak. *O. tholiaphor* differs in its maximum width anterior to midvalve.

**Occurrence.** Changhsingian (late Lopingian) to Griesbachian (earliest Triassic); China.

Order **Spiriferinida** Ivanova, 1972

Suborder **Spiriferinidina** Ivanova, 1972

Superfamily Pennospiriferinoidea Dagys, 1972

Family Spiriferellinidae Ivanova, 1972

Genus *Spiriferellina* Frederiks, 1924

### *Spiriferellina* sp. 1

Fig. 7V-W

**Material:** An external mould of a ventral valve (LZ001133); an internal mould of a ventral valve (LZ001112).

**Brief description.** Small in size for the genus, reverse-trapezoidal to subelliptical in outline; maximum width near midlength of ventral valve. Ventral valve moderately convex, maximum convexity at middle to posterior part; beak swollen and wide, overhanging hinge; sulcus broadly angular, smooth; external surface with 10-12 simple costae, originating from umbo, and densely and irregularly distributed micro punctae; interior with long median septum, extending close to anterior margin.

**Discussion.** It is similar to *Spiriferellina disciformis* Liang, 1990 in size and outline, but the current species has thinner costae, longer median septum and shorter hinge. It resembles *Spiriferellina*

*trivosa* Cooper & Grant, 1976 in shape and sulcus development, but the latter has larger size and maximum width mostly at hinge.

**Occurrence.** Changhsingian (late Lopingian); China.

### *Spiriferellina* sp. 2

Fig. 7X

**Material:** An external mould of a conjoined shell (LZ001115).

**Brief description.** Shell medium in size for the genus, subrhombic in outline; maximum width slightly anterior to midlength. Ventral valve with beak highly over hinge; delthyrium large and triangular. Dorsal valve slightly convex; fold broad anteriorly and angular; external surface with 12 costae, simple and originating from umbo.

**Discussion.** The species is different from most species in the genus by its subrhombic outline, except for *Spiriferellina zewanensis* (Diener, 1915). *S. zewanensis* differs from the current species in its much thicker costae and maximum width at hinge.

**Occurrence.** Changhsingian (late Lopingian); China.

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