

Brachiopods Near the  
Permian-Triassic Boundary  
in South China

GUIRONG XU  
and  
RICHARD E. GRANT

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## ABSTRACT

Xu, Guirong, and Richard E. Grant. Brachiopods Near the Permian-Triassic Boundary in South China. *Smithsonian Contributions to Paleobiology*, number 76, 68 pages, 54 figures, 7 tables, 1994.—Sixty-eight genera and 164 species in the Changxingian Stage and 12 genera and 20 species in the lower Griesbachian Stage are recorded on the basis of brachiopod fossils collected from 32 sections in South China and from review of the Chinese literature. Of these, 24 genera and 34 species are described here, including three new genera (*Fanichonetes*, *Prelissorhynchia*, and *Rectambitus*) and 24 new species (*Acosarina strophiria*, *Enteletes asymmatosis*, *Peltichia schizoloides*, *Derbyia pannuciella*, *Perigeyerella altilosina*, *Chonetinella cursothonia*, *C. volitanliopsis*, *Fanichonetes campigia*, *Cathaysia spiriferoides*, *Uncinunellina multicostifera*, *Prelissorhynchia triplicatioid*, *Cyrolexis antearcus*, *Cyrolexis beccojectus*, *Cartorhium xikouensis*, *C. twifurcifer*, *Callispirina rotundella*, *Araxathyris subpentagulata*, *A. beipeiensis*, *Spirigerella discsella*, *S. ovaloides*, *Squamularia formilla*, *Hustedia orbicostata*, *Rostranteris ptychiventria*, and *Notothyris bifoldes*).

The *Cathaysia chonetoides*-*Chonetinella substrophomenoides* assemblage zone and the *Cathaysia sinuata*-*Waagenites barsiensis* assemblage zone represent respectively faunas of the lower Changxingian and the upper Changxingian in clastic lithofacies; whereas the *Peltichia zigzag*-*Prelissorhynchia triplicatioid* assemblage zone and the *Spirigerella discussella*-*Acosarina minuta* assemblage zone represent faunas in limestone lithofacies. The *Crurithyris pusilla*-*Lingula subcircularis* assemblage zone and Permian-type brachiopods are present in the lower Griesbachian.

The Changxingian brachiopod fauna can be correlated with the Dorashamian fauna of Armenia; the brachiopod faunas of the Ali Bashi Formation, North-West Iran; unit 7 of the Hambast Formation, Central Iran; and the upper part of the *Bellerophon* Formation of the Southern Alps.

The genera *Cathaysia*, *Peltichia*, and *Prelissorhynchia* are especially characteristic of the *Cathaysia* Tethyan Subprovince. In contrast, the West Tethyan Subprovince is characterized by the genera *Costiferina*, *Ombonia*, *Comelicania*, and many other species. Four brachiopod ecofacies are recognized in the Changxingian of South China: (1) antibiohermal dwellers; (2) calcareous substratum dwellers; (3) biohermal dwellers; and (4) ubiquitous substrate dwellers. In the lower Griesbachian, the brachiopod fauna of *Lingula* and *Crurithyris* spreads across the entire Tethys and is called the Circum-Pangaea brachiopod fauna.

Massive extinction of brachiopod faunas occurred at the close of the Changxingian, with only a few Permian-types surviving into the early Griesbachian, and they completely vanished after the early Griesbachian except for harbingers of Mesozoic brachiopods.

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# Brachiopods Near the Permian-Triassic Boundary in South China

*Guirong Xu and Richard E. Grant*

## Introduction

The study of brachiopods near the Permian-Triassic boundary provides fossil evidence useful in establishing and correlating the stratigraphic boundary stratotype of the Permian-Triassic. Such a study also enables one to reconstruct the environment where brachiopods lived and adapted during the passage from the Paleozoic to the Mesozoic and to elucidate the evolutionary relationship between Paleozoic and Mesozoic brachiopods.

Former works that systematically described brachiopods from the Late Permian of South China are by Chao (1927, 1928, 1929) and Huang (1932, 1933). Investigations of coal deposits of the Late Permian and research on the Permian-Triassic boundary stratotype in South China in the last decade has provided continued impetus to this line of endeavor. Papers by Chan (in Hou et al., 1979), Liao (1979, 1980a, 1981), Liao and Meng (1986), and Xu (in Yang et al., 1987) reveal that brachiopods are abundant in rocks of Late Permian age in South China and that several Permian-type brachiopods extend into the lowermost Triassic.

This paper deals with the Changxingian Stage (formerly spelled Changhsingian) and the lower Griesbachian Stage brachiopods in South China, based upon materials collected from 32 sites whose locations are shown in Figure 1. (Hereafter, all collection spots will be referred to by their spot number and will not include the reference to Figure 1.)

The study area is situated mainly in the Yangtze platform, which was essentially surrounded by "old lands" (i.e., emergent at the time) during the Late Permian and Early Triassic. North of the area is the North China platform, which was completely above sea level and, at that time, was the source of erosional

sediments. The Cathaysia old landmass extended north-eastward from the North China platform. The Kangdian old landmass was to the west, and the Yun-Kai old land was located south of the platform. Therefore, during the Late Permian and Early Triassic, this area was a barrier sea basin. Another old landmass, called the Jiangnan old landmass, was located in the middle of the basin. The sedimentary characters to a certain extent relate to that very complicated landform (Figure 3).

The Changxingian Stage with its abundantly preserved brachiopods has several sedimentary types in the Yangtze basin, largely of three types: limestone, silicalite (i.e., particulate chert), or arenite. The Changxing Formation, type section located at Meishan, Changxing County, Zhejiang Province (spot 26), consists of gray to dark medium-bedded pure limestone, bituminous limestone and limy dolomite, and intercalated cherty limestone. The Changxing Formation is most widely distributed in Zhejiang, Sichuan, and North Guizhou, generally in the platform facies of the basin. Chert sediments are represented in the Dalong Formation, whose type locality is at Matan, Geshan County, Guangxi Province (near spot 15), where it is composed of gray or black thin-bedded silicalite, yellowish brown siliceous tuffite, and intercalated siliceous or tuffaceous arenite.

Distribution of the Dalong Formation follows closely the distribution of volcanoclastic rocks extending along a narrow belt in South Guizhou, Guangxi, and Hubei Provinces. On the east side of the Kangdian old landmass, the west side of Cathaysia old landmass, and the north side of the Yun-Kai old landmass are mostly arenites of the Xuanwei Formation (type locality is at Xuanwei, Yunnan Province) and the Yanshi Formation (type locality is at the Yanshi section, Longyan County, Fujian Province) (spot 31). The former consists of intercalated terrigenous sediments and the latter is marine arenite containing dark gray, yellowish green, and grayish yellow calcareous siltstone and silty mudstone, interbedded

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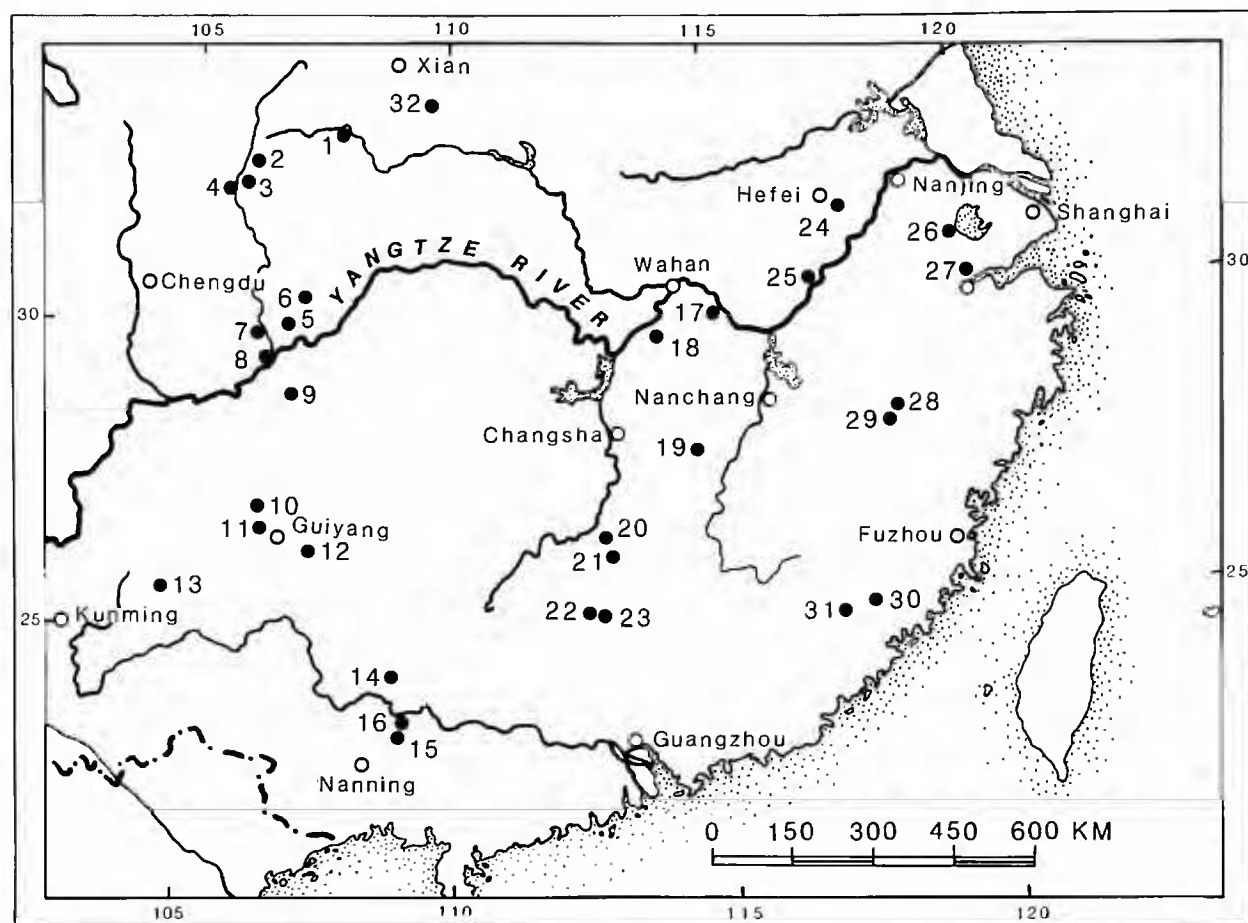


FIGURE 1.—Distribution of the Permian-Triassic boundary sections of South China.

- |  |  |
|--|--|
| 1. Kucaoping section, Xixiang County, Shaanxi Province     | 17. Shatian section, Huangshi County, Hubei Province       |
| 2. Mingxuexia section, Guangyuan County, Sichuan Province  | 18. Guanyinshan section, Fuqi County, Hubei Province       |
| 3. Xindianzi section, Guangyuan County, Sichuan Province   | 19. Baimu section, Yiahun County, Jiangxi Province         |
| 4. Shangsi section, Guangyuan County, Sichuan Province     | 20. Jueguangsi section, Laiyang County, Hunan Province     |
| 5. Xinjiacao section, Guangan County, Sichuan Province     | 21. Matian section, Yongxi County, Hunan Province          |
| 6. Huayingchan section, Linshui County, Sichuan Province   | 22. Xiaoyuanchong section, Jiahe County, Hunan Province    |
| 7. Yanjingxi section, Hechuan County, Sichuan Province     | 23. Meitian section, Yizhang County, Hunan Province        |
| 8. Liangfengya section, Zhingqing County, Sichuan Province | 24. Majiashan section, Chao County, Anhui Province         |
| 9. Banzhuyuan section, Nantong County, Sichuan Province    | 25. Yueshan section, Huaining County, Anhui Province       |
| 10. Liuchang section, Qingzhen County, Guizhou Province    | 26. Meishan section, Changxing County, Zhejiang Province   |
| 11. Yingpanpo section, Guiyang County, Guizhou Province    | 27. Huangzhishan section, Wuxing County, Zhejiang Province |
| 12. Xiaochehe section, Guiyang County, Guizhou Province    | 28. Minfa section, Guangfeng County, Jiangxi Province      |
| 13. Huopu section, Pan County, Guizhou Province            | 29. Xijia section, Shangroa County, Jiangxi Province       |
| 14. Longtoujiang section, Yishan County, Guanxi Province   | 30. Yading section, Shangping County, Fujian Province      |
| 15. Paoshui section, Laibin County, Guanxi Province        | 31. Yanshi section, Longyan County, Fujian Province        |
| 16. Penglaitan section, Laibin County, Guangxi Province    | 32. Xikou section, Zhenan County, Shaanxi Province         |

with fine sandstone and lenses of limestone.

Lower Griesbachian strata, which bear poor brachiopod fossils, are petrographically more uniform than are the underlying Changxingian rocks. They can be divided into two kinds of rocks: limestone and arenite. The lower Daye and the lower Qinglong formations consist mainly of limestone and calcareous mudstone. They occur on the platform facies belt of the basin. The clastic-type strata are dispersed along the margins of old land provinces, such as the Xikou Formation, which is located on the west of Cathaysia, the Kayitou Formation, and the lower Feixianguan Formation, which occurs to the east of the Kangdian old landmass. The Yinkeng Formation is currently becoming known internationally because its reference section is situated at the same location as the

type section of the Changxingian Stage (spot 26). It contains many fossils indicative of the Griesbachian Stage. It overlies the Changxing Formation; therefore, it is a prime candidate for the Permian-Triassic boundary stratotype. It consists of grayish yellow-green calcareous mudstone intercalated with a few thin- and medium-bedded limestone stringers (Table 1).

Brachiopods from the 32 sections that are recorded in the literature of South China consist of about 68 genera and 164 species in the Changxingian and about 12 genera and 20 species that extend into the lower Griesbachian (Table 6). Permian-type brachiopods are completely absent above the Griesbachian. Twenty-four genera and 34 species are described in this paper, including 3 new genera and 24 new species.

TABLE 1.—Summary of formations and general lithology near the Permian-Triassic boundary in South China.

Stratigraphic Units		Zhejiang and Jiangsu Provinces	Hubei, Hunan and Guangxi Provinces	Sichuan Province	Fujian Province	West Guizhou and Yunnan Provinces
Series	Stage					
Lower Triassic	Griesbachian	Yinkeng or lower Lower Qinglong Fm.: calcareous mudstone intercalated thin and medium limestone	Lower Daye Fm.: thin and medium bedded limestone interbedded calcareous and silt mudstone	Lower Feixianguan Fm.: purple mudstone and grey muddy limestone	Lower Xikou Fm.: calcareous siltstone and sandstone, mudstone	Kayitou Fm.: sandstone, siltstone
Upper Permian	Changxingian	Changxing Fm.: limestone and chert limestone	Dalong Fm.: silicalite intercalated limestone and mudstone	Changxing Fm.: limestone intercalated siliceous limestone and calcareous mudstone	Yanshi Fm.: calcareous siltstone and mudstone	Upper Xuanwei Fm.: siltstone intercalated coal beds

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G. Arthur Cooper and Norman D. Newell contributed through their useful discussions of stratigraphy and brachiopods. Rex A. Doescher provided us the use of his database at the Smithsonian International Brachiopod Information Center, which helped to make the manuscript consistent. The typescript was reviewed for scientific content by Yang Zunyi, China University of Geosciences, Stanley S. Beus, Northern Arizona University, and Bruce R. Wardlaw, United States Geological Survey, whom we thank for substantial insights.

The collections of brachiopods described in this paper from 32 sections of South China were contributed by teachers and students of the Wuhan College of Geology who worked in the field every summer from 1980 to 1984. Data on stratigraphic

sections were published by Z.Y. Yang et al. (1987). Other fossils referred to in this paper include ammonoids identified by F.Q. Yang, conodonts by M.H. Ding, and fusulinids by R.G. Gu. We appreciate their help greatly.

Illustrated specimens are deposited in the collections of the former United States National Museum (USNM), now in the National Museum of Natural History, Smithsonian Institution, Washington, D.C.

## Zonation and Correlation

Several schemes of brachiopod zonation near the Permian-Triassic boundary in South China have been advanced during the past two decades (Table 2). Summing up the brachiopod sequences of the 32 sections as well as information taken from other works, we put forward the brachiopod zonation presented in the left column in Table 2. Brachiopod faunas are closely related to lithofacies in the Changxingian, so brachiopod assemblage zones are linked to the several lithofacies of that stage.

1. *Cathaysia chonetoides* (Chao)-*Chonetinella substrophomenoides* (Huang) assemblage zone (abbreviation C-C): The representative brachiopod fauna in the clastic lithofacies of the lower Changxingian is not highly diverse, being composed mainly of Chonetoidea, such as *Waagenites*, *Chonetinella*, and *Fanichonetes*, new genus; Chonetellidae, such as *Cathaysia*; and Meekellidae, such as *Orthothenina* and *Perigeyerella*. The following species play important roles in this assemblage zone: *Cathaysia chonetoides* (Chao), *C.*

TABLE 2.—The course of zonation change of brachiopods near the Permian-Triassic boundary in South China.

Stratigraphic Units		Hou et al. 1980	Liao, 1980	Yang, et al. 1987	this paper	
Series	Stage				clastic lithofacies	limestone lithofacies
Lower Triassic	Griesbachian			<i>Crurithyris speciosa</i> -- <i>Lingula subcircularis</i> assemblage zone	<i>Crurithyris pusilla</i> --- <i>Lingula subcircularis</i> assemblage zone	
Upper Permian	Changxingian	<i>Cathaysia sinuata</i> , <i>Oldhamina minor</i> , <i>Crurithyris pusilla</i> , <i>Hustedia indica</i>	<i>Enteletina zigzag</i> *--- <i>Cathaysia sulcatifera</i> **	<i>Waagenites barusiensis</i> - <i>Crurithyris pusilla</i> assemblage	<i>Cathaysia sinuata</i> - <i>Waagenites barusiensis</i> assemblage	<i>Spingerella discusella</i> -- <i>Acosarina minuta</i> assemblage
		<i>Tschernyschewia geniculata</i> , <i>Enteletina sinensis</i> *, <i>Meekella kueichowensis</i>	assemblage	<i>Enteletina zigzag</i> *-- <i>Neowellerella pseudoutah</i> † assemblage	<i>Cathaysia chonetoides</i> -- <i>Chonetinella substrophomenoides</i> assemblage	<i>Peltichia zigzag</i> -- <i>Prelissorhynchia triplicatioid</i> assemblage

\* *Enteletina zigzag* = *Peltichia zigzag*; *E. sinensis* = *P. sinensis*.

\*\* *Cathaysia sulcatifera* = *C. sinuata*.

† *Neowellerella* = *Prelissorhynchia*? (see discussion in systematic descriptions).

*spiriferoides*, new species, *Chonetinella substrophomenoides* (Huang), *Waagenites wangina* (Chao), *Orthoethina regularis* (Huang), and *Prelissorhynchia pseudoutah* (Huang). The standard section is the Yanshi section, Longyan County, Fujian Province (spot 31). The distribution of the assemblage zone usually coincides with the occurrence of fine clastic rocks (Figures 2, 3).

2. *Peltichia zigzag* (Huang)-*Prelissorhynchia triplicatioid*, new species, assemblage zone (abbreviation P-P): The brachiopod fauna in the limestone lithofacies of the lower Changxingian is composed of *Peltichia zigzag* (Huang), *P. sinensis* (Huang), *P. schizoloides*, new species, *Prelissorhynchia triplicatioid*, new species, *P. pseudoutah* (Huang), *Araxathyris beipeiensis*, new species, *Uncinunellina multicostifera*, new species, *Cyrolexis antearcus*, new species, *Squamularia formilla*, new species, and *Spinomarginifera kueichowensis* (Huang). Three important features characterize this assemblage zone. First, the genus *Peltichia* of the Superfamily Enteletoidea reached its greatest abundance. Secondly, members of the order Rhynchonellida are more abundant than in brachiopod faunas of underlying and overlying beds. The third characteristic is that several relatively large-size genera, such as *Dictyoclostus*, *Spinomarginifera*, *Edriosteges*, and *Tyloplecta*, occur plentifully. The Huayingshan section, Linshui County, Sichuan Province (spot 6), is the reference locality of the assemblage zone. Limestone, marl, calcareous dolomite, and minor lithotypes are its main matrices (Figures 2, 3).

3. *Cathaysia sinuata* Chan-*Waagenites barusiensis* (Davidson) assemblage zone (abbreviation C-W): This clastic lithofacies brachiopod fauna of the upper Changxingian is less diverse than the fauna in the same lithofacies of the lower Changxingian. It consists of *Cathaysia sinuata* Chan, *Waagenites barusiensis* (Davidson), *Crurithyris pusilla* Chan, *Orthoethina regularis* (Huang), and *Leptodus nobilis* (Waagen). The reference section is the same as that of assemblage zone 1, but the distribution of this assemblage zone is somewhat wider than that of assemblage zone 1 (Figures 2, 3).

FIGURE 2 (opposite page).—Stratigraphic sequences and brachiopod faunal ranges near the Permian-Triassic boundary in South China. The section numbers correspond to the numbers on Figure 1. (A = *Araxathyris* spp.; Ac = *Acosarina* spp.; C = *Crurithyris* spp.; CC = *Cathaysia chonetinella*; Cs = *Cathaysia* spp.; Cu = Cuiplingshan Formation; LC = lower Changxing Formation; L = *Lingula* spp.; LD = lower Dalong Formation; LF = lower Feixianguan Formation; LJ = lower Jinjiling Formation; LL = Longdongchuan Formation; LLu = lower Loulou Formation; LM = lower Majiaoling Formation; Lo = Longtan Formation; LP = lower Paoshui Formation; LX = lower Xikou Formation; LYa = lower Yanshi Formation; M = *Uncinunellina multicostifera*; Ma = Majiashan Formation; O = *Cathaysia obicularis*; P = *Prelissorhynchia pseudoutah*; R = *Richthofenia*?; S = *Chonetinella substrophomenoides*; TLD = lower Daye Formation; U = *Uncinunellina* spp.; UC = upper Changxing Formation; UD = upper Dalong Formation; UL = upper Longdongchuan Formation; UP = upper Paoshui Formation; UYa = upper Yanshi Formation; W = *Waagenites* spp.; Wu = Wujiaping Formation; Y = Yundoutan Formation; Yi = Yinkeng Formation; Z,A = zone of *Acosarina*; Z.P = zone of *Prelissorhynchia*; Z.R = zone of *Richthofenia*.)



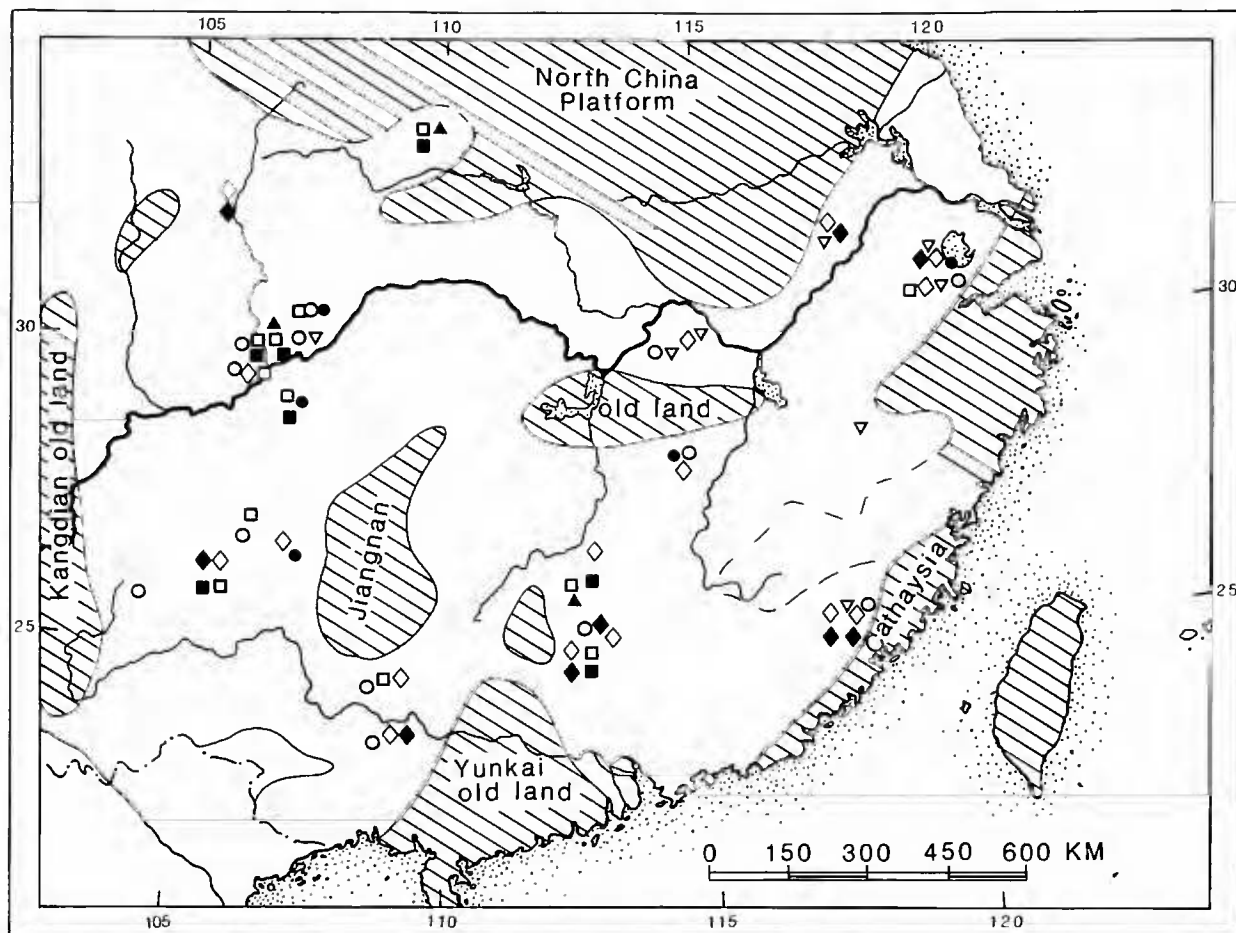


FIGURE 3.—Stratigraphic distribution of brachiopod assemblage zones and biofacies near the Permian-Triassic boundary in South China. (♦ *Cathaysia chonetoides*-*Chonetella substrophomenoides* assemblage zone and antibiohermal dwellers biofacies; ◇ *Cathaysia sinuata*-*Waagenites brusiensis* assemblage and antibiohermal biofacies; ■ *Peltichia zigzag*-*Prelissorhynchia triplicatioid* assemblage zone and calcareous substratum biofacies; □ *Spirigerella discussella*-*Acosarina minuta* assemblage zone; ▲ biohermal biofacies; ● *Lingula* present in top of Changxingian Formation; ○ *Crurithyris pusilla*-*Lingula subcircularis* assemblage zone; ▽ Permian-type survivors biofacies.)

4. *Spirigerella discussella*, new species-*Acosarina minuta* (Abich) assemblage zone (abbreviation S-A): The reference locality and distribution of this limestone lithofacies assemblage zone of the upper Changxingian is essentially the same as that of assemblage zone 2. It contains many small-size species, for example, *Acosarina minuta* (Abich), *A. indica* (Waagen), *Crurithyris pusilla* Chan, *Spirigerella discussella*, new species, *Uncinunellina theobaldi* Waagen, and *Rugosomarginifera chengyaeyenensis* (Huang), but it still has several medium- and large-size species, for example, *Spinomarginifera alphas* (Huang), *Meekella langdaiensis* Liao, and *Perigeyerella attilosina*, new species.

5. *Crurithyris pusilla* Chan-*Lingula subcircularis* Wirth assemblage zone (abbreviation C-L): The lower Griesbachian brachiopod fauna contains abundant *Lingula*, *Crurithyris*, and several Permian-type (Changxingian) survivors, such as *Waagenites brusiensis* (Davidson), *Cathaysia sinuata* Chan, *C. orbicularis* Liao, and *Fusichonetes pigmaea* (Liao). Many individuals of *Crurithyris* sp. lie scattered on the bedding surface near the bottom of the lower Daye and lower Feixianguan formations at many sections, e.g., the Shatian section, Daye City, Hubei Province (spot 17), the Liangfengya

section, Zhongqing City, Sichuan Province (spot 8), and the Shandongqiao section, Qingzun County, Guizhou Province (spot 10). These brachiopods typically are small, usually only 0.5 mm, so they are difficult to identify; without magnification they could be mistaken for ostracods. *Crurithyris pusilla* Chan is abundant in the lower Griesbachian, but it originates in the upper Changxingian and can extend high into strata of the upper Griesbachian. *Lingula* ranges commonly from the top of the Changxingian, into the Lower Triassic, and thence into the Dienerian. A shell-bed occurring in the third member of the Feixianguan Formation of Liangfengya section (spot 8) has *Lingula* along with the bivalves *Eumorphotis multiformis* (Bittner), *Claraia aurita* (Ktauer), and *C. stachei* (Bittner), all of which are regarded as index fossils of the upper Griesbachian to the Smithian (Yang et al., 1987, table 2-15). Nevertheless, the truly Permian-type survivors are strictly limited to the lower Griesbachian.

#### Relationship with Other Biozones

No identifiable ammonoid or fusulinid fossils have been found in the lower Yanshi Formation at the Yanshi section

(spot 31), the reference section of the C-C assemblage zone. In the upper Yanshi Formation, however, about 20 m up into the C-C assemblage zone, is found the ammonoid *Pseudotiroilites*, the index fossil to the upper Changxingian (Table 3). A rich ammonoid fauna, which has about 17 species including those in *Tapashanites* and *Pseudostephanites*, and conodont *Mesogondolella subcarinata* (Sweet et al.) co-occur in the C-C assemblage zone in a darkish gray, medium-bedded, bituminous sparite to microsparite intercalated with siltstone, about 6 m thick, in the lower Changxing Formation at the Meishan section (spot 26). In that section, however, the C-C assemblage zone extends upward about 6 m where there appear conodonts of the species *Mesogondolella changxingensis* (Wang and Z.H. Wang), which is regarded as a representative of the upper Changxingian (Table 3). It can be seen that the top boundary of the C-C assemblage zone is higher than that of the *Mesogondolella subcarinata* zone. In the Paoshui section (spot 15), some important members of the C-C assemblage, such as *Prelissorhynchia pseudoutah* (Huang) and *Waagenites wongiana* (Chao), are associated with the upper Changxingian ammonoids *Rotodiscoceras*, *Pseudotiroilites*, and *Pleuronodoceras* in a light to dark gray, thin-bedded, silicified tuffaceous claystone. This claystone is somewhat less than 1 m thick, and it occurs about 2 m above the top of the Heshan Formation (Wujiaping Stage), approximately 280 m below the Permian-Triassic boundary. This may indicate that the top of the C-C assemblage zone is higher than that of the *Tapashanites-Shevyrevites* zone (Table 3). In the Meitian section, Yizhang

County, Hunan Province (spot 23), typical members of the C-C assemblage zone, namely, *Cathaysia chonetoides* (Chao), *Prelissorhynchia pseudoutah* (Huang), and *Waagenites wongiana* (Chao), along with ammonoids of the genus *Tapashanites*, occur in the same beds of the lower Paoshui Formation.

The P-P assemblage zone is associated with the fusulinid *Palaeofusulina* sp. and the conodonts *Hindeodus "minutus"* (Ellison) (perhaps *typicalis* or *julfensis*, according to Wardlaw, pers. com. 1992) and *Mesogondolella elongata* (Wang and Z.H. Wang) in the Huayingshan section (spot 6). Previously we thought this conodont fauna represented the lower Changxingian (Table 3). At the Liangfengya section (spot 8) the important brachiopods *Prelissorhynchia pseudoutah* (Huang) and *Araxathyris beipeiensis*, new species, of the P-P assemblage zone co-occur with the fusulinids *Nanlingella simplex* (Sheng and Chang) and *Reichelina changhsingensis* Sheng and Chang, which usually occur in the lower Changxingian (Table 3). *Peltichia zigzag* (Huang), the typical member of the P-P assemblage zone, and conodont *Mesogondolella changxingensis* (Wang and Z.H. Wang) occur together in a gray, medium-bedded, cherty limestone only 1 m below the top of the upper Changxing Formation.

The ammonoid *Pleuronodoceras* and the conodont *Mesogondolella changxingensis* (Wang and Z.H. Wang) (see Table 3) are associated with the brachiopods *Cathaysia sinuata* Chan and *Waagenites barusiensis* (Davidson) in a dark gray, thin-bedded, calcareous, silty mudstone in the upper Yanshi Formation at the Yanshi section (spot 31). Brachiopods of the

TABLE 3.—Zonations of ammonoids, conodonts, and fusulinids near the Permian-Triassic boundary in South China. *Neogondolella* = *Mesogondolella*.

Stratigraphic Units		Ammonoid zones		Conodont zones	Fusulinid zones	
		Zhao et al. 1981	Yang et al. 1987	Yang, et al. 1987	Sheng 1983	Yang et al. 1987
Series	Stage					
Lower Triassic	Griesbachian	<i>Otoceras</i> , <i>Hypophiceras</i>	<i>Otoceras</i>	<i>Hindeodus parvus</i>		
		<i>Rotodiscoceras</i> , <i>Pseudotiroilites</i> , <i>Pleuronodoceras</i>	<i>Rotodiscoceras</i> --- <i>Pseudotiroilites</i>	<i>Neogondolella deflecta</i> -- <i>Neogondolella changxingensis</i>	<i>Palaeofusulina laxa</i>  <i>Palaeofusulina mutabilis</i>	<i>Palaeofusulina sinensis</i> --- <i>Reichelina changhsingensis</i>
Upper Permian	Changxingian	<i>Pseudostephanites</i> --- <i>Tapashanites</i>	<i>Tapashanites</i> --- <i>Shevyrevites</i>	<i>Neogondolella subcarinata</i> -- <i>Neogondolella elongata</i>	<i>Reichelina changhsingensis</i>	<i>Nanlingella simplex</i> --- <i>Gallowaiinella meitiensis</i>

*C-W* assemblage zone, *Crurithyris pusilla* Chan and *Orthothetina regularis* (Huang), occur in a bed of light gray, medium-bedded biosparrodite about 1 m below the top of the Changxing Formation, along with the conodont *Mesogondolella changxingensis* (Wang and Z.H. Wang), at the Meishan section (spot 26). At the Majiashan section (spot 24) at the top of the Changxingian, *Crurithyris pusilla* Chan and *Waagenites barusiensis* (Davidson) are associated with conodont *Mesogondolella deflecta* (Wang and Z.H. Wang) in a bed of white-yellow claystone. The members of the *C-W* assemblage zone, *Crurithyris pusilla* Chan and *Cathaysia sinuata* Chan, co-occur with ammonoids of the genera *Pleuronodoceras* and *Pseudotirolites* and with conodont *Mesogondolella deflecta* (Wang and Z.H. Wang) in the upper part of the Changxing Formation at the Shangsi section, Guangyuan County, Sichuan Province (spot 4). At the Meitien section (spot 23), the beds that contain the *C-W* assemblage zone overlie beds that yield the ammonoid genus *Tapashanites*, which is associated with the *C-C* assemblage zone.

The *S-A* assemblage zone occurs in limestone of the upper Changxing Formation that also yields the conodonts *Mesogondolella deflecta* (Wang and Z.H. Wang) and *M. changxingensis* (Wang and Z.H. Wang) at the Huayingshan section (spot 6). *Rugosomarginifera chengyaenensis* (Huang), *Uncinunellina theobaldi* Waagen, and *Spinomarginifera alphas* (Huang) are associated with fusulinids of the genus *Palaeofusulina* and conodonts *Mesogondolella deflecta* (Wang and Z.H. Wang) and *M. changxingensis* (Wang and Z.H. Wang) at the Liangfengya section (spot 8). At the Longtoujiang section, Yishan County (spot 14), the brachiopods *Acosarina minuta* (Abich) and *Uncinunellina theobaldi* Waagen are mixed with brachiopods of the *C-W* assemblage zone, *Waagenites barusiensis* (Davidson) and *Spinomarginifera alphas* (Huang), in the upper Dalong Formation and are associated with the ammonoid *Pseudotirolites*(?).

As mentioned above, the genera *Lingula* and *Crurithyris* have long ranges, but the species *Crurithyris pusilla* Chan and *Lingula subcircularis* Wirth occur together only in the lower Griesbachian. The Permian-type brachiopods are confined to the *C-L* assemblage zone. In the Huayingshan section (spot 6), *Crurithyris pusilla* Chan is associated with *Lingula subcircularis* Wirth and *L. borealis* Bittner in the bottom beds of the lower Daye Formation. These bottom beds are composed of gray, thin-bedded limestone intercalated with calcareous mudstone about 1 m thick and also contain *Acosarina minuta* (Abich). This brachiopod fauna coexists with the ammonoid *Ophiceras* and bivalves *Claraia griesbachi* (Bittner) and *Pseudoclaraiia wangi* (Patti).

Similar associations occur in many sections, such as the Xinjiacao section, Guangan County (spot 5); Yanjingxi section, Hechuan County (spot 7); Liangfengya section, Zhongqing City (spot 8); Huangzhishan section, Wuxing County (spot 27); Yading section, Zhangping County (spot 30); Baimu section, Yichun County (spot 19); and Paoshui section, Laibin County

(spot 15). In several sections the Permian-type survivors are fairly abundant, occurring in the bottom beds of the lower Griesbachian. For example, the bottom bed of the Yinkeng Formation, which is bluish gray intrasparite-intramicroite intercalated dark mudstone at the Meishan section (spot 26), preserves many Permian-type brachiopods, such as, *Waagenites barusiensis* (Davidson), *Fusichonetes pigmaea* (Liao), *Cathaysia sinuata* Chan, *C. orbicularis* Liao, *Acosarina* sp., and *Araxathyris* sp., associated with the ammonoids *Hypophiceras* and *Otoceras* (by reference to J.Z. Sheng et al., 1984:143, text-fig. 6). At the bottom of the Yinkeng Formation in the Majiashan section (spot 24), *Cathaysia orbicularis* Liao and *Waagenites barusiensis* (Davidson) co-occur with *Ophiceras* in a bed of yellowish green, thin-bedded, hydromicaceous quartz siltstone. A similar situation can be found at the Shatian section (spot 17), Puqi section (spot 18), and Meitian section (spot 23).

Brachiopod assemblage zones correlate fairly well with ammonoid and conodont zones in the Changxingian except that the top boundary of the *C-C* and *P-P* assemblage zones might link to a somewhat higher horizon than the ammonoid and conodont zones in the lower Changxingian. The *C-L* assemblage zone in the lower Griesbachian coincides roughly with the ammonoid zone *Hypophiceras* and ?*Otoceras*.

#### Correlations within Tethys

Places reported to have Changxingian faunas that are continuous with the lower Griesbachian occur throughout much of the extent of the Tethys. North Tibet of China, Transcaucasia of Georgia and Armenia, Kuh-e-Ali Bashi area of Iran, the Salt Range of Pakistan, and Guryul Ravine of Kashmir are well-known areas that have been reported to have Changxingian brachiopod faunas (e.g., Grant, 1970). Lately the island of Hydra, Greece, has been reported to have Changxingian brachiopods and foraminifera (Grant et al., 1991), thus providing a Changxingian link within Tethys between the Middle East and the Dolomite Alps of Italy, the westernmost marine occurrence.

A Changxingian brachiopod fauna was discovered in the Shuanghu area (33.6°N, 86.8°E) of North Tibet. Jing and Sun (1981) confirmed the existence of the Changxingian brachiopod fauna and described *Peltichia zigzag* (Huang) and *Spinomarginifera pseudosintanensis* (Huang) that were collected from the Reggyorcaka Formation by Wen (in Ching, Liang, and Wen, 1979), and identified known species of other brachiopod fossils (Jing and Sun, 1981:167) including *Cathaysia chonetoides* (Chao), *Squamularia waageni* Loczy, and *Leptodus* sp. from the lower part of the Reggyorcaka Formation (J.Z. Sheng et al., 1984:153). The brachiopod fauna in the Tanggula-Qamdo region of North Tibet is the *Peltichia sinensis-Squamularia superba* assemblage, which is representative of the Changxingian in the Toba Formation (Jing and Sun, 1981:169). Those faunas undoubtedly correlate with the



*P-P* assemblage zone in South China; therefore, the lower part of the Reggyorcaka Formation and some part of the Toba Formation may be early Changxingian.

In the Transcaucasia region of Armenia and Azerbaijan, the sequence of the Dzhulfa section was divided into 15 units by Stoyanow (1910; see also Ruzhentsev and Sarycheva, 1965:10; Teichert et al., 1973:364), of which units 1 to 6 contain brachiopod fossils. The fauna in unit 5 was named "zone of *Productus djulfensis* Stoyanow," and it also contains *Orthis indica* Waagen and *Marginifera spinocostata* (Abich). *Orthotichia indica* (Waagen) (= *Orthis indica*) was recorded from various strata of the Lower and Upper Permian in South China. Liao (1980a:145, table 1) reported *Stepanoviella djulfensis* (Stoyanow) (= *Productus djulfensis*) in the Longtan and Changxing formations in Guizhou Province. When they synthesized 5 sections (including the Dorasham section) of the Transcaucasia region, Arakelyan, Grunt, and Schevyrev (in Ruzhentsev and Sarycheva, editors, 1965:25) wrote that "horizon 3 with *Bernhardites*" constitutes the "Induan stage." As T.K. Zhao (1965) pointed out, most of the Induan stage actually was Permian. Rostovtsev and Azaryan (in Logan and Hills, editors, 1973:383) proposed to set up a new Permian stage, the Dorashamian, which has *Araxathyris araxensis minor* Grunt. "Horizon 4 with *Paratirolites*" possesses *Enteleles dzhagrensis* Sokolov, *Orthotichia parva* Sokolov, *Orthothetina* sp., *Spinomarginifera pygmaea* Sarycheva, *Haydenella kiangsiensis* (Kayser), *H. minuta* Sarycheva, *Terebratuloida* sp., *Araxathyris ogbinensis* Grunt, and *A. araxensis minor* Grunt (Arakelyan, Grunt, and Schevyrev in Ruzhentsev and Sarycheva, editors, 1965:25). The brachiopod fauna shown by Sarycheva, Sokolov, and Grunt in their table 9 (in Ruzhentsev and Sarycheva, editors, 1965:69) consists of the same members as mentioned in horizon 4, 454 specimens collected from the Induan stage of three sections (Dorasham, Ogbin, and Prochie) of the Transcaucasia region. Teichert et al. (1973:383) pointed out that of a total of 454 specimens recorded from the Induan, 389 of those are assigned to one species, *Araxathyris araxensis minor* Grunt. This species was reported in the Yinkeng Formation of the Meishan section of South China (Sheng et al., 1984:143, text-figs. 6, 144). Our collections did not include this species, but the genus *Araxathyris* surely exists in the Changxingian of South China. *Haydenella kiangsiensis* (Kayser) occurs widely in the Lower to Upper Permian in South China, but it is most common in the Wujiapingian. *Spinomarginifera*, *Enteleles*, and *Orthothetina* occur commonly in the Changxingian; therefore, it is true that the brachiopod fauna of horizon 4 of the Induan part of the Dorashamian in the Transcaucasia region can be correlated with the Changxingian brachiopod fauna.

Teichert et al. (1973:382) reported brachiopod fossils from the Ali Bashi Formation at Kuh-e-Ali Bashi of Northwest Iran that later were identified by G.A. Cooper as *Araxathyris araxensis minor* Grunt and *Araxathyris* sp. *Araxathyris araxensis minor* Grunt is the main member of the Dorashamian

brachiopod fauna. In the Abadeh region of Central Iran, the Surmag, Abadeh, and Hambast formations preserved abundant brachiopod fossils. The Iranian-Japanese Research Group (1981:101, table 3) concluded that unit 5 of the Abadeh Formation and unit 6 of the Hambast Formation correlate with the Wujiapingian of South China, based on fusulinids.

Unit 7 of the Hambast Formation can be compared with the Dorashamian based on ammonoids; therefore, it also can be correlated with the Changxingian. The brachiopod fauna in unit 7 of the Hambast Formation, however, contained only four species: *Spinomarginifera helica* (Abich), *Araxathyris minor* Grunt?, *Notothyris* aff. *nucleolus* (Kutorga), and *Leptodus* sp. (Iranian-Japanese Research Group, 1981:89, fig. 8). Nonetheless, the aspect of the brachiopod fauna in both the Ali Bashi Formation and unit 7 of the Hambast Formation is similar to the Dorashamian brachiopod fauna belonging to the age of the Changxingian, even though they are not the typical Changxingian brachiopod fauna.

Because brachiopod fossils are poorly preserved and long ranging in the topmost beds of the Chhidru Formation of the Salt Range and Trans-Indus ranges, Pakistan, the ages of the brachiopod faunas are difficult to determine. An identifiable brachiopod fauna was found preserved in the topmost bed of the white sandstone of the Chhidru Formation by Grant (1970) at two places in the Trans-Indus Khisor Range, but some of the fossils have long ranges. The Pakistan-Japanese Research Group (1981, 1985) worked in the Salt Range and Surghar Range, Pakistan, and considered that five different assemblages named K, C1 to C4 can be distinguished in the Chhidru-I section (1985:254, 257, fig. 12).

The K assemblage correlates to the Kalabagh unit just below the C assemblages.

The assemblage C4 consists of seven species: *Oldhamina decipiens* (Koninck), *Richthofenia lawrenciana* Koninck, *Spirigerella carinata* Reed, *Enteleles socialis* Reed, *Whit-spakia acutangula* (Waagen), *Crurithyris* sp., *Derbyia* sp., and *Spinomarginifera* sp. Three of the species extend from the C3 assemblage; others have long ranges that are hard to date precisely.

The brachiopod faunas of C1-C3 zones are composed of *Callispirina ornata* (Waagen), *Cleiothyridina subexpansa* (Waagen), *C. grossula* (Waagen), *Costiferina indica* (Waagen), *Derbyia altistriata* Waagen, *D. grandis* Waagen, *D. hemisphaerica* Waagen, *D. subsinuata* Reed, *Enteleles socialis* Reed, *Hemiptychina himalayensis* (Davidson), *Kiangsiella pectiniformis* (Davidson), *Linoproductus lineatus* (Waagen), *Marginifera ornata* Waagen, *Megasteges nepalensis* Waterhouse, *Notothyris djoulfensis* Abich, *Oldhamina decipiens* (Koninck), *Spirigerella alata* Waagen, *S. carinata* Reed, *S. fusiformis* Waagen, *S. grandis* (Davidson), *S. minuta* Waagen, *Strophalosia indica* Waagen, *Waagenites deplinata* Waagen, *Waagenoconcha abichi* (Waagen), and *W. purdoni* (Davidson). According to the opinion of the Pakistan-Japanese Research Group (1985:257, table 2), the brachiopod faunas from zones

C1 to C3, which are referred to units 2 and 3 of the Chhidru Formation, could be correlated with the Wujiapingian to Changxingian (Changhsingian).

We conclude that the brachiopod fauna of zones C1–C3 of the Chhidru Formation most likely correlates with the fauna of the Wujiapingian on the basis of the following three factors. (1) Most of the zone C1–C3 species have long ranges, for example, *Spirigerella derbyi* (Waagen) is recorded from the Maokou to the Wujiaping Formation; *Oldhamina decipiens* (Koninck) and *Waagenoconcha abichi* (Waagen) extend from the Wujiaping to the Changxing Formation; and most species of the genera *Kiangsiella* and *Marginifera* have long ranges before the Changxingian in South China. (2) Several species, for example, *Waagenites deplanata* (Waagen) and *Chonetella nasuta* (Waagen), occur mainly in the Wujiapingian in South China. (3) Zones C1–C3 lack typical elements of both the Changxing brachiopod fauna and the Dorashamian fauna. Furthermore, only the fusulinid genus *Codonofusiella*, and not *Palaeofusulina*, occurs in the Chhidru Formation.

From the Kathwai Member, Mianwali Formation, Salt Range and Surghar Range, Kummel and Teichert (1966) collected several brachiopod fossils from the same beds that also had the preserved ammonoid *Ophiceras connectens*. These brachiopods subsequently were identified by G.A. Cooper who pointed out that they are Permian-type brachiopods that might be reworked from the underlying Chhidru Formation because of their fragmentary preservation. Several arguments against this hypothesis were enumerated by Grant (1970). The members of the brachiopod fauna in the Kathwai Member are composed of *Crurithyris? extima* Grant, *Derbyia? sp.*, dielasmatic undet., *Enteletes sp. 2*, *Linoproductus sp.*, *Lyttonia sp.*, *Martinia sp.*, *Ombonia sp.*, *Orthothenina cf. O. arakeljani* Sokolskaya, *Orthothenina sp.*, *Spinomarginifera sp.*, and *Whitspakia sp. 2* (Grant, 1970:123). A lingulid was described by Rowell (1970:113–116) as *Lingula sp. cf. L. borealis* Bittner, and *Orbiculoidea sp.* was recorded by Kummel and Teichert (1970:63). Numerous specimens of *Crurithyris? extima* Grant occur 5–6 feet above the base of the dolomitic unit at Khan Zaman Nala, which is well into the Triassic *Ophiceras* zone (Grant, 1970:144), and one specimen of *Spinomarginifera sp.* was collected above the lowest occurrence of the Triassic ammonoid *Ophiceras* (Grant, 1970:137). The situation of the brachiopod fauna in the Kathwai Member resembles the C–L assemblage zone of the lower Griesbachian in South China; the common ground of both faunas is the presence of *Crurithyris*, *Lingula*, and Permian-type survivors *Spinomarginifera*, *Enteletes*, *Orthothenina*, *Spirigerella*, etc., co-occurring with *Ophiceras*. Typical Changxingian survivors, such as, *Cathaysia*, *Waagenites*, and *Preliissorhynchia*, do not occur in the Kathwai Member, and *Lyttonia* and *Linoproductus* are not found in the C–L assemblage zone.

Waterhouse and Gupta (1983) discussed the Kathwai brachiopod fauna that was described and illustrated by Grant

(1970) who placed the fragmentary and specifically unidentifiable material in “open nomenclature.” These steinkerns and fragments were assigned specious specific names by Waterhouse and Gupta (1983), illustrating a long-standing pattern of scientific mendacity that has been called to attention and documented by Talent (1989), Ahluwalia (1989), Bhatia (1989), Bassi (1989), and Janvier (1989).

According to Nakazawa et al. (1975:56, 57, table 8), brachiopods of division IV or E1 of the lowermost Khunamuh Formation at Guryul Ravine in Kashmir consist of *Athyris cf. subexpansa* Waagen (Nakazawa et al., 1970, text-fig. 2), *Derbyia sp.*, Dictyoclostid?, *Dielasma? sp.*, *Linoproductus cf. lineatus* (Waagen), *Lissochonetes morahensis* (Waagen), *Marginifera himalayensis* Diener, *Neospirifer sp.*, *Pustula sp.*, *Schellwienella sp.*, and *Waagenoconcha purdoni* (Davidson). In addition, Diener (1915) described fossils *Chonetes lissarenensis* Diener, *Chonetes? aff. variolata* d’Orbigny, *Costiferina indica* (Waagen), *C. spiralis* Waagen, *Linoproductus cora* (d’Orbigny), *Spinomarginifera cf. helica* (Abich), *Waagenoconcha abichi* (Waagen), and *W. gangetica* (Diener) from the same area. The fauna of division IV or E1 of the lowermost Khunamuh is similar to that of the underlying divisions of the Zewan Formation. Within that fauna, *Waagenoconcha abichi*, *W. purdoni*, *Costiferina indica*, and *Linoproductus lineatus* occur in K–C3 assemblages of the Chhidru Formation, and *Spinomarginifera helica* was recorded from unit 1 of the Surmaq Formation to unit 7 of the Hambast Formation. The brachiopod fauna of division IV of the lowermost Khunamuh as a whole may be correlated with those of the Chhidru Formation; therefore, it also may be correlated with the Wujiapingian in South China. In E2 of the Khunamuh Formation, bed 52, two brachiopod species, *Marginifera himalayensis* Diener and *Pustula sp.*, were reported (Nakazawa et al., 1975:59, table 9) to occur in the same bed with ammonoids *Otoceras woodwardi* and *Glyptophiceras himalayicum*. These two Permian-type brachiopod survivors are in the same stratigraphic position in the Khunamuh as other brachiopods are in the C–L assemblage zone, but without species in common they can not be compared.

The Southern Alps in Italy contain a brachiopod fauna that includes *Ombonia*, *Araxathyris*, *Janiceps*, and *Comelicania*. Rare specimens of the Spiriferoidea and Dielasmatoidea occur in the upper part of the Bellerophon Formation, accompanied by ammonoids *Paraceltites sextensis* (Diener) in the Puseria Valley near Sesto (Assereto et al., 1973:185). This fauna is older than the Dorashamian according to the view of Assereto et al. (1973:188), but Waterhouse (1976:168) considered it to be Dorashamian. The genus *Araxathyris* is the most abundant brachiopod in the Dorasham Formation in Transcaucasia. *Ombonia* was reported by Grant (1970) from the Kathwai Member, Mianwali Formation of the Surghar Range, Pakistan, and *Janiceps* was reported from the Longtan Formation, Guizhou Province of South China, by Liao (1980a:277, pl. 9:

figs. 10–13). Therefore, the brachiopods seem to indicate that the fauna of the uppermost part of Bellerophon Formation correlates to the Wujiapingian and part of the Changxingian. A fauna from the Bukk Mountains of Hungary has *Crurithyris*, *Martinia*, *Comelicania*, *Tyloplecta*, and Licharewinids (Schreter, 1963). Assereto et al. (1973:187, 188) considered it to be older than the fauna of the Southern Alps.

The *Marginalosia kalikotei* zone of Northwest Nepal, specifically the Nisal, Nambo, and Luri Members of the Senja Formation, was named by Waterhouse (1978:136). The fauna is composed of *Marginalosia kalikotei* (Waterhouse), *Megasteges nepalensis* Waterhouse, *Neospirifer ravaniformis* Waterhouse, *Platyconcha grandis* Waterhouse, *Spiriferella oblata* Waterhouse, and *S. rajab* (Salter). The latter two species are predominant in the upper part of the zone, the Luri Sandstone Member (Waterhouse, 1978:16, 17). Waterhouse considered that the following pairs of fossils have similarities between them: *Rugaria nisalensis* Waterhouse of Nepal and *R. soochowensis* (= *Waagenites soochowensis*) (Chao) of the Lopingian in China; *Marginalosia kalikotei* (Waterhouse) of Nepal with *M. planata* (Waterhouse) from the Stephens Formation of New Zealand, of Vedian age; and *Martiniopsis* aff. *inflata* Waagen with the same species from the Chhidru Formation of the Salt Range. Based upon those comparisons he said, "This could imply a Djulfian (*sic* for Dzhulfian) or early Dorashamian (Vedian?) age" (Waterhouse, 1978:153).

Waterhouse correlated his *Aperispirifer nelsonensis* zone, with the Changxing? (1976, table 2, p. XVII) and the Vedian (1976:128, table 37), but he did not expound in detail. Waterhouse (1976) correlated the Stephens Formation with the Tatarian Stage, citing evidence in the South Island, New Zealand, based chiefly on the similarity of *Neospirifer nelsonensis* Waterhouse (= *Aperispirifer nelsonensis*) to Greenland shells described as "*Spirifer*" *striato-paradoxus* Toulou by Dunbar (1955). The Greenland species was found with *Cyclolobus*, which Dunbar considered to be probably Tatarian age (Waterhouse, 1967:77). Another reason for a Late Permian age assignment was that *Strophalosia planata* Waterhouse (= *Marginalosia planata*) is close to *Strophalosia gerardi* W. King from the Upper Permian of Ladakh and *S. blandfordi* Reed from the upper Productus Limestone of the Punjab. According to Stepanov (1973), however, the Tatarian Stage includes both the Dzhulfian and the Dorashamian, and the upper Productus Limestone spans the Chhidru Formation and the Kathwai Member as shown in the table by Kummel and Teichert (1970:18, table 1). We conclude that the use of brachiopods to correlate the *Aperispirifer nelsonensis* zone with the Changxingian is questionable.

A brachiopod fauna almost certainly of Changxingian age was discovered on Hydra Island, Greece (Grant et al., 1991). The Barmari Group of Late Permian age is subdivided into the Episkopi Formation below and the Miras Formation above. Abundant silicified brachiopods were collected from the

Episkopi Formation at several localities, and several new species await description. The lower part of the Episkopi contains the foraminifera *Codonofusiella* aff. *C. schubertelloides* Reitlinger, *Nankingella* sp., and *Reichelina* sp. The upper part of the formation contains *Palaeofusulina*, e.g., *P. sinensis* Sheng, and *Colaniella*, e.g., *C. lapida* Wang. Therefore, the brachiopod fauna in the Episkopi Formation contains constituents of both the Wujiapingian and the Changxingian. According to Nestell and Wardlaw (1987), conodonts indicate that the Episkopi is slightly older than the Changxing Formation at its type locality.

As previously mentioned, Griesbachian lingulids are distributed throughout the world, with the exception of South China and Pakistan. Species of *Lingula* have been reported in the following regions: the Southern Alps, Greenland, Hungary, Australia, and Iran. In the Southern Alps, *Lingula tenuissima* Bronn was identified from the Mazzin Member of the Werfen Formation; the fauna was called the *Lingula-Neoschizodus* assemblage, and it coexists with *Bellerophon vacceki* Bittner, which occurs with *Claraia stachei* (Bittner) above the bed with *Otoceras woodwardi* Griesbach at Shalshal Cliff (Assereto et al., 1973:188). *Lingula* cf. *borealis* Bittner occurs in the Siusi Member of the Werfen Formation with *Claraia clarae* (von Hauer) at the same stratigraphic position as *Lingula* cf. *borealis* (Broglia Loriga et al., 1980). In Eastern Greenland, *Lingula borealis* was found in the lower *Ophiceras* beds (Spath, 1930, 1934). In Iran, *Lingula* sp. was found in the lower part of the Elika Formation, and, within the dolomite, *Claraia* is associated with conodonts *Anchignathodus typicalis* Sweet and *A. isarcicus* Huckriede (Broglia Loriga et al., 1980). In the Maizuro zone of Japan, *Lingula* cf. *borealis* occurs in the strata of probable lower Scythian age (Bando, 1964). In Australia, *Lingula* is present in the Perth Basin, the Canning Basin, and the Bonaparte Gulf Basin; in the Perth Basin *Lingula* occurs about 1100 ft (~330 m) above the Permo-Triassic boundary, co-occurring with *Claraia stachei* (Bittner); in the Canning Basin and Bonaparte Gulf Basin *Lingula* is associated with the microflora *Kraeuselisporites saeptatus* zone, which is considered to be of Griesbachian-Dienerian age (Gorter, 1978; Tasch and Jones, 1979); in Siberia *Lingula borealis* Bittner was reported by Dagys (1965) from the Induan stage of Littoral Province, but it was not certain that the species occurred in the Griesbachian. In western North America, Newell and Kummel (1942) reported finding the *Lingula* zone in the Dinwoody Formation above the basal siltstone in western Wyoming, and resting on the Permian Phosphoria Formation in the western part of the Owl Creek and Wind River mountains where it is overlapped by the *Claraia* zone in the southeastern part of the Wind River Mountains. *Lingula borealis* Bittner is accompanied by *Ophiceras* and by the brachiopods *Spiriferina mansfieldi* Girty and *Mentzelia* sp.? in the *Lingula* zone; *Lingula borealis* rarely extends into the *Claraia* zone.

### Brachiopod Provinces and Biofacies

The paleogeographic distribution of Permian brachiopods was discussed in detail by Nakamura et al. (1985). They defined two Late Permian provinces in the Tethyan Realm: Middle Tethyan and Gondwana Tethyan. These realms make sense from the viewpoint of the tectonics of continental massifs. Here we try to describe the Changxingian paleogeography of brachiopods, which supplements their work, and in addition, we offer a preliminary discussion of the paleogeography of brachiopods in the lower part of the Griesbachian.

The Middle Tethyan province of the Tethys Sea can be divided into two subprovinces: Cathaysia Tethyan and West Tethyan. The Middle Tethyan province of brachiopods is characterized by the occurrence of *Araxathyris*, *Spinomarginifera*, *Waagenites*, and *Orthothenina* in the Changxingian. Places with this fauna include the Southern Alps, Transcaucasia, Iran, Pakistan, Kashmir, North Tibet, and South China, essentially coinciding with the limits shown in Nakamura et al. (1985:189, 192, figs. 2, 3). Brachiopods of the Cathaysia Tethyan subprovince are mainly species of *Cathaysia*, *Peltichia*, and *Prelissorhynchia*, genera considered endemic by Nakamura et al. (1985:193). The subprovinces are based upon their content of characteristic genera that represent various stages of evolutionary development. The genera *Costiferina*, *Ombonia*, and *Comelicania* represent the West Tethyan subprovince that extends from Kashmir and Pakistan in the east to the Southern Alps in the west.

The fauna of the Senja Formation, Northwest Nepal, with its rare Strophomenida, numerous Strophalosioidea, few Productoidea, and numerous Spiriferida, belongs to a polar biome that links to the fauna of New Zealand (Waterhouse, 1978:161). Therefore, the brachiopod faunas of the *Marginalosia kalikotei* zone and the *Aperispirifer nelsonensis* zone represent Gondwana Tethys.

The brachiopod fauna of the lower Griesbachian is characterized by *Lingula*, *Crurithyris*, and a few Permian-type survivors. The former extends throughout the Tethys Sea along the margin of the Pangaea continent (Broglio Loriga et al., 1980:99, fig. 3). We shall refer to this fauna as the Circum-Pangaea brachiopod fauna.

### Biofacies

Brachiopod biofacies were classified by Grant (1971) into three types, based upon study of large numbers of collections from West Texas. They are reef dwellers, antireef dwellers, and neutral or ubiquitous forms. The Huatang brachiopod fauna has "analogous phenomena" with the ecologic classification of West Texas Permian Brachiopods, as Liao and Meng (1986:73) pointed out in their analysis of the brachiopod biofacies of the Changxingian at Huatang, Chenxian County, Hunan Province. Liao (1979, 1980b) divided the brachiopod biofacies of the Changxingian into two types: brachiopods related to limestone

and those related to silicalite. In his view, brachiopods are firmly linked to lithofacies. This paper treats brachiopods of the Changxingian in regard to biofacies, lithology, and paleogeographic position.

### CHANGXINGIAN BRACHIOPOD BIOFACIES

Four brachiopod biofacies are distinguished in the Changxingian and two in the lower Griesbachian (Tables 4, 5).

**ANTIBIOHERMAL BIOFACIES.**—The main representatives of this facies are *Waagenites*, *Chonetinella*, and *Orthothenina*, all of which are characterized by a narrow coelomic cavity. Their habits were adapted to the muddy, silty, or siliceous substrate and were usually near a source of sediment adjacent to an old landmass or a site of volcanic activity. Their typical sympatriots were bivalves. This biofacies is widespread, occurring for example, at spots 30 and 31 where strata consist mainly of arenite (Yanshi Formation) and near the west margin of *Cathaysia*; at spots 17 and 24 where sections are an alternation of silicite and silty mudstone or clay rock beds, and near the south margin of the North China old land; and at spots 20 and 23 where strata mainly are siliceous and clay rocks, coinciding with the basal siliceous and clay rock facies (Sheng et al., 1985:69, fig. 7). It is difficult to procure brachiopods from the bioherms; only one specimen of *Waagenites* sp. has been reported from the Huatang fauna (Liao and Meng, 1986:73).

TABLE 4.—Brachiopod biofacies of the Changxingian stage in South China.

Antibiohermal dwellers	Calcareous substratum dwellers	Biohermal dwellers	Ubiquitous dwellers
<i>Cathaysia</i>	<i>Araxathyris</i>	<i>Enteletes</i>	<i>Acosarina</i>
<i>Chonetinella</i>	<i>Cartorhium</i>	<i>Meekella</i>	<i>Crurithyris</i>
<i>Orthothenina</i>	<i>Derbyia</i>	<i>Notothyris</i>	<i>Leptodus</i>
<i>Spinomarginifera</i>	<i>Dictyoclostus</i>	<i>Peltichia</i>	<i>Oldhamina</i>
<i>Waagenites</i>	<i>Notothyris</i>	<i>Richthofenia</i>	<i>Prelissorhynchia</i>
	<i>Peltichia</i>	<i>Rostranteris</i>	
	<i>Rostranteris</i>		
	<i>Spirigerella</i>		
	<i>Squamularia</i>		

TABLE 5.—Brachiopod biofacies of the lower Griesbachian stage in South China.

<i>Lingula</i> biofacies	Permian-type survivors
<i>Lingula</i>	<i>Acosarina</i>
<i>L. borealis</i>	<i>Araxathyris</i>
<i>L. subcircularis</i>	<i>Chonetinella</i>
<i>L. tenuissima</i> var. <i>sinensis</i>	<i>Fanichonetes</i>
<i>L. spp.</i>	<i>Fusichonetes</i>
<i>Crurithyris</i>	<i>Prelissorhynchia</i>
	<i>Waagenites</i> and other chonetids

These genera are absent elsewhere in South China.

**CALCAREOUS SUBSTRATUM DWELLERS.**—Most brachiopods are attached by a pedicle to the substrate in all or part of their lives. Permian examples are *Araxathyris*, *Spirigerella*, *Squamularia*, *Notothyris*, *Rostranteris*, and *Peltichia*. These brachiopods lived on the platform, in relatively shallow water of low energy, attached to abandoned shells, concretions, or clastic particles. The distributive area of this biofacies includes the Sichuan and Hunan basins, such as spots 5–9.

**BIOHERMAL DWELLERS.**—During the last decade, several calcareous buildups of Late Permian age have been found in South China in such areas as in Lichuan County, Hubei Province; Huayingshan, Linshui County, Sichuan Province; and Huatang, Chenxian, and Longdongchuan, Zhenan County, Shaanxi Province. The Longdongchuan buildup is composed of gray or light pink, massive- to thick-bedded limestone or dolomitic limestone, bearing abundant fossils including corals, bryozoans, algae, foraminifera, and brachiopods. It is limited to a small region, laterally becoming an alternation of arenite and limestone beds. Brachiopods of this facies consist of richthofeniids, with their coralliform shells; *Meekella* and *Perigeyerella*, which have higher than normal interareas; and *Araxathyris*, *Peltichia*, *Enteletes*, *Notothyris*, and *Rostranteris*, whose attachments were mostly by pedicle.

Typical antibiohermal dwellers, the inarticulates and Chonetoida, are not found in the Longdongchuan fauna. The Huatang Fauna is similar to the Longdongchuan fauna, but contains a few richthofeniids, a large group of pediculate brachiopods, and almost no chonetids or inarticulates.

**UBIQUITOUS DWELLERS.**—These are brachiopods that occur in various lithofacies, and they include such Changxingian examples as the small-size genera *Acosarina*, *Crurithyris*, and *Prelissorhynchia*, and leptodids whose shapes vary according to habitat conditions. For instance, *Oldhamina* is usually large and strongly inflated when preserved in limestone or bioherm; in other habitats it can be relatively small and flat.

#### BRACHIOPOD BIOFACIES OF THE LOWER GRIESBACHIAN

**Lingula BIOFACIES.**—The genus *Lingula* (including species *L. subcircularis* Wirth, *L. borealis* Bittner, *L. tenuissima* var. *sinensis* Wirth, and *L. spp.*) is spread widely in the lower Griesbachian in South China, and it commonly is accompanied by *Crurithyris*. At the top of the Changxingian, *Lingula* occurs in several sections, such as spots 5, 9, 12, and 19, and also in the Mashishan of Xidongtingshan Island, Wuxian County, Zhejiang Province (J.Z. Sheng et al., 1984:149, text-fig. 14). This distribution implies that a regression (sea level retreat) began as the epeiric sea became shallower in areas of central Sichuan, North Guizhou, Zhejiang, and North Jiangxi.

**PERMIAN-TYPE SURVIVOR BIOFACIES.**—Several areas were found to contain Permian-type brachiopod survivors: Zhejiang (spot 26), South Anhui (spot 24), Central Hubei (spot 17), Central Sichuan (spot 6), and South Hunan (spot 23). Most of

these brachiopod fossils were preserved in calcareous mudstone or marlite, many associated with bivalves.

#### Extinction and Evolution

Brachiopods underwent a massive extinction at the close of the Changxingian. Of the 21 superfamilies in the Changxingian, eight were extinguished completely, ending their long Paleozoic history. The extinct superfamilies are the Derbyioidea, Orthotetoidea, Aulostegoidea, Lyttonioidea, Richthofenoidea, Stenoscismatoidea, Reticularioidea, and Cryptonelloidea; Paleozoic members of the Rhynchonelloidea, Retzioidea, and Dielasmatoidea also disappeared. Only a few genera of the Enteletoidea, Chonetoidea, Productoidea, and Cyrtioidea survived into the lower Griesbachian (Tables 6, 7). Sixty-five genera and 148 species are preserved in sediments of the lower Changxingian, and 62 genera and 119 species occur in the upper Changxingian, so there is little difference between the lower and upper Changxingian in number of genera. However, the number of genera and species dropped sharply to 12 genera and 20 species in the lower Griesbachian (Tables 6, 7). The only genus known to survive of the Enteletoidea is *Acosarina*, a species of which was found in the Meishan section (spot 26; J.Z. Sheng et al., 1984:143, text-fig. 6) about 10 cm above the topmost bed of the Changxing Formation and was accompanied by *Claraia wangi* (Patte) and *Ophiceras* sp. *Acosarina minuta* (Abich) was identified from the Huayingshan section (spot 6) and was preserved in a calcareous mudstone about 1 m above the boundary between the Changxing and Daye formations in association with *Claraia wangi*, *Eumorphotis multiformis* (Bittner), and *Ophiceras* sp. The members of Chonetoidea and Productoidea that extend into the lower Griesbachian are the most important of the Permian-type survivors. *Chonetinella cursothornia* new species, accompanied by *Fusichonetes pigmaea* (Liao), was found in the lower Daye Formation of the Guanyinshan section (spot 18), about 20 cm above the topmost boundary of the Dalong Formation. *Fanichonetes campigia*, new species, was preserved in the lowermost part of the Xikou Formation in the Yading section (spot 30) in association with *Eumorphotis multiformis*. *Fusichonetes pigmaea* (Liao), *F. nayongensis* (Liao), *Waagenites barusiensis* (Davidson), *Cathaysia sinuata* Chan, and *C. orbicularis* Liao occur together in the lower Griesbachian, for instance, in the Meishan section (spot 26) where they are associated with *Ophiceras* sp. in the lower part of the Yinkeng Formation, and in the Majiashan, Shatian, and Guanyinshan sections (spots 24, 17, and 18, respectively). The Chonetoidea and Productoidea disappeared after the early Griesbachian in South China.

A possible cause of the massive extinction between Paleozoic and Mesozoic was the sharp change of environment that resulted from the splitting of the supercontinent Pangaea that led to the deepening of the ocean basins and the draining of epicontinental seas. Refugia along the coastal margins of the

TABLE 6.—Brachiopod faunas of the Changxingian and the Lower Griesbachian in South China.

Fossil	Changxingian		Lower Griesbachian	Fossil	Changxingian		Lower Griesbachian
	Lower	Upper			Lower	Upper	
LINGULACEA Waagen, 1885			×	AULOSTEGACEA Muir-Wood and Cooper, 1960			
<i>Lingula actaugula</i> Liao				<i>Edriosteges subplicatilis</i> (Frech)			×
<i>L. borealis</i> Bittner			×	<i>E. tumitus</i> Liao	×		×
<i>L. fuyuanensis</i> Liao			×	<i>Falafer hunanensis</i> Liao and Meng	×		×
<i>L. subcircularis</i> Wirth			×	<i>Strophalosina chenzianensis</i> Liao and Meng	×		×
<i>L. tenuissima</i> var. <i>sinensis</i> Wirth			×	<i>Tschernyschewia sinensis</i> Chao	×		
<i>L. sp.</i>			×	<i>T. pseudoirginae</i> (Huang)	×		×
ACROTRETACEA Schuchert, 1896				PRODUCTACEA Gray, 1840			
<i>Orbiculoidea elegans</i> Liao		×		<i>Anidanthus interruptus</i> (Huang)	×		
<i>O. uucleola</i> Liao				<i>A. sinosus</i> (Huang)	×		
ENTELETACEA Waagen, 1884				<i>Asioproductus bellus</i> Chan	×		×
<i>Acosariua minuta</i> (Abich)	×	×		<i>Buxtonia</i> sp.	×		×
<i>A. regularis</i> Liao	×	×	×	<i>Cathaysia chonetoides</i> (Chao)	×		×
<i>A. strophiria</i> sp. nov.	×			<i>C. corculum</i> Liao	×		×
<i>Enteletes asymmatrosis</i> sp. nov.	×	×		<i>C. orbicularis</i> Liao [and <i>C. tri-</i> <i>quetra</i> Liao]	×		×
<i>E. bisulcata</i> Liao and Meng		×		<i>C. sinuata</i> Chan			×
<i>E. hemiplicata</i> (Hall)	×	×		<i>C. spiriferoides</i> sp. nov.	×		×
<i>Orthotichia iudica</i> (Waagen)	×	×		<i>Chenxianoproductus changxin-</i> <i>gensis</i> Liao and Meng	×		×
<i>Peltichia schizoloides</i> sp. nov.	×			<i>C. intercedens</i> Liao and Meng	×		×
<i>P. sinensis</i> (Huang)	×	×		<i>C. nitens</i> Liao and Meng	×		×
<i>P. transversus</i> (Huang)	×	×		<i>Chonetella nasuta</i> (Waagen)	×		
<i>P. zigzag</i> (Huang)	×			<i>Huatangia sulcatifera</i> Liao and Meng	×		×
<i>Schizophoria</i> cf. <i>tani</i> Huang	×			<i>Dictyoclostus margaritatus</i> (Man- suy)	×		×
DERBYIACEA Stehli, 1954				<i>D. cf. tratavicus</i> (Tschernyschew)	×		×
<i>Derbyia? mutabilis</i> Liao	×	×		<i>Haydenella elongata</i> Liao	×		
<i>D. pannuciella</i> sp. nov.	×	×		<i>H. kiangsiensis</i> (Kayser)	×		×
<i>Meekella arakeljani</i> (Sokolskaja)	×			<i>H. orientalis</i> Chan	×		
<i>M. deltoides</i> Liao	×			<i>H. qinglongensis</i> Liao	×		×
<i>M. kueichowensis</i> Huang	×			<i>Incisius luatangensis</i> Liao and Meng	×		×
<i>M. langdaiensis</i> Liao	×			" <i>Linoproductus</i> " <i>kayseri</i> (Chao)	×		×
<i>M. sanheensis</i> Liao and Meng	×	×		<i>Rugosomarginifera chengyaoyensis</i> (Huang)	×		×
<i>Perigeyerella altulosina</i> sp. nov.	×	×		<i>R. psuedosintanensis</i> (Huang)	×		×
<i>P. costellata</i> Wang		×		<i>R. sintanensis</i> (Huang)	×		×
<i>P. fastigata</i> Liao and Meng	×	×		<i>Kurtomarginifera crassoestata</i> Xu	×		×
ORTHOTETACEA Waagen, 1884				<i>K. spinatus</i> Xu	×		
<i>Orthotetina frechii</i> (Huang)	×	×		<i>Spinomarginifera alpha</i> (Huang)	×		×
<i>O. regularis</i> (Huang)	×	×		<i>S. jiaozishanensis</i> Liao	×		×
<i>O. ruber</i> (Frech)	×	×		<i>S. kueichowensis</i> Liao	×		×
CHONETACEA Bronn, 1862				<i>S. lopingensis</i> (Kayser)	×		×
<i>Chonetinella cursolhornia</i> sp. nov.	×	×	×	<i>Stepanoviella djulfensis</i> (Stoya- now)	×		×
<i>C. substrophomenoides</i> (Huang)	×			<i>Tyloplecta yangtzeensis</i> (Chao)	×		
<i>C. volitanliopsis</i> (Xu)	×			<i>Waagenoconcha abichi</i> (Waagen)	×		×
<i>Fauichonetes campigia</i> sp. nov.	×	×	×	LYTTONIACEA Waagen, 1883			
<i>Fusichonetes dissulcata</i> (Liao)	×	×		<i>Leptodus deminutus</i> Liao	×		×
<i>F. nanyougeusis</i> (Liao)	×	×	×	<i>L. latiseptella</i> Xu	×		×
<i>F. pigmaea</i> (Liao)	×	×	×	<i>L. nobilis</i> (Waagen)	×		×
<i>Lissochonetes</i> sp.	×	×					
<i>Neochonetes convexa</i> Liao	×	×					
<i>N. elegans</i> Liao	×	×					
<i>N. zhougyingensis</i> Liao	×	×					
<i>Waageutes barnsiensis</i> Davidson (and <i>W. soochowensis</i> (Chao))	×	×	×				
<i>W. guizhouensis</i> Liao	×	×					
<i>W. wongiaua</i> (Chao)	×						

TABLE 6.—Continued.

Fossil	Changxingian		Lower Griesbachian	Fossil	Changxingian		Lower Griesbachian
	Lower	Upper			Lower	Upper	
<i>L. richthofeni</i> Kayser	×	×		SPIRIFERININACEA Davidson, 1884			
<i>L. tenuis</i> (Waagen)	×	×		<i>Callispirina? rotundella</i> sp. nov.	×		
<i>Oldhamina anshuensis</i> Huang	×	×		<i>Paraspiriferina alpha</i> (Huang)	×	×	×
<i>O. decipiensis</i> (Koninck)	×	×		<i>Spiriferellina elegantula</i> Liao	×	×	
<i>O. decipiensis</i> var. <i>regularis</i> Huang	×	×		<i>S. fastigata</i> (Schellwien)	×	×	
<i>O. grandis</i> Huang	×			ATHYRIDIDACEA M'Coy, 1844			
<i>O. minor</i> Chan		×		<i>Araxathyris</i> cf. <i>araxensis</i> Grunt	×	×	
<i>O. subdecipiensis</i> Liao	×			<i>A. minuta</i> Grunt	×	×	×
<i>O. subsquamosa</i> Liao	×			<i>A. beipeiensis</i> sp. nov.	×	×	
RICHTHOFENIACEA Waagen, 1885				<i>A. subpentangulata</i> sp. nov.	×	×	
<i>Richthofenia anshuensis</i> Liao	×			<i>Rectambitus bisulcatus</i> (Liao)	×	×	
<i>R.? sinensis</i> Liao	×			<i>Spirigerella discusella</i> sp. nov.	×	×	
<i>R. tilita</i> Liao and Meng	×	×		<i>S. guizhouensis</i> (Liao)	×	×	
<i>Richthofeniaceae</i> gen. and sp. un- determinable	×	×		<i>S. ovaloides</i> sp. nov.	×		
WELLERELLACEA Xu and Liu, 1983				<i>S. shuizhutangensis</i> (Chan)	×		
<i>Preliissorhynchia triplicata</i> Liao	×			<i>Tongzithyris anshuensis</i> Liao	×	×	
<i>P. triplicatoid</i> sp. nov.	×	×		<i>T. extensa</i> Liao	×		
<i>P. pseudoutah</i> (Huang)	×	×	×	<i>T. sichuanensis</i> Xu	×		
<i>Uncinunellina theobaldi</i> Waagen	×	×		RETICULARIACEA Waagen, 1883			
<i>U. jabiensis</i> (Waagen)	×			<i>Martiuia abrupta</i> Liao and Meng	×	×	
<i>U. multicostifera</i> sp. nov.	×			<i>M. acutirostris</i> Liao	×	×	
<i>U. timorensis</i> (Beyrich)	×			<i>M. chidruensis</i> Waagen	×	×	
RHYNCHONELLACEA Gray, 1848				<i>M. lopingensis</i> Chao	×		
<i>Terebratuloidea davidsoni</i> Waagen	×			<i>M. squamularioides</i> Huang	×	×	
<i>T. depressa</i> Waagen	×	×		<i>M. tongmugiaoensis</i> Liao and Meng	×	×	
STENOSCISMATACEA Oehlert, 1887(1883)				<i>Phricodolthyris guizhouensis</i> Liao	×	×	
<i>Cyrolexis antearcius</i> sp. nov.	×	×		<i>Squamularia elegantula</i> (Waagen)	×	×	
<i>C. beccojectus</i> sp. nov.	×	×		<i>S. formilla</i> sp. nov.	×	×	
<i>Hybostenoscisma bambusoidea</i> Liao and Meng	×	×		<i>S. grandis</i> Chao	×		
SPIRIFERACEA King, 1846				<i>S. inaequilateralis</i> (Gemmellaro)	×		
<i>Cartorhium twifurcifer</i> sp. nov.	×	×		RETZIACEA Waagen, 1883			
<i>C. xikouensis</i> sp. nov.	×	×		<i>Hustedia indica</i> (Waagen)	×	×	
<i>Eliva? depressa</i> Liao and Meng	×	×		<i>H. orbicostata</i> sp. nov.	×	×	
<i>Semibrachythyris anshuensis</i> Liao	×	×		<i>H. remota</i> (Eichwald)	×		
CYRTIACEA Fredericks, 1924				DIELASMATACEA Schuchert, 1914			
<i>Ambocoelia pianoconvex</i> (Shu- mard)		×		<i>Dielasma acutangulum</i> Waagen	×		
<i>Crurithyris flabelliformis</i> Liao		×	×	<i>Qinglongia tumita</i> Liao and Meng	×	×	
<i>C. longa</i> Liao	×	×		<i>Q. zhouyingensis</i> Liao	×	×	
<i>C. pusilla</i> Chan		×	×	CRYPTONELLACEA Thomson, 1926			
<i>C. speciosa</i> Wang	×	×	×	<i>Notothyris bifoldes</i> sp. nov.	×	×	
<i>C. subspeciosa</i> Liao	×	×		<i>N.? dapaichongensis</i> Liao and Meng	×	×	
<i>Eolaballa pristina</i> Liao and Meng	×	×		<i>N. djoulfensis</i> (Abich)	×	×	
				<i>N. warthi</i> Waagen	×		
				<i>Rostranteris ptychiventria</i> sp. nov.	×	×	

TABLE 7.—Genus distribution of superfamilies from the Changxingian to the lower Griesbachian, showing massive extinction after the Changxingian. Each line represents a genus.

	<i>Lower Changxing</i>	<i>Upper Changxing</i>	<i>Lower Griesbach</i>
<i>Lingulacea</i>	— — — —		
<i>Acrotretacea</i>			
<i>Enteletacea</i>			
<i>Derbyiacea</i>			
<i>Orthotetacea</i>			
<i>Chonetacea</i>			
<i>Aulostegacea</i>			
<i>Productacea</i>			
<i>Lyttoniaceae</i>			
<i>Richthofeniaceae</i>			
<i>Wellerellaceae</i>			
<i>Rhynchonellaceae</i>			
<i>Stenascismataceae</i>			
<i>Spiriferaceae</i>			
<i>Cyrtiaceae</i>	— — — —		
<i>Spiriferininaceae</i>			
<i>Athyrididaceae</i>			
<i>Reticulariaceae</i>			
<i>Retziaceae</i>			
<i>Dielasmataceae</i>			
<i>Cryptonellaceae</i>			

vast supercontinent allowed some marine organisms, including brachiopods, to survive the crisis.

Genera *Preliissorhynchia* of the Wellerelloidea, *Paraspiriferina*(?) of the Spiriferinoidea, and *Araxathyris*(?) of the Athyrididoidea represent harbingers of Mesozoic brachiopods rather than Permian-type survivors. These genera occur in the lower Griesbachian and are accompanied by other Permian-type brachiopods and the mollusks *Ophiceras* and *Claraia*, for example, in the Meishan section (spot 26). They vanished after the lower Griesbachian, giving way to the Mesozoic brachiopods.

Some fragments of brachiopods, including *Spiriferina* sp. and Retzioidae, were found by Wuhan geology students in the Fourth Member (Dienerian) of the Daye Formation, a thick bed of gray sparite near the top of the Xiushan, Daye County. *Spirigerella* sp. of the Athyrididoidea was recorded in the Kathwai Member of the Mianwali Formation, Pakistan, and *Spiriferina mansfieldi* Girty of the Spiriferinoidea was described in West-central North America, in the *Lingula* zone (Newell and Kummel, 1942). In the Littoral Province of Siberia, *Fletcherina margaritovi* (Bittner) of the Order Terebra-

tulida, *Spiriferina* aff. *mansfieldi* Girty, and poorly preserved rhynchonellids (probably *Piarorhynchia? triassica* Girty) were reported in the upper Induan (Dagys, 1965:160). *Fletcherina margaritovi* also was found in the Olenekian Stage of Manguslaka, Siberia. Brachiopods of the Lower Triassic, however, are extremely rare. What direction had brachiopod evolution been taking from the lower Griesbachian to Middle Triassic? Why were so few brachiopods preserved in the Lower Triassic? These puzzles remain to be solved.

### Conclusions

The clastic and limestone lithofacies of the Changxingian have different brachiopod assemblages (Table 2) that basically coincide with ammonoid, conodont, and fusulinid zones of the Changxingian in South China (Table 3). The Dorashamian brachiopod fauna of Transcaucasia correlates with the Changxingian fauna; the brachiopod faunas of the Ali Bashi Formation, North-West Iran; and with unit 7 of the Hambast Formation, Central Iran. The upper part of the Bellerophon Formation, Southern Alps; the upper Episkopi Formation; and



the Miras Formation of Hydra, Greece, resemble the Dorashamian fauna, and so they also are correlated with the Changxing.

Two brachiopod subprovinces can be recognized in the Middle Tethyan province of the Changxingian; namely, the Cathaysian Tethys and the West Tethys. Four biofacies exist in the Cathaysian subprovince of the Changxingian.

The *Crurithyris pusilla*-*Lingula subcircularis* assemblage zone of the lower Griesbachian in South China closely resembles the brachiopod fauna of the Kathwai Member in Pakistan.

The *Lingula* fauna of the Griesbachian is distributed throughout the world, which suggests that the margins of the Pangaeon supercontinent had stabilized by that time.

Massive extinction of brachiopod faunas occurred after the Changxingian, and only a few Permian-type brachiopods survived into the Lower Griesbachian. All but the few forerunners of Mesozoic brachiopods vanished completely after the early Griesbachian.

### Systematic Listing

- Order ORTHIDA Schuchert and Cooper, 1932  
 Superfamily RHIPIDOMELLOIDEA Schuchert, 1913  
 Family SCHIZOPHORIIDAE Schuchert and LeVene, 1929  
 Genus *Acosarina* Cooper and Grant, 1969  
*Acosarina strophiria* sp. nov.  
 Superfamily ENTELETOIDEA Waagen, 1884  
 Family ENTELETIDAE Waagen, 1884  
 Genus *Enteletes* Fischer de Waldheim, 1825  
*Enteletes asymmatrosis* sp. nov.  
 Genus *Peltichia* Jing and Liao, 1981  
*Peltichia schizoloides* sp. nov.  
 Order STROPHOMENIDA Opik, 1934  
 Suborder ORTHOTETIDINA Waagen, 1884  
 Superfamily DERBYIOIDEA Stehli, 1954  
 Family DERBYIDAE Stehli, 1954  
 Subfamily DERBYINAE Stehli, 1954  
 Genus *Derbyia* Waagen, 1884  
*Derbyia pannuciella* sp. nov.  
 Family MEEKELLIDAE Stehli, 1954  
 Genus *Meekella* White and St. John, 1867  
*Meekella langdaiensis* Liao, 1980  
 Superfamily ORTHOTETOIDEA Waagen, 1884  
 Family ORTHOTETIDAE Waagen, 1884  
 Genus *Perigeyerella* Wang, 1955  
*Perigeyerella altilosina* sp. nov.  
 Suborder CHONETIDINA Muir-Wood, 1955  
 Superfamily CHONETOIDEA Bronn, 1862  
 Family RUGOSOCHONETIDAE Muir-Wood, 1962  
 Subfamily CHONETINELLINAE Muir-Wood, 1962  
 Genus *Chonetinella* Ramsbottom, 1952  
*Chonetinella cursothornia* sp. nov.  
*Chonetinella volitanliopsis* Xu, 1987

- Subfamily RUGOSOCHONETINAE Muir-Wood, 1962  
*Fanichonetes* gen. nov.  
*Fanichonetes campigia* sp. nov.  
 Suborder PRODUCTIDINA Waagen, 1883  
 Superfamily PRODUCTOIDEA Gray, 1840  
 Family CHONETELLIDAE Likharev, 1960  
 Genus *Cathaysia* Ching, 1966  
*Cathaysia sinata* Chan, 1979  
*Cathaysia spiriferoides* sp. nov.  
*Cathaysia obicularis* Liao, 1980  
 Superfamily RICHTHOFENIOIDEA Waagen, 1885  
 Richthofeniid, genus and species undetermined  
 Order RHYNCHONELLIDA Kuhn, 1949  
 Superfamily WELLERELLOIDEA Xu and Liu, 1983  
 Family WELLERELLIDAE Likharev, 1956  
 Genus *Uncinunellina* Grabau, 1932  
*Uncinunellina multicostifera* sp. nov.  
 Family PONTISIIDAE Cooper and Grant, 1976  
 Subfamily LISSORHYNCHIIDAE Xu and Liu, 1983  
*Prelissorhynchia* gen. nov.  
*Prelissorhynchia pseudoutah* (Huang, 1933)  
*Prelissorhynchia triplicatioid* sp. nov.  
 Superfamily STENOSCISMATOIDEA Oehlert, 1887 (1883)  
 Family ATRIBONIIDAE Grant, 1965  
 Subfamily ATRIBONIINAE Grant, 1965  
 Genus *Cyrolexis* Grant, 1965  
*Cyrolexis antearcus* sp. nov.  
*Cyrolexis beccojectus* sp. nov.  
 Order SPIRIFERIDA Waagen, 1883  
 Suborder SPIRIFERIDINA Waagen, 1883  
 Superfamily SPIRIFEROIDEA King, 1846  
 Family SPIRIFERIDAE King, 1846  
 Subfamily NEOSPIRIFERINAE Waterhouse, 1968  
 Genus *Cartorhium* Cooper and Grant, 1976  
*Cartorhium xikouensis* sp. nov.  
*Cartorhium twifurcifer* sp. nov.  
 Superfamily CYRTIOIDEA Frederiks, 1924  
 Family AMBOCOELIIDAE George, 1931  
 Genus *Crurithyris* George, 1931  
*Crurithyris pusilla* Chan, 1979  
 Suborder SPIRIFERINIDINA Cooper and Grant, 1976  
 Superfamily SPIRIFERINOIDEA Davidson, 1884  
 Family PARASPIRIFERINIDAE Cooper and Grant, 1976  
 Genus *Paraspiriferina* Reed, 1944  
*Paraspiriferina alpha* (Huang, 1933)  
 Genus *Callispirina* Cooper and Muir-Wood, 1951  
*Callispirina? rotundella* sp. nov.  
 Suborder ATHYRIDIDINA Boucot, Johnson, and Staton, 1964  
 Superfamily ATHYRIDIDOIDEA McCoy, 1844  
 Family ATHYRIDIDAE McCoy, 1844  
 Subfamily SPIRIGERELLINAE Grunt, 1965  
 Genus *Araxathyris* Grunt, 1965  
*Araxathyris beipeiensis* sp. nov.  
*Araxathyris subpentangulata* sp. nov.

*Rectambitus* gen. nov.*Rectambitus bisulcatus* (Liao, 1980), new combinationGenus *Spirigerella* Waagen, 1883*Spirigerella discussella* sp. nov.*Spirigerella guizhouensis* (Liao, 1980), new combination*Spirigerella ovaloides* sp. nov.*Spirigerella shuizhutangensis* (Chan, 1979), new combinationGenus *Tongzithyris* Ching, Liao, and Fang, 1974*Tongzithyris sichuanensis* Xu, 1987

Superfamily RETICULARIOIDEA Waagen, 1883

Family ELYTHIDAE Frederiks, 1924

Genus *Squamularia* Gemmellaro, 1899*Squamularia formilla* sp. nov.

Suborder RETZIIDINA Boucot, Johnson, and Staton, 1964

Superfamily RETZIOIDEA Waagen, 1883

Family RETZIIDAE Waagen, 1883

Genus *Hustedia* Hall and Clarke, 1893*Hustedia orbicostata* sp. nov.

Order TEREBRATULIDA Waagen, 1883

Superfamily CRYPTONELLOIDEA Thomson, 1926

Family NOTOTHYRIDIDAE Likharev, 1960

Genus *Rostranteris* Gemmellaro, 1899*Rostranteris ptychiventria* sp. nov.Genus *Notothyris* Waagen, 1882*Notothyris bifoldes* sp. nov.

Order ORTHIDA Schuchert and Cooper, 1932

Superfamily RHIPIDOMELLOIDEA Schuchert, 1913

Family SCHIZOPHORIIDAE Schuchert and LeVene, 1929

Genus *Acosarina* Cooper and Grant, 1969*Acosarina strophiria* sp. nov.

FIGURES 4, 5(1-17, 19, 20)

Small for genus, subequally biconvex; outline transversely subelliptical except protruding beaks, width greater than length, greatest width somewhat anterior to midlength; hinge line short, about equal to  $\frac{1}{2}$  width; slightly asymmetrical, having beaks bent slightly rightward, sides rounded; anterior commissure with slightly ventrad wave and slightly emarginate; surface multicostellate, 15-17 costellae in 3 mm, grow laminae irregularly spaced, most frequent at anterior margin.

Pedicle valve flatly convex, umbonal region more convex and slightly curved forward in lateral profile; anterior profile faintly convex with gentle slopes; beak small, slightly incurved, interarea triangular, slightly curved; delthyrium proportionately large, opened. Brachial valve somewhat strongly convex, posterior  $\frac{1}{2}$  moderately curved and anterior  $\frac{1}{2}$  gently inclined in lateral profile; anterior profile slightly

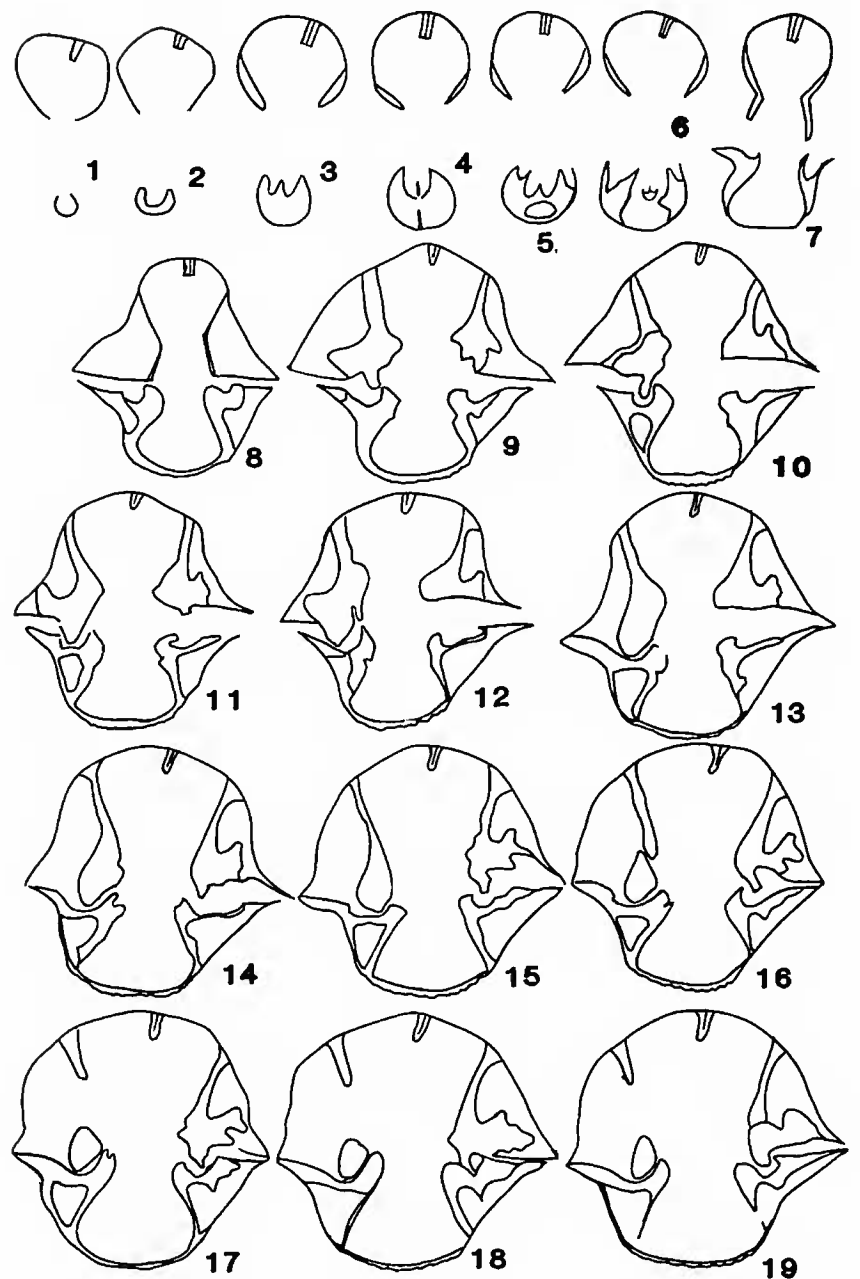


FIGURE 4.—Serial sections of *Acosarina strophiria*, new species, illustrating the interior features.

flattened, weakly ditched at medium region, sides relatively steep; beak strongly incurved; interarea very low with perceptible notothyrium, opened; sulcus narrow and shallow, originating somewhat anterior to beak.

Pedicle valve interior with proportionately large, cone-shaped teeth having large but shallow foscettes; dental plates thick, steeply tilted, fused into shell wall in umbonal cavity, flaring anteriorly, extending about  $\frac{1}{4}$  valve length; median septum low but rather long, extending near anterior edge of shell. Brachial valve interior with small cardinal process, triangular, single-edge myophragm; hinge sockets wide and shallow; fulcral plates short, hanging under socket bottoms, not reaching to shell floor, inner-socket ridges stout; brachiophore supports thick, widely flaring; posterior pair of adductor-muscle scars elongately elliptical, anterior pair of adductor-muscle scars subtriangular; median ridge long, extending more than  $\frac{1}{2}$  length.

HOLOTYPE.—USNM 455970.

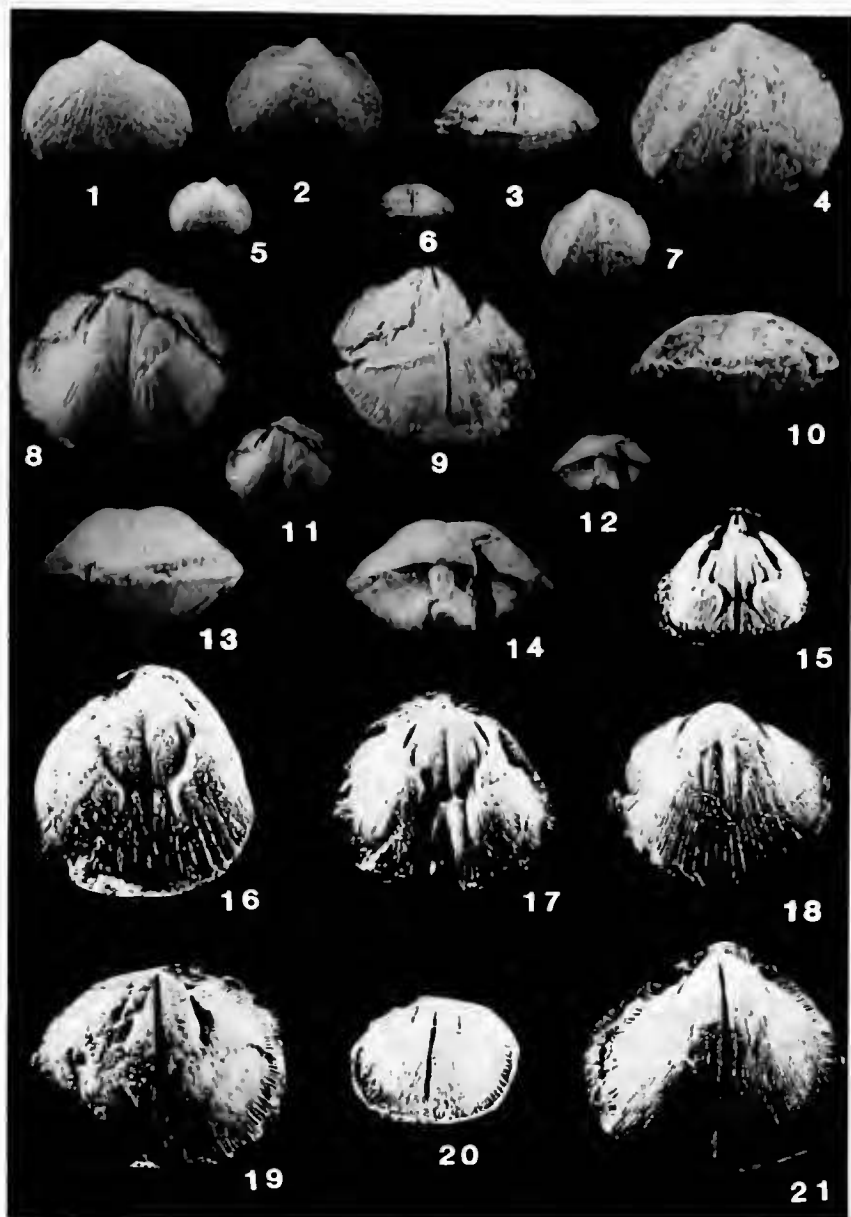


FIGURE 5.—*Acosarina*. 1-17, 19, 20, *Acosarina strophiria*, new species: 1-3, ventral, dorsal, and anterior views ( $\times 2$ ); 5, 6, dorsal and anterior views ( $\times 1$ ), from section 27, USNM 455970, holotype. 4, 10, dorsal and anterior views ( $\times 2$ ); 7, dorsal view ( $\times 1$ ), from section 8, USNM 455969. 8, 9, 13, and 14, dorsal, ventral, anterior, and posterior views ( $\times 2$ ); 11, 12, dorsal and posterior views ( $\times 1$ ), from section 6, USNM 455968, paratype. 15, dorsal interior impress ( $\times 2$ ), from section 27, USNM 455971. 16, dorsal interior ( $\times 2$ ), USNM 455972; 17, dorsal interior ( $\times 2$ ), 455973, both from section 10. 19, ventral interior impress ( $\times 2$ ), from section 10, USNM 455974. 20, ventral interior impress ( $\times 2$ ), from section 8, USNM 455975. 18, 21, *A. circularis* Xu: 18, dorsal view ( $\times 2$ ), USNM 455976; 21, ventral view ( $\times 2$ ), USNM 455977, both from section 23. (Reduced to 95 $\frac{1}{2}$ % for publication.)

MEASUREMENTS (mm).—

USNM	Pedicle valve length	Brachial valve length	Width	Hinge width	Thickness
455968	9.5	9.6	11.5	5.3	6.4
455969	9.1	9.2	11.2	4.8	6.2
455970	7.2	6.9	9.0	4.3	4.8

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—  
Changxing Formation: Huangzhishan section, Wuxing County,

Zhejiang Province; Beipei section, Zhongqing City and Huayingshan section, Linshui County, Sichuan Province.

DIAGNOSIS.—Small, transversely subelliptical, sulcus on brachial valve and long median septum in pedicle valve.

COMPARISON.—This new species closely resembles *A. dorsisulcata* Cooper and Grant (1969:2, pl. 5: figs. 19-23; 1976b:2621, pl. 667: figs. 1-26, pl. 673: figs. 1-6) in that both species are characterized by small size and have the sulcus on the dorsal valve. The Texas species has somewhat strong costellae and a relatively short median septum in the pedicle valve. The present new species has a special feature in being slightly asymmetrical; these features allow the species to be readily distinguished from each other. *Acosarina regularis* Liao (1980a:253, pl. 1: figs. 29-34) has a long median septum comparable to the new species, but it is large and has a fold on the brachial valve and a sulcus on the pedicle valve. (It is possible that Liao's species may be not a species of *Acosarina*.) It is similar to *A. circularis* Xu (in Yang et al., 1987:216, 217, pl. 13: figs. 12, 13, 17) in its small size, long median septum in the pedicle valve, and median ridge in brachial valve; it differs in the latter's having a subcircular outline and no sulcus.

ETYMOLOGY.—From the Greek, *strophos*, meaning turn or twist.

Superfamily ENTELETOIDEA Waagen, 1884

Family ENTELETIDAE Waagen, 1884

Genus *Enteletes* Fischer de Waldheim, 1825

*Enteletes asymmatrosis* sp. nov.

FIGURE 6(1-8)

Medium size for genus, subequally biconvex with brachial valve deep and large; outline transversely subelliptical, asymmetrically crooked, maximum width somewhat anterior to midlength; lateral profile subcircular; hinge line short with blunt hinge extremities; anterior commissure uniplicate and strongly serrated, emarginate at middle; lateral commissure straight or slightly curved; surface with plications, smoothly rounded, originating from umbonal area, having a smooth lateral area, no plicae; costellate evenly spaced.

Pedicle valve convex with maximum curvature at posterior  $\frac{1}{2}$  in lateral profile; anterior profile strongly serrate at median area, smoothly tilted at sides; sulcus narrow with angular floor, beginning from umbonal area; each side with 4 plications; beak strongly incurved, partly covering interarea and delthyrium; interarea small, curved; delthyrium large. Brachial valve strongly and evenly convex, maximum inflation at midvalve in lateral profile; anterior profile slightly flattened at median part, steeply sloped on each side; fold narrow with smoothly rounded crest; each side with 4 plications; beak strongly incurved, slightly over hinge line; interarea relatively large but partly covered by beak. Interior features unknown.

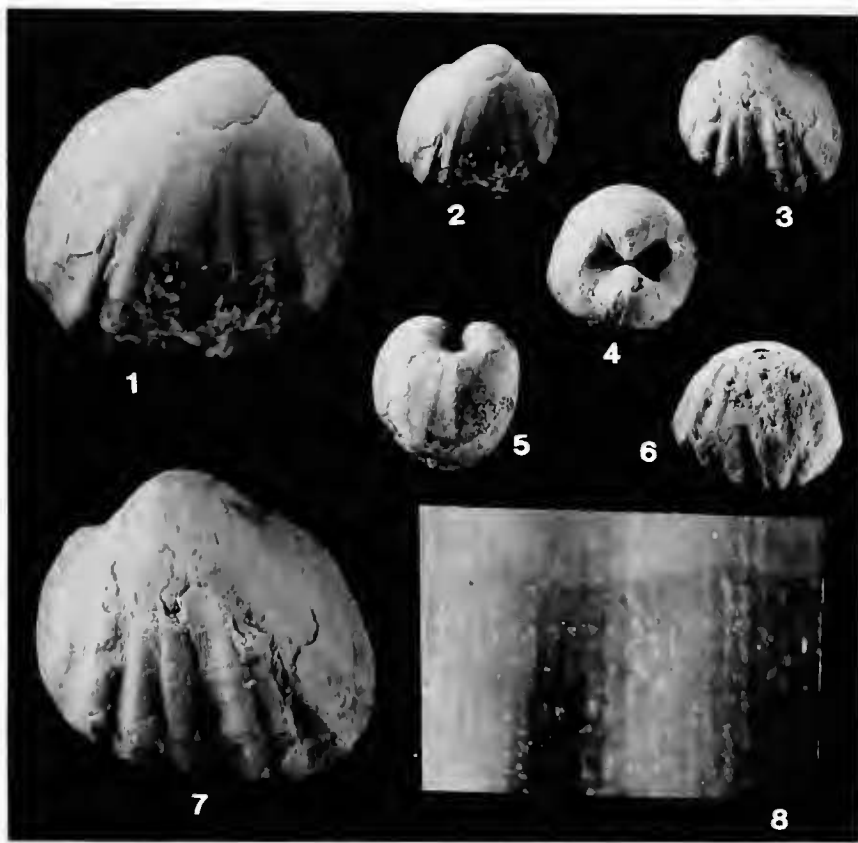


FIGURE 6.—*Enteletes asymmatrosis*, new species, from section 32, USNM 455978, holotype: 1, 2, ventral views ( $\times 2$ ,  $\times 1$ ); 3, 7, dorsal views ( $\times 1$ ,  $\times 2$ ); 4, posterior view ( $\times 1$ ); 5, lateral view ( $\times 1$ ); 6, anterior view ( $\times 1$ ); 8, a part of shell showing fine costellae ( $\times 20.8$ ). (Reduced to 95 $\frac{1}{2}$ % for publication.)

HOLOTYPE.—USNM 455978.

MEASUREMENTS (mm).—

USNM	Pedicle valve length	Brachial valve length	Width	Hinge width	Thickness
455978	17.0	17.6	18.5	11.8	16.5

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Longdongchuan Formation: Xikou section, Zhenan County, Shaanxi Province.

DIAGNOSIS.—Medium-size *Enteletes* with globular outline, strongly incurved beaks, small interarea, and narrow fold and sulcus.

COMPARISON.—The new species is closely similar to *Enteletes tschernyschewi* Diener (1897:67, 68, pl. 5: figs. 7–10; Wang et al., 1964:149, 150, pl. 19: figs. 22–26) in its shape of shell, narrow sulcus, and number of plications; it differs in its relatively longer hinge line, smoothly rounded plications, and large smooth lateral area. Another Himalayan species, *E. waageni* Gemmellaro (Diener, 1903:28, 29; Wang, 1955b:162, pl. 95: figs. 19, 21–24) is comparable to the new species in the relatively high interarea and strongly incurved beaks, but the former has sharply angular plications and fold, strongly convex shell, and well-developed growth lines. *Enteletes leonardensis* R.E. King (Cooper and Grant,

1976b:2634, 2635, pl. 680: figs. 1–13, pl. 683: figs. 1–48, pl. 684: figs. 16–20) has a narrow sulcus, rounded plications reaching to umbonal region, and its fold and sulcus are without much more relief than its lateral plications. These features are analogous to those of the new species, differing in that the former has a larger maximum size, a high degree of convexity, and a short brachial interarea. The new species is readily distinguishable from *E. plummeri* R.E. King (Cooper and Grant, 1976b:2636–2638, pl. 680: figs. 14–38, pl. 682: figs. 1–68) because King's species has sharp plications, a relatively high fold, and nearly equal valves.

ETYMOLOGY.—From the Greek, *asymmetros*, meaning different.

### Genus *Peltichia* Jing and Liao, 1981

FIGURES 7, 8

Medium to large size; unequally biconvex with strongly inflated brachial valve; subpentagonal in outline; anterior commissure paraplicate, lateral commissure serrate; surface completely capillate and only weak plications near anterior margin or completely obsolete.

Pedicle valve moderately convex; beak pointed and slightly or strongly incurved; hinge line short; cardinal area relatively small with proportionately large open delthyrium; fold low, limited by lateral furrows. Brachial valve strongly inflated; beak strongly incurved; sulcus shallow, bounded by rounded plications.

Pedicle valve interior with sturdy dental plates and low median septum. Brachial valve interior with rod-like, stout brachiophores, supported by strong crural plates divergently attached to floor; callus filling between crural plates, forming shovel-like pseudocruralium; median ridge low, covered by callus; 2 pairs of muscle scars, posterior pair elliptical, attached on callus platform, anterior pair slightly depressed.

COMPARISON.—*Peltichia* is similar to *Enteletina* in most external and internal features, but the latter has conspicuous plications on the lateral surfaces and no pseudocruralium in the brachial valve. It resembles *Parenteletes* in having a sulcus on the brachial valve and a fold on the pedicle valve; it differs in that the latter has strong lateral plications and a V-shape camera

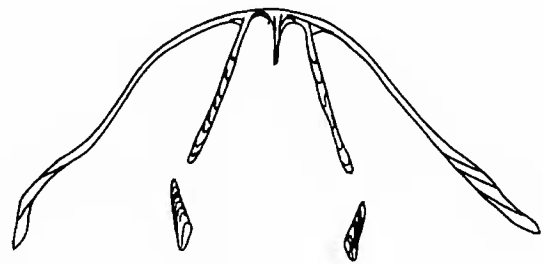


FIGURE 7.—A ventral section of *Peltichia sinensis* (Huang) showing dental plates, teeth, and median septum.

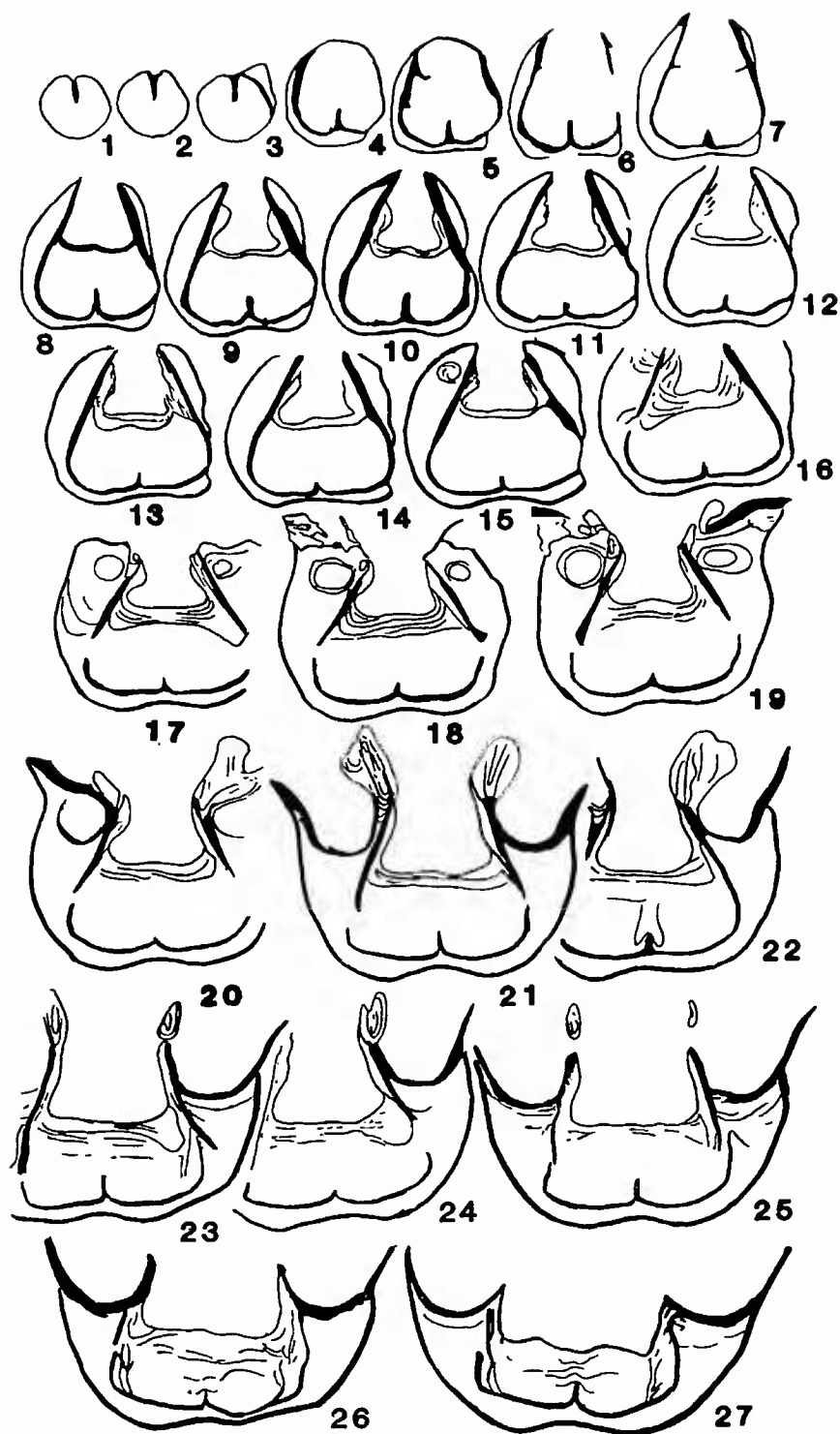


FIGURE 8.—Serial sections of the brachial valve of *Peltichia sinensis* (Huang) showing interior features.

under the median septum in the pedicle valve.

DISCUSSION.—Specimens of the type species *Peltichia sinensis* mut. *zigzag* were ascribed to the genus *Parenteletes* by Huang (1933:13) and were later regarded as *Enteletina* by many authors (e.g., Wang et al., 1964:151, 152); but no interior structures were revealed in detail by them.

Schuchert and Cooper (1931:247) characterized the genus *Enteletina* as: "Externally like *Parenteletes* but internally like *Enteletes*. Equal to Waagen's 'dorsosinuates' of *Enteletes*." Their subsequent monograph (Schuchert and Cooper, 1932:148) states that "the dental plates are not strongly divergent and there is a crested median septum which does not have the peculiar V-shaped camera so characteristic of *Parenteletes*." The type species of *Enteletina*, *E. latesinuatus*,

was shown to have strong plications and triple plates consisting of dental plates and a median septum in the pedicle valve, which are almost parallel to each other (Schuchert and Cooper, 1932, pl. 24: figs. 17, 19, 20).

Cooper and Grant (1976b:2626–2628) pointed out that the dental plates among species of *Enteletes* may be parallel or inclined, the shell may be thickened to form a narrowly divided platform between the crural plates or not thickened, and a median ridge may exist in the brachial valve or is absent, as special variations within the genus *Enteletes*. This statement suggests that other *Enteletinae* may have the same range of special variations. The triple plates of the pedicle valve appear to be parallel on the exfoliated shell or internal molds of *Peltichia sinensis*, but the dental plates diverge ventrally and the median septum is relatively low (Figure 7). The callus between the crural plates unites an undivided platform called the pseudocruralium in the brachial valve. If the thickened shell and callus are peeled, the appearance is that of an elongated or flattened muscle-scar track at the umbonal region. These features occur consistently in the genus, so it is reasonable to discriminate *Peltichia sinensis* from *Enteletina*.

Liao's (1979:207) first use of the name *Peltichia* contained no description, and furthermore, he continued to assign the specimens to *Enteletina* (Liao, 1980:253). When Jing and Liao (in Jing and Sun, 1981:129, 130, text-fig. 2, pl. 1: figs. 3, 4) described species of this genus they illustrated internal features by serial sections of specimens from Xizang (Tibet). These are completely in concordance with specimens from South China.

TYPE SPECIES.—*Parenteletes sinensis* mut. *zigzag* Huang, 1933:10–13, pl. 2: figs. 7a–c.

SPECIES OF THE GENUS.—The five species from the Changxing Formation of South China are as follows: *Peltichia sinensis* (Huang) (Figure 9(11–16, 20, 23, 27), Figure 10(1–15)); *P. zigzag* (Huang), which usually occurs in the lower part of the Changxing Formation (Figure 9(25, 26, 28–31)); *P. transversus* (Huang) (Figure 9(17, 18, 21, 22, 24)); *P. kwangtungensis* (Chan) (in Hou et al., 1979:62, 63, pl. 10: figs. 1, 3); and *P. schizoloides*, new species (Figure 9(1–10)).

#### *Peltichia schizoloides* sp. nov.

FIGURE 9(1–10)

Small for genus, unequally biconvex; outline subpentagonal to subcircular, transverse, widest at midlength; anterior commissure plicate, not serrate at lateral commissure; surface with completely capillate and irregularly spaced growth laminae.

Pedicle valve weakly convex, lateral profile evenly and shallowly bowed, anterior profile somewhat flattened at midline, gently inclined at lateral slopes; beak small, pointed, slightly incurved at tip; hinge area small, delthyrium open, proportionately big; fold low, beginning from near midvalve, lateral furrows shallow. Brachial valve strongly inflated, lateral

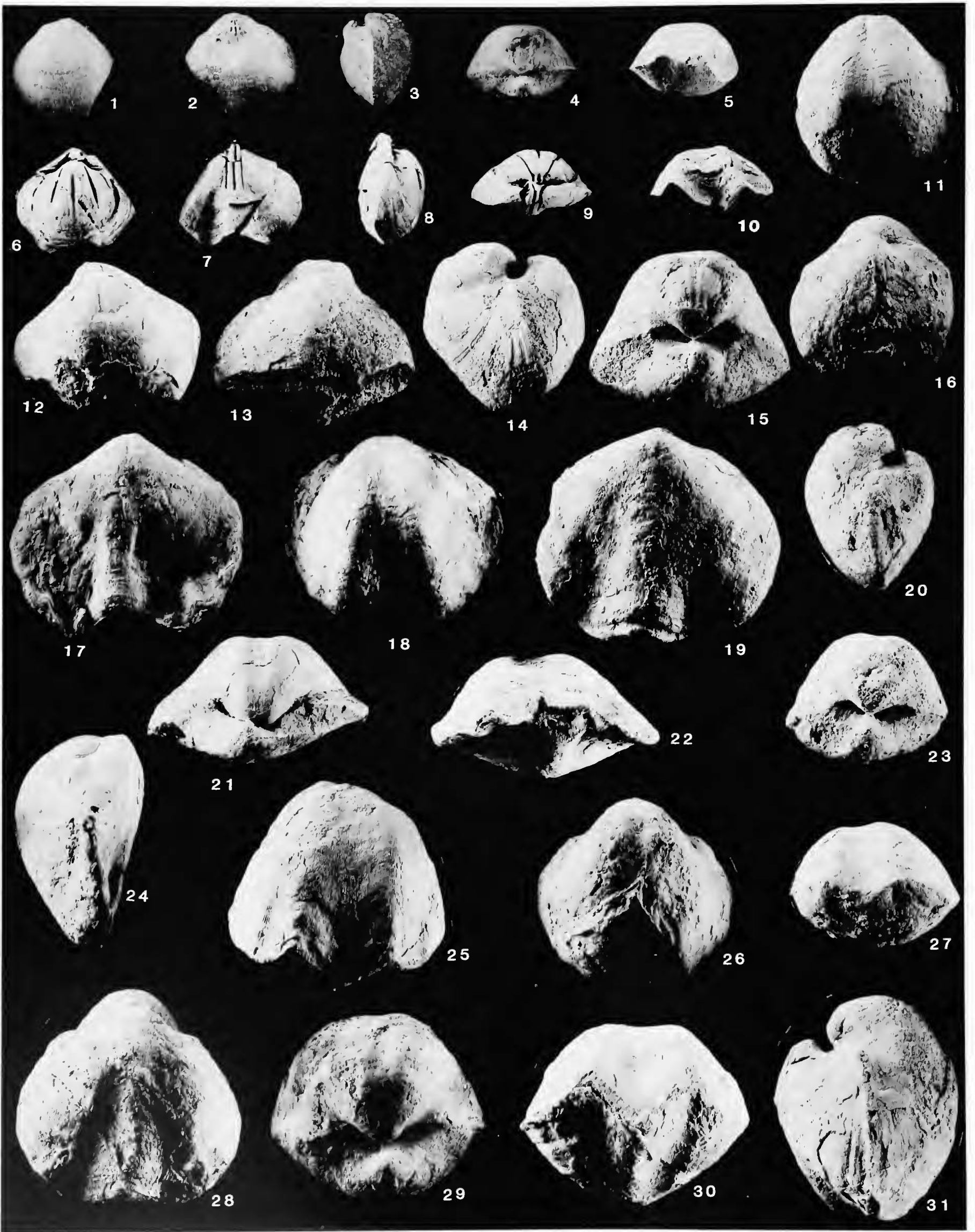


FIGURE 9 (opposite page).—*Peltichia* Jing and Liao. 1-10, *Peltichia schizoloides*, new species: 1-5, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), from section 6, USNM 455980, holotype; 6-10, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), from section 27, USNM 455979, paratype. 11-16, 20, 23, 27, *Peltichia sinensis* (Huang): 11, 16, 20, 23, and 27, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), USNM 455981; 12-15, dorsal, ventral, lateral, and posterior views ( $\times 1$ ), USNM 455982, both from section 10. 17-19, 21, 22, and 24, *Peltichia transversus* (Huang): 17, 18, 21, 22, and 24, ventral, dorsal, posterior, anterior, and lateral views ( $\times 1$ ), from section 6, USNM 455984; 19, dorsal view ( $\times 1$ ), from section 10, USNM 455985. 25, 26, 28-31, *Peltichia zigzag* (Huang): dorsal, dorsal-posterior, ventral, posterior, anterior, and lateral views ( $\times 1$ ), from section 9, USNM 455986.

profile strongly curved at umbonal region, sloped to anterior margin; beak small, pointed, and strongly incurved; sulcus wide and shallow, originating slightly posterior to midvalve.

Pedicle valve interior with triple plates extending to near midvalve. Brachial valve interior with strong crural plates, diverging forward, they and median ridge extending to midvalve; cardinal process a single small protuberance at posterior view and bilobate in anterior view.

HOLOTYPE.—USNM 455980.

MEASUREMENTS (mm).—

USNM	<i>Pedicle valve</i>		<i>Brachial valve</i>		Width	Thick-ness
	Length	Curved length	Length	Curved length		
455979	17.9	20.5	18.6	26.1	20.8?	14.4
455980	16.7	19.3	19.3	24.7	19.5	11.3

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Changxing Formation: Huayingshan section, Linshui County, Sichuan Province and Huangzhishan section, Wuxing County, Zhejiang Province.

DIAGNOSIS.—Small with shallow and broad sulcus on brachial valve, low fold on pedicle valve, not serrate at lateral commissure.

COMPARISON.—*Peltichia schizoloides*, new species, can be recognized easily by its small size, markedly transverse and broad sulcus, and smooth lateral commissure. Among other species of the genus, it most closely resembles *P. transversus* (Huang). The latter is usually larger than the new species and has a relatively narrow sulcus that begins near the beak and is acutely angled and serrate at the lateral commissure. *Peltichia kwangtungensis* (Chan) is the largest species of the genus and is convex-plane in lateral profile; therefore, it can be discriminated from *P. schizoloides*, even though they are analogous in their smooth lateral commissure and broad sulcus. *Peltichia sinensis* (Figure 10) and *P. zigzag* are large in average size, markedly elongated, and have proportionately narrow sulcus and serrate lateral commissure, so they are distinguishable readily from the new species.

ETYMOLOGY.—From the Greek, *schizos*, meaning a chip (small).

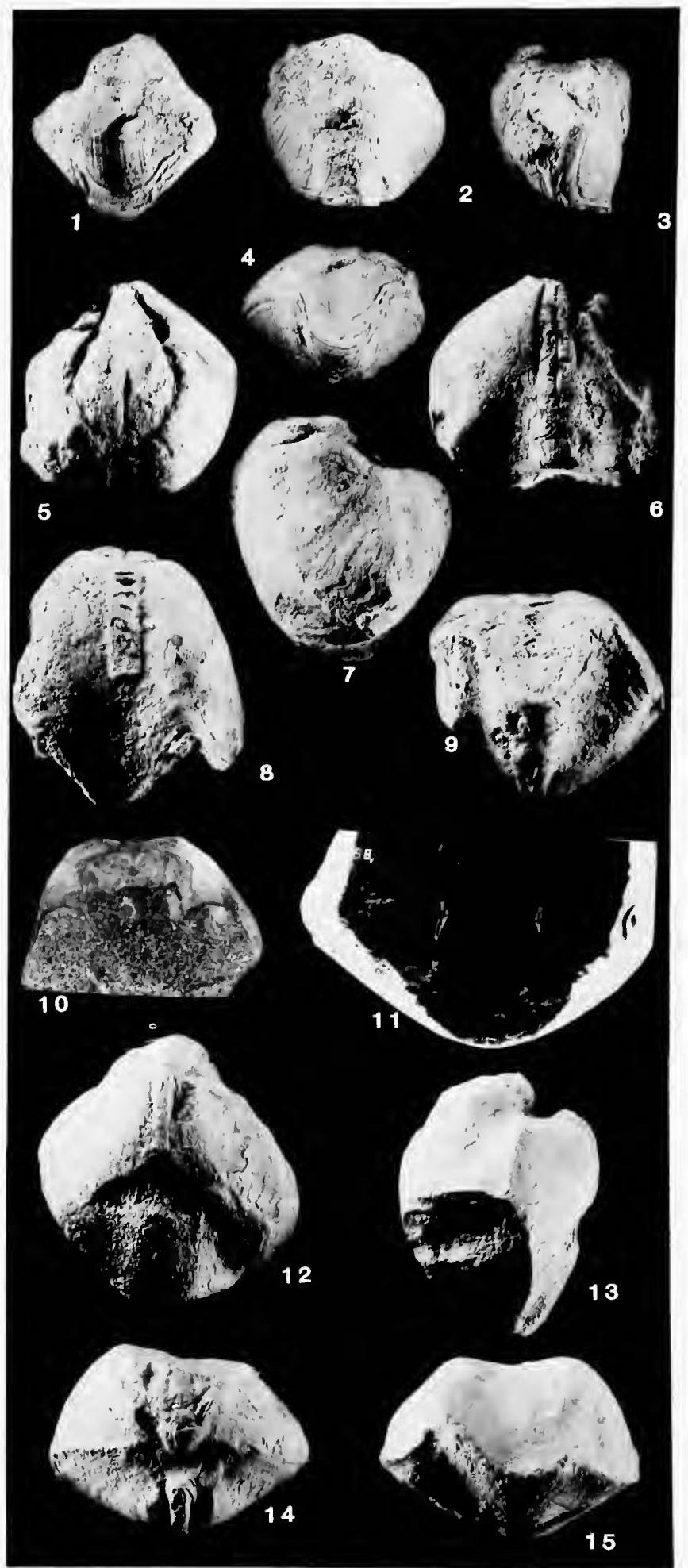


FIGURE 10.—*Peltichia sinensis* (Huang): 1-4, dorsal, ventral, lateral, and anterior views ( $\times 1$ ), from section 8, USNM 455987; 5-9, dorsal-posterior, ventral, lateral, dorsal, and anterior views ( $\times 1$ ), from section 8, USNM 455988; 10, 11, thin sections showing dorsal and ventral internal structures, from sections 10 and 8, USNM 455983, 455989, respectively; 12-15, ventral, lateral, posterior, and anterior views ( $\times 1$ ), from section 32, USNM 455990. (Reduced to 95 $\frac{1}{2}$ % for publication.)

## Order STROPHOMENIDA Opik, 1934

## Suborder ORTHOTETIDINA Waagen, 1884

## Superfamily DERBYIOIDEA Stehli, 1954

## Family DERBYIDAE Stehli, 1954

## Subfamily DERBYINAE Stehli, 1954

Genus *Derbyia* Waagen, 1884*Derbyia pannuciella* sp. nov.

FIGURE 11(1-5)

Medium size for genus, moderately biconvex; subrhomboidal in outline, asymmetrical; hinge line straight, about  $\frac{3}{5}$  as wide as midwidth, slightly auriculate at hinge extremities; anterior commissure slightly sulcate; surface with moderately strong costellae, somewhat alternating in strength, number on either valve 10-13 in 5 mm, increasing by bifurcation; plications intersecting costellae, extending directions of plicae differently at each side of shell, forming rhombic reticulation, reflected in interior surface of both valves.

Pedicle valve moderately convex; interarea low, nearly flat, apsacline, ornamented by very fine lines perpendicular to hinge; pseudodeltidium narrowly arched, perideltidium wide, reaching about  $\frac{1}{3}$  width of hinge. Brachial valve somewhat less strongly inflated; sulcus shallow, beginning near beak, gradually widening forward.

Pedicle valve interior with high median septum. Other interior features unknown.

HOLOTYPE.—USNM 455991.

MEASUREMENTS (mm).—

USNM	Pedicle valve length	Brachial valve length	Maximum width length	Hinge line width	Inter-area width	Thickness
455991	36.0	37.4	42.7	24.6	8.0?	22.2

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Changxing Formation: Huangzhishan section, Wuxing County, Zhejiang Province.

DIAGNOSIS.—Medium size, moderately biconvex, shallow sulcus on brachial valve, and tilted extending plications forming rhombic reticulate "braided" ornament pattern.

COMPARISON.—*Derbyia pannuciella*, new species, is similar to *D. pannucia* Cooper and Grant (1974:308-311, pl. 68: figs. 1-3, pl. 83: figs. 1-12, pl. 84: figs. 1-8, pl. 85: figs. 1-7, pl. 86: figs. 1-11) in its braided plication pattern, narrow pseudodeltidium, and wide interarea; but the latter is very large, with a nearly semicircular outline, rather wide perideltidium, and no sulcus. It resembles *D. cincinnata* Cooper and Grant (1974:294-297, pl. 79: figs. 1-21, pl. 80: figs. 1-17) in its strongly braided, bumpy ornament; it differs in that the West Texas species has a wide pseudodeltidium, catacline interarea, and no sulcus. Actually, the braided, bumpy ornament is more

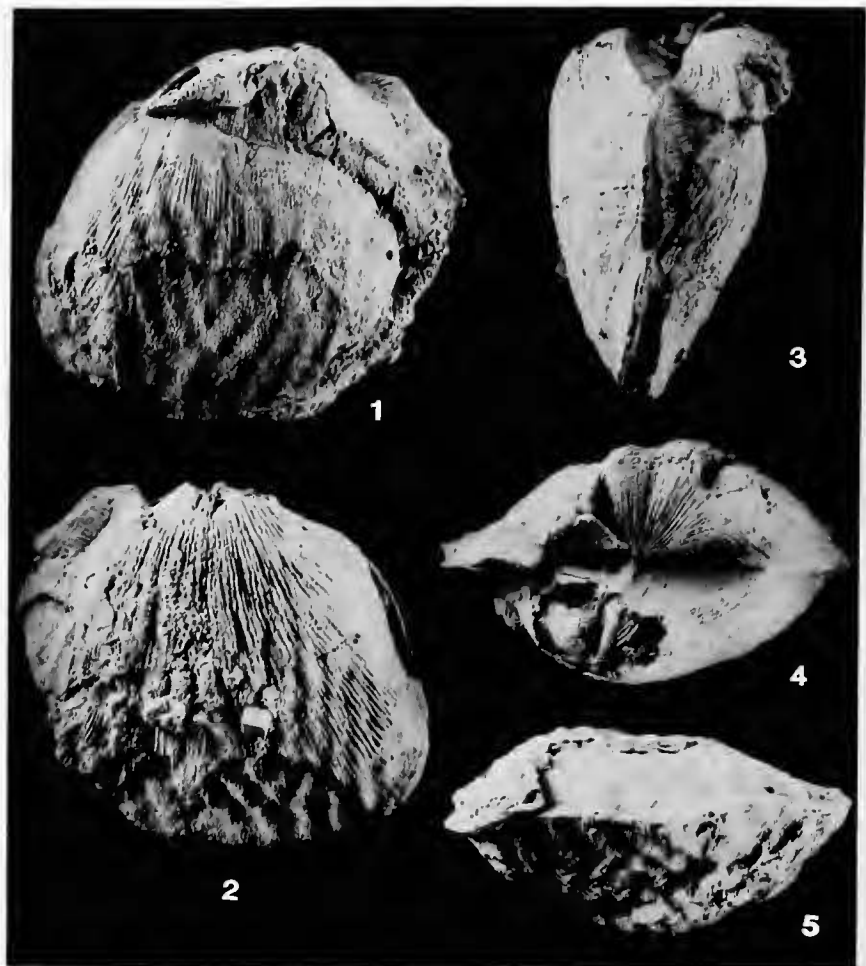


FIGURE 11.—*Derbyia pannuciella*, new species: 1-5, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), from section 27, USNM 455991, holotype. (Reduced to 97 $\frac{1}{2}$ % for publication.)

strongly developed in *D. pannucia* and *D. cincinnata* than in *D. pannuciella*.

ETYMOLOGY.—From the Latin, *pannucia*, meaning wrinkled, and *-ella*, meaning small.

## Family MEEKELLIDAE Stehli, 1954

Genus *Meekella* White and St. John, 1867*Meekella langdaiensis* Liao, 1980

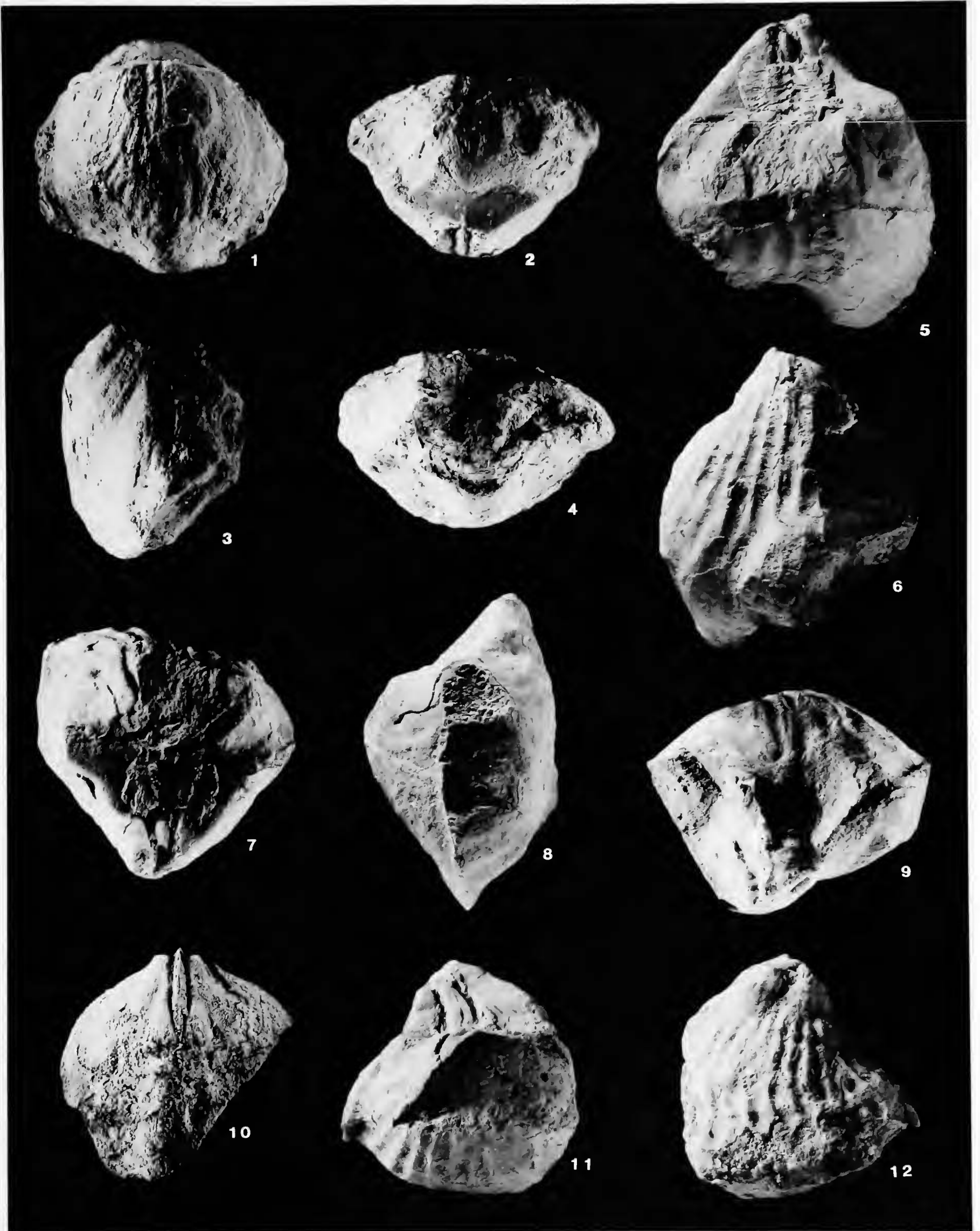
FIGURE 12(1-12)

*Meekella langdaiensis* Liao, 1980:255, pl. 3: figs. 20-23.

Large, subequally biconvex; dorsal view subcircular; sides broadly rounded; anterior commissure sulcate; hinge shorter than greatest width; plications coarse, increasing by bifurcation, crests angular to subangular, beginning from umbonal region, numbering 12-18 each valve; costellae fine and closely

FIGURE 12 (opposite page).—*Meekella langdaiensis* Liao: 1-4, ventral, posterior, lateral, and anterior views ( $\times 1$ ), from section 27, USNM 455992; 5-9, dorsal, ventral, posterior, lateral, and anterior views ( $\times 1$ ), from section 32, USNM 455993; 10, internal cast showing impressions of dental plates ( $\times 1$ ), from section 3, USNM 455994; 11, 12, dorsal and ventral views ( $\times 1$ ), from section 32, USNM 455995.





spaced, usually weak, prominent at umbonal region.

Pedicle valve conical; beak moderately sharp, slightly twisted; interarea a subequilateral triangle, fairly flat or slightly concave, apsacline; pseudodeltidium narrow, fold narrow, occupying about  $\frac{1}{2}$  of valve length. Brachial valve moderately convex, maximum convexity at umbonal region; beak strongly incurved; sulcus moderately deep, occupying about  $\frac{1}{4}$ – $\frac{1}{3}$  of greatest width of valve.

Pedicle valve interior with short dental plates, extending about  $\frac{1}{4}$  of valve length, parallel and nearly equally distanced at floor, slightly divergent dorsally. Brachial valve interior with high brachiophore supports, divergent forward, forming about  $60^\circ$  angle.

MEASUREMENTS (mm).—

USNM	Pedicle valve length	Brachial valve length	Maximum width	Hinge width	Inter-area length	Thickness
455992	40.9?	43.0	48.2	26.5	11.0?	33.7
455993	57.2	44.0	47.2?	38.8	20.8	36.9

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Longdongchuan Formation: Xikou section, Zhenan County, Shaanxi Province. Longtan Formation: Huangzishan section, Wuxing County, Zhejiang Province.

DIAGNOSIS.—Large, pauciplicate, obvious sulcus on brachial valve, dominant fold on pedicle valve.

COMPARISON.—*Meekella langdaiensis* Liao is similar to *M. kueichowensis* Huang (1933:27, 28, pl. 3: figs. 19–21, pl. 4: figs. 1–4) in its large size and in features of the interarea; it differs in that the latter has no sulcus and fold and its dental plates are rather thin and close at the valve floor. *Meekella* cf. *kueichowensis* Huang (1933:28, 29, pl. 3: fig. 2, pl. 4: figs. 5, 6) has more widely separated and much shorter dental plates than *M. kueichowensis*, and thus resembles *M. langdaiensis*, but it has more than 20 plications in adult specimens (Liao, 1980a:256) and no fold on the pedicle valve.

Superfamily ORTHOTETOIDEA Waagen, 1884

Family ORTHOTETIDAE Waagen, 1884

Genus *Perigeyerella* Wang, 1955

*Perigeyerella altilosina* sp. nov.

FIGURE 14(10–14)

Medium size for genus; biconvex but shallowly inflated; outline subelliptical, slightly distorted, greatest width at midvalve of brachial valve; hinge line straight, shorter than widest part of shell; anterior commissure rectimarginate, slightly waved dorsally; surface with multicostellae, numbering about 32 per cm, concentric wrinkles irregularly spaced.

Pedicle valve inflated at umbonal region and slightly depressed at anterior  $\frac{1}{3}$  in lateral profile; anterior profile inflated at middle, with gently inclined slope at each side; beak

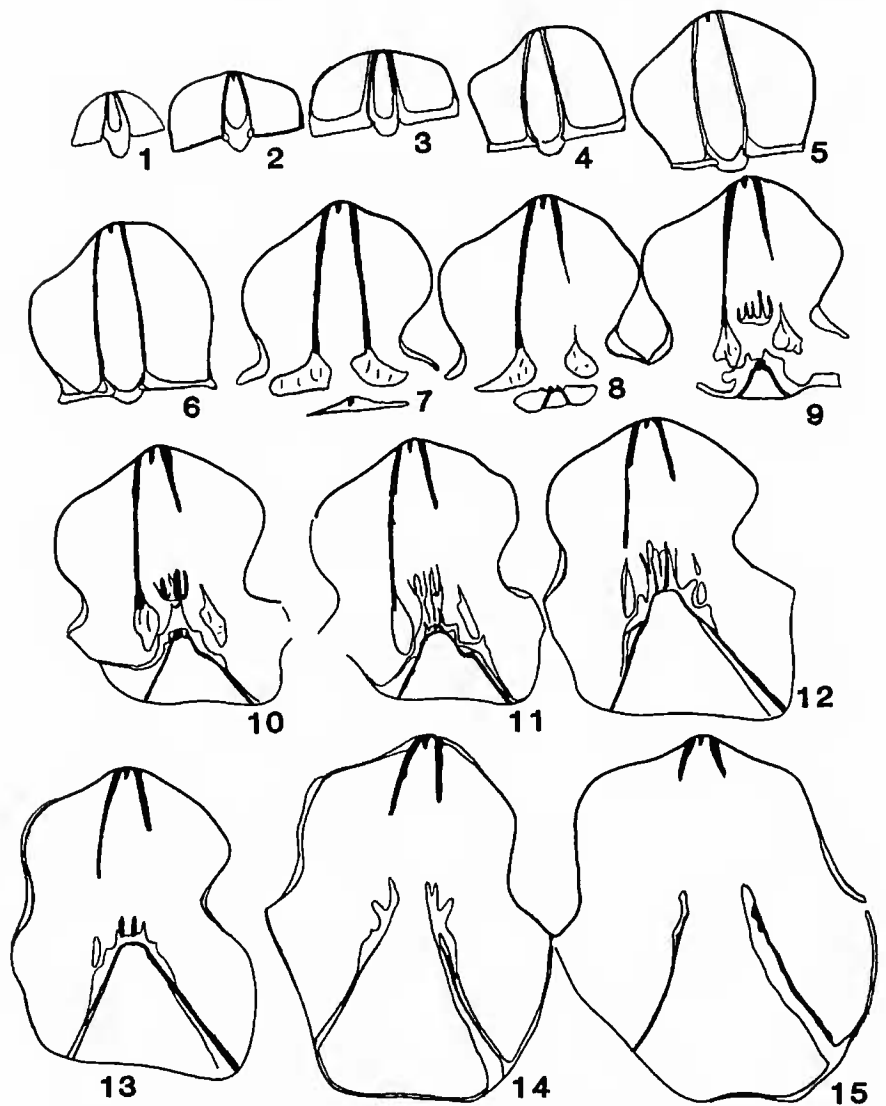


FIGURE 13.—Serial sections of *Perigeyerella costellata* Wang, USNM 455999, showing internal features.

blunt, erect; interarea proportionately large, flat, apsacline but nearly orthocline; pseudodeltidium completely arched, narrow, about  $\frac{1}{8}$  of hinge line, perideltidial area obscure, each side narrower than pseudodeltidium. Brachial valve weakly and evenly convex, forming gentle arciform in both lateral and anterior profiles; beak small, inclined; no sulcus.

Pedicle valve interior with thin, nearly parallel dental plates. Brachial valve interior with flaring extended brachiophore plates. Other features unknown.

HOLOTYPE.—USNM 455996.

MEASUREMENTS (mm).—

USNM	Pedicle valve length	Brachial valve length	Maximum width	Hinge width	Inter-area length	Thickness
455996	38.8	27.9	33.9	28.5	13.2	15.0

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Longdongchuan Formation: Xikou section, Zhenan County, Shaanxi Province.

DIAGNOSIS.—Medium size, shallow *Perigeyerella* with large interarea, almost orthocline, and no sulcus on brachial valve.

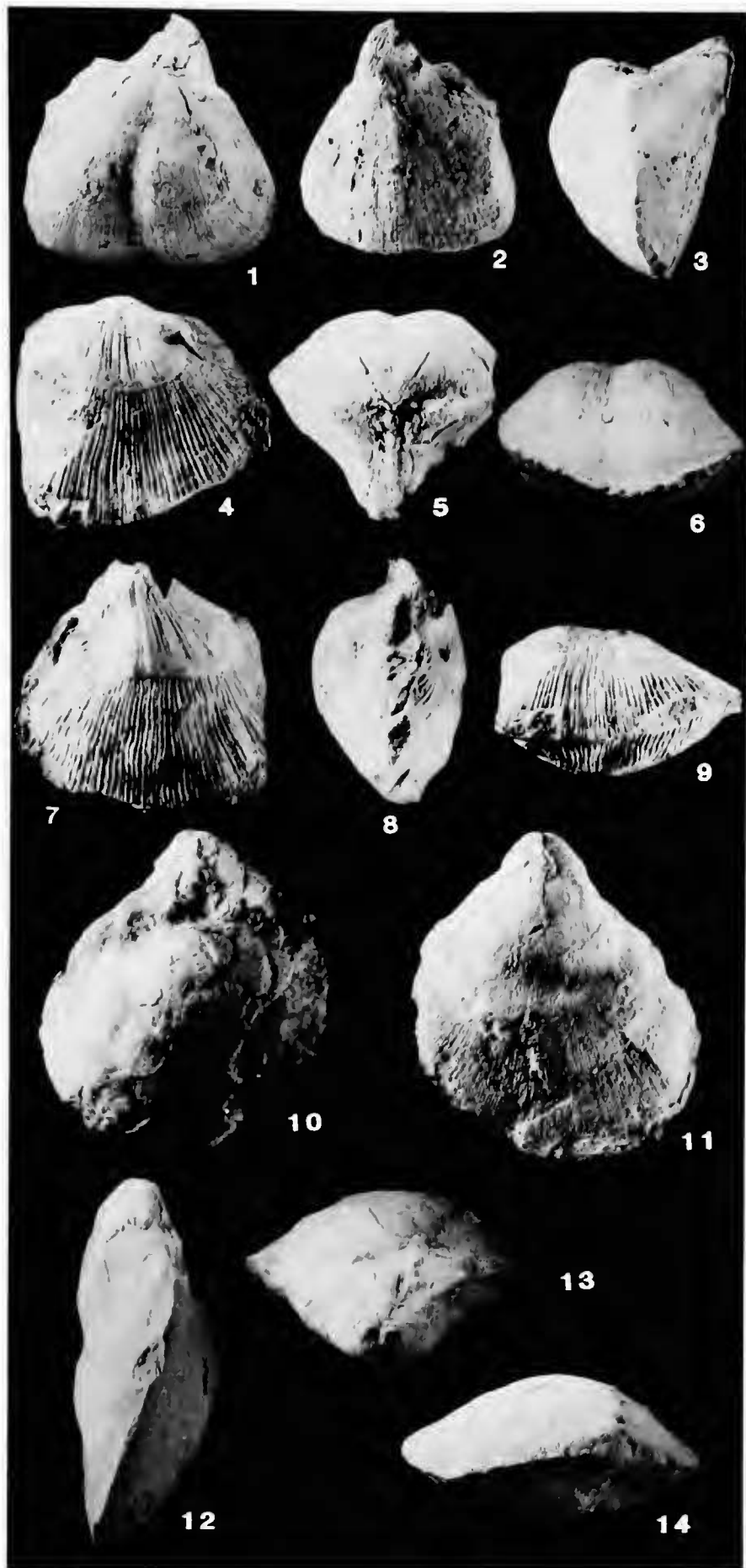


FIGURE 14.—*Perigeyerella* Wang. 1-9, *Perigeyerella costellata* Wang: 1-3, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), from section 6, USNM 455997; 4, 7-9, dorsal, ventral, lateral, and anterior views ( $\times 1$ ), from section 27, USNM 455998. 10-14, *Perigeyerella altilosina*, new species: dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), from section 32, USNM 455996, holotype. (Reduced to 97 $\frac{1}{2}$ % for publication.)

COMPARISON.—This new species differs from *P. costellata* Wang (1955a:347-349, pl. 4A: figs. 1-10) in that the latter has the sulcus on the brachial valve and a semipyramidal pedicle valve (Figure 13). It is similar to *P. tricosa* Grant (1976:63, 64, pl. 11: figs. 1-30) in its brachial valve, which lacks a median depression and is evenly and slightly inflated, but it is readily distinguishable in that the latter is small for the genus and has a lower interarea.

DISCUSSION.—Internal features of this new species were not excavated because traces of dental plates and brachiophore plates on the specimen are comparable to those in specimens of *P. costellata* for which we made serial sections to show internal features of the genus (Figure 13).

The serial sections show a low median septum between the dental plates. This septum extends about the same distance as the dental plates, nearly  $\frac{1}{3}$  of the pedicle valve length. Wang (1955) recorded "a low spondylium support at posterior extremity" when he set up the genus; therefore, we recommend emending the original description to include the following statement: sometimes having a low median septum in the pedicle valve as a variety of internal features. "*Ombonia*" magna Greco (1938:24, pl. 1: figs. 18-20, pl. 2: figs. 1-7), which Grant (1976:63) assigned to the genus *Perigeyerella*, has a median septum in the pedicle valve; its occurrence in this species provides collateral evidence that a ventral median septum may occur in the genus.

ETYMOLOGY.—From the Latin, *altilis*, meaning fattened and *-ina* (diminutive suffix), meaning small.

#### Suborder CHONETIDINA Muir-Wood, 1955

#### Superfamily CHONETOIDEA Bronn, 1862

#### Family RUGOSOCHONETIDAE Muir-Wood, 1962

#### Subfamily CHONETINELLINAE Muir-Wood, 1962

#### Genus *Chonetinella* Ramsbottom, 1952

#### *Chonetinella cursothornia* sp. nov.

FIGURE 15(4, 6, 8-16)

Small to medium size, transversely subrectangular in outline; widest at hinge; cardinal extremities approximately rectangular or sharply pointed; sides nearly parallel in posterior  $\frac{1}{2}$ , rounded or sloping medially toward anterior; anterior margin broadly rounded, anterior commissure slightly folded; surface costellae numbering about 5-6 per mm at front margin, fine spicule bases arranged along crests of costellae; posterior margin with 3-4 oblique, coarse, hollow spines at high angle to hinge line on each side of beak.

Pedicle valve gently to moderately convex, anterior profile arched in central region; ears proportionately large, with fine costellae somewhat subdued near hinge; sulcus originating on

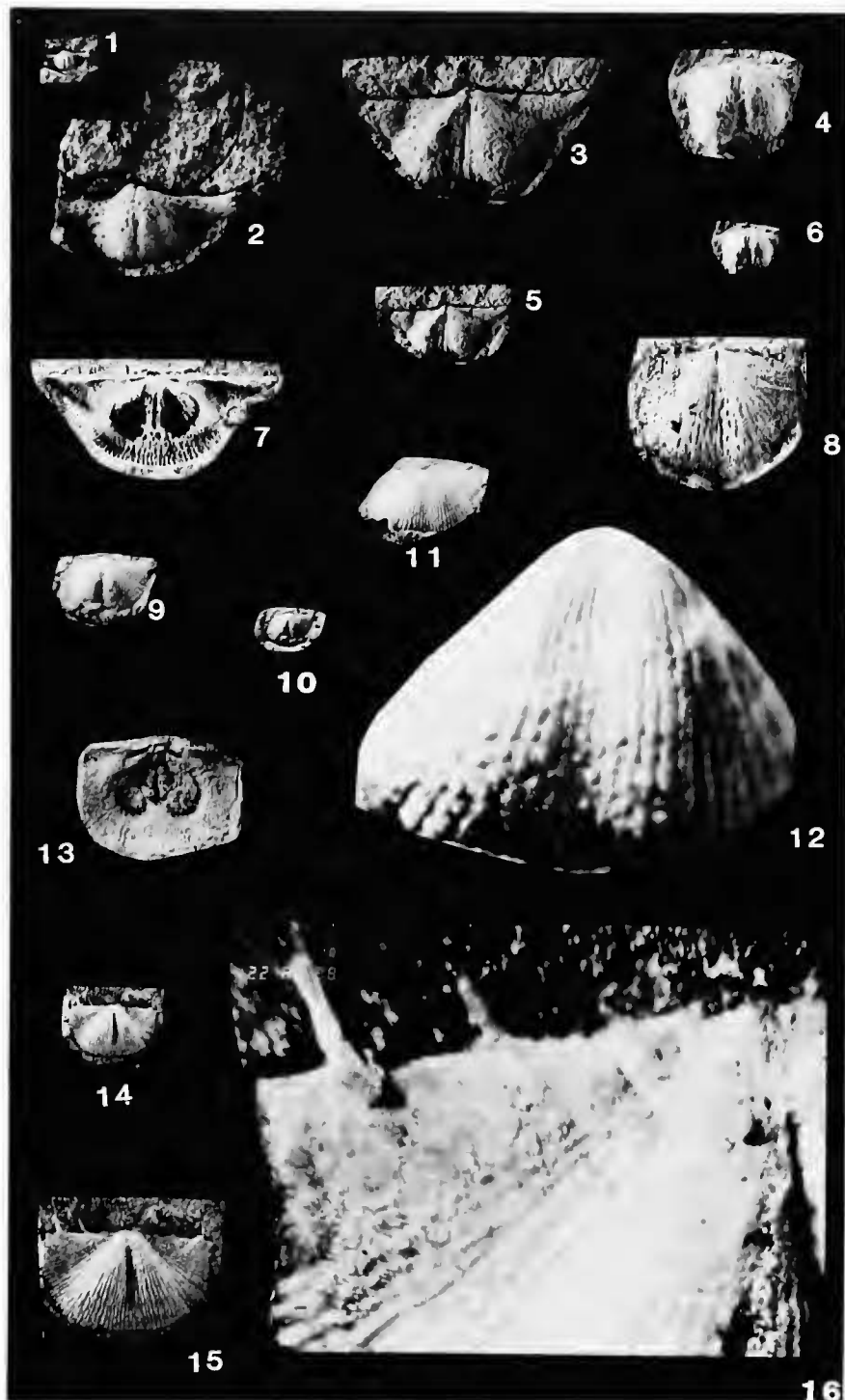


FIGURE 15.—*Chonetinella* Ramsbottom. 1-3, 5, 7, *Chonetinella volitanliopsis* (Xu): 1, 2, ventral views ( $\times 1$ ,  $\times 4$ ), USNM 456004; 7, dorsal view ( $\times 2$ ), USNM 456005, both from section 6. 3, 5, ventral views ( $\times 2$ ,  $\times 1$ ), USNM 456003, from section 31. 4, 6, 8-16, *Chonetinella cursothornia*, new species: 4, 6, ventral views ( $\times 2$ ,  $\times 1$ ), USNM 456001, from section 8. 8, ventral view ( $\times 2$ ), USNM 456007b; 9, 10, ventral views ( $\times 2$ ,  $\times 1$ ), USNM 456007a, both from section 17. 11, 12, ventral view and part magnification ( $\times 2$ ,  $\times 10.4$ ), USNM 456008; 13, dorsal view ( $\times 2$ ), USNM 456002, paratype; both from section 27. 14-16, ventral views and magnification of part of hinge region ( $\times 1$ ,  $\times 2$ ,  $\times 20.8$ ), USNM 456000, holotype, from section 6. (Reduced to 97% for publication.)

umbo, moderately deep and narrow near umbonal area, widened and getting shallower from midlength forward. Brachial valve with narrow, low fold.

Pedicle valve interior with short median septum; endospines arranged in radial rows, coarse on ears and sulcus. Brachial valve interior with inner-socket ridges almost parallel to hinge; well-defined brachial ridges; median septum extending to midvalve.

HOLOTYPE.—USNM 456000.

MEASUREMENTS (mm).—

USNM	Pedicle valve length	Surface length	Hinge width	Midwidth
456000	5.65	6.10	9.30	9.30
456006	7.20	7.60	8.60?	8.60
456001	5.20	6.70	7.00	6.10
456008	4.30	4.70?		6.50
456007	3.30	3.90	4.80	4.70

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation: Huayingshan section, Linshui County, Sichuan Province; Beipei section, Zhongqing City, Sichuan Province; Huangzhishan section, Wuxing County, Zhejiang Province. Yinkeng Formation: Meishan section, Changxing County, Zhejiang Province. Lower Daye Formation: Guanyinshan section, Puqi County, Hubei Province.

DIAGNOSIS.—Transverse subrectangular *Chonetinella* with 3-4 coarse, hollow spines on each side of hinge and moderately deep sulcus beginning from near umbonal area of pedicle valve.

COMPARISON.—*Chonetinella cursothornia*, new species, is readily distinguishable from *C. volitanliopsis* (Xu) by its subrectangular outline, large ears, and strong spines at posterior margin. It is somewhat similar to *C. costellata* Cooper and Grant (1975:1273, 1274, pl. 479: figs. 1-23) in its subrectangular outlines, fine costellae, and strong spines at posterior margin. But the West Texas species has a relatively large shell, many more spines at the posterior margin, and a poorly developed sulcus.

ETYMOLOGY.—From the Latin, *cursor*, meaning rapid or brief plus thorn; thus meaning short spines.

#### *Chonetinella volitanliopsis* (Xu, 1987)

FIGURE 15(1-3, 5, 7)

*Neochonetes volitanliopsis* Xu in Yang et al., 1987:222, pl. 10: fig. 1.

DIAGNOSIS.—Small to medium size, transversely reversely subtrapezoidal outline; cardinal extremities acutely pointed; posterior margin with 3 spines on each side of the beak, 1 at middle of each  $\frac{1}{2}$  of hinge line; spines long, obliquely originated from hinge line then curved as they grew forward; sulcus narrow or getting wider anteriorly.

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Yanshi Formation: Jacing section, Zhanping County, Fijian Province. Lowest Daye Formation: Huayingshan section, Linshui County, Sichuan Province.

DISCUSSION.—This species originally was assigned to *Neochonetes*, but now it is placed in *Chonetinella* because it differs from typical species of *Neochonetes*, which have strong lateral vascular trunks parallel to each other in the pedicle valve and no narrow and deep sulcus on that valve. Instead, *C. volitanliopsis* is small, has endospines in radial rows on both valves that are coarse on the ears and the sulcus area, has

brachial ridges that extend along the lateral and anterior margins to near the median septum that then recurve at a sharp angle, and has a short septum in the pedicle valve. These features suggest that it should be attributed to the genus *Chonetinella*.

### Subfamily RUGOSOCHONETINAE Muir-Wood, 1962

#### *Fanichonetes* gen. nov.

Small- to medium-size shell, transversely subrectangular to semicircular in outline; hinge slightly shorter or equal to maximum width; cardinal extremities varying from slightly acute to slightly obtuse; shallow sulcus on pedicle valve; ears large, usually well defined; surface strongly costellate, increasing by bifurcation, subdued on ears, becoming smooth near hinge line; growth lines irregularly spaced, extending to ears; spines inclined mesially at low angle to hinge line, crowded near beak, distally inclined near cardinal extremities.

Pedicle interior with short median septum; endospines in radial rows, coarse on ears and middle part. Brachial valve with bifid cardinal process and alveolus.

DIAGNOSIS.—Transverse outline, strongly costellate, well-developed growth lines, and spines mostly inclined toward midline.

COMPARISON.—This genus is most like *Rugosochonetes* Sokolskaya (1950:23; see also Muir-Wood, 1962:64–68) in its transverse outline, well-developed growth lines, internal features, spines that incline toward the midline, and strong costellae. It resembles *Neochonetes* Muir-Wood (1962:87–89, pl. 10: figs. 8–15, pl. 11: figs. 7, 8; Cooper and Grant, 1975:1217, 1218) in its transverse outline, but it is readily distinguished from *Neochonetes* by its spines that mostly incline mesially. *Fanichonetes* has no strong lateral vascular trunks and has strong costellae that normally are coarser than in *Neochonetes*. *Chonetinella* Ramsbottom (1952:13; Muir-Wood, 1962:85–87, pl. 9: figs. 10–17), with strong costellae and deep sulcus, is somewhat similar to *Fanichonetes*, however, it differs in not having well-developed growth lines and inwardly inclined spines.

TYPE SPECIES.—*Fanichonetes campigia* sp. nov.

ETYMOLOGY.—From the Latin, *fanum*, meaning temple. The gender of -etes is ambiguous; it is treated here as feminine.

#### *Fanichonetes campigia* sp. nov.

FIGURE 16(1–32)

DIAGNOSIS.—Small to medium size; transversely subrectangular; sulcus shallow on pedicle valve; strongly costellate, numbering about 11–13 per 5 mm at anterior margin; ears large; spines on posterior margin mostly inclined toward midline, numbering about 6–10, crowded near beak; growth lines well developed.

HOLOTYPE.—USNM 456011.

### MEASUREMENTS (mm).—Pedicle valve.

USNM	Surface length	Hinge length	Width	Midwidth	Spines per side
456009	10.1	11.3	12.8	14.5	8
456010	9.8	10.6	14.3	14.3	7
456011	6.5	7.0	9.8	10.7	6
456012	8.2	9.1	11.8	13.7	-
456013	7.6	7.9	13.3	13.7	-
456014	7.5	7.8	10.6	12.8	-
456015	6.3	6.5	8.9?	10.4	-

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Upper Member of Paoshui Formation: Paoshui section, Laibin County, Guangxi Province. Wangpanli Formation: Lian County, Guangdong Province. Changxing Formation: Huangzhishan section, Wuxing County, Zhejiang Province. Lowermost Xikou Formation: Yading section, Zhuangping County, Fujian Province.

ETYMOLOGY.—From the Greek, *camar*, a vaulted chamber, and *pygia*, posterior, tail.

### Suborder PRODUCTIDINA Waagen, 1883

### Superfamily PRODUCTOIDEA Gray, 1840

### Family CHONETELLIDAE Likharev, 1960

#### Genus *Cathaysia* Ching, 1966

*Cathaysia* Ching in Wang et al., 1966:372–374, fig. 287.

Small, transverse outline; moderately concavo-convex; ears large, well demarcated from visceral disc of shell by either narrow trough, strong concavity, or different ornamentation; sulcus usually originating about midlength, shallow and widened on geniculation; interarea narrow; surface strongly costellate, crests rounded, increasing by bifurcation; ears normally smooth; central wrinkles well developed, especially on ears; cardinal spines oblique, about 2–3 per side, biggest spines on cardinal extremities; both sides of sulcus on geniculation bearing several spines.

Pedicle valve interior with 2 pairs of adductor marks, 1 pair near umbonal area small, kidney-shape, another pair distal, somewhat large; diductor marks elongate oval surrounding adductors; no median septum. Brachial valve interior with bifid cardinal processes; median septum thin and low; brachial ridges lunate; 2 pairs of adductors posterior to brachial ridges; endospines around brachial ridges large, those near anterior margin of shell small.

COMPARISON.—The genus *Cathaysia* Ching is similar to *Chonetella* Waagen (1884:613, 657; Muir-Wood and Cooper, 1960:219–221, pl. 69: figs. 1–7) in its “Chonetoid-shape, narrow coelomic cavity, large ears, spines at posterior margin...” (Ching, 1966:373). In establishing the genus, Ching (1966:373, 374) pointed out that *Cathaysia* has “geniculation” formed gently, wrinkles dominant on ears, only

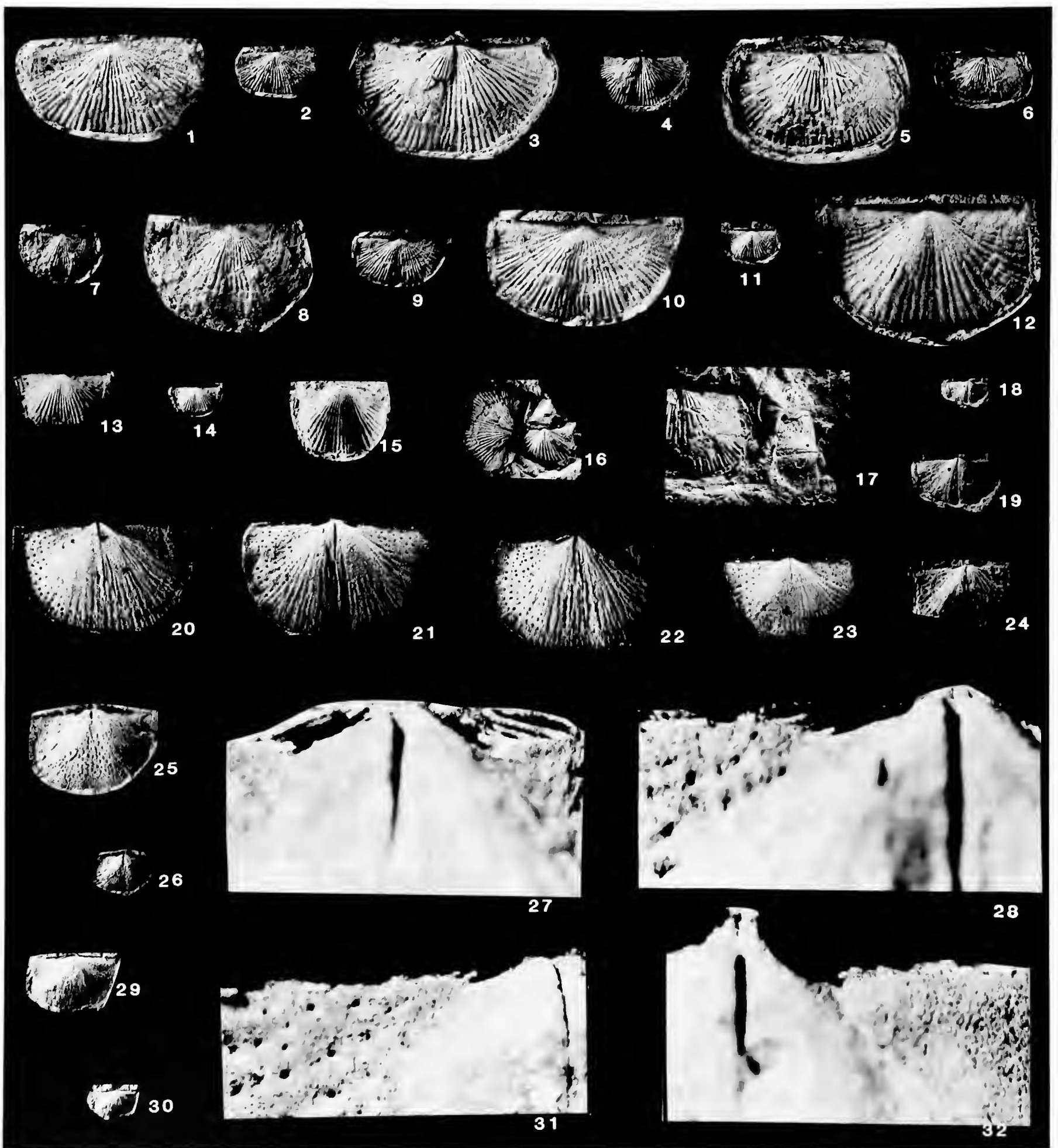


FIGURE 16.—*Fanichonetes campigia*, new species: 1, 2, ventral views ( $\times 2$ ,  $\times 1$ ), USNM 456012; 5, 6, ventral views ( $\times 2$ ,  $\times 1$ ), USNM 456014a; 7, 8, ventral views ( $\times 1$ ,  $\times 2$ ), USNM 456013; 17–19, ventral views ( $\times 2$ ,  $\times 1$ ,  $\times 2$ , respectively), USNM 456014b; all from section 31. 3, 4, 16, ventral valves ( $\times 2$ ,  $\times 1$ ,  $\times 1$ , respectively), USNM 456015, from section 34. 9, 10, ventral valve ( $\times 1$ ,  $\times 2$ ), USNM 456019a; 13, 14, ventral valve ( $\times 2$ ,  $\times 1$ ), USNM 456019b; 24, ventral valve ( $\times 2$ ), USNM 456017; 25, 26, ventral valve ( $\times 2$ ,  $\times 1$ ), USNM 456018a; 29, 30, ventral valve ( $\times 2$ ,  $\times 1$ ), USNM 456018b; all from section 30.

11, 12, ventral valves ( $\times 1$ ,  $\times 4$ ), USNM 456016. 15, ventral valve ( $\times 2$ ), USNM 456206, from section 26. 20, 32, dorsal interior mold ( $\times 2$ ) and magnification of part of hinge region ( $\times 10.4$ ), USNM 456009, paratype; 22, 27, 31, ventral valve interior mold ( $\times 2$ ) and magnification of part of hinge region ( $\times 10.4$ ), USNM 456010a; 23, ventral valve interior mold, USNM 456010b; 21, 28, ventral valve interior mold ( $\times 2$ ) and magnification of part of hinge region ( $\times 10.4$ ), USNM 456011, holotype; all from section 15.

2–3 spines in row per side of the beak, and 2–4 spines existing on geniculation at each side of sulcus; in contrast, the genus *Chonetella* has no geniculation, wrinkles on ears, and spines in a row, excepting along posterior margin, existing between ears and visceral disc. Furthermore, the important features of *Chonetella* are the pedicle valve, which has an anterior median fold that forms a V-shape extension, and the brachial valve, which has an anterior sulcus.

GEOLOGIC RANGE.—Permian, Asia.

TYPE SPECIES.—*Productus chonetoides* Chao (1927:62, 63, pl. 16: figs. 1–5).

### *Cathaysia sinuata* Chan, 1979

FIGURE 17(1–22)

*Cathaysia sinuata* Chan in Hou et al., 1979:76, 77, pl. 13: figs. 6–9.—Chan in Z.Y. Yang et al., 1987:223, pl. 10: figs. 19, 20, 22, 23.

*Cathaysia sulcatifera* Liao, 1979, pl. 1: figs. 19, 20; 1980a:261, pl. 6: figs. 8–10.—Liao in Zhao et al., 1981:53, pl. 8: figs. 15, 16.

DIAGNOSIS.—Small, transversely trapezoidal or semicircular; strongly concavo-convex; interarea rather narrow; beak incurved; cardinal extremities blunt; ears large, either flat or slightly arched; sulcus narrow and deep, originating from umbonal area, usually becoming shallow, flattened, or forming small low fold at trail; surface with strong costellae, rounded at crest, casually bifurcate, numbering about 14–30 near anterior margin; wrinkles faint but clearly visible on ears; 2–3 spines at posterior margin in a row at each side of beak, oblique posterior-laterally at high angle to hinge line, biggest one extending from each cardinal extremity, sometimes horizontal extension.

Interior structures mostly unknown, but endospine scars visible in some specimens; no median septum in pedicle valve.

MEASUREMENTS (mm).—Pedicle valve.

USNM	Surface length	Hinge length	Width	Midwidth	Spines per side
456020	6.2	8.1	8.8	9.1	2
456021	5.2	5.9	8.1	7.8	2
456022	6.3	7.8	10.0	8.2	2–3?
456023	7.6	8.2	8.7	8.8	2
456024	6.5	9.4	10.4	9.8?	2
456025	7.9	9.7	11.7	11.7?	–
456026	5.0	5.6	8.0?	8.5	2

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Lower Yinkeng Formation and Upper Changxing Formation: Meishan section, Changxing County, Zhejiang Province; Yutangjiao section, Nantong County, Sichuan Province. Cuiplingshan and Yanshi formations: Yanshi section, Longyan County, Fujian Province.

COMPARISON.—*Cathaysia sinuata* Chan is characterized by having a narrow, deep sulcus extending from the umbonal area to the trail on the pedicle valve, strong coarse costellae, proportionately large ears with faint wrinkles on it, and only

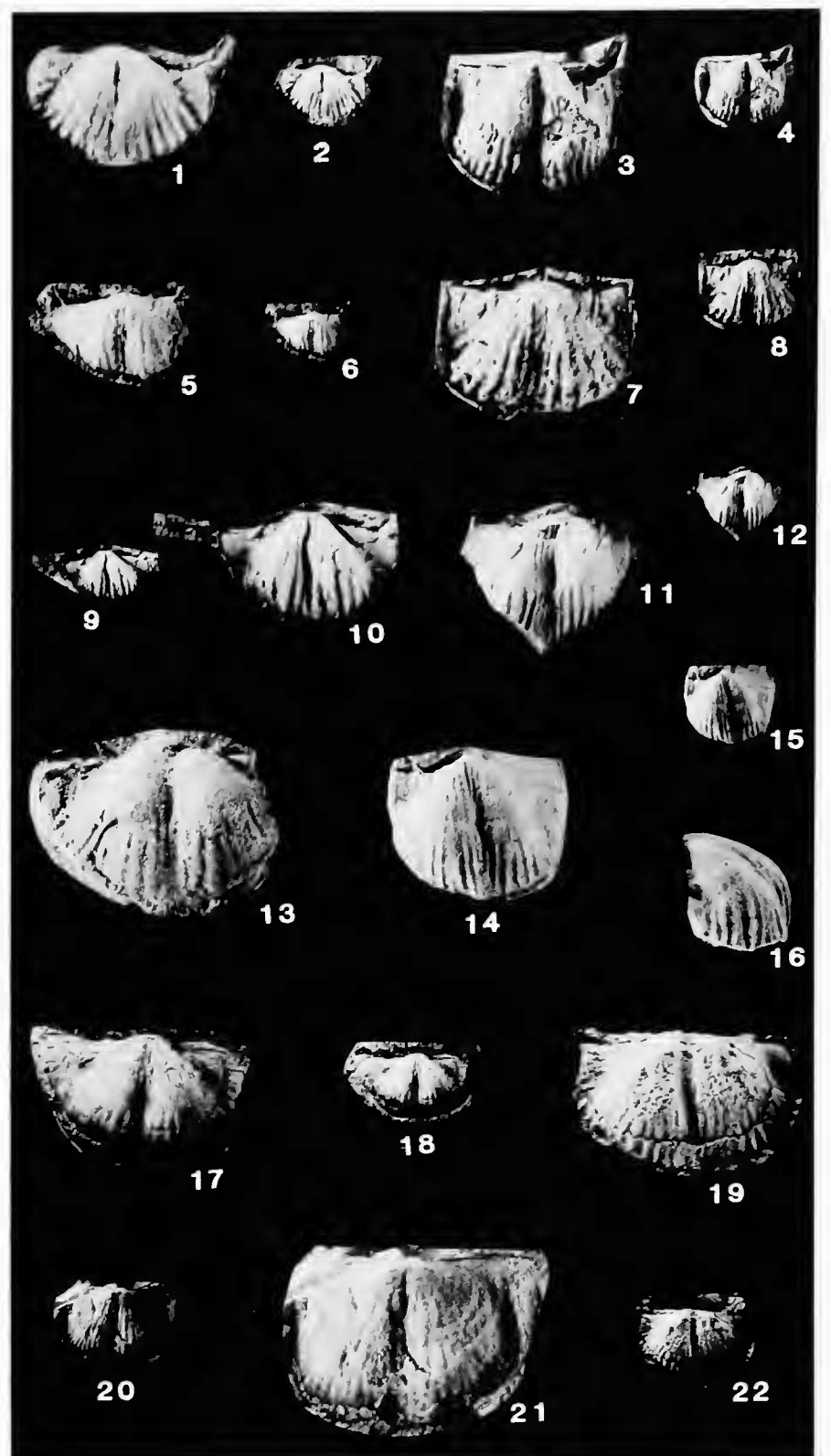


FIGURE 17.—*Cathaysia sinuata* Chan, all ventral valves: 1, 2 ( $\times 2$ ,  $\times 1$ ), USNM 456020; 17, 18 ( $\times 2$ ,  $\times 1$ ), USNM 456021; both from section 26. 3, 4 ( $\times 2$ ,  $\times 1$ ), USNM 456023; 5, 6, ( $\times 2$ ,  $\times 1$ ), USNM 456006; 13 ( $\times 2$ ), USNM 456026; all from section 27. 9, 10 ( $\times 1$ ,  $\times 2$ ), USNM 456022, from section 9. 7, 8 ( $\times 2$ ,  $\times 1$ ), USNM 456207; 11, 12 ( $\times 2$ ,  $\times 1$ ), USNM 456024; 14, 15 ( $\times 2$ ,  $\times 1$ ), and 16, lateral view ( $\times 2$ ), USNM 456208; 19, 22 ( $\times 2$ ,  $\times 1$ ), USNM 456025a; 20, 21 ( $\times 1$ ,  $\times 2$ ), USNM 456025b; all from section 31.

2–3 spines at each side of the beak. These features, therefore, are readily distinguishable from *C. chonetoides* (Chao, 1927:62, 63, pl. 16: figs. 1–5). It is similar to *Cathaysia orbicularis* Liao (1980a:261, pl. 6: figs. 1–4) in its transverse outline, strong costellae, and variable ears, but it differs in its deep sulcus, faint wrinkles on ears, and relatively large number of costellae.

DISCUSSION.—Liao (1980a:261, pl. 6: figs. 8–10) named the species *Cathaysia sulcatifera*, based on specimens from the Changxing Formation of the Qiaozishan section, Anshun County, Guizhou Province, which are the same as specimens from the north area of Guangdong Province that were named *C. sinuata* by Chan (in Hou et al., 1979). This name has priority, so the name *C. sulcatifera* must be abandoned.

Liao (in Zhao et al., 1981:53, 83, 84) named the genus *Paryphella*, based upon the type species *C. sulcatifera*, which is a junior synonym of *C. sinuata* Chan. The reasons that he advanced for separating this species from *Cathaysia* are that the genus *Cathaysia* is large, has fine costellae, spines on the visceral disc, and no “ear-curtains” (Liao in Zhao et al., 1981:53). The author explains the concept of ear-curtains as “posterial lateral margins bent abruptly to brachial valve” (1981:83) and encircling postero-laterally the ears of the brachial valve (1981:53). It is true that the phenomenon of ear-curtained commonly occurs in every species of the genus *Cathaysia*, even in *C. chonetoides* (Chao, 1927, pl. 16: fig. 4; Huang, 1932, pl. 1: figs. 10, 11), because the shape of the ears is variable in *Cathaysia*. If the ears were strongly inflated, that would produce the phenomenon of ear-curtained; on the other hand, ears in many specimens are flat, for instance, some specimens of *C. sulcatifera* Liao (1980a, pl. 6: fig. 9) seem not sufficiently inflated to produce the ear-curtained effect, as the author described “ears large, flat” (Liao, 1980a:261). The specimens from South China indicate that the phenomenon of ear-curtained may be an inconstant feature. Definitely, adults of *C. chonetoides* are relatively large and have fine costellae; these features are useful for discriminating among species rather than among genera. Visceral-disc spines were not found in our collections of *C. chonetoides* and *C. sinuata* except for a few tubercles that may represent spine scars. It could not be decided which is correct: Liao’s description of the species *C. sulcatifera* (1980a:261) as “having several spines on lateral surface of shell” or the description of the genus *Paryphella* (Liao, 1981:53, 83) as having “no spines on shell surface [and a] lack of ventral and lateral spines.” In view of these inconsistencies, we consider that *Paryphella* is a synonym of *Cathaysia*.

*Cathaysia speciosa* Chan (in Hou et al., 1979:76, pl. 9: figs. 4–7) is characterized by its strongly convex, relatively coarse costellae, slightly curved ears, and clearly visible coarse wrinkles. These features seemingly cannot be distinguished from *C. sinuata* Chan except for the sulcus. The holotype of *C. speciosa* is shown in Chan (in Hou et al., 1979, pl. 9: figs. 4, 5) to have a narrow, deep sulcus as in *C. sinuata* (1979, pl. 9: figs. 8, 9). Judging from illustrations of other specimens assigned to *C. speciosa* by Chan (in Hou et al., 1979, pl. 9: figs. 6, 7), it is so much like *C. chonetoides* that it seems unnecessary to keep the name *C. speciosa* Chan.

### *Cathaysia spiriferoides* sp. nov.

FIGURE 18(1–15)

Medium size for genus; reversely trapezoid in outline; pedicle valve moderately convex and brachial valve shallowly concave; widest along hinge, cardinal extremities acute and slightly alate; beak sharply pointed, bent over hinge line; ears moderately large, usually slightly inflated; sulcus shallow or moderately deep, originating from anterior to umbonal region, gradually widening to anterior margin forming triangular shape; surface with strong costellae, rounded at crest, simple at sulcus floor, bifurcated at lateral sides; strong and irregular wrinkles, especially at ears, extending to lateral sides of visceral disc; 3–5 pairs of spines at posterior margin, vertical to hinge.

Pedicle valve interior having no median septum; endospines fine, distributed radially along traces of interspaces between costellae. Brachial valve interior with low, single(?) cardinal process; median septum extending to midvalve, unconnected to cardinal process, suggesting alveolus existed; brachial ridges present.

SYNTYPES.—USNM 456006a–f, 456027a,b, 456030, 456209.

MEASUREMENTS (mm).—Pedicle valve.

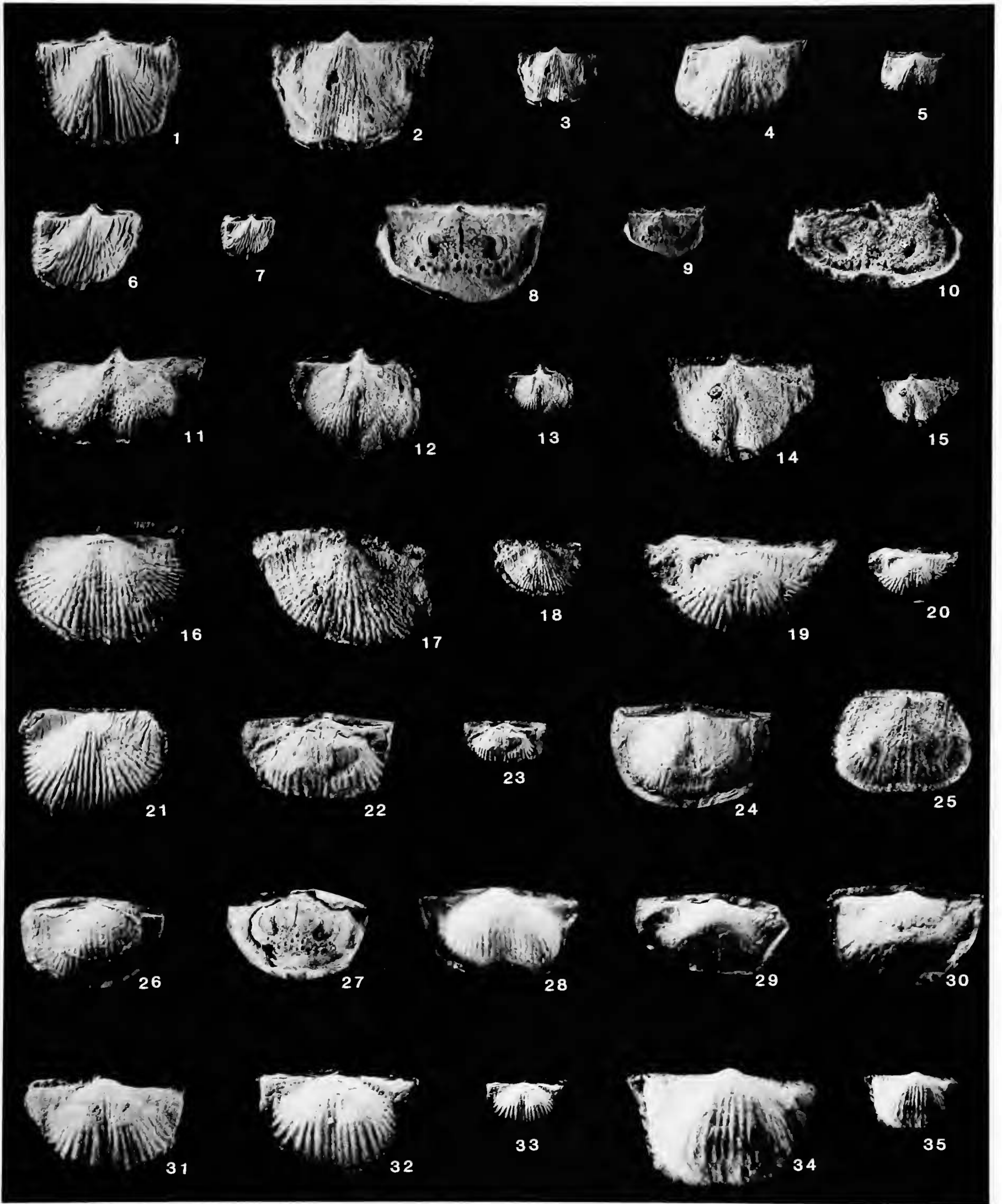
USNM	Surface length	Hinge length	Width	Midwidth
456027	9.3	12.3	12.4	10.9
456028	9.7	10.1	?	12.0
456030	8.4	8.8	9.0	8.4

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Longtan Formation: Meitian section, Yizhang County, Hunan Province. Upper Cuiplingshan to Lower Yanshi formations: Yanshi section, Longyan County, Fujian Province.

COMPARISON.—*Cathaysia spiriferoides*, new species, resembles *C. chonetoides* (Chao) in its size, numerous costellae,

FIGURE 18 (opposite page).—*Cathaysia*. 1–15, *Cathaysia spiriferoides*, new species: 1 (×2), ventral valve, USNM 456027a; 2, 3 (×2, ×1), ventral valve, USNM 456027b, both syntypes from section 23. 4, 5 (×2, ×1), ventral valve, USNM 456006f; 6, 7 (×2, ×1), ventral valve, USNM 456030; 8, 9 (×2, ×1), brachial interior molds, USNM 456006a; 10 (×2), brachial interior mold, USNM 456006b; 11 (×2), ventral valve, USNM 456006c; 12, 13 (×2, ×1), ventral valve, USNM 456006d; 14, 15 (×2, ×1), ventral valve, USNM 456006e, all syntypes, all from section 31. 16–35, *Cathaysia chonetoides* (Chao), all ventral valves except 25 and 27, which are brachial interior molds: 16 (×2), USNM 456027c; 17, 18 (×2, ×1), USNM 456027d; 21 (×2), USNM 456027e; all from section 23. 19, 20 (×2, ×1), USNM 456026, from section 27. 22, 23 (×2, ×1), USNM 456032, from section 26. 24 (×2), USNM 456034, from section 10. 25 (×1), USNM 456035, from section 15. 26 (×2), USNM 456037a; 27 (×2), USNM 456037b, both from section 27. 28 (×2), USNM 456036, from section 8. 29 (×2), USNM 456031b; 30 (×2), USNM 456031c; 31 (×2), USNM 456031a, all from section 26. 32, 33 (×2, ×1), USNM 456038, from section 31. 34, 35 (×3, ×1), USNM 456033, from section 6.





and spines at posterior margin; it differs in its alate cardinal extremities, erect and sharply pointed beak, triangular-shape sulcus, and strong central wrinkles. It is readily distinguishable from *C. sinuata* Chan by its shallow and triangular-shape sulcus, erect and sharply pointed beak, and acute cardinal extremities. It is easily discriminated from *C. orbicularis* Liao, owing to the latter's very small size, strongly convex pedicle valve, and weakly developed wrinkles.

ETYMOLOGY.—From the genus *spirifer* plus *-oides*, Greek for “looks like.”

### *Cathaysia orbicularis* Liao, 1980

FIGURE 19(1-21)

*Paryphella triquetra* Liao, 1979, pl. 1: fig. 18.—Liao in Zhao et al., 1981:53, 54, 84, pl. 8: figs. 18-22.

*Cathaysia orbicularis* Liao, 1980a:261, pl. 6: figs. 1-4.

DIAGNOSIS.—Small for genus, subtriangular in outline; strongly convex at visceral disc of pedicle valve; ears variable, usually large and strongly or moderately arched; beak slightly swollen, protruding over hinge line; cardinal extremities rectangular or slightly rounded; sulcus absent, very shallow, or a slight depression at middle part of pedicle valve, in several specimens forming small anterior fold including 2-3 costellae, slightly protuberant over lateral costellae; 2-3 spines at posterior margin at each side of beak.

MEASUREMENTS (mm).—Pedicle valve.

USNM	Surface length	Hinge length	Width	Midwidth
456041	3.2	4.2	6.8	4.8
456042	3.0	3.9	4.3	3.6
456043	2.8	3.2	3.1	3.8
456039	4.9	6.4	7.3	7.3
456040	4.3	5.7	5.8	5.5
456044	4.6	6.6	7.8?	6.3
456045	5.3	6.0	7.2	6.9

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation and lower member of Yinkeng Formation: Meishan section, Changxing County, Zhejiang Province. Lower Yinkeng Formation: Majiashan section, Chao County, Anhui Province. Lower Member of Daye Formation: Huaying-shan section, Linshui County, Sichuan Province.

COMPARISON.—*Cathaysia orbicularis* Liao obviously differs from *C. chonetoides* (Chao) in its small size, strongly convex visceral disc of pedicle valve, relatively coarse and few costellae. It is similar to juvenile individuals of *C. sinuata* Chan in its outline, variable ears, relatively coarse costellae, and small anterior fold on the pedicle valve, but it usually has no sulcus, even though sometimes it has a very shallow sulcus, rather strongly inflated pedicle valve, and a few costellae that are especially visible on adult individuals.

DISCUSSION.—*Paryphella triquetra* Liao, described as a new species in 1981, but also a nomen nudum in 1979, actually is no different from *C. orbicularis* Liao. Comparing both species, he said that *P. triquetra* has a very small shell, lower convexity,

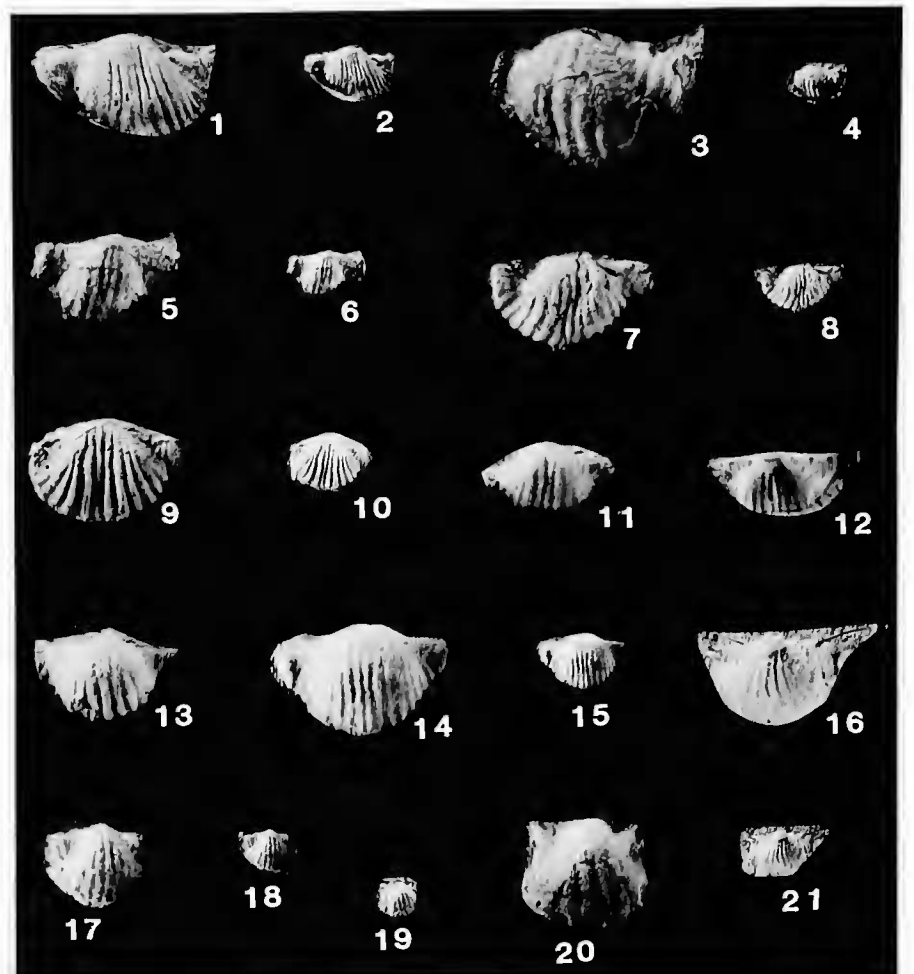


FIGURE 19.—*Cathaysia orbicularis* Liao, all ventral valves: 1, 2 ( $\times 2$ ,  $\times 1$ ), USNM 456042, from section 32. 3, 4 ( $\times 3.5$ ,  $\times 1$ ), USNM 456041a; 5, 6 ( $\times 2$ ,  $\times 1$ ), USNM 456039; 7, 8 ( $\times 2$ ,  $\times 1$ ), USNM 456041b; 11 ( $\times 2$ ), USNM 456040a; 16, 21 ( $\times 2$ ,  $\times 1$ ), USNM 456040b; 19, 20 ( $\times 1$ ,  $\times 3$ ), USNM 456043; all from section 27. 9, 10 ( $\times 2$ ,  $\times 1$ ), USNM 456046, from section 24. 12 ( $\times 2$ ), USNM 456048; 13 ( $\times 2$ ), USNM 456047, both from section 26. 14, 15 ( $\times 2$ ,  $\times 1$ ), USNM 456045; 17, 18 ( $\times 2$ ,  $\times 1$ ), USNM 456044, both from section 6.

triangular-shape outline except ears; whereas the species *C. orbicularis* has a strongly convex shell (semispheroidal) and many more costellae (Liao, 1981:53, 54). To judge by our collections and by the pictures (Liao, 1979, pl. 1: fig. 18; 1980a, pl. 6: figs. 1-4; Liao in Zhao et al., 1981, pl. 8: figs. 18-22) and tables comparing species (Liao, 1984:282) presented by Liao, the two species range in size and convexity along a continuous spectrum that renders it impossible to separate species on such ephemeral features. The number of costellae in “*Paryphella triquetra*” is about 10-15 by Liao's account, and in *Cathaysia orbicularis* it is about 14-17, measuring from Liao's pictures. Our collections indicate about 10-17. It seems reasonable to regard *Paryphella triquetra* as a synonym of *Cathaysia orbicularis* Liao.

### Superfamily RICHTHOFENIOIDEA Waagen, 1885

#### Richthofeniid, genus and species undetermined

FIGURE 20(1-8)

Small, crateriform or squat cone-shape; apex pointed in one specimen; posterior side evenly rounded, arched, or flattened

with a shallow furrow; interarea narrow and flat, occupying nearly entire length of pedicle valve; elytridium convex, narrow, occupying only  $\frac{1}{3}$  of interarea; surface irregularly wrinkled.

**STRATIGRAPHIC OCCURRENCE AND LOCALITY.**—Longdongchuan Formation: Xikou section, Zhenan County, Shaanxi Province.

**COMPARISON.**—These specimens from the Longdongchuan Formation of Shaanxi Province are somewhat similar to *Richthofenia sinensis* Waagen (1884:742, 743, pl. 82: fig. 4) from the middle division of Productus Limestone in the Salt Range, but the limited material does not permit us to judge that they are identical. They are externally comparable to specimens collected from Upper Permian of Loping, Jiangxi Province, identified as *Richthofenia lawrenciana* Koninck by Kayser (in Richthofen, 1883:195–198, pl. 24: figs. 4, 5); however, they differ in that *R. lawrenciana* has strong rugae and distinct spine-scars. These specimens are closely similar to the specimen of *Richthofenia guangdeensis* Liao (1984:280, pl. 1: figs. 21–23), but, owing to the fact that no trace of myocoelidium was found in these specimens, there is insufficient evidence to assign these specimens to the genus *Richthofenia*.

#### Order RHYNCHONELLIDA Kuhn, 1949

#### Superfamily WELLERELLOIDEA Xu and Liu, 1983

#### Family WELLERELLIDAE Likharev, 1956

#### Genus *Uncinunellina* Grabau, 1932

#### *Uncinunellina multicositifera* sp. nov.

FIGURES 21, 22(1–27)

Medium size for genus; biconvex; transversely subovate, widest anterior to midlength; hinge slightly curved; sides rounded; commissure strongly uniplicate; costae beginning slightly anterior to beaks, crests low and slightly angular, becoming flattened toward margins, each crest bearing slight groove; interlocking spines visible in well-preserved specimens; costae increasing by bifurcation.

Pedicle valve slightly inflated; beak small; geniculated in a dorsal direction, curving to form tongue with truncated or slightly curved anterior edge; sulcus shallow with flat or slightly round floor; 9–10 costae in sulcus, 12–14 costae on each side. Brachial valve strongly inflated, with short geniculation at anterior margin, low fold beginning at anterior  $\frac{1}{3}$ , crest flattened or slightly arched, sometimes slightly depressed, bearing 10–11 costae, anterior-lateral margin steeply declined toward ventral, with 12–15 costae.

Pedicle valve interior with stout teeth; dental plates short, subparallel but wide apart. Brachial valve interior with shallow dental socket, inner socket ridge proportionately high and strong; hinge plates thin and separated; crural bases attached at



FIGURE 20.—Richthofeniid, genus and species undetermined: 1–3, 6, posterior transverse section, ventral, and lateral views ( $\times 1$ ), USNM 456049; 4, 7, lateral and ventral views ( $\times 1$ ), USNM 456050; and 5, 8, ventral and lateral views ( $\times 1$ ), USNM 456051, all from section 32.

insides of hinge plates, crescent-shape.

**HOLOTYPE.**—USNM 456052.

**MEASUREMENTS (mm).**—

USNM	Pedicle valve		Brachial valve		Width	Thick-ness	Ratio (length to width)
	Length	Curved length	Length	Curved length			
456057	15.0?	25.5	13.8	15.0	21.1	12.0	0.71
456052	12.3	20.4	11.2	14.0	17.3	11.0	0.71
456053	12.0	19.3	10.5	13.3	16.5	10.0	0.73
456054	11.6	18.5	9.9	12.5	15.7	9.3	0.74
456055	10.9?	20.3	10.9	11.3	16.7	11.1	0.65
456056	10.5	13.1		15.6	14.9	9.8	0.70

**STRATIGRAPHIC OCCURRENCES AND LOCALITIES.**—Changxing Formation: Huayingshan section, Linshui County, Sichuan Province; Beifengjing section, Zhongqing City; Beipei section, Zhongqing City, Sichuan Province; Shatian section, Huangshi City, Hubei Province; Huangzhishan section, Wuxing County, Zhejiang Province.

**DIAGNOSIS.**—Transverse subovate outline; 9–10 costae in sulcus, more than 12 costae at each side, costate beginning near each beak.

**COMPARISON.**—The new species is similar to *U. theobaldi* Waagen (1883:425–427, pl. 34: fig. 1; Grant, 1976, pl. 48: figs. 1–9) in outline and occurrence of multiple costae at the sides; it is different in that its costae begin on or near the beaks, and

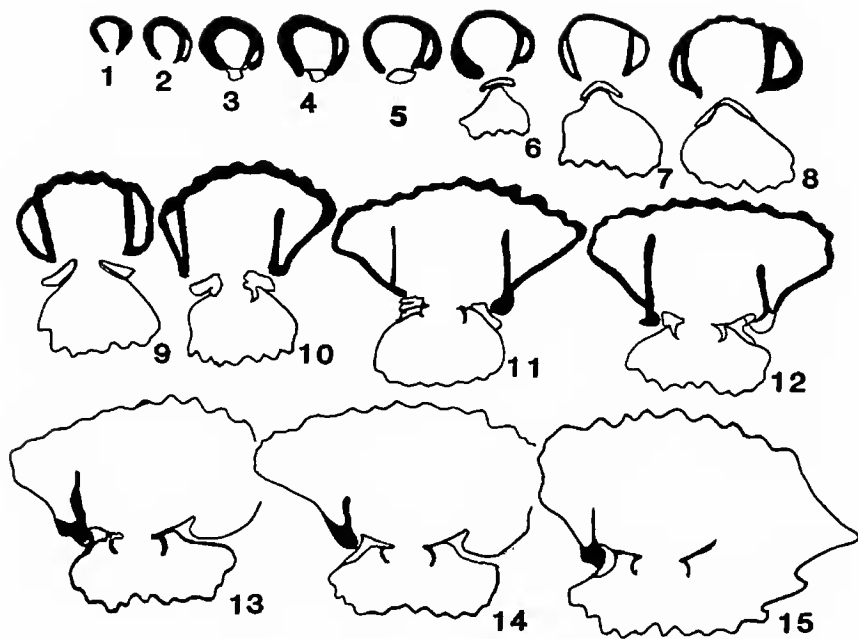


FIGURE 21.—Serial sections of *Uncinunellina multicostifera*, new species, showing the internal features.

there are more costae in the sulcus than on the fold. It differs from *U. mitigata* Grant (1976:179, 180, pl. 48: figs. 10–17) in its rather transverse outline, low fold, and costae beginning near the beaks. Internally, the dental plates of the new species are not fused to the valve wall, and the crural bases are crescentic. *Uncinunellina mongolicus* (Grabau, 1931:209–211, pl. 5: figs. 7, 8, pl. 6: figs. 3, 4) also has the costae beginning near the beaks, but this species is very small and subcircular, slightly transverse in outline, and its costae express the pattern of ten-seven-ten, or twenty-seven plications in all. The new species resembles *U. wangenheimi* (Pander) from the Maping limestone of Nantan, in Guizhou (Kweichow) Province, China, which was characterized by Grabau (1936:175–178, pl. 18: figs. 1, 2) as having multiple costae and costae beginning near the beaks. That species, however, is large (shell length 16–19 mm) and slightly narrower than the new species, and its ratio of shell length to width is ~0.81–0.83, which is much higher than the new species. Furthermore, Grabau (1936:178) recorded “two well-developed dental plates, somewhat converging toward the bottom of the valve,” which obviously differs from the new species. Liao and Meng (1986:81, pl. 4: figs. 22–26) described *U. tenuis*, which has 9 costae in the sulcus and 10–11 costae on the sides and seemingly resembles the new species, but that species is small, with a thin coelomic cavity and simple costate (no bifurcations).

DISCUSSION.—Grant (1976:178) was the first to exhaustively investigate the structure of the genotype species, *Uncinulus theobaldi* Waagen, which proved *Uncinunellina* is an available genus. Internal features of specimens from South China, which are revealed in the serial sections, are consistent with specimens of the Salt Range. Wang et al. (1966), referring to *Uncinunellina*, wrote that the “median septum [is] straight and long” in the dorsal interior, but specimens of *U. theobaldi* from the Salt Range and *U. multicostifera*, the new species

from South China, have not verified this feature. We did find, however, a low ridge in a specimen of the new species, which suggests that the genus had a median ridge whose presence depended upon the separation of the muscle scars.

Waagen (1883:425) recorded the presence of “very fine ribs which commence not very far from the apex of the valve” in the description of *U. theobaldi*, and this character was considered a proper feature of the genus by Grabau (1932:100), who wrote that “the plications ... may become obsolete in the earlier part of the shell.” As Grant pointed out, the costae can be used to divide the genus into two groups: (1) species whose costae begin in the umbonal region, such as, *U. theobaldi*, *U. mitigata*, and *U. jabiensis*; and (2) those whose costae begin near the beaks, such as, *U. mongolicus*, *U. wangenheimi*, *U. darwasica*, and *U. multicostifera*, new species. Comparison of the internal structures of these two groups shows them to be quite comparable to each other, and externally, no radical feature separates them realistically into different genera.

ETYMOLOGY.—From the Latin, *multi*, meaning many, *costi*, meaning ribs, and *fera*, meaning bearing.

#### Family PONTISIIDAE Cooper and Grant, 1976

#### Subfamily LISSORHYNCHINAE Xu and Liu, 1983

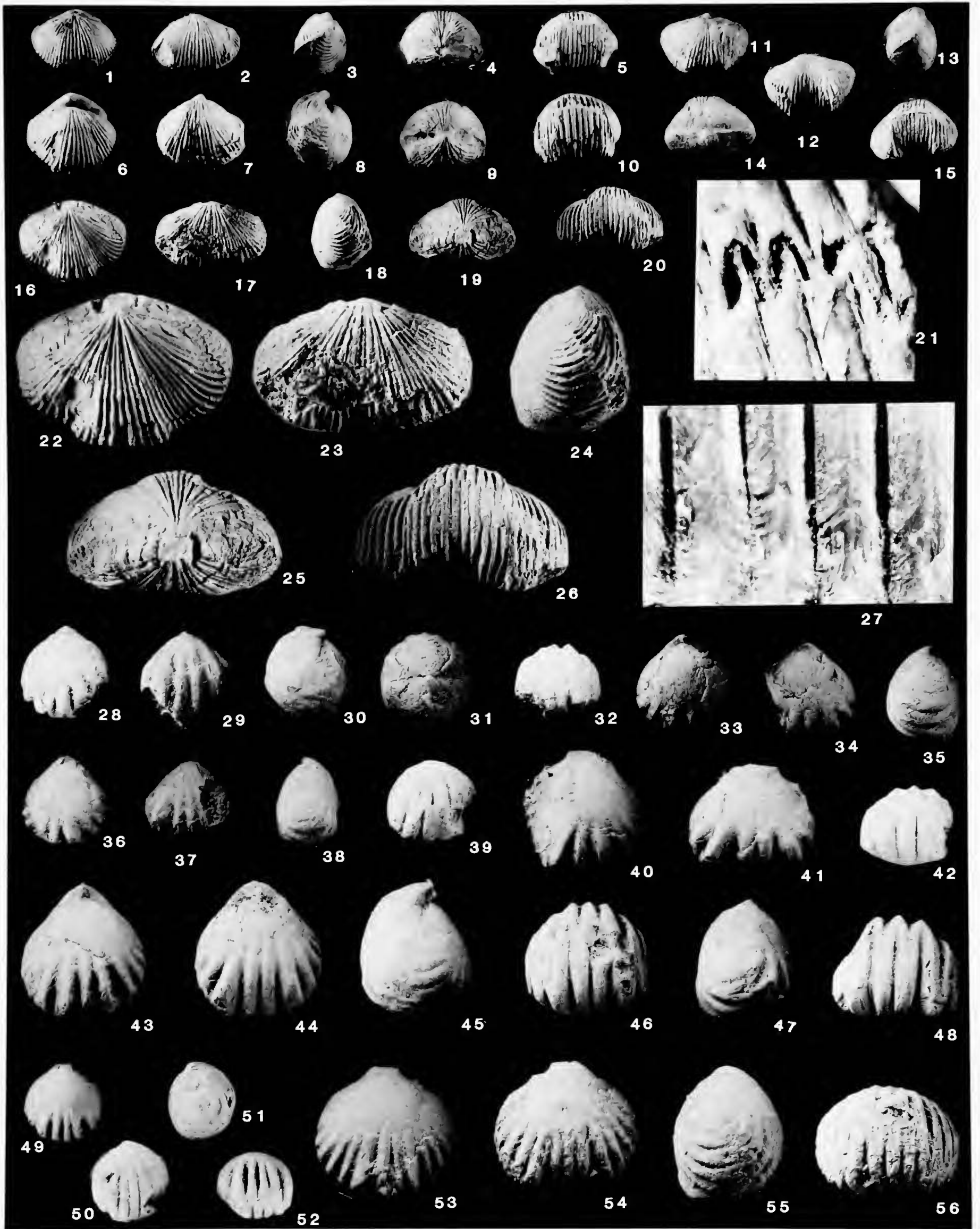
#### *Prelissorhynchia* gen. nov.

Small, subtriangular to subcircular; unequally biconvex, brachial valve more convex; pedicle beak suberect or slightly incurved; delthyrium opened or covered by short deltidial plates; anterior commissure strongly uniplicate; costae beginning at anterior  $\frac{1}{3}$  or at midlength.

Pedicle valve interior with large, knob-like teeth; dental plates strong and subparallel extended. Brachial valve interior with undivided hinge plate, but hinge plates separating socket ridges and crural bases, inner hinge plates forming arched bridge; sockets shallow, socket ridges low; crura crescentic; median septum absent.

DIAGNOSIS.—Small semicostate, strongly uniplicate with deep indentation at anterior commissure; interior with subparallel dental plates and undivided arched hinge plate.

FIGURE 22 (opposite page).—1–27, *Uncinunellina multicostifera*, new species: 1–5, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), from section 8, USNM 456053; 6–10, idem ( $\times 1$ ), USNM 456058; 11–15, idem ( $\times 1$ ), USNM 456057, all from section 6. 16–20, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), 22–26, idem ( $\times 2$ ), and 21, 27 ( $\times 20.8$ ), showing interlocking spines, USNM 456052, holotype, from section 27. 28–48, *Prelissorhynchia pseudoutah* (Huang): 28, 29, and 32, dorsal, ventral, and anterior views, USNM 456059; 30, 31, lateral and anterior views, USNM 456060; 33, 34, 35, and 42, dorsal, ventral, lateral, and anterior views, USNM 456065; 36–39, idem, USNM 456064a; 40, 41, 47, and 48, idem, USNM 456063; 43–46, idem, USNM 456064b; all  $\times 3$ , from section 9. 49–56, *Prelissorhynchia triplicatioid*, new species: 49–52, dorsal, ventral, lateral, and anterior views ( $\times 2$ ), USNM 456062, paratype, from section 9; 53–56, idem ( $\times 3$ ), USNM 456061, holotype, from section 6.



COMPARISON.—Internally, members of the new genus resemble *Pontisia* Cooper and Grant (1969:13; 1976a:2019) and *Lissorhynchia* Yang and Xu (1966:14, 94). *Pontisia* is triangular, somewhat less strongly inflated, its costae begin near the beaks, and it has an elongate-oval foramen. *Lissorhynchia* is parasulcate and has few plications near the anterior margin. The new genus has relatively long, crescentic crura but lacks median ridges in either valve; these may be the main bases for discrimination of this new genus.

TYPE SPECIES.—*Pugnax pseudoutah* Huang (1933:64–66, pl. 10: figs. 1–8).

ETYMOLOGY.—From the Latin, *pre*, meaning before; hence, before *Lissorhynchia*. The name is feminine.

*Prelissorhynchia pseudoutah* (Huang, 1933),  
new combination

FIGURES 22(28–48), 23

*Pugnax pseudoutah* Huang, 1933:64–66, pl. 10: figs. 1–8.—Wang, 1955b:134, pl. 73: figs. 13–16.—Wang et al., 1964:396, 397, pl. 66: figs. 12–15.—Hou et al., 1979:95, pl. 13: figs. 21, 22.

*Neowellerella pseudoutah* (Huang).—Liao, 1980a, pl. 7: figs. 38, 39.

*Lissorhynchia pseudoutah* (Huang).—Xu in Z.Y. Yang et al., 1987:229, pl. 13: figs. 15, 16, pl. 14: figs. 10, 12.

DIAGNOSIS.—Small, subtriangular to subcircular, semi-costate; sulcus and fold commencing from somewhat anterior to midlength; 2 costae in sulcus and 3 on fold, 2–3 costae each lateral side.

MEASUREMENTS (mm).—

USNM	Pedicule valve		Brachial valve		Width	Thickness
	Length	Curved length	Length	Curved length		
456064	9.2	12.0	7.0	7.9	8.7	7.8
456063	8.1	11.9	6.9	7.4	8.1	6.6
456059	7.9	11.3	7.1	7.6	7.0	6.7
456065	6.5	7.8	4.4	5.9	6.3	4.5
456060	6.3	9.0	5.4	6.5	6.0	4.8

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation: Yutangjiao section, Jijiang section, Nantong County, Sichuan Province; Beipei section, Zhongqing City, Sichuan Province.

DISCUSSION.—The description of internal features of the genus is based on specimens of *P. pseudoutah* from South China. These internal features clearly show that *P. pseudoutah* is not subordinate to *Pugnax*, which has separated hinge plates and crura supported by crural plates. Liao (1980a) regarded this species to be a member of the genus *Neowellerella* Dagys, a junior synonym of *Lissorhynchia* Yang and Xu. Xu and Liu (in Z.Y. Yang et al., 1987) concurred with the placement of *P. pseudoutah* in *Neowellerella*. Careful study, however, has found essentially the same distinctions mentioned in the "Comparison" section of the genus description, so it is reasonable to establish a new genus.

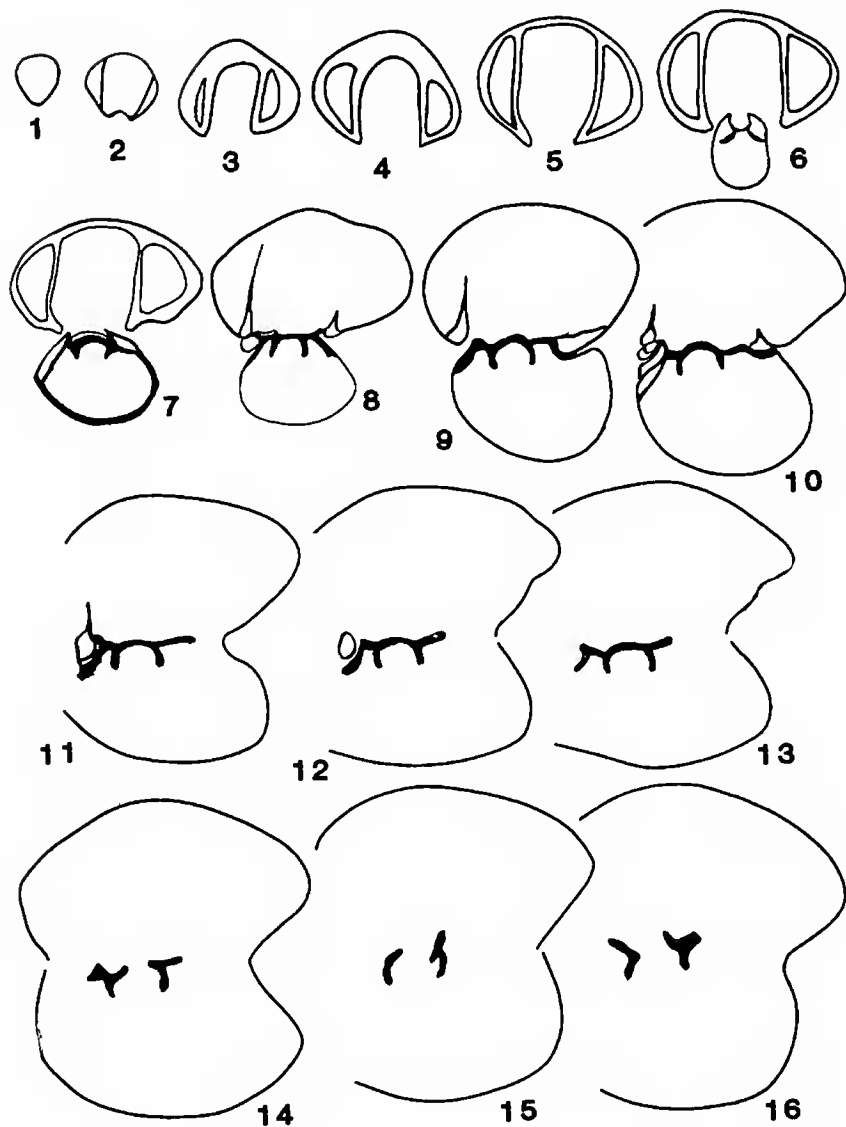


FIGURE 23.—Serial sections of *Prelissorhynchia pseudoutah* (Huang) showing internal features.

*Prelissorhynchia triplicatioid* sp. nov

FIGURES 22(49–56), 24

Small size, unequally biconvex to subequally biconvex; subcircular or subglobular in outline; anterior commissure strongly uniplicate with sharp zigzag; surface semicostae beginning somewhat anterior to midvalves, crest of each costa slightly rounded, but subangular on fold, 4 costae on fold, 3 in sulcus, and 3–6 on flanks.

Pedicule valve gently convex with roundly turned-up tongue; sulcus originating somewhat anterior to midlength, shallow and moderately broad with reverse-trapezoid shape in transverse profile; beak suberect but often not preserved. Brachial valve strongly inflated with steeply turned-down lateral sides, fold low, only bare anterior edge dominated over flanks, with a short, roundly bent edge.

Pedicule valve interior with stout, knob-like teeth; dental plates subparallel. Brachial valve interior with shallow socket, inner-socket ridges low; hinge plate undivided, outer hinge plates proportionately wider, inner hinge plate arched; crura

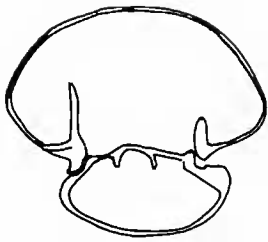


FIGURE 24.—A thin section of *Prelissorhynchia triplicatioid*, new species, showing the internal features.

crescent-shape.

HOLOTYPE.—USNM 456061.

MEASUREMENTS (mm).—

USNM	Pedicule valve		Brachial valve		Width	Thick-ness
	Length	Curved length	Length	Curved length		
456061	9.3	13.4	8.7	10.5	9.2	7.2
456063	7.5	7.8	6.4	7.2	7.3	6.5

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Lower Changxing Formation: Huayingshan section, Linshui County and Yutangjiao section, Nantong County, Sichuan Province.

DIAGNOSIS.—Small, subcircular in outline, semicostate, 3 costae in sulcus, 4 on fold, and 3–6 on flanks.

COMPARISON.—*Prelissorhynchia triplicatioid*, new species, resembles *P. pseudoutah* in almost all internal features and in most external features, such as semicostae, low fold, sulcus beginning somewhat anterior to midvalve, and strongly uniplicate anterior commissure; it differs in its subcircular outline and more costae. “*Wellerella*” *dorashamensis* Sokolskaya (1965:233, pl. 40: fig. 7) is externally similar to *P. triplicatioid*, but it has a flat undivided hinge plate with crural bases attaching at the sides of the hinge plate (Sokolskaya, 1965, text-fig. 37). Another species, “*Neowellerella*” *triplicata* Liao (1980a), with 3 costae in the sulcus, appears to be comparable to the new species, but this South China species has costae commencing from the “anterior of apex of shell” and has a “flat hinge plate” (Liao, 1980a:263, 264, pl. 8: figs. 18–20); such features obviously differ from the new species.

ETYMOLOGY.—From the Latin, *tri* meaning three, *plica* meaning fold, and *oid* meaning like, similar.

#### Superfamily STENOSCISMATOIDEA Oehlert, 1887 (1883)

##### Family ATRIBONIIDAE Grant, 1965

##### Subfamily ATRIBONIINAE Grant, 1965

##### Genus *Cyrolexis* Grant, 1965

##### *Cyrolexis antearcus* sp. nov.

FIGURES 25, 26(1–20)

Small, moderately biconvex, subcircular or transversely subovate; thickest near anterior margin; commissure strongly

uniplicate; semicostate, costae high and sharp at anterior margin, numbering 2–3 on fold, 1–2 in sulcus, and 2–4 at each side.

Pedicule valve slightly or moderately convex in lateral profile, anterior profile flattened or gently arched; beak short, suberect, sharply pointed; sulcus originating from midvalve, widening forward, tongue bent upward, anterior edge truncated. Brachial valve moderately or strongly convex, fold elevated over flanks.

Pedicule valve interior with small hinge teeth; dental plates thin, converging to form deep spondylium, supported by low septum duplex, sessile in extreme apex, spondylium extending anteriorly about  $\frac{1}{3}$  valve length. Brachial valve interior with knob-like cardinal process, becoming comb-like at top of hinge plate; hinge plate undivided, outer hinge plates flat and relatively wide, inner hinge plate narrow, slightly arched; camarophorium beginning in apex, extending about  $\frac{1}{4}$  valve length, supported by high median septum duplex, fairly small and narrow, its lateral edges directly connected to crura that attach between inner and outer hinge plates; intercamarophorial plate short but visible near beak.

SYNTYPES.—USNM 456066, 456067.

MEASUREMENTS (mm).—

USNM	Pedicule valve		Brachial valve		Width	Thick-ness
	Length	Curved length	Length	Curved length		
456065	9.3	15.5	8.3	11.0	8.7	7.9
456066	7.4	11.3	6.2	6.5	8.0	4.8
456067	6.8?	9.6?	6.5	6.8	8.4	5.2

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation: Huangzhishan section, Wuxing County, Zhejiang Province; Yutangjiao section, Nantong County, Hunan Province; Huayingshan section, Linshui county, Sichuan Province.

DIAGNOSIS.—Small, maximum thickness near anterior edge; strongly uniplicate anterior commissure; usually 2–3 costae on fold and each flank.

COMPARISON.—*Cyrolexis antearcus*, new species, resembles *C. beccojectus* (see below) in its semicostae and suberect and pointed beak; it differs in its high and sharp costae, only 1–2 costae in the sulcus, and rather obviously elevated fold. It is readily distinguishable from *C. haquei* Grant (1965:91–95, pl. 6: fig. 1–5) in its stronger costae, rather wide sulcus, and small camarophorium.

ETYMOLOGY.—From the Latin, *ante*, meaning before, and *arcus*, meaning curve.

##### *Cyrolexis beccojectus* sp. nov.

FIGURE 27(1–12)

Small, strongly or moderately biconvex; outline subglobular, young individuals subtriangular, shell thick in umbonal region; anterior commissure uniplicate; costae low, originating at

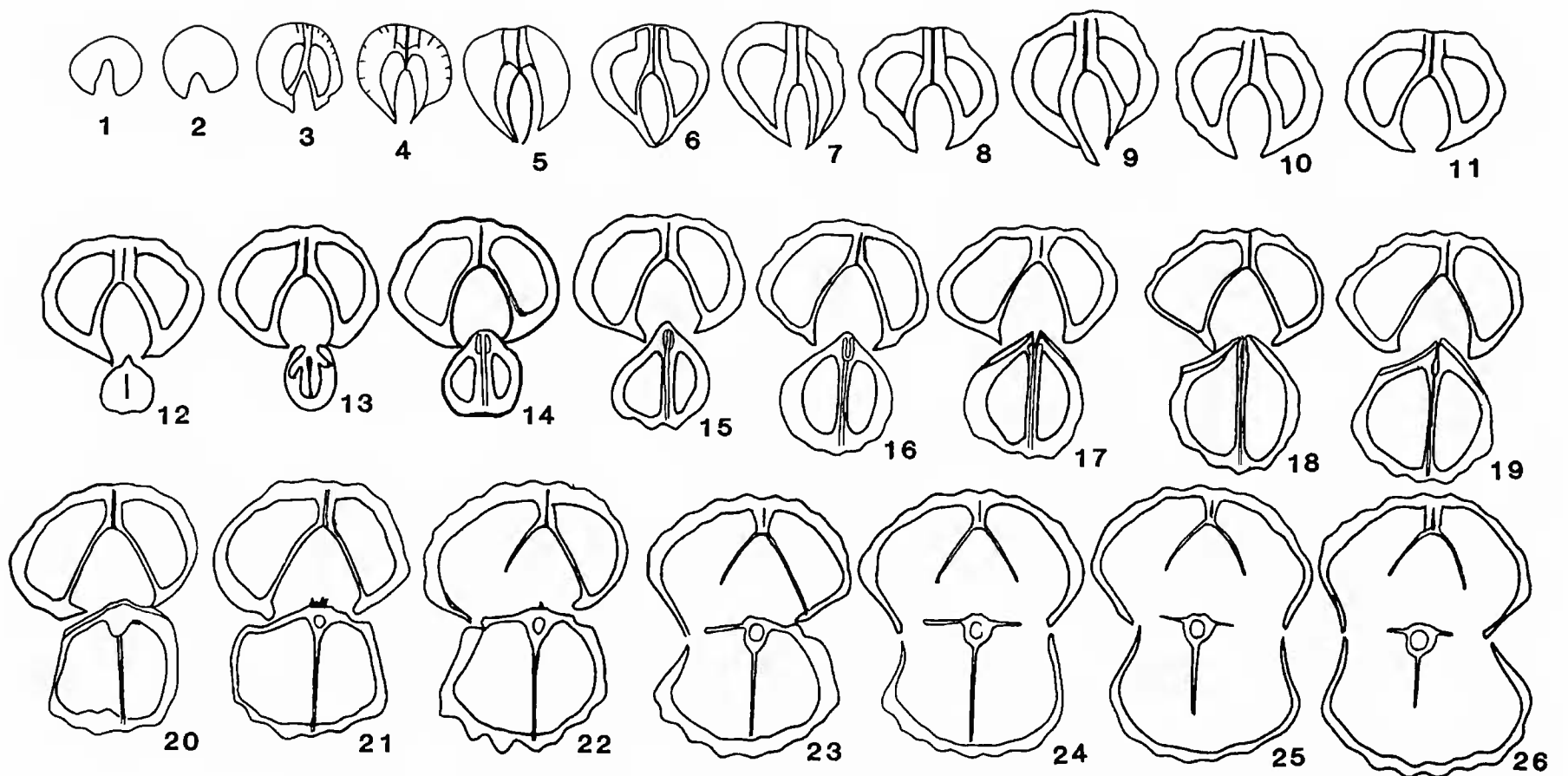


FIGURE 25.—Serial sections of *Cyrolexis antearcus*, new species, showing interior features.

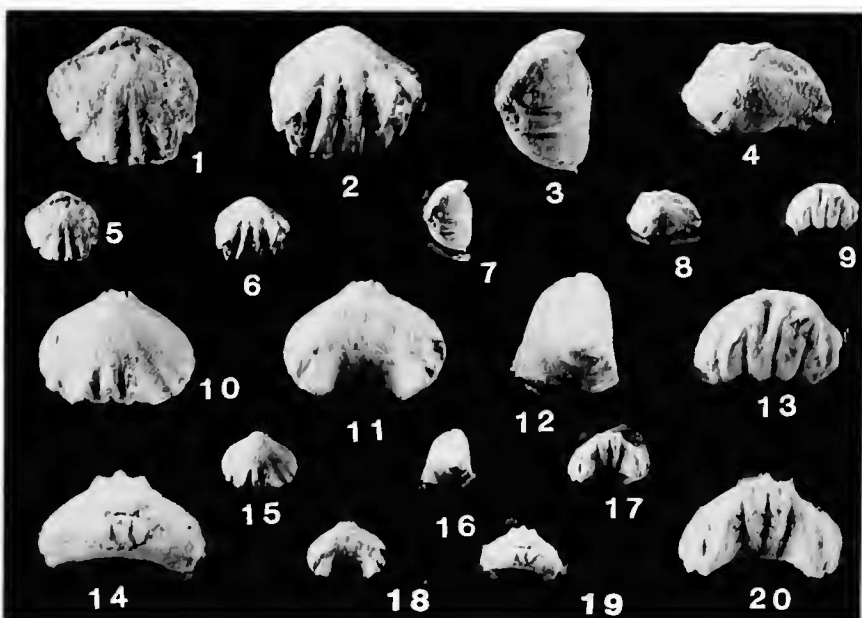


FIGURE 26.—*Cyrolexis antearcus*, new species: 1-4, 13 ( $\times 2$ ) and 5-9 ( $\times 1$ ), dorsal, ventral, lateral, posterior, and anterior views, from section 27, USNM 456066, syntype; 10-12, 14, 20 ( $\times 2$ ) and 15-19 ( $\times 1$ ), idem, from section 6, USNM 456067, syntype. (Reduced to 97 $\frac{1}{2}$ % for publication.)

midvalve, crests rounded at origin, becoming sharp toward anterior, numbering 4-5 on fold, 3-4 in sulcus, and 4-5 on each flank; no stolidium preserved.

Pedicle valve moderately convex; beak small, pointed, suberect; delthyrium opened; sulcus beginning near midlength,

shallow, about  $\frac{1}{3}$  shell width, forming tongue roundly bent dorsally. Brachial valve more strongly convex; beak small, incurved; fold low, beginning at midvalve, elevated over flanks near anterior margin, anterior flanks turned down steeply.

Pedicle valve interior with deep spondylium.

HOLOTYPE.—USNM 456142.

MEASUREMENTS (mm).—

USNM	Pedicle valve		Brachial valve		Width	Thick- ness
	Length	Curved length	Length	Curved length		
456142	9.5	16.7	7.9	11.5	10.4	9.4
456143	7.8	12.6	7.5	10.2	8.1	6.8
456144	7.8	9.5	6.6	8.4	6.2	4.2

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation: Huangzhishan section, Wuxing County, Zhejiang Province. Longdongchuan Formation: Xikou section, Zhenan County, Shaanxi Province.

DIAGNOSIS.—Small, subglobular; uniplicate anterior commissure; beak small and suberect; usually 4-5 costae on fold and each flank.

COMPARISON.—*Cyrolexis beccojectus*, new species, is similar to *C. haquei* Grant (1965:91-95, pl. 6: figs. 1-5) from the Salt Range in most interior and exterior features. They differ in that the new species is wider in juvenile stages and thicker in mature stages, has more costae, and has a smaller camaro-



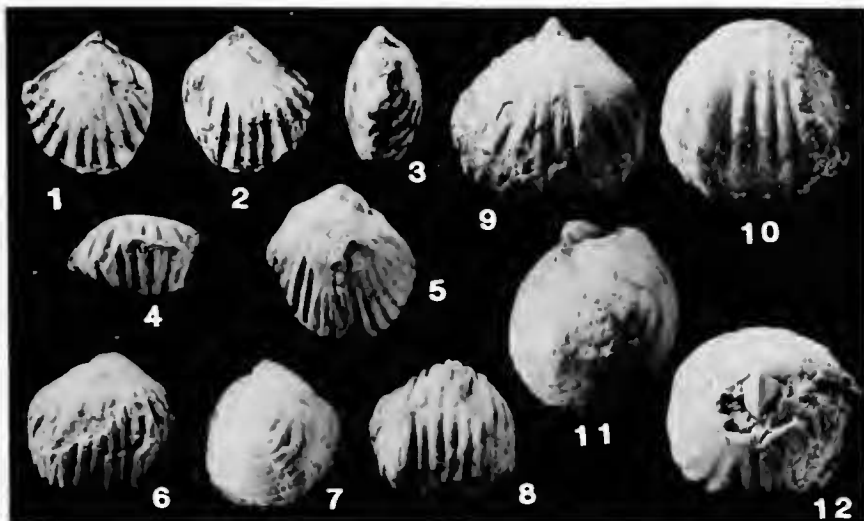


FIGURE 27.—*Cyrolexis beccojectus*, new species: 1-4, dorsal, ventral, lateral, and anterior views ( $\times 2$ ), USNM 456143; 5-8, idem ( $\times 2$ ), USNM 456144, both from section 32. 9-12, dorsal, ventral, lateral, and posterior views ( $\times 2$ ), from section 27, USNM 456142, holotype. (Reduced to 97 $\frac{1}{2}$ % for publication.)

phorium. It resembles *C. ussuricum* (Maslennikov) (Koczyrkevich, 1979:57-59, pl. 13: figs. 3-20) in such respects as small size, greatest width and thickness near midlength, sulcus shallow and beginning near midlength, and big U-shape spondylium, but *C. ussuricum* usually is more elongate with costae originating somewhat anterior to midvalve, and internally it has a deeper hinge socket and lower septum duplex.

ETYMOLOGY.—From the Latin, *becco*, meaning beak, and *jectus*, meaning cast down (referring to the curved beak).

#### Order SPIRIFERIDA Waagen, 1883

#### Suborder SPIRIFERIDINA Waagen, 1883

#### Superfamily SPIRIFEROIDEA King, 1846

#### Family SPIRIFERIDAE King, 1846

#### Subfamily NEOSPIRIFERINAE Waterhouse, 1968

#### Genus *Cartorhium* Cooper and Grant, 1976

#### *Cartorhium xikouensis* sp. nov.

FIGURES 28, 29(1-8)

Small size for genus; moderately biconvex; subcircular in outline, widest near midlength, hinge line short, extremities rounded; commissure uniplicate; costae arranged in fascicles without plication of shell, asymmetrical bifurcation, numbering about 2 or 3 bifurcations per fascicle, total numbering about 20-27 per valve; concentric growth laminae weak, irregularly spaced.

Pedicle valve with maximum convexity about half way between beak and midvalve; beak moderately curved; interarea triangular, relatively small, curved sharply near beak but

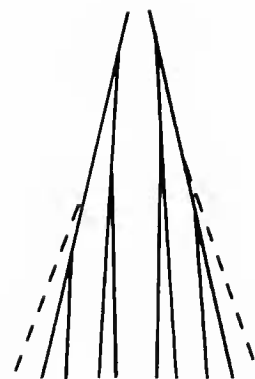


FIGURE 28.—The costellar formula for the sulcus of *Cartorhium xikouensis*, new species, is shown; dashed lines represent lateral branches out of the sulcus.

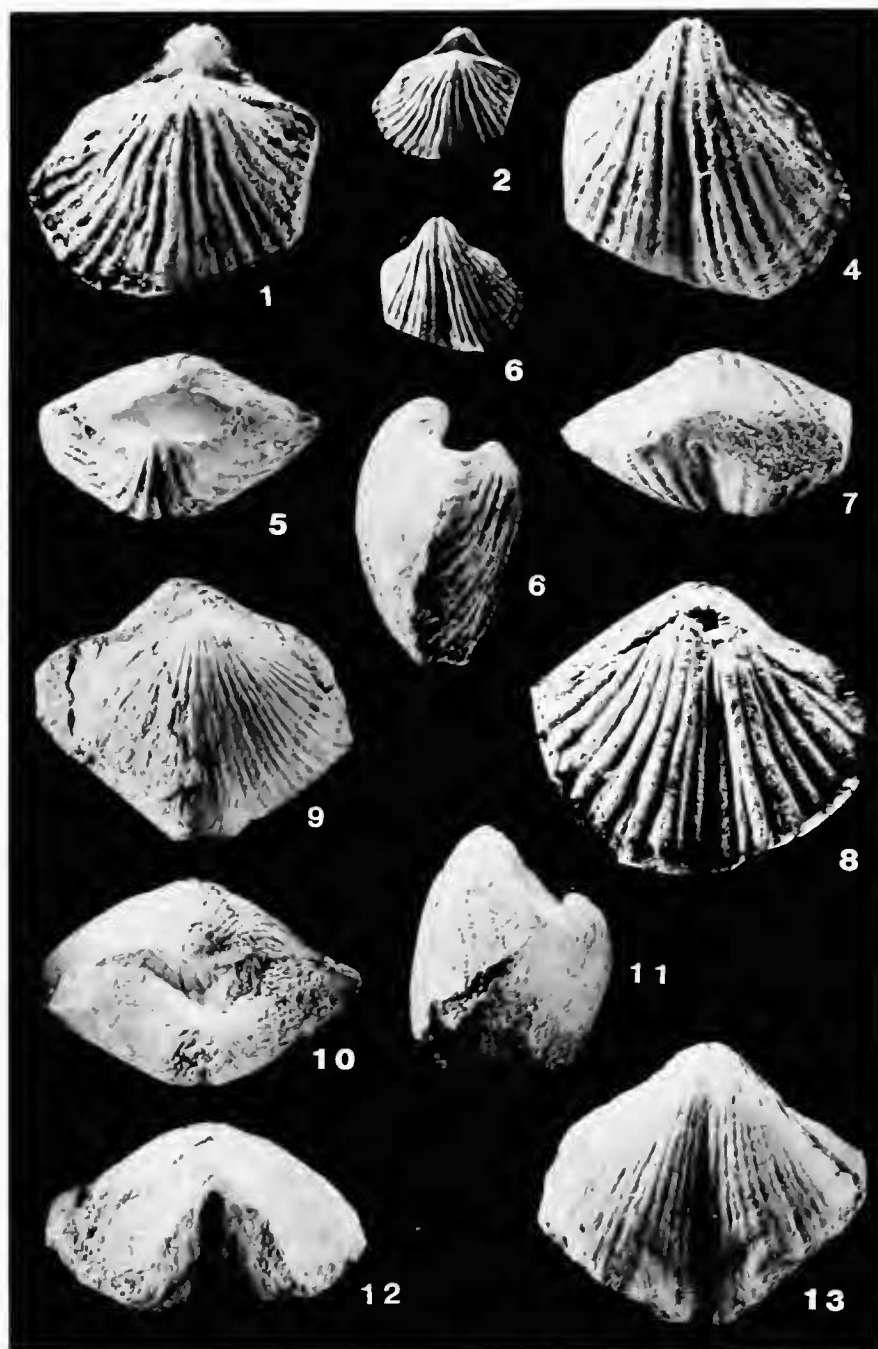


FIGURE 29.—*Cartorhium* Cooper and Grant. 1-8, *Cartorhium xikouensis*, new species: 1, 4-7, dorsal, ventral, posterior, lateral, and anterior views ( $\times 2$ ); 2, 3, dorsal and ventral views ( $\times 1$ ), from section 32, USNM 456145, holotype. 8, ventral view ( $\times 2$ ), from section 15, USNM 456146. 9-13, *Cartorhium twifurcifer*, new species: dorsal, posterior, lateral, anterior, and ventral views ( $\times 1$ ), from section 32, USNM 456147, holotype.

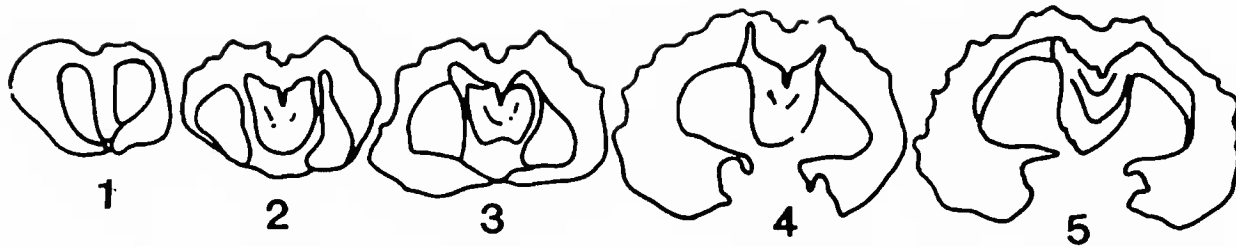


FIGURE 30.—Serial sections of *Cartorhium twifurcifer*, new species, showing the internal features of the pedicle valve.

flattened anteriorly; delthyrium proportionately large, open; sulcus shallow, bisected by median groove, bounded by original costa beginning from beak on each side, bifurcated asymmetrically forward, forming fascicle. Brachial valve less strongly convex; beak suberect; fold low, an original costa beginning from beak extending along fastigium, forming fascicle forward having 5 costae at anterior margin. Internal features unknown.

HOLOTYPE.—USNM 456145.

MEASUREMENTS (mm).—

USNM	Pedicle valve		Brachial valve		Hinge width	Thickness	
	Length	Curved length	Length	Curved length			
456145	14.5	20.2	17.1	18.2	9.7	15.5?	8.6

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Longdongchuan Formation: Xikou section, Zhenan County, Shaanxi Province. Paoshui Formation: Paoshui section, Laibin County, Guangxi Province.

DIAGNOSIS.—Small *Cartorhium*, low fold has one fascicle, shallow sulcus has two fascicles.

COMPARISON.—*Cartorhium xikouensis*, new species, differs from West Texas species described by Cooper and Grant (1976a) by its small size and subcircular outline, but it somewhat resembles juveniles of some species, for instance, *C. latum* (R.E. King), *C. chelomatium* Cooper and Grant, *C. retusum* Cooper and Grant, and *C. orbiculatum* Cooper and Grant. *Cartorhium latum* (Cooper and Grant, 1976a:2195–2197, pl. 615: figs. 1–33, pl. 616: figs. 1–23, pl. 624: figs. 1–10) has a rounded outline and low fold, so that the new species is similar to juveniles of that species, but *C. xikouensis* juveniles have somewhat thicker costae or low plications and only a few incipient bifurcations on the lateral slopes. *Cartorhium retusum* (Cooper and Grant, 1976a:2200, 2201, pl. 617: figs. 21–26, pl. 618: figs. 1–29), *C. chelomatium* (Cooper and Grant, 1976:2192, 2193, pl. 613: figs. 1–35), and *C. orbiculatum* (Cooper and Grant, 1976:2198–2200, pl. 617: figs. 1–20) all have transverse outlines and rather coarse costae in juveniles; thus, they are readily distinguishable from the new species.

ETYMOLOGY.—From the Latin suffix, *-ensis*, meaning occurring at the Xikou section.

### *Cartorhium twifurcifer* sp. nov.

FIGURES 29(9–13), 30, 31

Medium size, strongly biconvex; transversely subelliptical in outline, hinge line shorter than greatest width, near midlength; anterior commissure uniplicate, not plicated laterally, weakly emarginate; costae fine, asymmetrical bifurcation, poorly fasciculate, total numbering about 46–52 per valve, most bifurcation in posterior area; growth laminae irregularly spaced, especially near anterior margin.

Pedicle valve with strongly convex, semipyramidal shape; beak suberect; interarea triangular, moderately long, slightly curved, apsacline but almost catacline; delthyrium proportionately large, open; sulcus roundly V-shape, forming broad tongue gently bent dorsally, median groove beginning from beak. Brachial valve somewhat less strongly convex; beak slightly incurved; fold rounded, prominent near anterior commissure, no definite boundary at posterior part.

Pedicle valve interior with short apical plates, almost parallel to one another, limited at beak area; median ridge fine, filling callosity between apical plates in apical cone, forming strong pseudoseptum; posterior part of valve thickened. Brachial valve interior features unknown.

HOLOTYPE.—USNM 456147.

MEASUREMENTS (mm).—

USNM	Pedicle valve		Brachial valve		Hinge width	Mid-length width	Thickness
	Length	Curved length	Length	Curved length			
456147	29.3	38.2	23.4	28.8	26.9?	35.0?	20.1

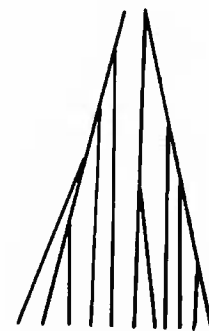


FIGURE 31.—A diagram showing the costellar formula in the sulcus of *Cartorhium twifurcifer*, new species.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Longdongchuan Formation: Xikou section, Zhenan County, Shaanxi Province.

DIAGNOSIS.—Transversely subelliptical *Cartorhium* with high, near catacline interarea and broad, anterior tongue of sulcus large.

COMPARISON.—*Cartorhium twifurcifer*, new species, is similar to *Semibrachythyris fasciculatus* Yang (in Yang et al., 1962:104, 105, pl. 42: figs. 8–10) in that both have fasciculate costae that begin at the posterior and range about the same in number, but the new species has short apical plates in the pedicle valve, a relatively short hinge, and a prominent fold and sulcus. Those differences are the reasons to put the new species into *Cartorhium*. *Semibrachythyris anshuensis* Liao (1980a:264, pl. 7: figs. 29–34) and *S. ziyunensis* Feng (in Feng and Jiang, 1978:287, 288, pl. 103: figs. 2a–e) resemble the new species somewhat in ornamentation, but both of them have low or narrow interareas, a low acute angle between the interarea and commissural plane, and no apical plates. *Spirifer mahaensis* Huang (1933:41–43, pl. 6: figs. 1–3) has a high and near catacline interarea, but the relatively wide hinge and median costa in the sulcus make it easy to distinguish from the new species.

ETYMOLOGY.—Latinized from Anglo-Saxon, *twi*, meaning two, and from the Latin, *furcifer*, meaning fork-bearing.

### Superfamily CYRTIOIDEA Frederiks, 1924

#### Family AMBOCOELIIDAE George, 1931

#### Genus *Crurithyris* George, 1931

#### *Crurithyris pusilla* Chan, 1979

FIGURES 32, 34(1–47, 52)

*Crurithyris pusilla* Chan in Hou et al., 1979:96, 97, pl. 13: figs. 24–26.

*Paracrurithyris pigmaea* (Liao), 1979:202, pl. 1: figs. 4–7.—Liao in Zhao et al., 1981:54, pl. 8: fig. 6.

*Crurithyris pigmaea* Liao, 1980a:264, pl. 8: figs. 1–4.

Medium size for genus, nearly planoconvex; outline nearly subelliptical to semielliptical, usually transverse, greatest width near midlength; narrow sulcus on pedicle valve, very shallow or undeveloped, but brachial valve without fold, anterior margin broadly rounded, anterior commissure rectimarginate; surface of most specimens smooth with a few fine growth lines, well-preserved specimens with regular concentric laminae closely spaced; minute bumps over surface considered scars of broken spines.

Pedicle valve strongly convex, semipyramidal; beak short, pointed or slightly swollen, slightly incurved; interarea moderately high, flatly concave; delthyrium narrowly triangular, open, lateral flanges low. Brachial valve slightly convex at posterior, flatter at anterior; beak small, notothyrium rather low and relatively narrowly triangular.

Pedicle valve interior with pedicle collar or vestigial delthyrium plates near apex of delthyrial cavity; hinge teeth knob-like, sturdy, dental ridges proportionately low and short, decreasing in thickness toward anterior; muscle scars elongate, visible when shell decorticated.

Brachial valve interior with shallow dental sockets with obscured socket ridges; cardinal process tuberculate, between socket walls; complete hinge plate thin, short; crura rod-like, crural plates thin, reaching to floor, nearly parallel, only slightly divergent, extending  $\frac{1}{3}$  of length of shell, strongly divergent rising from floor toward inside; spiralia flattened, ribbon-like, including 6 loops on each side, axes of coiling directed slightly obliquely posteriorly toward point of greatest shell width; elongated diductor scars between crural plates, weakly impressed, separated by rather low and obscure median ridge.

MEASUREMENTS (mm).—

USNM	<i>Pedicle valve</i>		<i>Brachial valve</i>		Width	Hinge width	Thick-ness
	Length	Curved length	Length	Curved length			
456148	7.5	9.7	5.0	5.1	6.5	5.4	4.6
456149	6.0	8.2	5.2	5.5	6.5	5.2	3.8
456150	5.7	7.5	4.8	4.9	5.5	4.6?	3.5
456151	5.4	6.8	4.5	4.6	5.5	5.6	3.1
456152	4.4	5.9	3.8	4.2	4.6	3.6	2.7
456154	3.8		3.2		4.3	3.0	2.3
070404	3.1		2.9		3.6	3.0	2.0

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation and lowest part of Feixianguan Formation: Huayingshan section, Linshui County; Shangsi section, Guanfyuan County; Beipei section, Zhongqing City; Yanjingxi section, Hechuan County, Sichuan Province; Huangzhishan section, Wuxing County, Zhejiang Province. Lower Xikou Formation: Yading section, Zhuangping County, Fujian Province.

DIAGNOSIS.—Medium size, near planoconvex, interarea relatively high, narrow median sulcus trace on pedicle valve usually visible.

COMPARISON.—*Crurithyris pusilla* Chan is similar to *C. urei* (Fleming) and *C. amoena* George (1931:45, 55, pl. 5: figs. 5, 6, pl. 4: figs. 1–4) in its size and outline, but the latter two species have sulci on both valves whereas *C. pusilla* has a narrow and very shallow median sulcus only on the pedicle valve. It most nearly resembles *C. longirostris* Cooper and Grant, particularly in its wide interarea; however, it differs in the fact that the West Texas species has no sulcus on the pedicle valve. It is comparable to *C. sulcata* Stehli in size, profile, and interarea, but *C. sulcata* has sulci on both valves and has an emarginate anterior. The species *C. speciosa* Wang (1955b:146, pl. 83: figs. 1–4; Wang et al., 1964:546, pl. 104: figs. 13–16) (Figure 33), which has a relatively large size, brilliant concentric lines, hairy spines, and no sulcus on the pedicle valve, is easy to discriminate from *C. pusilla*.

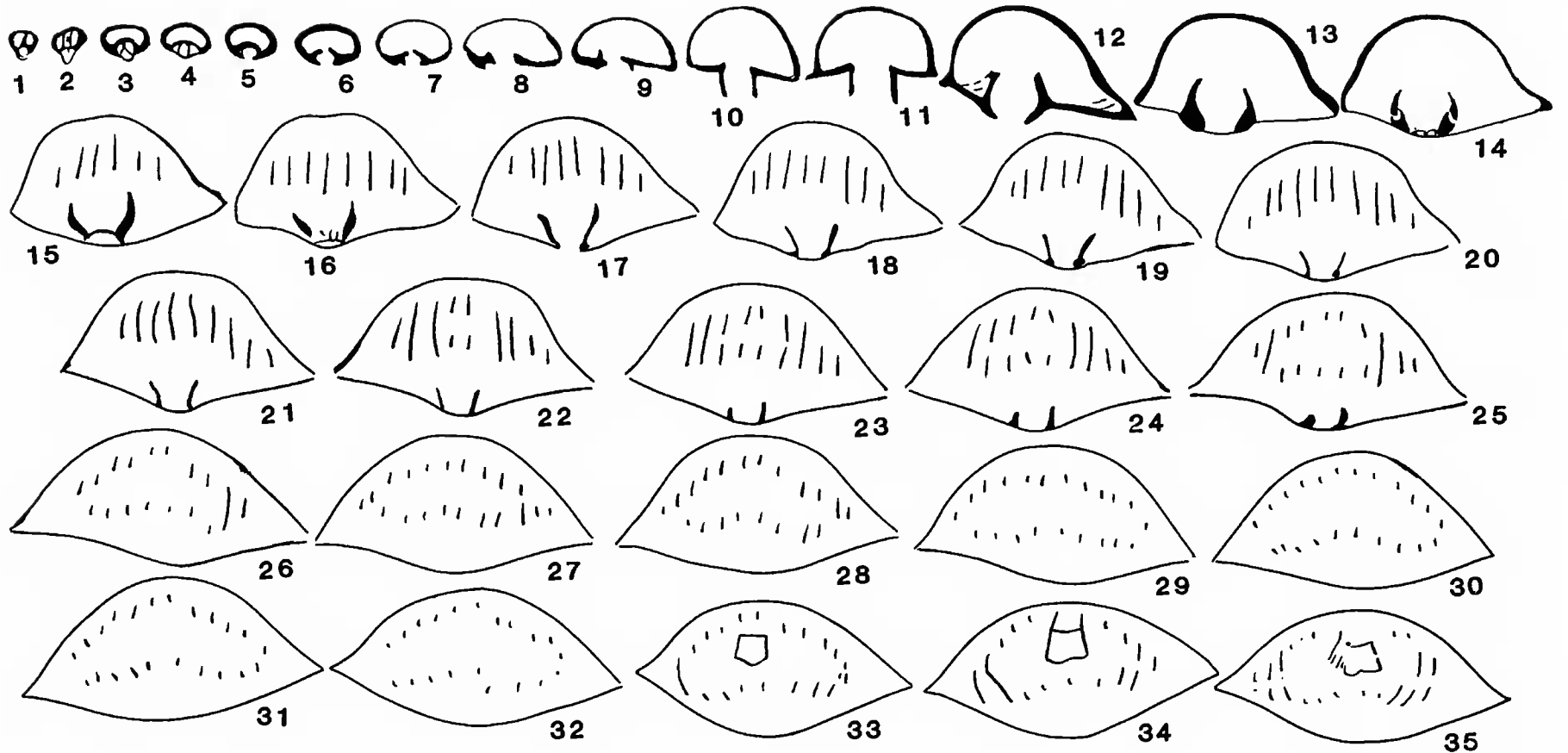


FIGURE 32.—Serial sections of *Crurithyris pusilla* Chan showing the internal features.

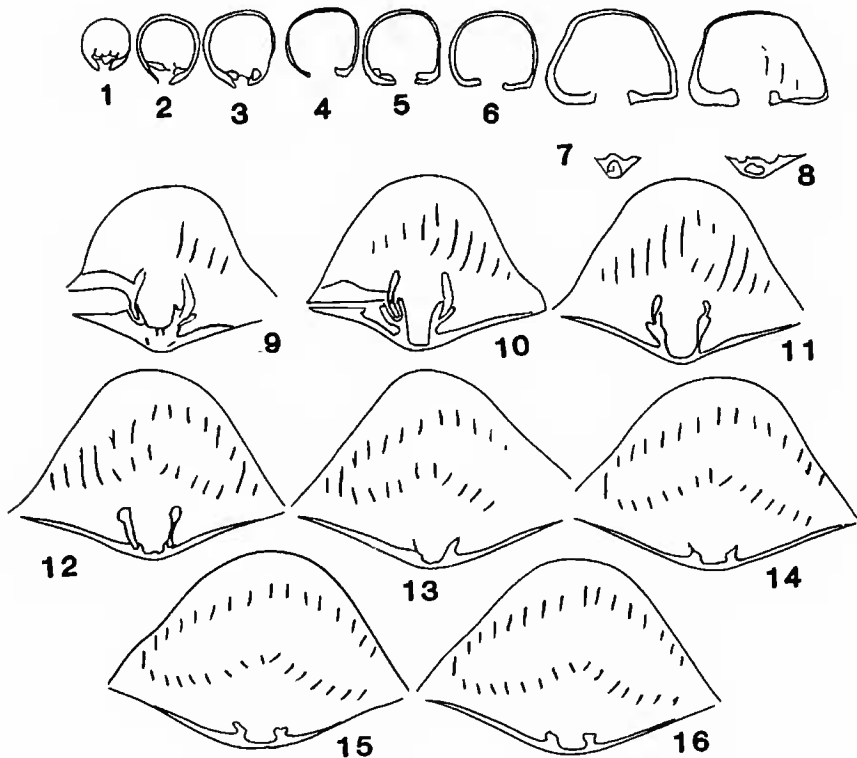


FIGURE 33.—Serial sections of *Crurithyris speciosa* Wang showing the internal features.

DISCUSSION.—Chan described this species in September 1979 (in Hou et al., 1979). Liao (1980a) described a species named *C. pigmaea* at almost the same time. Comparing Liao's description and figures (1980a:264, pl. 8: figs. 1-4) with Chan's (1979:96, pl. 13: figs. 24-26) leads to the conclusion

that *C. pigmaea* Liao is a synonym of *C. pusilla* Chan; therefore, the name of *C. pigmaea* should be abolished because it was published later. Actually, Liao published an earlier paper in September 1979 (Liao, 1979, pl. 1: figs. 4-7) in which he presented illustrations of a species that he named *Paracrurithyris pigmaea*, but he did not give a description of the species. *Paracrurithyris* as a new genus was not described by Liao until 1981 (Liao in J.K. Zhao et al., 1981) at which time he also designated *C. pigmaea* as the type species. He also compared *Paracrurithyris* with *Crurithyris* George, stating that "externally and in the pedicle valve this genus resembles *Crurithyris* George (1931), but the brachial valve has fundamental differences" (Liao, 1981:86). The following is a translation of his Chinese description: "COMPARISON: In its external shape and internal structures, it is similar to *Crurithyris* George (1931), but it is distinguished by the latter's lack of closely spaced concentric laminae, undeveloped muscle scars, and crural plates that reach to the floor and are parallel" (Liao, 1981:54). According to the features of the topotype, *C. urei* (Fleming) has "narrow elongate posterior muscle-impressions" in the ventral valve, and "the cavities of the crural plates...and the obliquely-sloping antero-lateral margins of the hinge-plate" (George, 1931:59, pl. 4: fig. 2a) should be understood as crural plates. These two features, of course, are the proper features of the genus *Crurithyris* because *C. urei* is the type species of the genus. Concerning the ornamentation of the shell, only spines were noted by George, but he pointed out that the spines were closely packed in irregular concentric rows on the dorsal valve

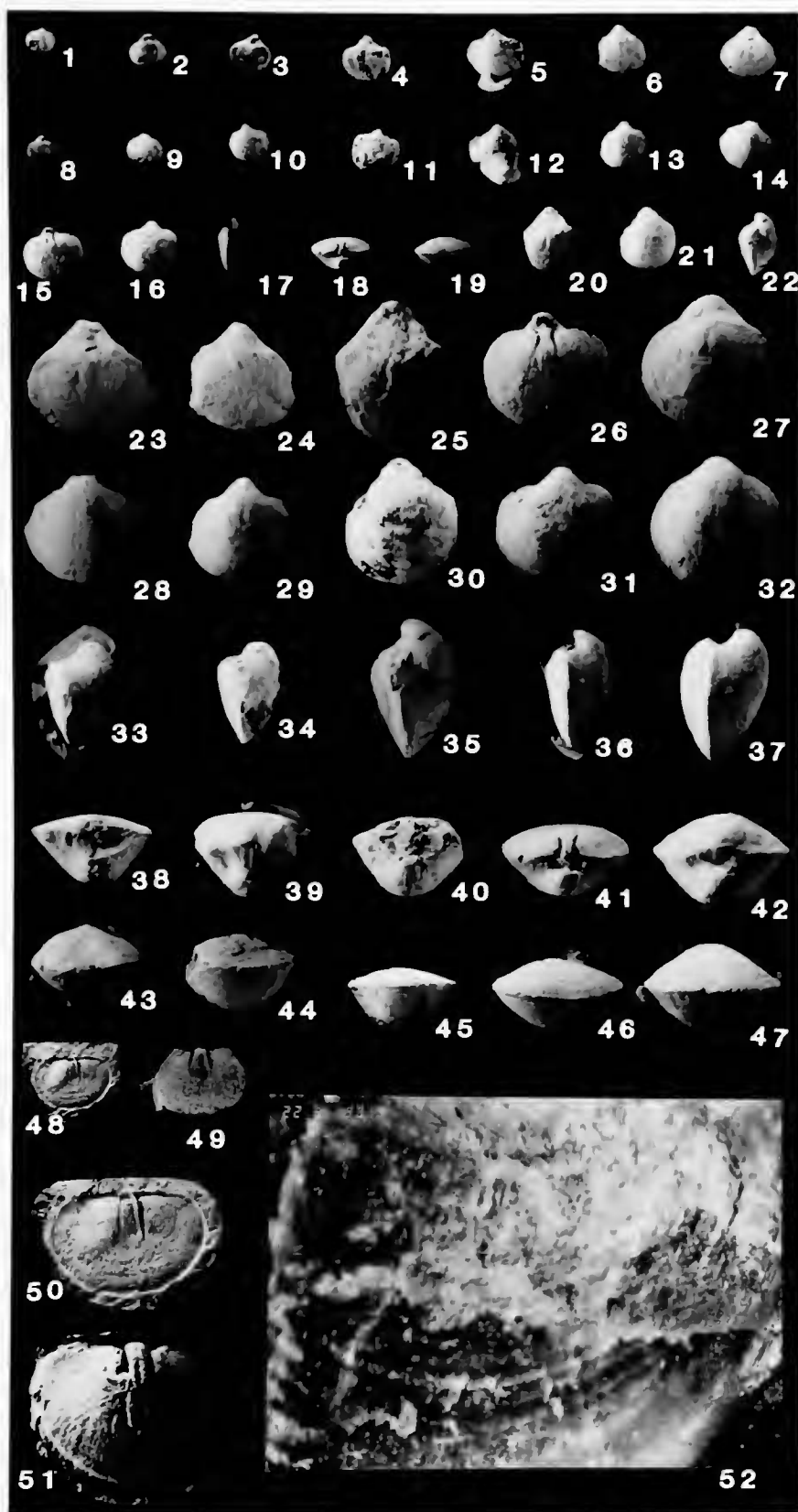


FIGURE 34.—*Crurithyris*. 1–47, 52, *Crurithyris pusilla* Chan: 1, 8, ventral and dorsal views ( $\times 1$ ), USNM 456151a; 2, 9, dorsal and ventral views ( $\times 1$ ), USNM 456151b; 3, 10, idem ( $\times 1$ ), USNM 456152; 4, 11, idem ( $\times 1$ ), USNM 456153; 5, 12, idem ( $\times 1$ ), USNM 456154; all from section 7. 6, 13, dorsal and ventral views ( $\times 1$ ), 24, 29, 34, 39, 44, dorsal, ventral, lateral, posterior, and anterior views ( $\times 3$ ), USNM 456148; 7, 14, dorsal and ventral views ( $\times 1$ ), 23, 28, 33, 38, 43, dorsal, ventral, lateral, posterior, and anterior views ( $\times 3$ ), 52, micro-ornamentation ( $\times 20.8$ ), USNM 456149; all from section 8. 15–19, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), and 26, 31, 36, 41, 46, idem ( $\times 3$ ), USNM 456155, from section 30. 20–22, dorsal, ventral, and lateral views ( $\times 1$ ), and 25, 30, 35, 40, 45, dorsal, ventral, lateral, posterior, and anterior views ( $\times 3$ ), USNM 456150, from section 27. 27, 32, 37, 42, 47, dorsal, ventral, lateral, posterior, and anterior views ( $\times 3$ ), USNM 456156, from section 6. 48–51, *Crurithyris speciosa* Wang: 48, 50 ( $\times 1$ ,  $\times 2$ ), USNM 456217; 49, 51 ( $\times 1$ ,  $\times 2$ ), USNM 456157, both from section 27. (Reduced to 97 $\frac{1}{2}$ % for publication.)

(1931:55). Cooper and Grant (1976a) described this genus in detail, including a thorough examination of the exposed internal structures. They provided the following description: “growth lines fine, closely spaced, visible only on well-preserved surfaces; growth laminae weak, irregularly spaced” (1976:2121). Examination of specimen USNM 100418 of *C. urei* (Fleming), which is from Wetton, Staffordshire, England (Accession 153400), revealed that regular growth laminae are visible on the pedicle valve and this feature is comparable with specimens of South China. The internal structures of *C. pusilla* that we revealed by making serial sections (Figure 32) is completely consistent with silicified specimens from West Texas. Considering this resemblance, we include the species *C. pusilla* in the genus *Crurithyris*. Jing and Sun (1981:157) suggested setting up a new genus named *Speciothyris* and assigned *C. speciosa* Wang as the type species of the new genus, but the serial sections of *Crurithyris speciosa* Wang (Figure 33; see also Jing and Sun, 1981:156, text-fig. 17) are essentially similar to the serial sections of *C. pusilla* Chan (Figure 32).

#### Suborder SPIRIFERINIDINA Cooper and Grant, 1976

#### Superfamily SPIRIFERINOIDEA Davidson, 1884

#### Family PARASPIRIFERINIDAE Cooper and Grant, 1976

#### Genus *Paraspiriferina* Reed, 1944

#### *Paraspiriferina alpha* (Huang, 1933)

FIGURES 35, 36(1–23)

*Spiriferina multiplicata* mut. *alpha* Huang, 1933:56–61, pl. 9: figs. 2, 3.  
*Punctospirifer alpheus* (Huang).—Wang, 1955b:164, pl. 97: figs. 5–8.—Wang et al., 1964:584, 585, pl. 113: figs. 8–11.—Liao, 1980a:277, pl. 8: fig. 49.  
*Crenispirifer alpheus* (Huang).—Yang et al., 1987:233, pl. 15: figs. 26–28.

Shell small to medium for genus, moderately or strongly biconvex; outline subelliptical, hinge line shorter than maximum width, located between midlength and hinge line; hinge extremities rounded; costae moderately high, rounded, beginning at beaks, numbering 3–5 on each side of both valves; fold obviously larger than costae; sulcus sub-V-shape, limited costae much stronger than others.

Ventral valve interior with stout, knob-like teeth; dental plates moderately thick, extending only over length of delthyrium chamber, slightly convergent ventrally, adminicula thin, short; median septum long, extending forward nearly  $\frac{2}{3}$  valve length, thick at posterior  $\frac{1}{2}$ , then becoming very thin at anterior  $\frac{1}{2}$ , almost same height for full length, braced against small apical plate coalescing with dental plates at umbonal region. Brachial valve interior with shallow hinge sockets formed by socket plates and partly roofed; inner-socket ridges small and low; crural plates very large, bow-like, attached from socket ridges; adminicula short, limited to umbonal region; crura extending forward from dorsally lowest part of crura

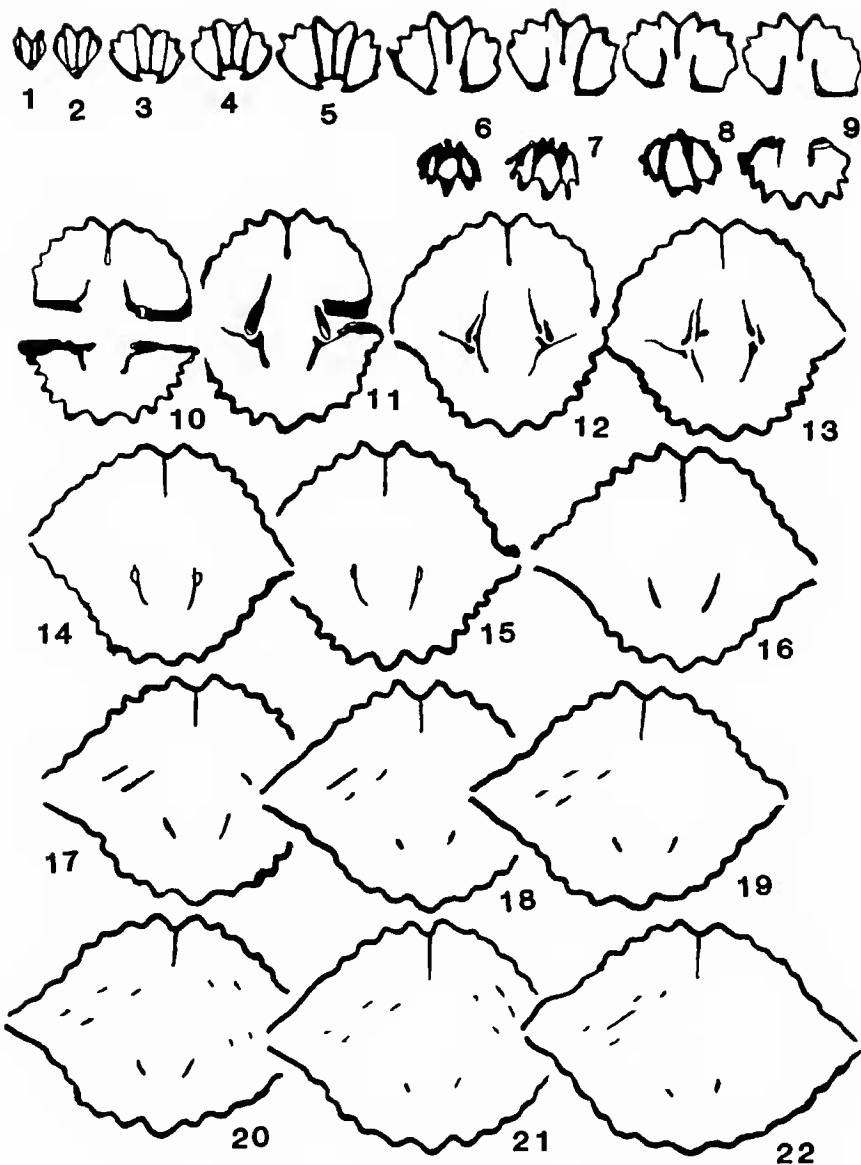


FIGURE 35.—Serial sections of *Paraspiriferina alpha* (Huang) showing the internal features.

plates; spiralia with only 2–3 coils at each side; cardinal process single, knot-like; low, thin, median ridge bisecting muscle area.

MEASUREMENTS (mm).—

USNM	Pedicle valve length	Brachial valve length	Maximum width	Hinge width	Thickness
456158	8.2	6.7	12.3	11.3	7.8
456159	6.9	5.5	8.2	6.7	6.1
456160	6.3	5.6	5.5	5.1	4.4?
456161	5.2?	-	9.2	5.5	
456162	6.1	-	9.8	6.9	

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Longtan Formation and Changxing Formation: Langfengya section, Zhongqing City, Sichuan Province; Huangzhishan section, Wuxing County, Zhejiang Province. Paoshui Formation: Paoshui section, Laibin County, Guangxi Province.

COMPARISON.—*Paraspiriferina alpha* (Huang) is similar to *P. gentilis* Grant (1976:236, pl. 64: figs. 1–36) in its small size, general outline, and number of costae; it differs from the Thailand species in the fact that the South China species has a

more strongly incurved beak, sub-V-shape sulcus, and moderately high costae. Because the specimens of South China are not silicified, the growth laminae are not well preserved, but their traces are still observable. In contrast, *P. gentilis* Grant has prominent, regularly spaced growth laminae, which seems to be the most important difference between these species.

In Waagen's (1883:502) description of *Spiriferina multiplicata* Sowerby (1829), he wrote that "on each side of the sinus are mostly four, sometimes six folds" and that it has rounded costae and a short hinge line. Those features are rather similar to *Paraspiriferina alpha* (Huang) except that Waagen's specimen is large and has a "broad, not deep and rounded," sinus (Waagen, 1883:502).

*Paraspiriferina amoena* Cooper and Grant (1976:2730, 2731, pl. 720: figs. 1–35) has a subelliptical outline and a few rounded costae, which resembles *P. alpha*, but it is distinguished by its shallow sulcus with flattened trough, low costae, and relatively short median septum.

DISCUSSION.—This species was assigned to *Punctospirifer* by many Chinese scientists (see synonymy) based on its spiriferinid shape. When studied in detail, Huang's species differs radically from any species of that genus. According to North (1920) who erected the genus, *Punctospirifer* is characterized by its wide hinge, wide and shallow mesial sinus, greater number of costae, and large spiral coils with jugum (1920:212, 213). The South China species has a narrow hinge line, few costae, and only 2–3 spiral coils per side. Fine hair-like spines and traces of growth laminae are visible in well-preserved specimens. On the basis of growth laminae, nearly angular costae, and sub-V-shape sulcus, this species has been considered a species of *Crenispirifer* (Yang et al., 1987:233, pl. 15: figs. 26–28). Actually, the costae of this species are not really angular when compared to West Texas specimens. The internal features revealed by serial sections (Figure 34) show that this species is properly attributed to the genus *Paraspiriferina*.

Grant (1976:236) first described the internal details of a species of *Paraspiriferina* (*P. gentilis* Grant), and Cooper and Grant (1976b:2729–2741) verified that many species of the genus have essentially the same internal features. *Paraspiriferina alpha* (Huang) has a long (more than  $\frac{1}{2}$  valve length) median septum braced by small apical plates and short adminicula in the ventral valve, and broad blade-like crural plates, a small cardinal process, and a low thin median ridge in the dorsal valve. These internal features, with the addition of the external features mentioned, combine to place this species in *Paraspiriferina*.

Huang (1933) originally described the species as a mutation of *Spiriferina multiplicata* Sowerby and designated it by the Greek letter *alpha*. Wang (1955b) first correctly promoted it to an independent species discriminable from "multiplicata" by its small size, subrhombical outline, and 4 costae on each side (1955b:164; 1964:585). Some specimens collected from South China really have 5 costae on one side and 4 costae on the other

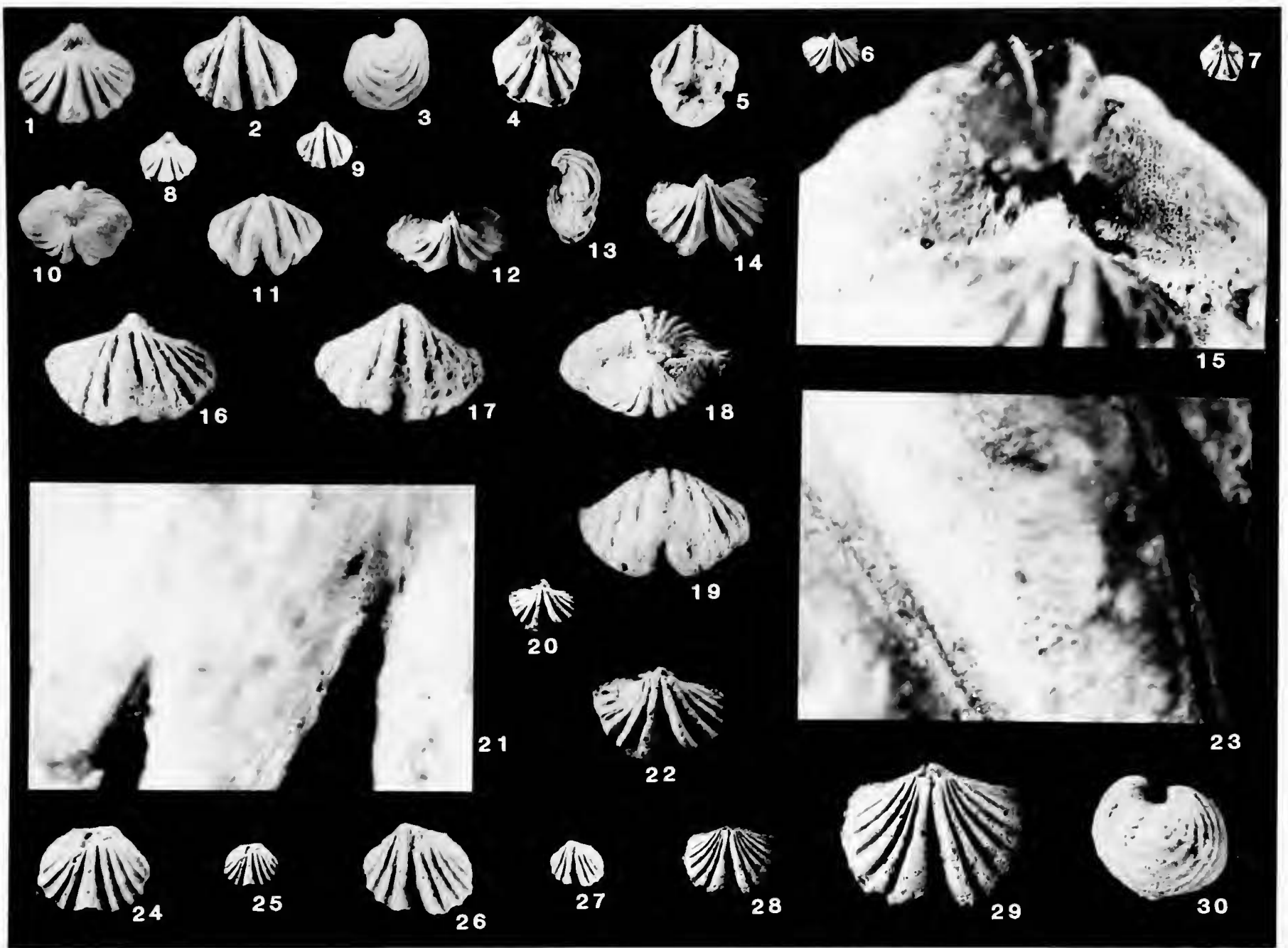


FIGURE 36.—1-23, *Paraspiriferina alpha* (Huang): 1-3, 10, 11, dorsal, ventral, lateral, posterior, and anterior views ( $\times 2$ ), and 8, 9, dorsal and ventral views ( $\times 1$ ), USNM 456158; 16-19, dorsal, ventral, posterior, and anterior views ( $\times 2$ ), and 21, 23, micro-ornamentation ( $\times 20.8$ ), USNM 456159; 4, 5, 13, dorsal, ventral, and lateral views ( $\times 2$ ); 7, dorsal view ( $\times 1$ ); and 15, micro-ornamentation ( $\times 20.8$ ), USNM 456160; all from section 27. 6, ventral view ( $\times 1$ ); 12, 14, posterior and ventral views ( $\times 2$ ), USNM 456161; 20, 22, ventral views ( $\times 1$ ,  $\times 2$ ), USNM 456162; all from section 16. 24-30, *Callispirina? rotundella*, new species: 24, 26 and 25, 27, dorsal and ventral views ( $\times 2$ ,  $\times 1$ ), USNM 456163a, holotype; 30, lateral view ( $\times 2$ ), USNM 456163b, both from section 27. 28, 29, ventral view ( $\times 1$ ,  $\times 2$ ), USNM 456164, from section 6.

(Figure 36(1, 16); Wang et al., 1964, pl. 113: fig. 6). Therefore, we hereby emend the definition of this species and will discuss the difference between "multiplicata" and "alpha" below.

### Genus *Callispirina* Cooper and Muir-Wood, 1951

#### *Callispirina? rotundella* sp. nov.

FIGURE 36(24-30)

*Spirifer multiplicata* Sowerby, 1829:119.

*Trigonotreta multiplicata* (Sowerby).—King, 1850:129.

*Spiriferina multiplicata* (Sowerby).—Davidson, 1858:19, pl. 1: figs. 38, 39, 45,

46.—Huang, 1933:57-59, pl. 9: figs. 4, 5.

*Punctospirifer multiplicata* (Huang).—Wang et al., 1964:584, pl. 113: figs. 12, 13.

*Spiriferellina multiplicata* (Huang).—Hou et al., 1979:97, pl. 12: fig. 14.

DIAGNOSIS.—Small size; subelliptical outline, slightly transverse, hinge line shorter than greatest width; profile bulbous; costae beginning at beaks, simple, high, angular, numbering 10-14; interspaces narrower than costae; sulcus deep with V-shape floor; fine growth lines, stronger growth laminae present at irregular intervals. Pedicle valve interior with high and long median septum reaching more than  $\frac{1}{2}$  length of valve.

LECTOTYPE.—USNM 456163.

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation: Huayingshan section, Linshui County, Sichuan Province; Huangzhishan section Wuxing County, Zhejiang Province; and other places of South China.

COMPARISON.—This species resembles *Callispirina australina* Grant (1976:231–235, pl. 63: figs. 1–37) and *C. rotunda* Cooper and Grant (1976b:2743, pl. 705: figs. 66–82) in its high, angular costae and deep V-shape sulcus. But *C. australina* has well-developed growth laminae, relatively wide interspaces of costae, and a proportionately shorter median septum in the pedicle valve. *Callispirina rotunda* has a long median septum reaching to midvalve in the pedicle valve and relatively narrow interspaces of costae. Those features are more closely similar to *C. rotundella*; however, *C. rotunda* has a proportionately wide hinge line, more transverse outline, and wider fold.

DISCUSSION.—Specimens collected from (1) Zunyi County (Tsunyihsien), Guizhou Province and Huayingshan section, Sichuan Province, described by Huang (1933) as *Spiriferina multiplicata* (Sowerby), (2) Hechuan section, Sichuan Province, identified by Wang et al. (1964) as *Punctospirifer multiplicata* (Sowerby), and (3) Lianxian section, Guangdong Province, reported by Hou et al. (1979) as *Spiriferellina multiplicata* (Sowerby), are straightforwardly identical with our specimens collected from Huayingshan section, Sichuan Province and Huangzhishan section, Zhejiang Province. But why not use the name “multiplicata”? The main reason is that the South China specimens do not correspond with the original definition of the species.

King (1850) first described and illustrated two specimens from England as *Trigonotreta multiplicata*, which corresponds to *Spirifer multiplicata*, the name given by Sowerby (1829, see Davidson, 1858:19). He described the species as having the following features: “generally ten rather prominent obtusely-rounded ribs...small valve (brachial valve) moderately rounded; median rib depressed; and nearly thrice the width of those immediately adjoining it” (King, 1850:129). In addition, the sulcus in King’s plate 8, fig. 5 is seen to be shallow and rounded. Obviously, the specimens from England differ at least in external features from South China specimens.

When he described the species *Spiriferina multiplicata* Sowerby, Davidson (1858:19) wrote: “The ribs are small, rounded, and rarely exceed ten in number; mesial fold not much produced and either rounded or flattened along its crest.” His figures included a specimen that has only 7–8 costae (pl. 1: figs. 45, 46) and a specimen that has subangular plications (pl. 1: figs. 38, 39). Even though the latter specimen may be comparable to specimens from South China, it does not represent the same species.

The specimens that Waagen (1883) identified as *Spiriferina multiplicata* are closely similar to *Paraspiriferina alpha* mentioned above.

*Callispirina? rotundella* (= *Spiriferina multiplicata* Huang) is characterized by its high, angular costae, narrow intercostal troughs, and deep V-shape sulcus. It differs from *Paraspirifer-*

*ina alpha* (Huang) (= *Spiriferina multiplicata* mut. *alpha* Huang) in that the latter has low and rounded costae and fold, in sharp contrast to the former. As Grant (1976:231) and Cooper and Grant (1976b:2742, 2743) pointed out, the genus *Callispirina* differs from the genus *Paraspiriferina* externally in its sharp plications and fine, regularly spaced growth lines. Although growth lines in our specimens that are preserved as casts are ill-preserved, one specimen partly reveals the fine growth lines that prompted us to place this species in the genus. We are not sure about internal features that will need to be verified in the future.

ETYMOLOGY.—From the Latin, *rotunda*, meaning round, plus *-ella*, meaning diminutive.

**Suborder ATHYRIDIDINA Boucot, Johnson,  
and Staton, 1964**

**Superfamily ATHYRIDIDOIDEA McCoy, 1844**

**Family ATHYRIDIDAE McCoy, 1844**

**Subfamily SPIRIGERELLINAE Grunt, 1965**

**Genus *Araxathyris* Grunt, 1965**

***Araxathyris beipeiensis* sp. nov.**

FIGURE 37(1–4)

Medium-size shell, biconvex with shallowly inflated profile; outline subpentagonal transversely; anterior commissure parasulcate and emarginate; growth laminae visible near anterior margin, evenly and regularly spaced.

Pedicle valve gently convex, evenly arched in anterior profile, lateral profile strongly curved near umbonal area; sulcus narrow, beginning near umbonal area, getting wider forward, forming tongue-like turn-up dorsally at anterior edge; no lateral plications; beak short and incurved. Brachial valve somewhat less strongly convex; fold low and flattened at top with median groove originating near umbonal area, getting wider forward; lateral sulci shallow, beginning at midvalve; beak short, incurved.

Pedicle valve interior with dental plates visible from weathered shell (Figure 37(2, 3)). Other internal features unknown.

HOLOTYPE.—USNM 456169.

MEASUREMENTS (mm).—

USNM	<i>Pedicle valve</i>		<i>Brachial valve</i>		Width	Thick- ness
	<i>Length</i>	<i>Curved length</i>	<i>Length</i>	<i>Curved length</i>		
456169	13.9	19.2	13.9	14.3	17.1	9.0

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Changxing Formation: Beipei section, Zhongqing City, Sichuan Province.

DIAGNOSIS.—Small and transversely subpentagonal *Araxathyris* with emarginate anterior commissure and flattened fold.



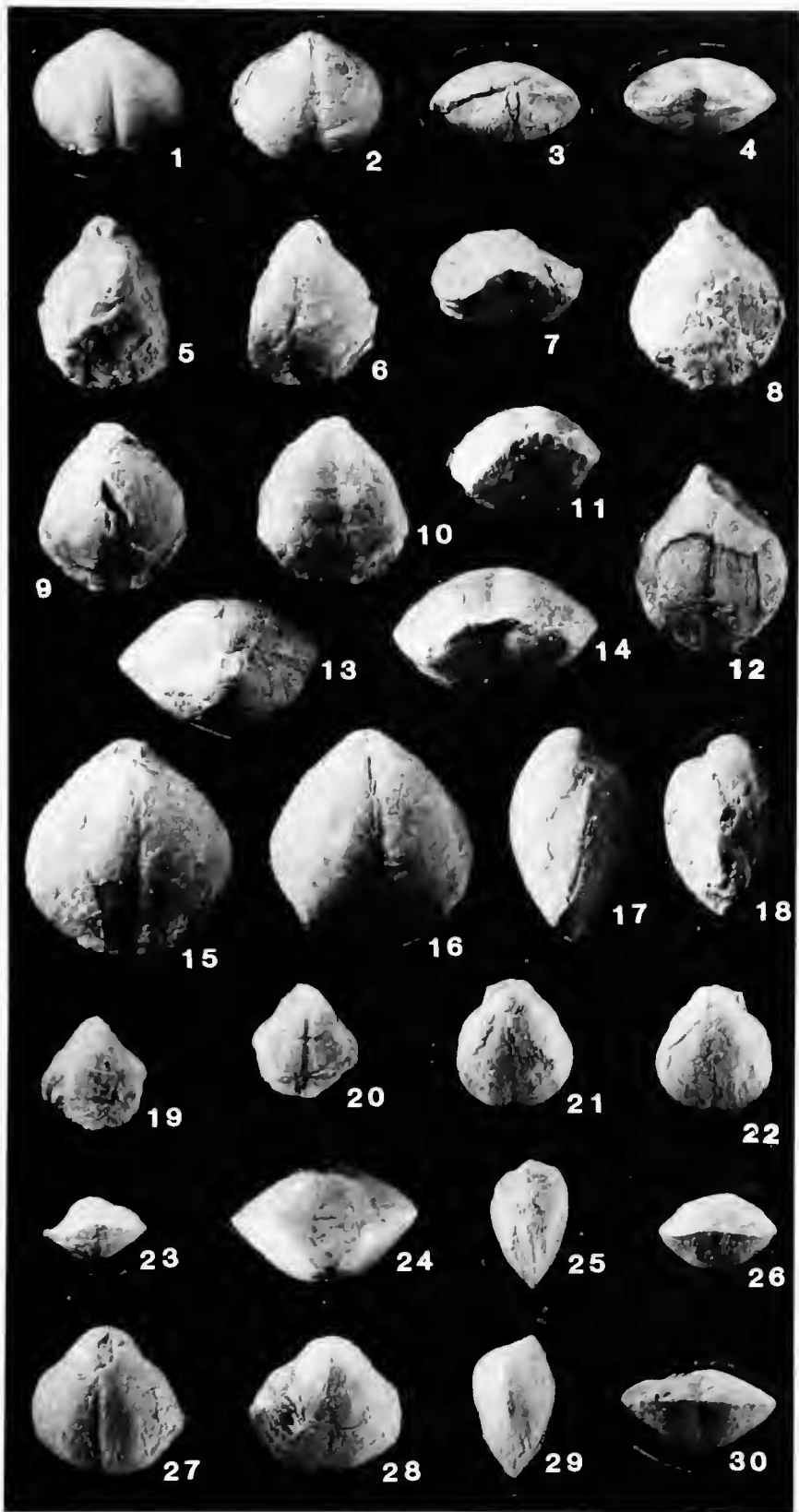


FIGURE 37.—1-4, *Araxathyris beipeiensis*, new species: dorsal, ventral, posterior, and anterior views ( $\times 1$ ), from section 8, USNM 456169, holotype. 5-18, *Araxathyris subpentangulata*, new species: 5-7, dorsal, ventral, and anterior views ( $\times 1$ ), USNM 456165; 8, 12, 18, idem ( $\times 1$ ), USNM 456166; 9-11, idem ( $\times 1$ ), USNM 456167; 13-17, posterior, anterior, dorsal, ventral, and lateral views ( $\times 1$ ), USNM 456168, holotype; all from section 32. 19-30, *Rectambitus bisulcata* (Liao): 19, 20, 23, dorsal, ventral, and anterior views ( $\times 1$ ), USNM 456170; 21, 22, 25, 26, dorsal, ventral, lateral, and anterior views ( $\times 1$ ), USNM 456171; 27-30, idem ( $\times 1$ ), USNM 456172; 24, a cut section showing interior features ( $\times 2$ ), USNM 456173; all from section 32. (Reduced to 98% for publication.)

COMPARISON.—The new species closely resembles *A. subpentangulata* in its anterior commissure and sulcus shape;

however, it differs in its transverse outline, valves gently convex, and more obvious lateral sulci. It differs from *A. zhijinensis* Liao (1980a:267, pl. 8: figs. 52, 53) in its transverse subpentagonal outline and parasulcate commissure.

ETYMOLOGY.—From the Latin suffix, *-ensis*, denoting place.

*Araxathyris subpentangulata* sp. nov.

FIGURES 37(5-18), 38

Medium size, moderately biconvex; outline subpentagonal to subelliptical, usually slightly elongate; hinge line short and curved, greatest width near midlength or somewhat anterior to midlength; narrow sulci on both valves, anterior commissure weakly parasulcate, sometimes slightly emarginated; surface smooth with few concentric laminae, irregularly spaced, most frequent near anterior margin.

Pedicle valve moderately and rather evenly convex, greatest

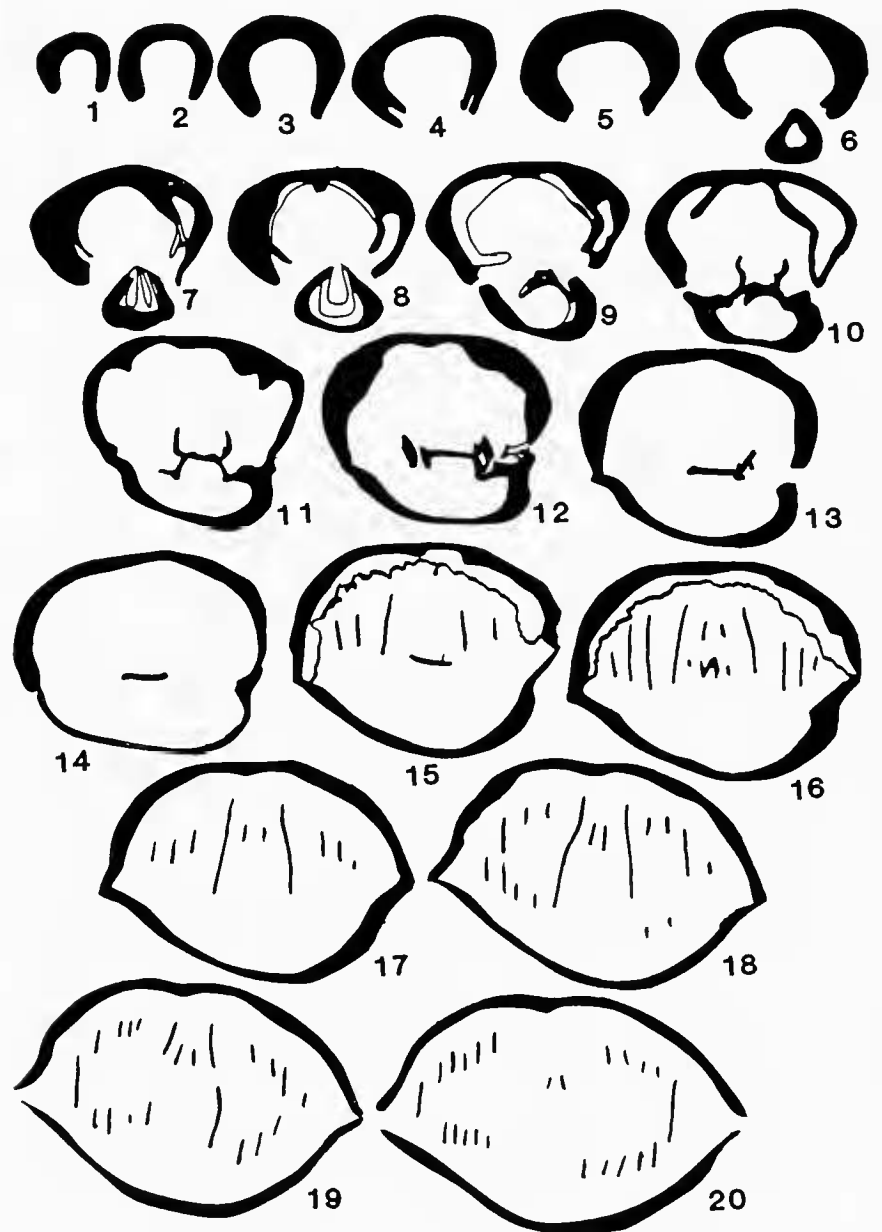


FIGURE 38.—Serial sections of *Araxathyris subpentangulata*, new species, showing the internal features.

convexity somewhat posterior to midlength; beak short, incurved; foramen covered by beak; sulcus from umbonal region narrow, extending over  $\frac{1}{2}$  length of valve, widening rapidly. Brachial valve somewhat less strongly convex; beak slightly incurved; sulcus narrow from umbonal region to near anterior margin, no fold, only flattened crest at anterior margin.

Pedicle valve interior with small teeth, short thin dental plates fused to wall, only anterior edge free, strongly divergent near floor then curved; muscle area deeply impressed, separated by very low median ridge. Brachial valve interior with thin plate, perforated near posterior margin, at middle part becoming a shallow furrow, short, disappearing when hinge plate flattened anteriorly; hinge socket shallow, inner-socket ridge proportionately high; cardinal process short, comb-like at posterior, bilobed at anterior; crural bases seemingly forming sides of hinge plate; axis of spiralia laterally pointed, including 5–6 volutions per spirillum.

HOLOTYPE.—USNM 456168.

MEASUREMENTS (mm).—

USNM	Pedicle valve		Brachial valve		Width	Thick-ness
	Length	Curved length	Length	Curved length		
456165	26.6	35.7	24.2	28.0	25.4	15.4
456166	22.9	28.9	20.0	21.7	18.5	13.1
456167	20.1	26.0	19.0	20.2	17.8	12.9
456168	13.5	16.7	11.9	12.8	12.7	7.8

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Longdongchuan Formation: Xikou section, Zhenan County, Shaanxi Province.

DIAGNOSIS.—Smooth, subpentagonal outline, with sulci on both valves, anterior commissure usually weakly parasulcate.

COMPARISON.—*Araxathyris subpentangulata* is characterized by its narrow sulci on both valves and a weakly parasulcate commissure. In these respects it resembles *A. quadrilobata* (Abich, 1878:53, 54, pl. 7: fig. 6, pl. 9: figs. 8, 9; Grunt, 1965:243, 244, pl. 43: figs. 1, 2); but it differs in its smaller maximum size, slightly elongated outline, and sulcus wider at the anterior margin of the pedicle valve. It differs from *A. zhijinensis* Liao (1980a:267, pl. 8: figs. 52, 53) in its subpentagonal outline and parasulcate commissure; the latter species has a triangular shape and an uniplicate anterior commissure.

ETYMOLOGY.—From the Latin prefix, *sub*, meaning somewhat; latinized from the Greek, *penta*, meaning five; and from the Latin, *angulata*, meaning having angles; hence, somewhat pentagonal.

### *Rectambitus* gen. nov.

Small to medium size, biconvex, outline subpentagonal to subelliptical slightly elongate or transverse; anterior commissure rectimarginate with emarginate anterior; narrow and shallow sulcus at each valve, brachial sulcus moderately or

weakly developed; growth laminae irregularly spaced, most frequent near anterior margin; pedicle beak somewhat incurved, arching over brachial beak.

Pedicle valve interior with strong knob-like teeth; dental plates thin, bow-like, converging together to form spondylium, attached at floor in apical cavity, and supported by low and broad median septum at anterior edge of spondylium; muscle scars narrow, elongate in spondylial floor. Brachial valve interior with undivided hinge plate, thin and flat; hinge socket shallow, inner-socket ridges relatively high; 2 comb-like processes interpreted as cardinal processes, separated widely; crural bases butting between outer and inner hinge plates; athyridid spiralia.

DIAGNOSIS.—Smooth Athyridoidea with rectimarginate commissure and emarginate anterior edge; narrow sulcus in both valves; internally, dental plates convergent, forming spondylium.

COMPARISON.—The new genus is comparable to *Araxathyris* in having a dorsal sulcus, thin dental plates, and undivided hinge plate. The obvious distinctions are that the new genus has a rectimarginate commissure and a spondylium. It resembles *Leptathyris* Siehl (1962:212) in its bisulcate and rectimarginate commissure, but that Devonian genus has deeply depressed hinge plates in the dorsal valve and dental plates in the ventral valve, and both plates are fused completely with the shell wall (see A.J. Boucot et al. in Moore, 1965:H633, fig. 538, 4).

TYPE SPECIES.—*Araxathyris bisulcata* Liao (1980a:268, pl. 9: figs. 14–17).

ETYMOLOGY.—From the Latin, *rectus*, meaning proper, and *ambitus*, meaning curvature (of margin). The gender is masculine.

### *Rectambitus bisulcatus* (Liao, 1980), new combination

FIGURES 38(19–30), 39

*Araxathyris bisulcata* Liao, 1980a:268, pl. 9: figs. 14–17.

DIAGNOSIS.—Average size for genus; moderately biconvex; greatest width somewhat anterior to midlength, maximum thickness near both umbonal regions; bisulcate, narrow and shallow, pedicle sulcus slightly wider than brachial sulcus; anterior commissure rectimarginate, rounded edge emarginate in middle. Pedicle valve spondylium supported by low and broad median septum extending about 2 mm at anterior edge of spondylium. Brachial valve with bilobate, comb-like hinge processes, diverging widely.

MEASUREMENTS (mm).—

USNM	Pedicle valve		Brachial valve		Width	Thick-ness
	Length	Curved length	Length	Curved length		
456170	17.9	21.2	14.1	16.0	16.6	8.8
456171	15.5	16.0	14.4	16.0	16.7	9.0
456172	15.3	18.9		16.1	13.5	8.8
456173	13.7	17.9	12.4	15.9	12.6	8.4

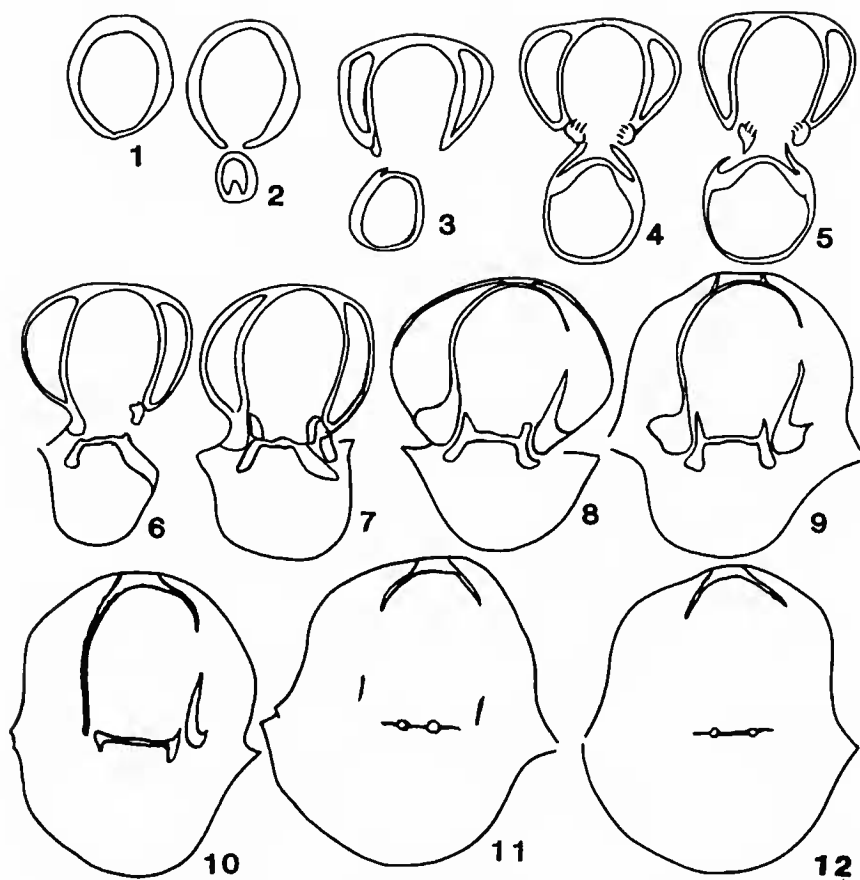


FIGURE 39.—Serial sections of *Rectambitus bisulcata* (Liao) showing internal features.

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Longtan Formation: Qiaozishan section, Anshun County, Guizhou Province. Longdongchuan Formation: Xikou section, Zhenan County, Shaanxi Province.

DISCUSSION.—Liao's (1980a:268) brief description of *Araxathyris bisulcata*, based on a single specimen from Qiaozishan section, Anshun County, Guizhou Province, emphasized its rectimarginate anterior commissure and narrow sulcus. Examination of our specimens from Xikou section, Zhenan County, Shaanxi Province, shows them to be externally identical to Liao's specimen. Liao did not illustrate the internal features of his specimen, but because he placed it in the genus *Araxathyris*, we must assume that the specimen has internal features compatible with those of that genus. *Rectambitus* and *Araxathyris* differ in that *Araxathyris* has a spondylium; however, this character easily may be overlooked, and otherwise the two genera share many similar internal features. In addition, the localities for Liao's specimen and our specimens are near the west margin of the South China Sea, and they also share a common age. Based upon all of this, we consider them to be the same species.

### Genus *Spirigerella* Waagen, 1883

DIAGNOSIS.—Smooth Athyrididae with strongly incurved pedicle beak, fairly sharp brachial beak, uniplicate or parasulcate anterior commissure; pedicle valve interior with bow-like

dental plates, with most parts merged into thickened wall; brachial valve interior with flat, undivided hinge plate, posterior part perforated, cardinal process usually well developed or with inner-socket ridges, position of crura usually near sides of hinge plates.

DISCUSSION.—Some species of smooth Athyrididae that occur in the Upper Permian of South China have been assigned incorrectly to the genus *Araxathyris*. For example, *A. shuizhutangensis* Chan (in Hou et al., 1979:99, pl. 8: figs. 7, 8, 10, 15, 16) and *A. guizhouensis* Liao (1980a:268, pl. 9: figs. 1-4) should be attributed to *Spirigerella*. Every species of *Araxathyris* has a distinct median groove in the dorsal valve. Examination of a large collection of *Araxathyris* compiled by Grant from Kuh-e-Ali Bashi, Iran (inventory of USNM), proves that this character is one of the most consistent features of the genus. *Araxathyris guizhouensis* Liao (= *Araxathyris shuizhutangensis* Chan) has a trace of a median groove that can be seen only dimly; this character essentially differs from the obvious median groove that is deeply scored and somewhat widened forward. Grant's comparison of *Composita* with the genus *Spirigerella* (Grant, 1976:204, 205) pointed out several features that belong especially to *Spirigerella*: strongly incurved beak with foramen absent or only very small; greatest width farther forward; thickened wall submerging most of dental plates; and crura normally extending from the sides of the hinge plate. In his original description, Waagen (1883:451) said that the genus *Spirigerella* has an "exceedingly large" cardinal process. The features mentioned by Grant (1976) and Waagen (1883) are visible in the species described below from South China (Figures 42-44). Grant (1976:204) suggested that the species under the name *Athyris timorensis* (Rothpletz) by Huang (1933) might belong to the genus *Spirigerella*. This work proves that analysis to be true. Based on its strongly incurved beak, no foramen, no median groove on the fold, thickened wall submerging dental plates in the pedicle valve, and flattened hinge plate in the brachial valve, we place *Athyris timorensis* in the genus *Spirigerella*. *Araxathyris* normally has a roof-like hinge plate (see Grant, 1965:241).

TYPE SPECIES.—*Spirigerella derbyi* Waagen (1883:450-455, pl. 35: figs. 4-7, 9-13).

### *Spirigerella discussella* sp. nov.

FIGURES 40, 43(36-47)

Average size for genus; moderately biconvex; outline nearly circular, an oblate spheroid with greatest width at midlength, maximum thickness somewhat posterior to midvalves; anterior commissure rectimarginate or weakly incurved with emarginate or straight edge; growth laminae irregularly spaced.

Pedicle valve evenly and moderately convex in both lateral and anterior profile; beak short and incurved; sulcus narrow and shallow, originating from umbonal region. Brachial valve evenly and slightly inflated in both lateral and anterior profile,

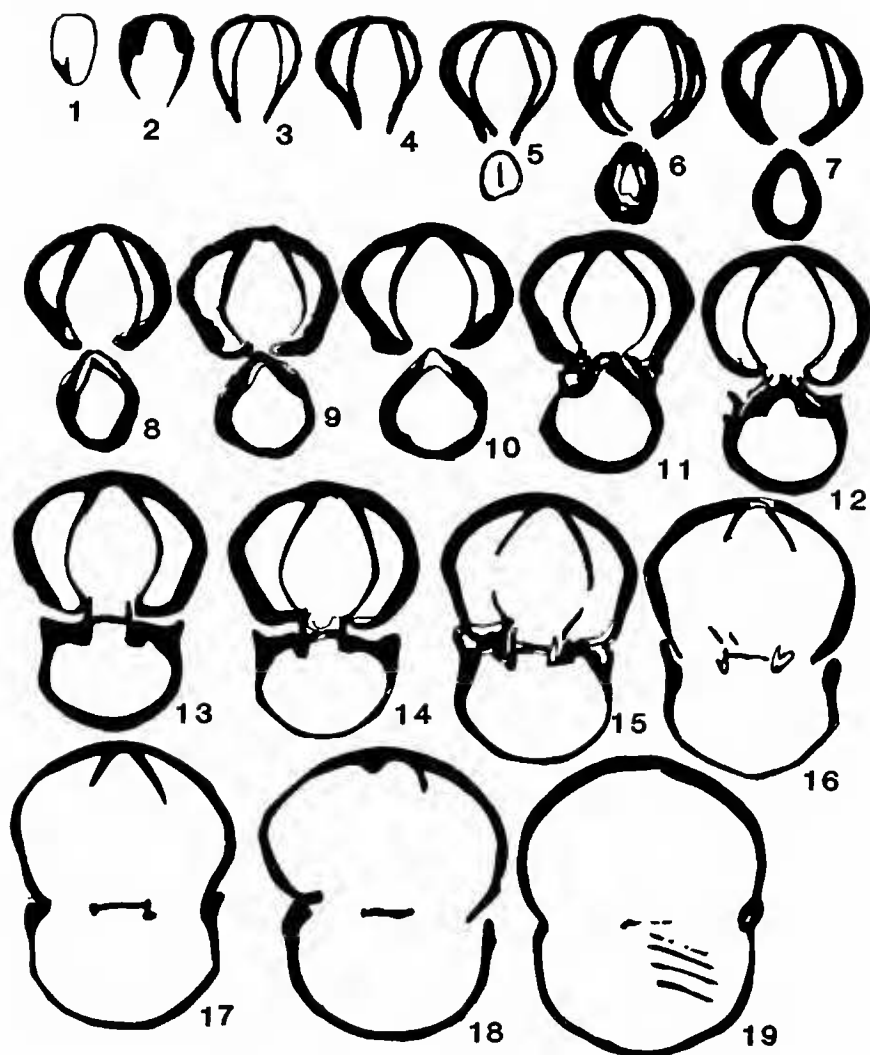


FIGURE 40.—Serial sections of *Spirigerella discussella*, new species, showing the internal features.

umbonal region roundly arched; no fold; brachial beak strongly incurved, attenuated, and sharply pointed.

Pedicle valve with relatively strong teeth; dental plates thin, converging at apical cavity. Brachial valve with undivided hinge plate; hinge sockets shallow, inner-socket ridges high; crural bases butting between outer and inner hinge plates.

HOLOTYPE.—USNM 456175.

MEASUREMENTS (mm).—

USNM	Pedicle valve		Brachial valve		Width	Thick-ness
	Length	Curved length	Length	Curved length		
456174	12.4	16.6	10.8	12.6	11.9	8.0
456175	14.4	18.2	13.2	14.5	13.1	6.7

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation: Beipei section, Zhongqing City, Sichuan Province; Huangzhishan section, Wuxing County, Zhejiang Province.

DIAGNOSIS.—Oblate spheroid in outline; no fold on brachial valve; anterior commissure rectimarginate or slightly up-curved.

COMPARISON.—*Spirigerella discussella*, new species, is

similar to *S. shuizhutangensis* (Chan in Hou et al., 1979:99, pl. 8: figs. 7, 8, 10, 15, 16) in its subcircular outline and strongly incurved and attenuated brachial beak; it differs from *S. shuizhutangensis* in its slightly up-curved anterior commissure and lack of fold.

ETYMOLOGY.—From the Latin, *discus*, meaning a circular plate, plus *-ella*, diminutive.

### *Spirigerella guizhouensis* (Liao, 1980), new combination

FIGURES 41(1-51), 42

*Athyris timorensis* (Rothpletz).—Huang, 1933:69-71, pl. 10: figs. 13-19.—

Wang et al., 1964:612, pl. 120: figs. 13-16.

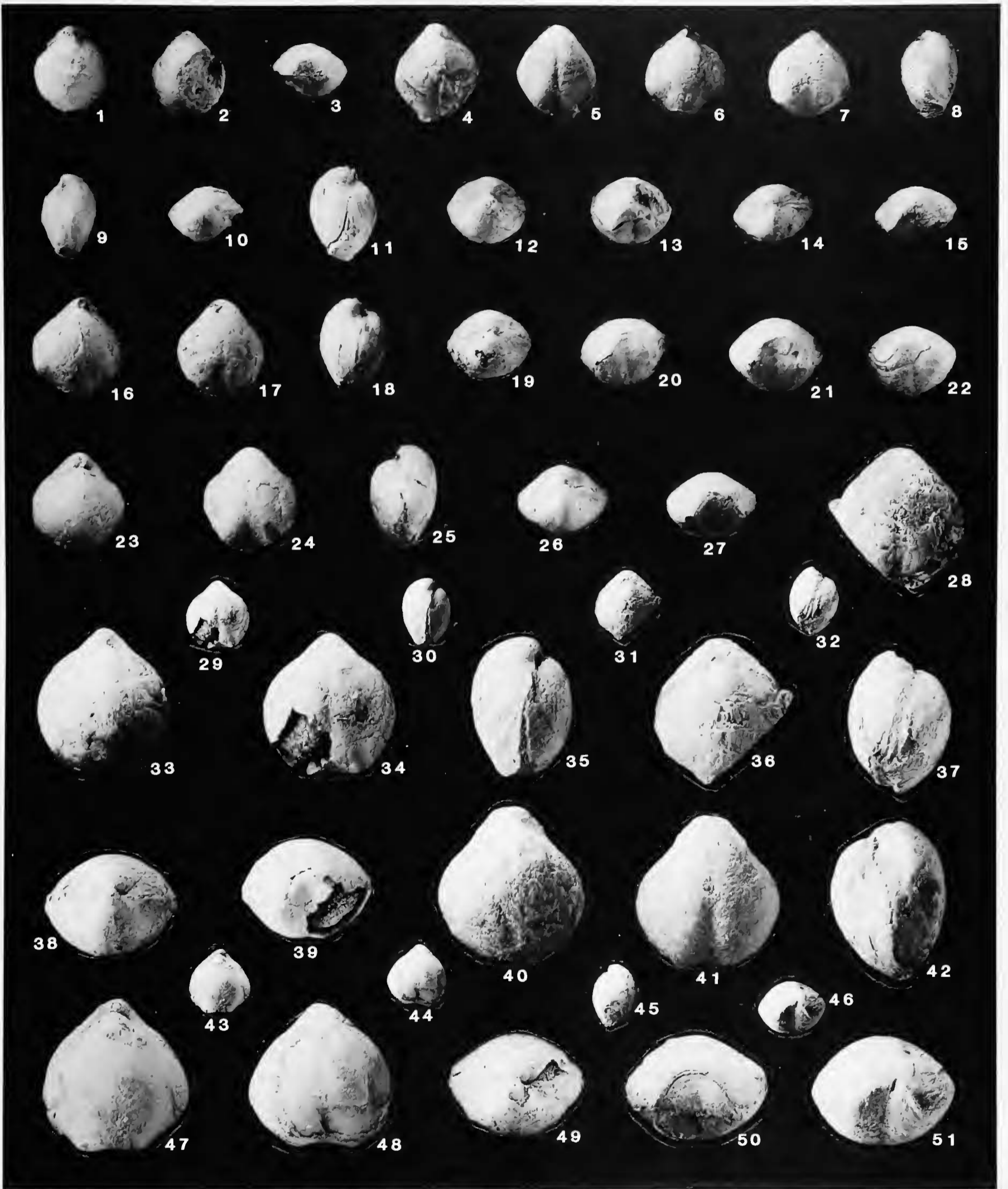
*Araxathyris guizhouensis* Liao, 1980a:268, pl. 9: figs. 1-4.

Medium size, strongly biconvex; outline subcircular, either slightly elongate or slightly transverse, greatest width normally anterior to midlength; anterior commissure parasulcate; growth lines fine, closely spaced, visible only in well-preserved specimens, growth laminae irregularly spaced, most frequent near anterior margin.

Pedicle valve strongly and evenly convex; beak short, pointed or slightly blunt, strongly incurved, usually embracing the brachial beak; sulcus shallow, beginning near midlength and widening rapidly, rounded floor forming relatively wide tongue-like edge, bounded by short, rounded lateral plicae at each side. Brachial valve somewhat less strongly convex, greatest inflation in umbonal region; fold gently arched, parasulcus on each side, shallowly rounded.

Pedicle valve interior with hinge teeth small; dental plates thin, bow-like, free entirely, extending about  $\frac{1}{3}$  or  $\frac{1}{4}$  length of valve, converging at floor. Brachial valve interior with small cardinal process, slightly elevated over the posterior edge of hinge plate; hinge plate flat, undivided; dental socket shallow; inner-socket ridges rather high, contacting at sides of hinge plate at approximately right angles; fulcral plates hanging under sockets, low and short; crural bases butting in hinge plate, between inner and outer hinge plates, continuing toward anterior after hinge plate disappears, and connecting with

FIGURE 41 (opposite page).—*Spirigerella guizhouensis* (Liao): 1-3, 9, 10, dorsal, ventral, anterior, lateral, and posterior views ( $\times 1$ ), USNM 456177; 4, 5, 11-13, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), USNM 456179a; 16-20, idem ( $\times 1$ ), USNM 456176; 40-42, 51, dorsal, ventral, lateral, and anterior views ( $\times 2$ ) and 46, anterior view ( $\times 1$ ), USNM 456179b; 43-45, dorsal, ventral, and lateral views ( $\times 1$ ) and 47-50, dorsal, ventral, posterior, and anterior views ( $\times 2$ ), USNM 456180; all from section 27. 6-8, 14, 15, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), USNM 456178, from section 4. 23-27, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), USNM 456181a; 21, 22, anterior views ( $\times 1$ ), USNM 456181b,c; 29, 30, ventral and lateral views ( $\times 1$ ); 33-35, 38, 39, dorsal, ventral, lateral, posterior, and anterior views ( $\times 2$ ), USNM 456182; all from section 6. 28, 36, 37, ventral, dorsal, and lateral views ( $\times 2$ ) and 31, 32, dorsal and lateral views ( $\times 1$ ), USNM 456218, from section 8.



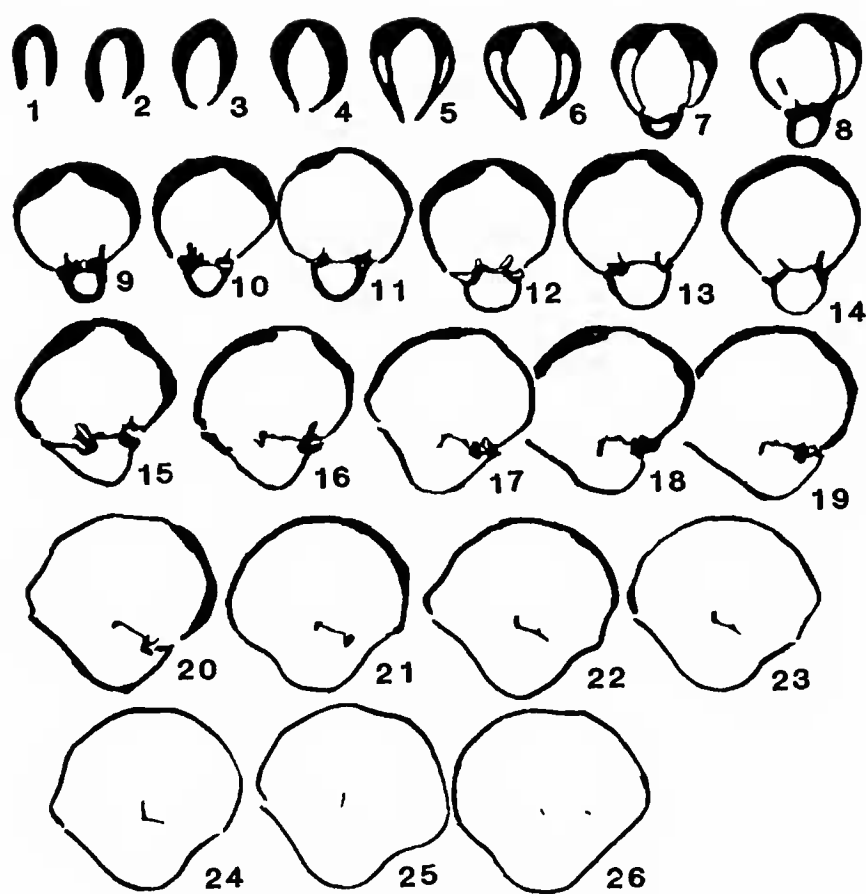


FIGURE 42.—Serial sections of *Spirigerella guizhouensis* (Liao) showing internal features.

spiralia; muscle scars narrow, separated by median ridge.

MEASUREMENTS (mm).—

USNM	<u>Pedicle valve</u>		<u>Brachial valve</u>			<u>Ratio</u>	
	<u>Length</u>	<u>Curved length</u>	<u>Length</u>	<u>Curved length</u>	<u>Width</u>	<u>Thick-ness</u>	<u>length to thickness</u>
456176	16.9	26.2	14.8	19.5	15.8	12.4	1.36
456177	14.8	22.0	13.2	15.2	13.5	9.6	1.54
456178	14.9	19.8	13.7	16.8	14.7	10.3	1.44

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation: Huayingshan section, Linshui County; Shangsi section, Guangyuan County; Beipei section, Zhongqing City, Sichuan Province; Huangzhishan section, Wuxing County, Zhejiang Province.

DIAGNOSIS.—Subcircular in outline; parasulcate anterior commissure; beak strongly incurved; internally, dental plates relatively long, converging at floor; hinge plate flat.

COMPARISON.—*Spirigerella grandis* (Davidson) and *S. obesa* were identified by Huang (1933), based on material from Huayingshan (Hanyuanhsien) section, Sichuan Province, and Zunyi County (Tsunyih sien), Guizhou Province, respectively. *Spirigerella guizhouensis* differs from them in that *S. grandis* and *S. obesa* are elongate in outline, their sulcus and fold are almost obsolete, and they have strongly swollen umbonal regions (Huang, 1933:75–78, pl. 10: figs. 27–29, pl. 11: figs. 1, 2).

DISCUSSION.—These specimens are identified here to be the same species as specimens from Guizhou Province that were assigned to *Athyris timorensis* (Rothpletz) by Huang (1933) and later assigned to *Araxathyris guizhouensis* by Liao (1980a). It is reasonable to discriminate specimens of South China from Timor's specimens, as Huang (1933:71) implied when he described *Athyris timorensis*, pointing out that "it is to be noted that our shells do differ from Broili's in some small but definite characters. Firstly, our shells are decidedly smaller in size; secondly, the lateral depressions on the brachial valve are better developed in ours than in the Timor specimens. ..." As stated in the "Discussion" of the genus *Spirigerella*, this work assigns *Athyris timorensis* (Rothpletz) to the genus *Spirigerella*.

*Spirigerella ovaloides* sp. nov.

FIGURES 43(1–15), 44

Small for genus, strongly biconvex; outline subovate; hinge short and curved, greatest width near midlength; commissure strongly parasulcate; growth lines fine and closely spaced, growth laminae irregularly distributed, most frequent near anterior margin.

Pedicle valve strongly convex; beak pointed and incurved over brachial beak; sulcus shallow, beginning somewhat anterior to midlength, rounded tongue-like at anterior edge, bounded by low, narrow and short plica, with median groove in sulcus, its trace extending to umbonal region in many specimens. Brachial valve somewhat equally strongly convex; beak incurved; fold roundly arched from midlength to anterior margin, parasulci beside fold shallow and narrow, visible only near anterior margin.

Pedicle valve interior with stout teeth; short thin dental plates fused to wall, anterior edge free only for about  $\frac{1}{2}$  their height; muscle area deeply impressed. Brachial valve interior with thin hinge plate, posterior part somewhat thickened and perforated by pit at posterior edge, becoming median furrow about midlength; hinge sockets shallow, inner-socket ridges forming sides of hinge plate, extending anteriorly, connected with crural bases.

SYNTYPES.—USNM 456183–456185.

MEASUREMENTS (mm).—

USNM	<u>Pedicle valve</u>		<u>Brachial valve</u>		<u>Width</u>	<u>Thickness</u>
	<u>Length</u>	<u>Curved length</u>	<u>Length</u>	<u>Curved length</u>		
456183	12.6	18.0	11.2	12.1	10.1	9.5
456184	11.8	16.0	10.5	11.9	10.3	8.9
456185a	11.2	16.1	10.0	11.8	9.9	8.8
456185b	11.2	16.0	10.2	12.5	10.7	8.3
456185c	9.7	15.5	8.4	12.0	8.3	6.7

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Changxing Formation: Yutangjiao section, Nantong County, Sichuan Province.

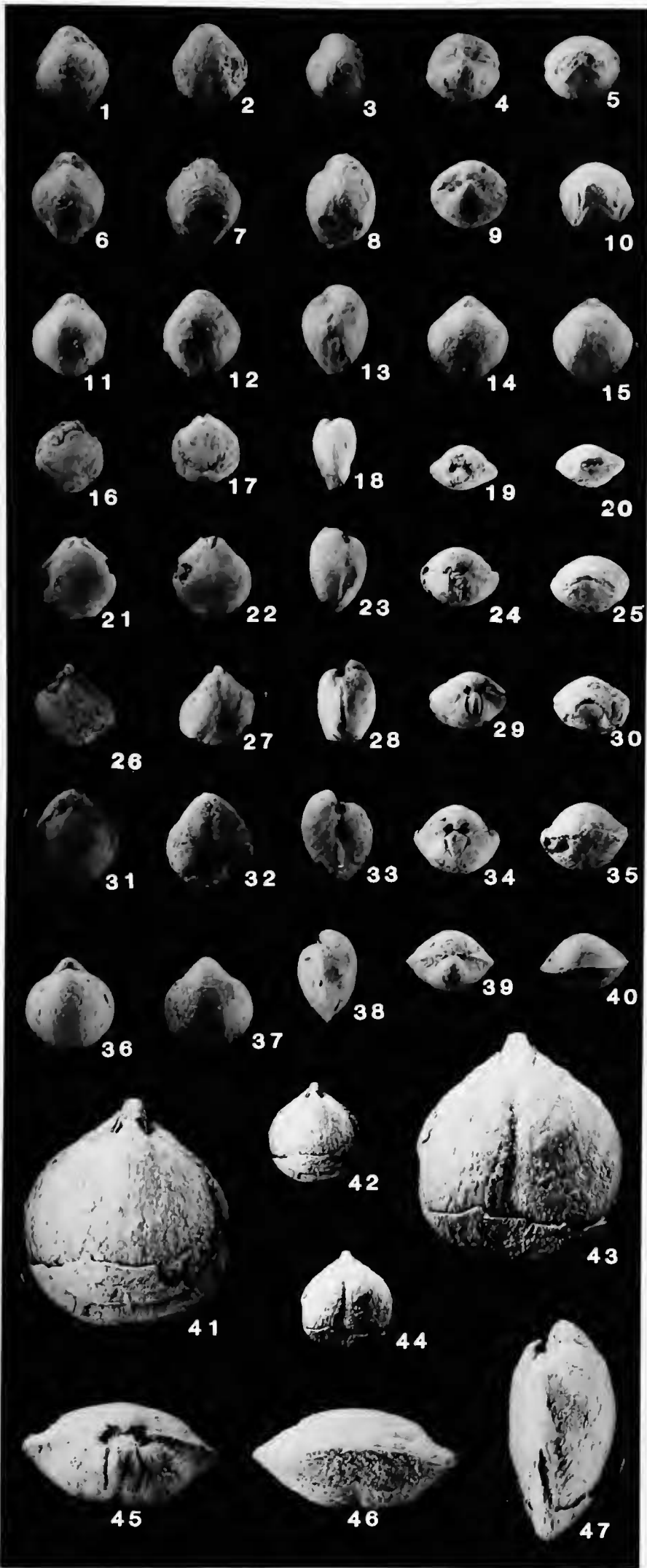


FIGURE 43 (opposite column).—*Spirigerella*. 1–15, *Spirigerella ovaloides*, new species: 1–5, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), USNM 456183; 6–10, idem ( $\times 1$ ), USNM 456184; 11–15, idem ( $\times 1$ ), USNM 456185; all from section 9, all syntypes. 16–35, *Spirigerella shuizhutangensis* (Chan): 16–20, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), USNM 456186; 21–25, idem ( $\times 1$ ), USNM 456187; 26–30, idem ( $\times 1$ ), USNM 456188; and 31–35, idem ( $\times 1$ ), USNM 456189; all from section 15. 36–47, *Spirigerella discussella*, new species: 36–40, dorsal, ventral, lateral, posterior, and anterior views ( $\times 1$ ), from section 27, USNM 456174, paratype; 41, 43, 45–47, dorsal, ventral, posterior, anterior, and lateral views ( $\times 2$ ) and 42, 44, dorsal and ventral views ( $\times 1$ ), from section 8, USNM 456175, holotype.

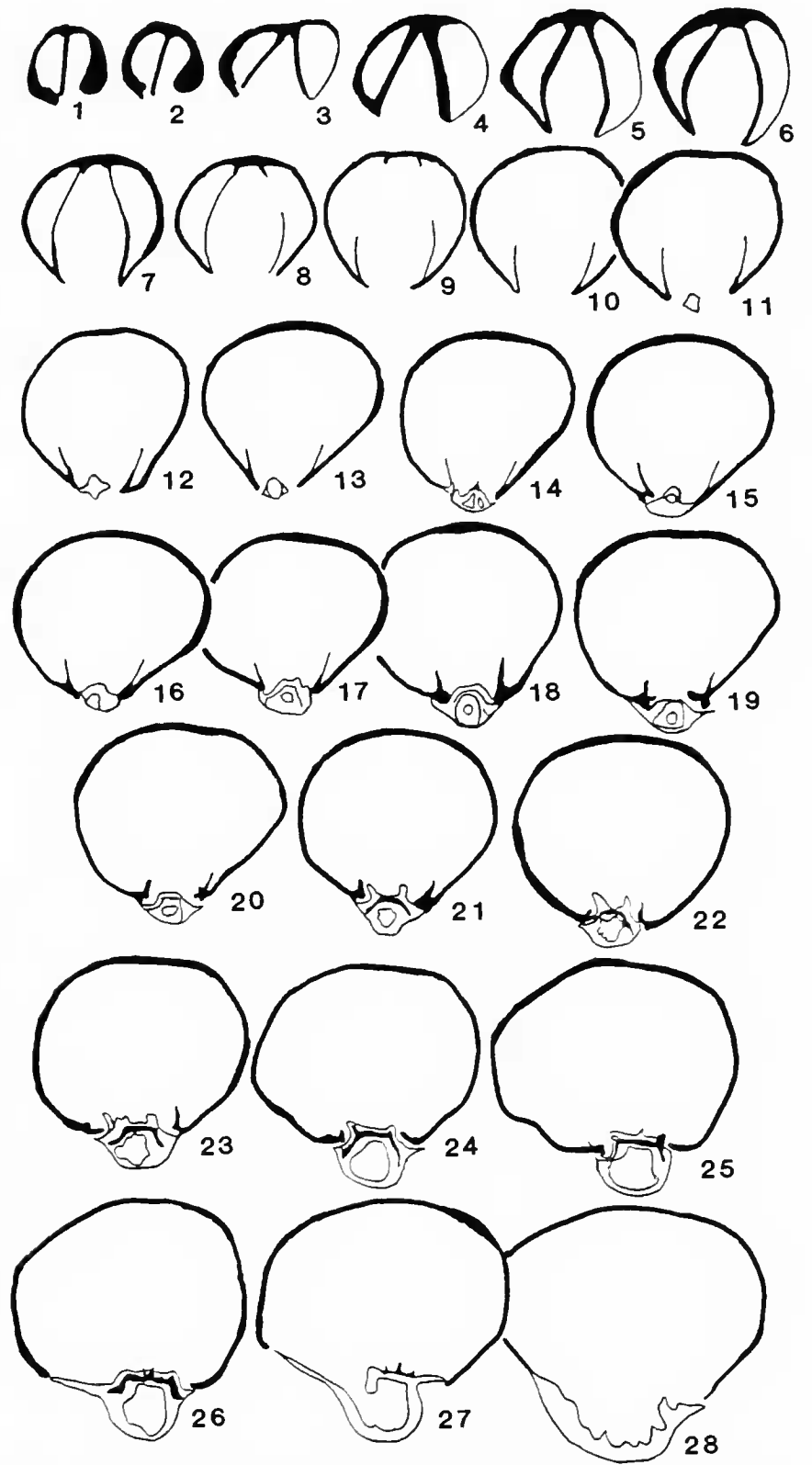


FIGURE 44.—Serial sections of *Spirigerella ovaloides* showing the internal features.

**DIAGNOSIS.**—Small, strongly biconvex, strongly parasulcate with narrow and short plica each side of sulcus at anterior edge of pedicle valve, and rounded tongue-like sulcus edge.

**COMPARISON.**—*Spirigerella ovaloides* is similar to *S. derbyi* Waagen (1883:453–455, pl. 35: figs. 4–7, 9–13, pl. 37: figs. 11–13; see also Grant, 1976:233, pl. 65: figs. 35–49) in its elongated elliptical, globular, strongly incurved beak, and tongue-like sulcus edge, but the new species has short plicae beside the sulcus, short parasulci beside the fold, and a median groove in the sulcus. The specimen from Qidi Village, Xizang (Tibet), identified by Diener (1897:63, pl. 11: fig. 14) as *S. derbyi* has a proportionately wide sulcus and small shell; therefore, it rather resembles the new species except for the differences mentioned above. The new species is most nearly comparable to *S. obesa* Huang (1933:77, 78, pl. 11: figs. 1, 2) in its size being small, elongate, and obese, but *S. obesa* has neither a fold nor a sulcus. It differs from *S. pentagonalis* Chao (1927:95–97, pl. 1: figs. 1a–d) in its obvious fold and short parasulci lateral to the fold, and its tongue-like sulcus edge.

**ETYMOLOGY.**—From the Latin, *ovalis*, meaning oval, and *-oides*, meaning similar.

*Spirigerella shuizhutangensis* (Chan, 1979),  
new combination

FIGURES 43(16–35), 45

*Araxathyris shuizhutangensis* Chan in Hou et al., 1979:99, pl. 8: figs. 7, 8, 10, 15, 16.

Medium size, moderately to strongly biconvex; outline subtriangular to subcircular, length nearly equal to width or slightly elongate; hinge short and curved, widest anterior to midlength; anterior commissure uniplicate to parasulcate, some specimens only weakly uniplicate; growth laminae irregularly spaced.

Pedicle valve with maximum convexity in posterior part, flattened from midvalve forward; sulcus very shallow to deep, flattened or rounded floor, narrow furrow from umbonal region, widened from midvalve forward; beak small, incurved. Brachial valve with even convexity; fold prominent only near anterior margin; brachial beak incurved, attenuated, and pointed.

Pedicle valve interior with short dental plates, almost converged at floor; teeth stout. Brachial valve interior with shallow hinge sockets, inner-socket ridges high; hinge plate flat, undivided.

**MEASUREMENTS (mm).**—

USNM	<i>Pedicle valve</i>		<i>Brachial valve</i>		Width	Thick- ness
	Length	Curved length	Length	Curved length		
456186	14.4	18.0	12.5	15.8	13.0	10.0
456187	12.6	16.5	11.4	14.2	11.8	8.7
456188	11.7	16.4	10.7	13.1	11.6	8.5
456189	10.5?	13.0	10.3	11.7	10.2	6.5

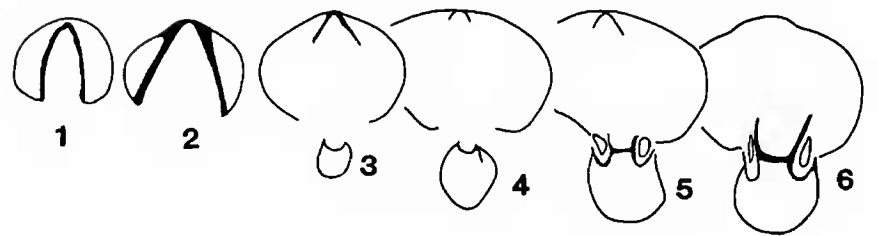


FIGURE 45.—Serial sections of *Spirigerella shuizhutangensis* (Chan) showing the interior features.

**STRATIGRAPHIC OCCURRENCES AND LOCALITIES.**—Paoshui Formation: Paoshui section, Laibin County, Guangxi Province. Changxing Formation: Huangzhishan section, Wuxing County, Zhejiang Province.

**DIAGNOSIS.**—Subcircular-shape *Spirigerella* with attenuated and pointed brachial beak.

**COMPARISON.**—*Spirigerella shuizhutangensis* (Chan) is similar to *S. guizhouensis* in its subcircular outline, shallow sulcus that widens rapidly from midvalve, and convergent dental plates, but the former usually has the anterior part of the pedicle valve more flattened, a wider anterior edge of sulcus, and an attenuated and pointed brachial beak. It differs from *S. ovaloides*, new species, in its medium-size shell, subcircular outline, flattened anterior part of pedicle valve, and attenuated and pointed brachial beak.

**Genus *Tongzithyris* Ching, Liao, and Fang, 1974**

*Tongzithyris* Ching, Liao, and Fang, 1974:313.—Liao, 1980a:268.

Large size, strongly or moderately inflated; outline subpentagonal to subcircular; anterior commissure para-episulcate (not typical episulcate because of no median fold in pedicle sulcus); growth laminae irregularly spaced, most frequent near anterior margin; shell thickened at posterior part.

Pedicle valve strongly convex, lateral slopes moderately steep or gently inclined; beak short, slightly incurved, foramen covered by beak; delthyrium covered by a pair of plates analogous to deltidial plates; sulcus beginning near beak, bounded by 2 gently arched plications, anterior edge tongue-shape. Brachial valve somewhat less strongly inflated; beak incurved; fold gently arched with median groove, lateral sulci originating somewhat posterior to midvalve.

Pedicle valve interior with strong teeth; dental plates proportionately thin, bow-like, convergent at floor, forming pseudospondylium by filling with callus. Brachial valve interior with bilobate or comb-like cardinal processes; hinge plate undivided, flat; inner-socket ridges high; muscle scars narrow and elongate, separated by median ridge; spiralia pointed laterally.

**COMPARISON.**—*Tongzithyris* resembles certain large species of *Araxathyris*, such as *A. protea* (Abich) from Dzhulfian



strata at Kuh-e-Ali Bashi, Northeast Iran, and at Dzhulfa, Azerbaijan (Smithsonian Accessions 284193 and 346823), in external features, but the former has more pronounced lateral sulci flanking the fold and a pseudospondylium in the pedicle valve.

DISCUSSION.—Ching et al. (1974) did not point out that this genus has a pseudospondylium in the pedicle valve when they established *Tongzithyris* as a genus. Liao (1980a:268) re-described the genus in more detail: "Ventral valve interior with big teeth; dental plates well-developed, bowlike, extending at both sides, converged at floor; median ridge low." After examining specimens of *T. anshunensis* Liao, which has a filled callus between convergent dental plates (Liao, 1980:269, fig. 2), we conclude that a pseudospondylium exists in *Tongzithyris*. Furthermore, a specimen of *Tongzithyris episulcata* from Tongzi County, Guizhou Province (Smithsonian Accession 339345), which is an inner core, verifies that a pseudospondylium is clearly visible in the umbonal area (Figure 47(5-8)).

TYPE SPECIES.—*Tongzithyris episulcata* Ching, Liao, and Fang (1974:313, pl. 165: figs. 10-13).

### *Tongzithyris sichuanensis* Xu, 1987

FIGURES 46, 47(1-4)

*Tongzithyris sichuanensis* Xu in Yang et al., 1987:233, 234, pl. 8: figs. 13, 14.

DIAGNOSIS.—Large size, moderately convex; subpentagonal in outline; anterior commissure para-episulcate; pedicle sulcus beginning near beak, roundly shallow with median groove at floor, anterior edge tongue-like, turn-up to dorsal, lateral furrows pronounced near anterior margin; brachial fold starting near umbonal region, dominated at anterior to midvalve with narrow and shallow groove, flanks of fold steeply tilted, lateral

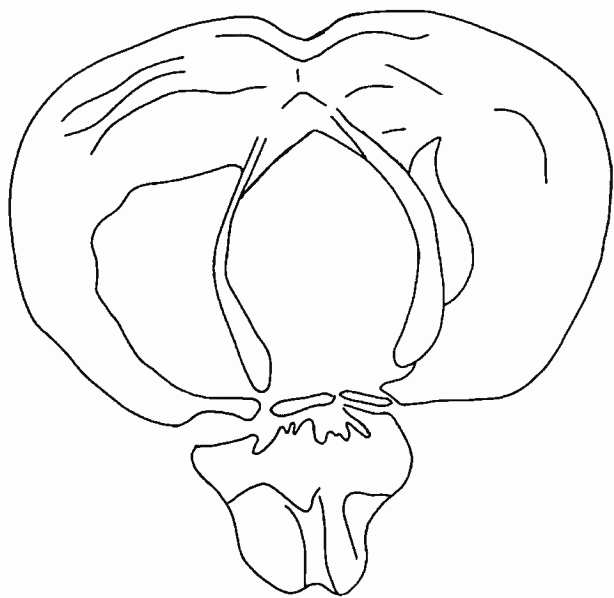


FIGURE 46.—A section near the beak of *Tongzithyris sichuanensis* Xu showing the pseudospondylium in the pedicle valve and the median ridge in the brachial valve.

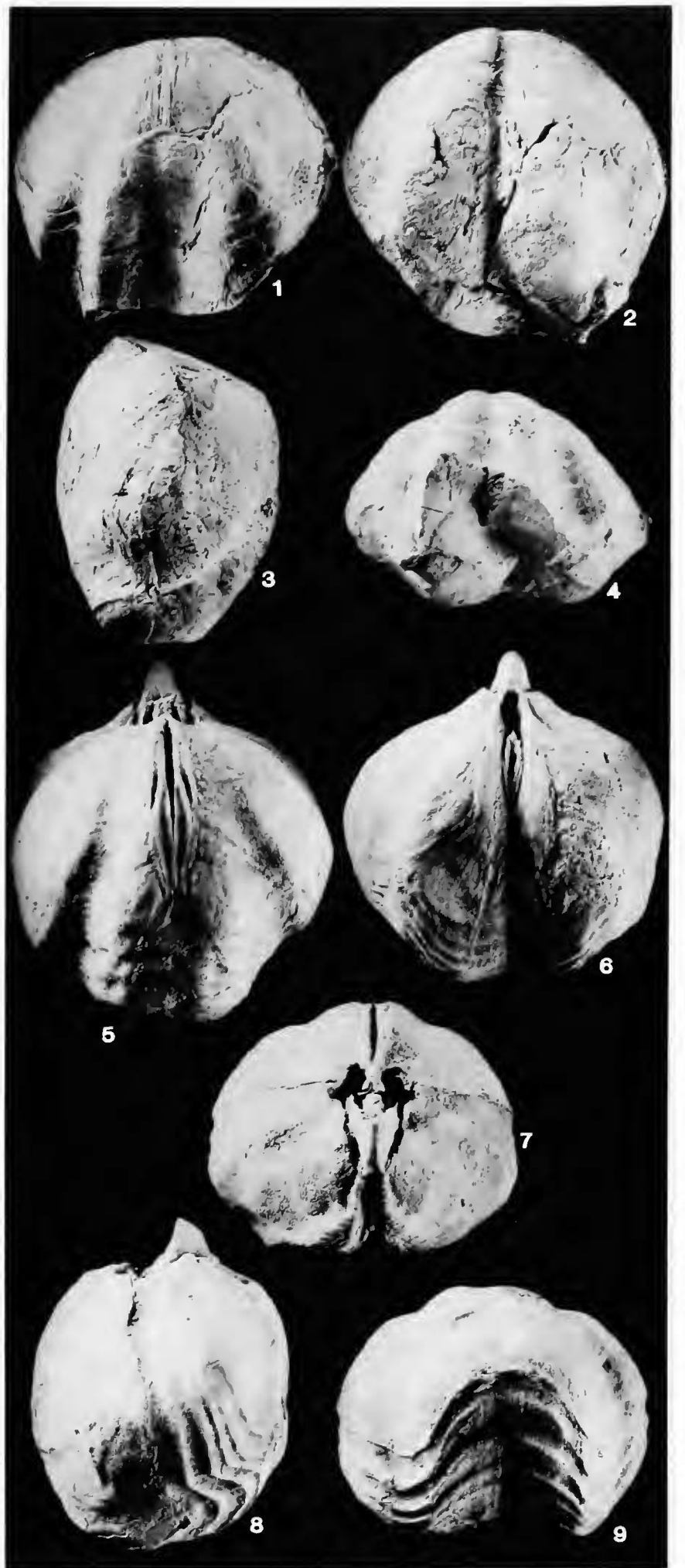


FIGURE 47.—*Tongzithyris*. 1-4, *Tongzithyris sichuanensis* Xu: dorsal, ventral, lateral, and anterior views ( $\times 1$ ), from section 6, USNM 456190, holotype. 5-9, *Tongzithyris episulcata* Ching, Liao, and Fang: dorsal, ventral, posterior, lateral, and anterior views ( $\times 1$ ), from Tongzi County, Guizhou Province, USNM 481645. (Reduced to 97 $\frac{1}{2}$ % for publication.)

plications gently arched, forming asymmetrical lateral sulci between fold and lateral plications.

MEASUREMENTS (mm).—

USNM	Pedicle valve		Brachial valve		Width	Thick-ness
	Length	Curved length	Length	Curved length		
456190	38.0	57.5	34.0	41.8	40.0	28.5

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Changxing Formation: Huayingshan section, Linshui County, Sichuan Province.

COMPARISON.—This species is characterized by its roundly shallow sulcus with median groove at floor, gently arched fold with shallow median groove that is flanked by asymmetrical lateral sulci. These features are similar to *T. episulcata*, but the latter has a more inflated and regular-shape shell, median groove that begins at the beak, and a deeply V-shape sulcus. It resembles *T. anshunensis* Liao in outline and features of the fold and sulcus, but it differs in that the latter has no lateral plications nor a median groove on either fold.

Superfamily RETICULARIOIDEA Waagen, 1883

Family ELYTHIDAE Frederiks, 1924

Genus *Squamularia* Gemmellaro, 1899

*Squamularia formilla* sp. nov.

FIGURE 48(1-24, 26, 27)

Small, outline subcircular, length and width about equal; widest posterior to midlength of brachial valve; biconvex with pedicle valve more inflated; commissure rectimarginate, neither fold nor sulcus, or, if present, only trace of sulcus on pedicle valve; growth lamellae regularly spaced, more closely spaced on brachial valve than on pedicle valve, numbering about 12-13 and 7-9 per 5 mm, respectively, in juvenile individuals and about 8-10 and 6-8 per 5 mm, respectively, in mature individuals; each edge of lamellae bearing 2 rows of fine pustules, upper row is spine-base scars, in well-preserved specimens fine spines visible, arranged radially with backward pointing spines attaching on each lamella, rarely preserved double-barrelled spine-scars.

Pedicle valve strongly convex with maximum convexity near umbonal area in lateral profile and evenly arched in anterior profile; beak thick, blunt, strongly incurved; interarea small, poorly defined; delthyrium proportionately large and open. Brachial valve slightly and evenly convex; beak short, suberect; notothyrium broad, shallow.

Pedicle valve interior with small teeth, short dental ridges; adminicula and septa absent; delthyrial ridges narrow, furrowed distally, hook-like in cross section view. Brachial valve interior with shallow hinge sockets.

SYNTYPES.—USNM 456191-456195.

MEASUREMENTS (mm).—

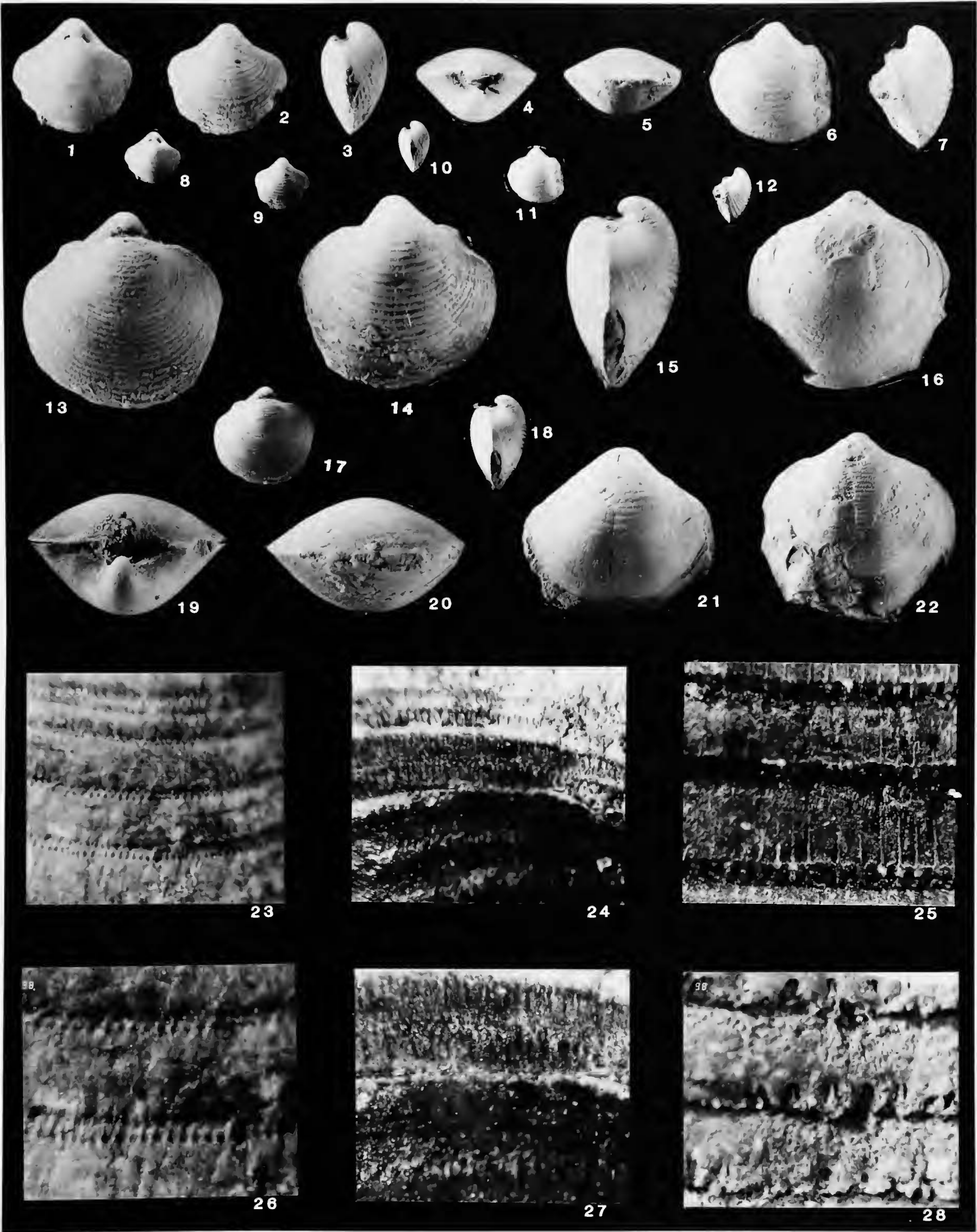
USNM	Pedicle valve length	Brachial valve length	Maximum width	Hinge width	Thickness
456191	10.1	9.0	10.6	6.5	6.1
456194	11.3		11.0?	7.0?	
456192	18.0		18.5		
456195	19.3	16.7	19.5	9.8	11.3

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Longtan Formation: Shatian section, Daye County, Hubei Province. Changxing Formation: Huayingshan section, Linshui County, Sichuan Province; Huangzhishan section, Wuxing County, Zhejiang Province.

DIAGNOSIS.—Small-size *Squamularia* with two rows of spine scars at edge of each growth lamella, neither fold nor sulcus, and proportionately wide delthyrium.

COMPARISON.—*Squamularia formilla*, new species, is similar to *Squamularia elegantuloides* Grabau (1931:198-200, pl. 16: figs. 1a-f, 2) in its wide delthyrium and its rectimarginate commissure with neither fold nor sulcus; however, the Mongolian species is larger, more transverse, and has more prominent concentric lamellae with very fine pustules. *Squamularia elegantula* (Waagen, 1883:545, 546, pl. 44: fig. 1) has a large shell and a narrow sulcus, so it is readily distinguishable from the new species. *Squamularia formilla* differs from *S. waageni* (Loczy) (see Chao, 1929:93-95, pl. 11: figs. 7-11; Grabau, 1931:204-206, pl. 16: figs. 5a-d) in that the latter has a medium-size shell, an elongately ovate outline, and a subelevated pedicle beak. Even though Chao's illustrated specimens present a shallow sulcus and Grabau's specimen has no sulcus, they seem to resemble the new species when characters of the hinge area and the delthyrium are considered. *Squamularia formilla* resembles *S. asiatica* Chao (1929:91-93, pl. 11: figs. 12-14), which was regarded as the type species when Likharev (1934) established the genus *Neophricadothyris*, but the spiralia of *S. asiatica* have yet to be found. The new species differs from *S. asiatica* in having a wide delthyrium, small hinge area, and a relatively less convex brachial valve. As Liao (1980a:265, 266) pointed out, *S. asiatica* is a Carboniferous species, but some specimens collected from the Upper Permian were identified as that species. A specimen from the Longtan Formation in Zunyi County, Guizhou Province, identified by Huang (1933:40, 41, pl. 6: figs. 7, 8), turns out not

FIGURE 48.—1-24, 26, 27, *Squamularia formilla*, new species: 1-5, dorsal, ventral, lateral, posterior, and anterior views ( $\times 2$ ), 8-10, dorsal, ventral, and lateral views ( $\times 1$ ), USNM 456191, from section 27; 6, 7, ventral and lateral views ( $\times 2$ ), 11, 12, ventral and lateral views ( $\times 1$ ), and 23, 26, micro-ornamentation ( $\times 10.4$ ,  $\times 20.8$ , respectively), USNM 456194, from section 6; 13-15, 19, 20, dorsal, ventral, lateral, posterior, and anterior views ( $\times 2$ ) and 17, 18, dorsal and lateral views ( $\times 1$ ), USNM 456195, from section 17; 16, 22, dorsal and ventral views ( $\times 2$ ) and 24, 27, micro-ornamentation ( $\times 10.4$ ,  $\times 20.8$ , respectively), USNM 456193; 21, ventral view ( $\times 2$ ), USNM 456192; all from section 6, all syntypes. 25, 28, *Neophricadothyris* sp.: micro-ornamentation ( $\times 10.4$ ), USNM 481647, 481646, respectively.



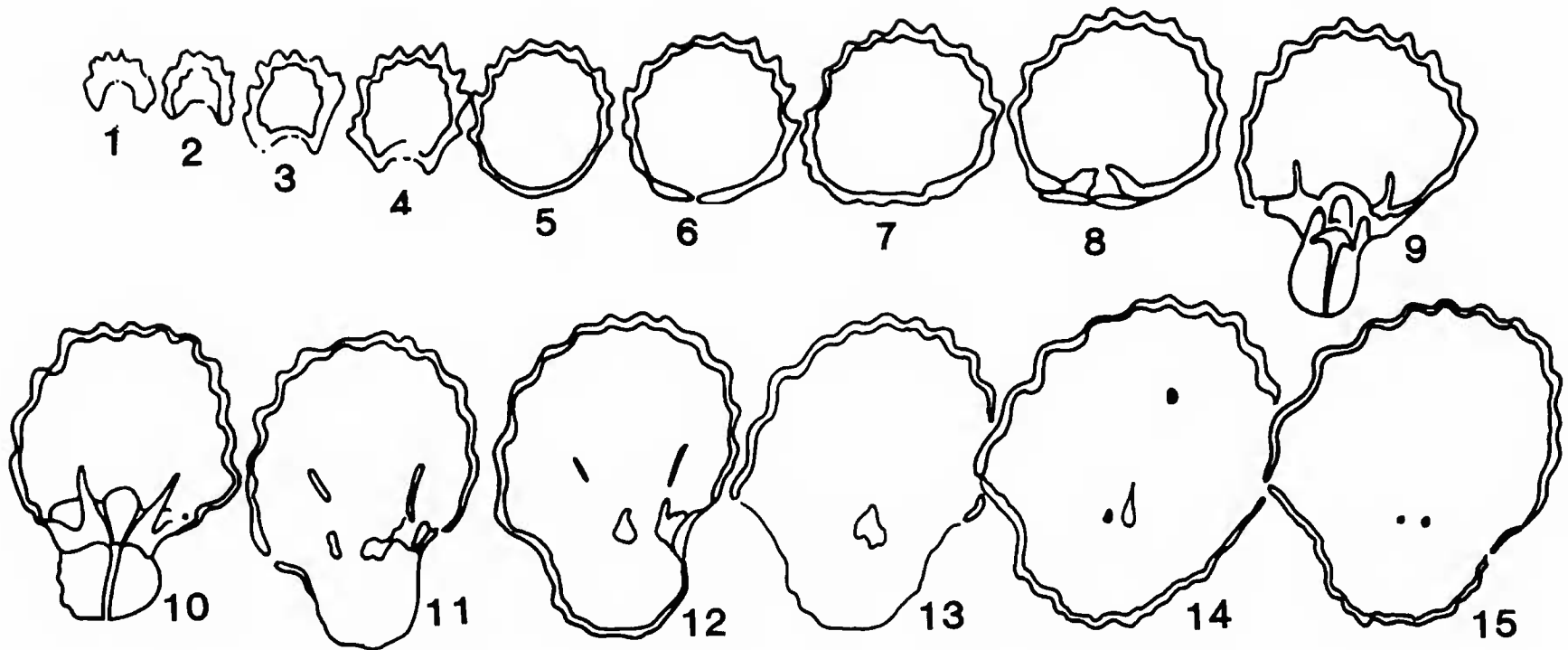


FIGURE 49.—Serial sections of *Hustedia orbicostata*, new species, showing the internal features.

to be that species. The new species differs from Huang's specimen in that it has no pseudodeltidium.

ETYMOLOGY.—From the Latin, *forma*, pretty, and *-illa*, diminutive.

#### Suborder RETZIIDINA Boucot, Johnson, and Staton, 1964

#### Superfamily RETZIOIDEA Waagen, 1883

#### Family RETZIIDAE Waagen, 1883

#### Genus *Hustedia* Hall and Clarke, 1893

#### *Hustedia orbicostata* sp. nov.

FIGURES 49, 50(1-23)

Medium size for genus, moderately biconvex; outline elongately subovate; commissure strongly serrate; neither fold nor sulcus present; costae strong, rounded, numbering 10-12 on pedicle valve, 9-11 on brachial valve.

Pedicle valve moderately convex, greatest convexity near umbo, slowly curved to anterior in lateral profile; anterior profile flattened or slightly arched with inclined sides; beak short, suberect; foramen round, mesothyridid; delthyrium relatively large, covered by deltidial plates. Brachial valve slightly more strongly convex with maximum convexity at posterior; beak blunt, slightly incurved over hinge.

Pedicle valve interior with stout teeth, tooth ridges very short; pedicle collar not well preserved. Brachial valve interior with median septum high but short, only in umbonal area; hinge plate greatly thickened with proportionately big hole at posterior part and ligulate process projecting anteriorly; hinge sockets narrow with high inner-socket ridges; crura rod-like,

short; spiralia unknown.

SYNTYPES.—USNM 456196-456198.

MEASUREMENTS (mm).—

USNM	Pedicle valve		Brachial valve		Width	Thick- ness	Pedicle valve costae
	Length	Curved length	Length	Curved length			
456196	9.8	12.7	7.8	8.1	7.5	6.1	10
456197	9.9	12.9	8.4	8.2	8.0	6.1	10

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation: Yutangjiao section, Nantong County; Beipei section, Zhogqing City, Sichuan Province. Lower Yinkeng Formation: Huangzhishan section, Wuxing County, Zhejiang Province.

DIAGNOSIS.—Medium-size *Hustedia* with rounded costae, no fold and sulcus, but with high median septum in brachial valve.

COMPARISON.—Two species of the genus, *Hustedia indica* (Waagen) and *H. remota* (Eichwald), have been reported in Upper Permian rocks of South China. *Hustedia orbicostata*, new species, most nearly resembles the specimen from Guiyang County, Guizhou Province that was identified as *H. indica* by Huang (1933:78, 79, pl. 11: figs. 3, 3a-c; see also Wang et al., 1964:639, 640, pl. 126: fig. 21). It differs from Huang's *H. indica* in that the new species has more than ten costae and lacks a sulcus and fold. *Eumetria indica* Waagen (1884:492-494, pl. 35: figs. 1, 2) has a globular outline, width nearly equal to length, and plications fewer than ten, thus, it is distinguished easily from the new species. According to Huang's description, *H. remota* has plications numbering 12 on the pedicle valve and 14 on the brachial valve and has a remarkable character in that "the interplical spaces are

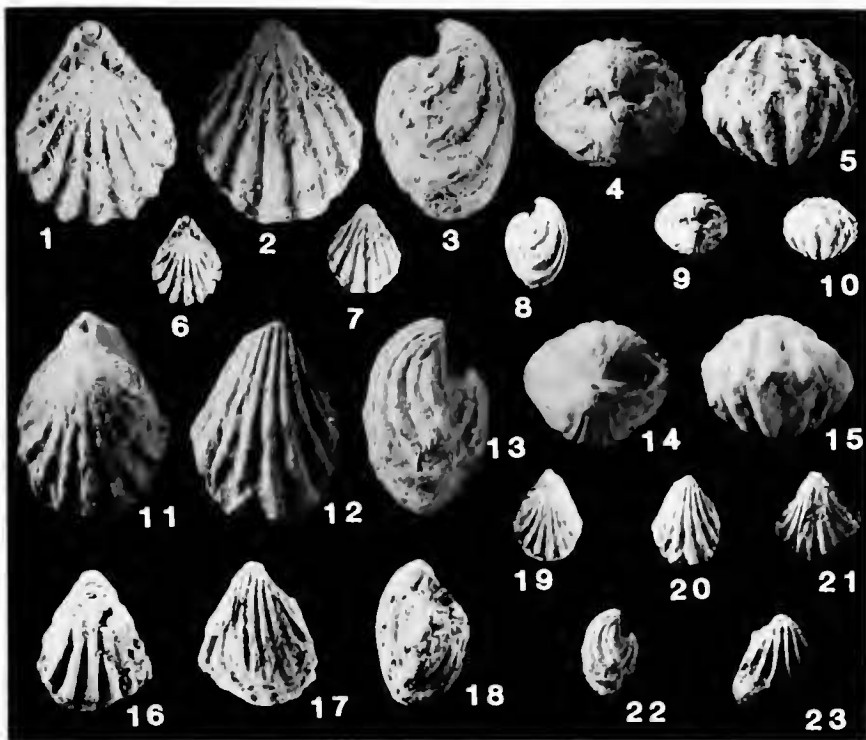


FIGURE 50.—*Hustedia orbicostata*, new species: 1–5, dorsal, ventral, lateral, posterior, and anterior views ( $\times 2$ ) and 6–10, idem ( $\times 1$ ), USNM 456197, from section 9; 11–15, dorsal, ventral, lateral, posterior, and anterior views ( $\times 2$ ) and 19, 20, 22, dorsal, ventral, and lateral views ( $\times 1$ ), USNM 456196, both from section 27; 16–18, dorsal, ventral, and lateral views, ( $\times 2$ ), USNM 456198, from section 8; 21, ventral view ( $\times 1$ ), USNM 456199; 23, idem ( $\times 1$ ), USNM 456200, both from section 27; all syntypes. (Reduced to 97½% for publication.)

distinctly flat-bottomed and appear wider than the plicae” (1933:81). Obviously, Huang’s specimens collected from Dading County (Tatinghsien), Guizhou Province, differ from the new species. Grabau (1931:125–128, pl. 7: fig. 8a–e; 1934:103, 104, pl. 7: fig. 3) emphasized the “sub-rotund” outline of *H. remota*, and the figure shown by Huang (1933, pl. 11: fig. 5) is virtually circular in outline. Another specimen of *H. remota*, described by Grabau (1934:103, 104, pl. 7: fig. 3), is “nearly as wide as long.” Thus, the new species is readily distinguishable from *H. remota*.

*Hustedia orbicostata*, new species, is similar to *H. spicata* Cooper and Grant (1976b:2799, 2800, pl. 741: figs. 12–40) in both nonelevated median costa on the brachial valve and high median septum, but it differs in that the new species has rounded costae and neither fold nor sulcus. It somewhat resembles *H. cepoidea* Cooper and Grant (1976b:2767–2769, pl. 732: Figs. 56–85) in its outline and costae numbers, but the latter has angular costae and a low median septum. *Hustedia decollatensis* Cooper and Grant (1976b:2778, 2779, pl. 735: figs. 54–68) is readily distinguishable from the new species in that the former has a low median ridge rather than a septum in the brachial valve even though they both are similar in their numbers of rounded costae and in having neither fold nor sulcus.

ETYMOLOGY.—From the Latin, *orbis*, meaning circle, and *costata*, meaning ribbed (rounded costae).

## Order TEREBRATULIDA Waagen, 1883

### Superfamily CRYPTONELLOIDEA Thomson, 1926

#### Family NOTOTHYRIDIDAE Likharev, 1960

#### Genus *Rostranteris* Gemmellaro, 1899

#### *Rostranteris ptychiventria* sp. nov.

FIGURES 51, 52(1–16)

Small, usual size for genus; unequally biconvex; elongate-ovate to subtriangular in outline, widest anterior to midvalve or near anterior margin; sides broadly rounded to slightly angular; anterior commissure antiplicate; surface of brachial valve with posterior ½ smooth but anterior ½ plicated, plicae on pedicle valve beginning from umbonal area, interspaces somewhat narrower than plicae; growth laminae well developed near anterior margin.

Pedicle valve strongly convex in lateral profile with umbonal area fairly strongly curved with maximum convexity near midvalve, anterior profile strongly domed, crest serrate and sides sloping steeply or moderately; 2 strongest median costae forming fold, each side having 1 or 2 moderate costae. Brachial valve gently inflated, with steep anterior slope in lateral profile, anterior profile flattened or slightly depressed at median region, forming steep slope at each side; sulcus observable near anterior margin, bounded by 2 strong plicae, median plica in sulcus sometimes weak, sometimes strong, but always slightly lower than lateral plicae; each side having 1–2 plicae.

Interior of pedicle valve without dental plates but with strong dental ridges, teeth stout. Brachial valve interior with small bilobate cardinal process; hinge sockets slit-like with strong inner-socket ridges; hinge plate undivided, flat, perforated at posterior edge; crural bases rod-like, butting in both sides of hinge plate and touching inner-socket ridges; loop centronelli-form, long, extending about 3.5 mm, with high median plate that extends beyond conjunction of main hands.

HOLOTYPE.—USNM 456201.

MEASUREMENTS (mm).—

USNM	Pedicle valve		Brachial valve		Width	Thick-ness
	Length	Curved length	Length	Curved length		
456201	10.1?	17.1	8.2	10.2	12.5	8.5
456203	10.2	14.9?	7.5	9.5	8.1	8.0
456202	11.2?	14.2	9.8	11.0	9.7	7.2

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Long-dongchuan Formation: Xikou section, Zhenan County, Shaanxi Province.

DIAGNOSIS.—Small, antiplicate commissure; anterior ½ plicated on brachial valve, plicae beginning from umbonal area on pedicle valve.

COMPARISON.—This new species is mainly characterized by its long plicae on the pedicle valve, which distinguishes it from

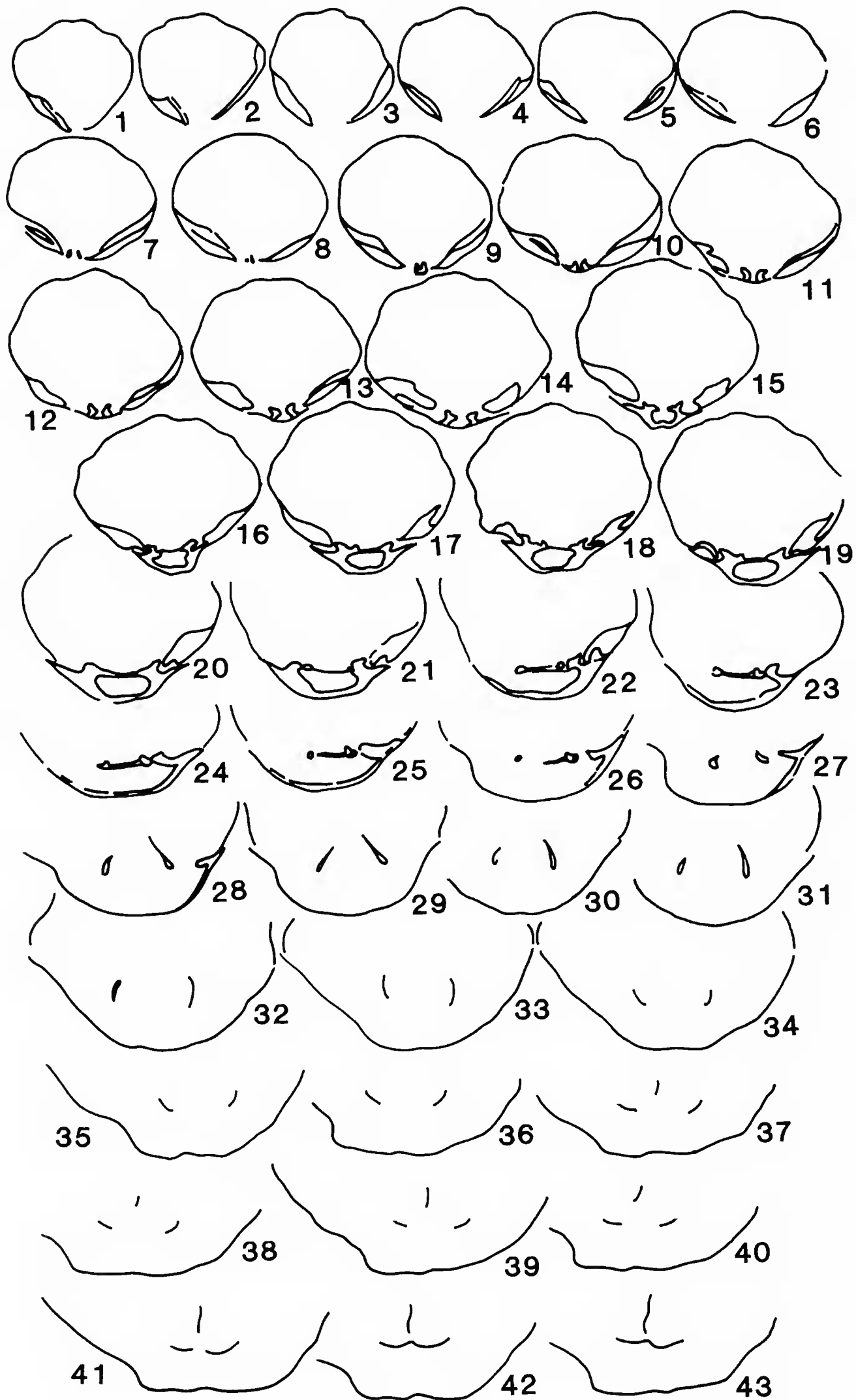


FIGURE 51.—Serial sections of *Rostranteris ptychiventria*, new species, showing the internal features.

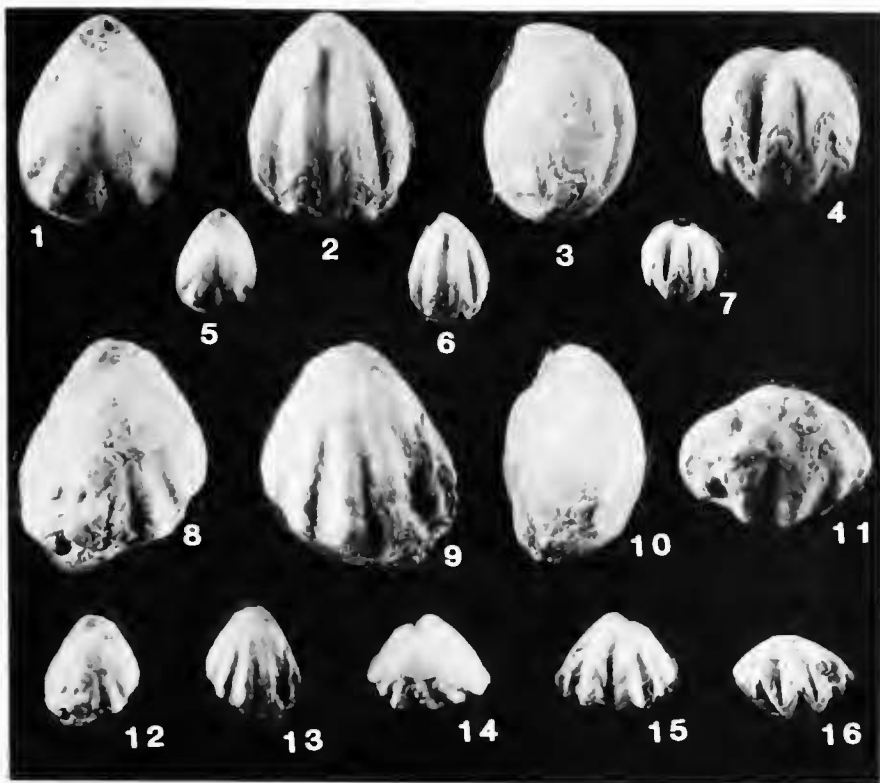


FIGURE 52.—*Rostranteris ptychiventria*, new species: 1-4, dorsal, ventral, lateral, and anterior views ( $\times 2$ ); 5-7, dorsal, ventral, and anterior views ( $\times 1$ ), USNM 456201, holotype; 8-11, dorsal, ventral, lateral, and anterior views ( $\times 2$ ), USNM 456203, paratype; 12, 13, dorsal and ventral views ( $\times 1$ ), USNM 456203, paratype; 14-16, dorsal, ventral, and anterior views ( $\times 1$ ), USNM 456202, paratype; all from section 32.

most other species of the genus *Rostranteris*. *Rostranteris adrianiensis* Gemmellaro (1899:105, 106, pl. 25: figs. 35-39; see also Stehli, 1962:100, pl. 20: group A) has five weak plicae, three on the brachial valve and two on the pedicle valve, which set out near the frontal margin. This arrangement forms a striking contrast to the new species, which has strong plicae, more than 4 on each valve. *Rostranteris pulchrum* Gemmellaro (1899:106, pl. 25: figs. 58-62) is similar to the new species in its size and outline, but it is readily distinguishable in that the former has rather less thickness and has weak and short plicae. *Rostranteris gibbosum* Gemmellaro (1899:110, pl. 25: figs. 40, 41) has a relatively big, swollen shell and a conspicuous pedicle sulcus (USNM Accession 180508), although it is comparable to the new species in having long plicae on the pedicle valve. *Rostranteris ptychiventria*, new species, closely resembles *R. inflatum* Gemmellaro (1899:109, pl. 25: figs. 42-45, pl. 30: fig. 41; Stehli, 1962:100, 101, pl. 20: group B) in its appearance, including shell size, outline, and profile, but it differs in that the latter has an obvious pedicle sulcus and relatively short plications originating near midvalve. It is externally comparable to *Mongolina subdieneri* Grabau (1931:103-105, pl. 8: figs. 5a-f), which has short plicae and whose interior features are not known.

DISCUSSION.—Several species of the genus have the pedicle valve sulcus, for example, *R. sinuatum* Gemmellaro (1899:111, pl. 25: figs. 52-57; USNM Accessions 180508, 183389, and 225239) has a typical sulcus in the pedicle valve and a rather broad interspace between the two main plications. In the new

species, however, the interspace between the two main plications on the pedicle valve is narrower than the plications, so it is unreasonable to call it a "sulcus" in this case.

ETYMOLOGY.—From the Greek, *ptychos*, meaning fold, and from the Latin, *venter*, meaning front (as in ventral).

### Genus *Notothyris* Waagen, 1882

#### *Notothyris bifoldes* sp. nov.

FIGURES 53, 54(1-4)

Small, moderately biconvex, elongate ovate in outline, greatest width near midlength; sides smoothly rounded, anterior margin subtruncated; anterior commissure rectimarginate with sharp angular indentation; surface smooth except for anterior  $\frac{1}{3}$  where marked by 8-9 plications; 5 somewhat strong plications forming low fold with slightly depressed crest, brachial valve of some specimens having 3 median plications somewhat lower than 2 bound-lateral plications; 2 somewhat strong plications bounding low fold on pedicle valve, those having 2 slightly weakened plications between them; 1 or 2 lateral plications at each side; growth lines weak, occasionally raised.

Pedicle valve strongly and evenly convex in lateral profile, with rounded bow-like curvature; anterior profile evenly rounded with steep sides; beak erect and slightly incurved; foramen circular, mesothyridid; delthyrium appearing to be covered by deltidial plates. Brachial valve somewhat less strongly convex; beak pointed, incurved.

Pedicle valve interior with strong pedicle collar in delthyrial cavity; no dental plates, teeth stout. Brachial valve interior with shallow hinge sockets, fulcral plates strong but short, inner-socket ridges low; hinge plates fused together, crural bases forming at sides of hinge plates; posterior foramen seemingly expressed as narrow tube; muscle scars narrow oval-shape at umbonal region.

HOLOTYPE.—USNM 456205.

MEASUREMENTS (mm).—

USNM	Pedicle valve		Brachial valve		Width	Thick-ness
	Length	Curved length	Length	Curved length		
456204	10.2	13.6	8.0	8.6	7.8	6.8
456205	10.4	13.3	9.0	9.5	8.4	7.1

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Changxing Formation: Huangzhishan section, Wuxing County, Zhejiang Province. Paoshui Formation: Paoshui section, Laibing County, Guangxi Province.

DIAGNOSIS.—Small, elongately ovate; anterior commissure rectimarginate with sharply indented margin; 7-8 plications; weak folds on both valves.

COMPARISON.—Multiple plications at anterior  $\frac{1}{3}$  and 2 weak folds on both valves distinguish this from other species of the genus. *Notothyris triplax* Grant (1976:253, 254, pl. 46: figs.

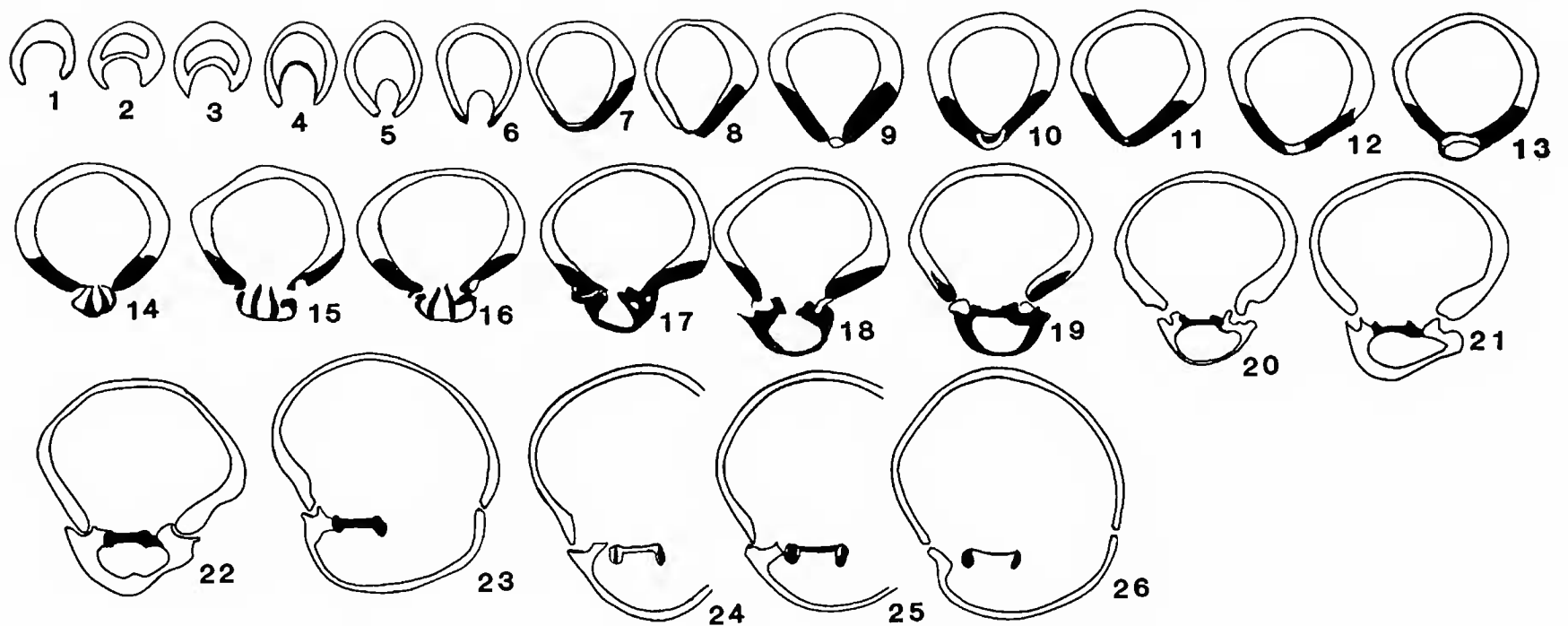


FIGURE 53.—Serial sections of *Notothyris bifoldes*, new species, showing the internal features.

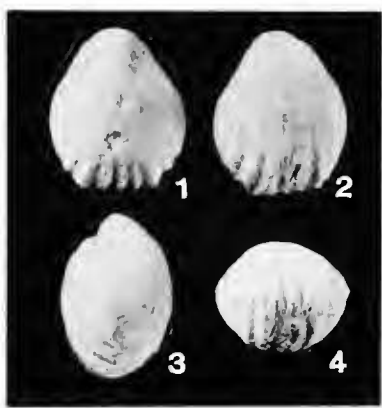


FIGURE 54.—*Notothyris bifoldes*, new species: 1–4, dorsal, ventral, lateral, and anterior views ( $\times 1.5$ ), from section 15, USNM 456205, holotype.

1–8) is similar to the new species in outline, but it differs in having 3 plications on the dorsal valve and 4 on the ventral valve. As Grant pointed out, *N. praelecta* Reed (not Waterhouse and Piyasin, 1970) has more than 5 plicae on the dorsal valve (Grant, 1976:253), and Reed (1944:167) described it as “bearing 6 subangular longitudinal plications.” Thus, the number of plicae of *N. praelecta* seems to resemble the new species; however, *N. bifoldes* is smaller than *N. praelecta*, and *N. praelecta* has 2 median plicae that are much stronger than others on the pedicle valve. *Notothyris bifoldes*, new species, strongly resembles *N. revocata* Reed in respect to number and nature of median plications, which initially caused us to

identify it as the same species, but considering the uncertain nature of the Salt Range species’ internal structures and obvious external differences, we describe this new species as differing from *N. revocata* in its small size, elongately ovate outline, no sulcus on the brachial valve, and fewer lateral plications.

DISCUSSION.—The interior structures of the new species basically coincide with genera *Notothyris* Waagen and *Rostranteris* Gemmellaro, but we have not ascertained what type of loop it contains. The cardinalia in several genera of the family Notothyrididae are almost the same, but the loops are different. The external dimension seems to reflect the shape of the loop among families within the Upper Permian. For example, *Notothyris* has numerous plications and an anterior commissure that is rectimarginate to faintly sulcate (Stehli in Treatise, 1965:H758; Grant, 1976:253); *Rostranteris* has an intraplicate anterior commissure (Stehli in Treatise, 1965:H759); and *Timorina* has 2, 3, or more median plications on the pedicle valve that are raised into a slight fold (Stehli in Treatise, 1965:H760). Accordingly, we hereby place the new species in the genus *Notothyris*, although it may be that *N. praelecta* is attributable to *Timorina* Stehli, 1961. Furthermore, the interior features of *N. bifoldes*, new species, is compatible with the internal features of four species of *Notothyris*, which Likharev (1936:268–271, figs. 4–7) revealed in his serial sections.

ETYMOLOGY.—From the Latin, *bi*, meaning two, and *foldes*, is a play on the word “fold.”



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