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EVALUATION OF THE ORDOVICIAN ACRITARCH GENUS *AMPULLULA* RIGHI

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(9 figures, 4 tables & 2 plates)

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ABSTRACT. The Ordovician acritarch genus *Ampullula* Righi 1991 is evaluated and emended based on a review of published literature and new studies on Arenigian material from the Dawan Formation, Upper Yangtze Region, Yangtze Platform, South China. *Ampullula* has been described as a monospecific genus with the type species *A. suetica* from Upper Arenigian to Llanvirnian sediments of Öland, Sweden. However, investigations on large populations from three South Chinese sections neccessitate the attribution of two further species to the genus: *Aremoricanium erchunense* Fang Xiaosi 1986 = *Ampullula erchunensis* comb. nov., emend., which is revised in this paper and *Ampullula princeps* which is introduced as a new species. *Cymatiogalea crassula* Vavrdová 1990 is considered a junior synonym of *A. erchunensis*. The palaeobiogeographical relationships between South China, peri-Gondwana and Baltica are discussed. While the acritarch assemblages from South China contain some characteristic forms which have also been recorded from Bohemia and Morocco (i.e., the peri-Gondwanan Palaeoprovince), the lithological character of the Chinese sections is generally more comparable to those of Baltica.

KEYWORDS: Ordovician, Arenigian, South China, Yangtze Platform, acritarchs, *Ampullula*.

RESUME. Evaluation du genre d'acritarches *Ampullula* Righi. Le genre d'acritarches Ordovicien *Ampullula* Righi 1991 est évalué et corrigé en se basant une révision de la litérature publiée et de nouvelles études sur de matériel l'Arénigien de la Formation de Dawan, région du Yangtze supérieur, plate-forme du Yangtze, Chine du Sud. *Ampullula* a été décrit dans des sediments de l'Arénigien supérieur- Llanvirnien de Öland, Suède, comme un genre monospécifique, avec pour espèce-type *A. suetica*. Des études de populations plus importantes dans trois coupes de la Chine du Sud nécessitent l'attribution de deux espèces supplémentaires au genre: *Aremoricanium erchunense* Fang Xiaosi 1986 = *Ampullula erchunensis* comb. nov., emend., revisée dans cette note, et *Ampullula princeps* qui est présentée comme espèce nouvelle. *Cymatiogalea crassula* Vavrdová 1990 est considéré comme un synonyme postérieur de *A. erchunensis*. Les relations paléogéographiques entre la Chine du Sud, peri-Gondwana et Baltica sont discutées. Si les assemblages d'acritarches du sud de la Chine contiennent quelques formes caractéristiques qui ont été trouvées également en Bohème et au Maroc (c.à.d., dans la paléoprovince peri-gondwanienne), le caractère lithologique des coupes chinoises est en revanche généralement plutôt comparable à celui des coupes de Baltica.

MOTS-CLES: Ordovicien, Arénigien, Chine du sud, plate-forme Yangtze, acritarches, *Ampullula*.

1. INTRODUCTION

Three sections from the Lower Arenigian Dawan Formation in the Upper Yangtze Region, Yangtze Platform, South China have been palynologically investigated. The stratigraphical interval of the *Azygograptus suecicus* graptolite Zone yields diversified and well preserved palynomorphs (acritarchs, chitinozoans and some scolecodonts). In the upper part of this zone or probably the lowest *Undulograptus sinodentatus* graptolite Zone the monospecific Ordovician acritarch genus *Ampullula* rarely occurs. The type species, *A. suetica*, is an easily recognizable acritarch and is distinctive from

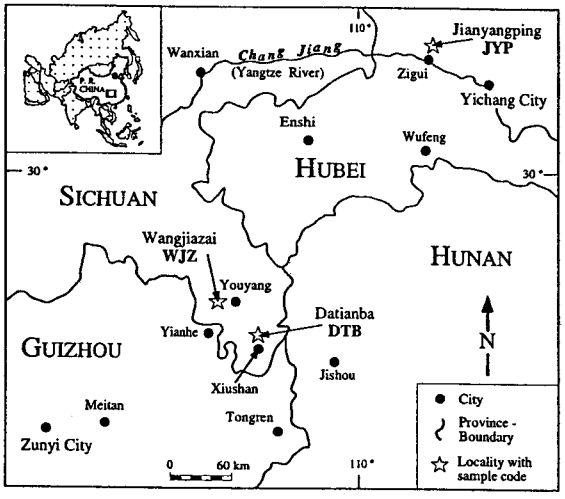

Figure 1. Location map of the sections investigated. Sample code is marked by a white star: Jianjiangping (JYP), Hubei Province; Wangjiazei (WJZ) & Datianba (DTB), Sichuan Province.

most other species. However, the genus should be revised because its morphological variability was too restricted in the original description, thus excluding further species which are assignable to this genus.

Within the Chinese assemblages, more than 65 acritarch specimens which although highly variable, fit very well in the wider concept of *Ampullula* presented herein. Based on the present investigation of the Chinese material, two additional species should be included in the genus. These are *Ampullula erchunensis* (Fang Xiaosi 1986) comb. nov., emend. (= *Aremoricanium erchunense*) and *Ampullula princeps* sp. nov., described herein. Currently, *Ampullula* is only known from Sweden and more recently from South China (Tongiorgi *et al.*, 1995).

Palynological results from the Upper Yangtze Region have led to the suggestion that the Mediterranean Province *sensu* Vavrdová (1974), e.g., Avalonia, Gondwana and supposed terranes as there are, for instance, Iberia, Perunica, Armorica, might be extended up to South China (Li Jun, 1987). In addition to the typical Mediterranean or peri-Gondwanan (Martin & Dean, 1988; *sensu* Van der Voo, 1988) taxa, some species occur in the Chinese material, which have so far only been recorded from the Baltic Province (Scandinavia, Baltic States, NE-Poland, etc.). Some taxa which have so far been only described from Australian levels are also present. Only small part of the Chinese assemblages is possibly endemic. Therefore, the South Chinese material is not clearly relatated or exclusive to any "province", but shows strong affinities to Bohemia and Morocco, both of which are classical parts of the Mediterranean Province *sensu* Vavrdová (1974).

The systematic study of the genus *Ampullula* Righi 1991 is part of an intensive palynological investigation of Ordovician sediments from China. This material partly yields rich and diversified acritarch assemblages. First palynological results have been already published (Brocke, 1992; Brocke *et al.*, 1995), and will be presented in the subsequent Ph.D. thesis (Brocke, 1997). The palynological investigation is involved in a research project beween the Yichang Institute of Geology and Mineral Resources and the Technische Universität Berlin.

2. MATERIAL AND METHODS

2.1. SECTIONS IN THE STUDY AREA

During two field campaigns, samples from Cambrian to Silurian sediments of different localities in the Upper Yangtze Region, Yangtze Platform, South China were collected. In this paper, three localities of the Lower Ordovician Dawan Formation are discussed. The Datianba and Wangjiazei sections are situated in the East Upper Yangtze Region, north of the town Xiushan, respectively west of the town Youyang, in the SE part of the Sichuan Province. The Jianjiangping section is located in the NW Upper Yangtze Region, near the Yangtze River north of Zigui, in Yichang area of the Hubei Province (Fig.1). These sections belong to a carbonate platform although they comprise of different lithological successions, indicated by the type of rocks and distinct thicknesses of the three members of the Dawan Formation (Fig. 2). The Lower Member of the Jiangjiangping section is mainly composed of greyish nodular limestones and bioclastic limestones, intercalated with thin bedded marlstones and grey-green shales. The Middle Member is characterized by reddish to greyish nodular limestones, bioclastic limestones, marlstones and glauconite minerals. The Upper Member comprises of greyish marlstones, bioclastic limestones, that are partly reddish and nodular. Shales are less represented. The total thickness of the Jianjiangping section is about 32 m. The two faults in the upper

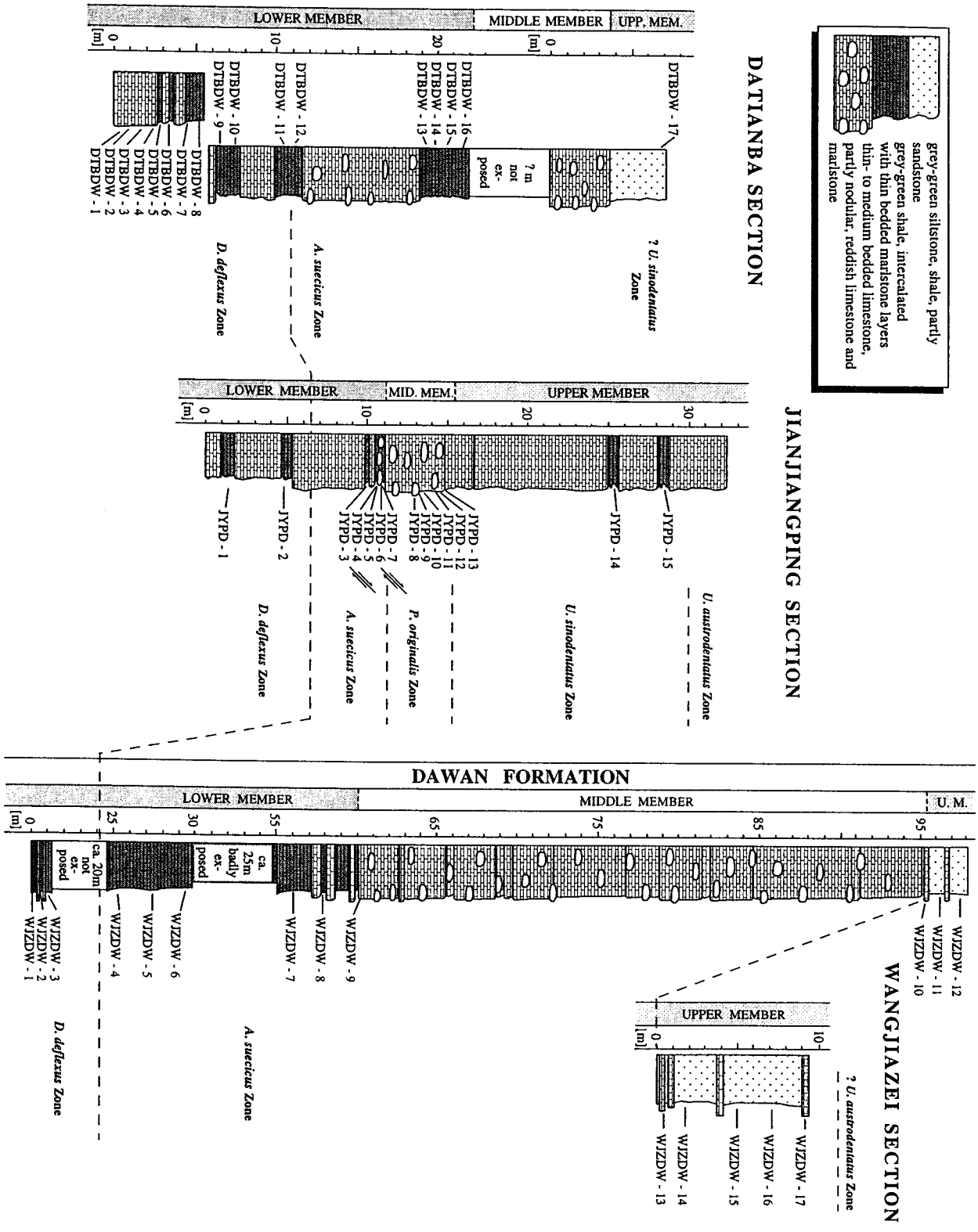

Figure 2. Three sections illustrating the lithostratigraphic division of the Arenigian Dawan Formation into a Lower, Middle and Upper Member. The corresponding biostratigraphical zonation is based on graptolites or conodonts (Middle Member). Observed specimens of the genus *Ampullula* are recorded in samples DTBDW-14 - 17 (Datianba section), JYPD-2 - 4 (Jianjiangping section), and WJZDW-4,5, 12, 14 - 16 (Wangjiazei section).

part of the Lower Member do not show any evidence for a significant reduction of the thickness. Lithology and total thickness of the Janjiangping sections are similar to the Daping section, which is about 37 m thick. The Huanghuachang section differs in the total thickness, which is about 63 m (Chen Xu *et al.*, 1995). Both localities are in the Yichang area, ca. 70 km to the east of the Jianjiangping section. The sedimentology of the Daping section was described in detail by Lindström *et al.* (1991).

The two southern sections are both near the eastern Jiagnan Region (so-called Old lands, or Jiangnan Islands), a complex of a Proterozoic Island Arc System (Xi Yaokun, 1985), probably active as a marginal uplift belt of the Yangtze Paraplatform (Ren Jishun *et al.*, 1987: 56) during the Palaeozoic. The lithological successions are influenced by a greater portion of clastic input especially in the Upper Member. Typical sediments of the Lower Members are siltstones, shales and marlstones. In the middle part carbonate rocks dominate. The Middle Members are similar to the lithology in the Jiangjiangping section, but reddish marlstones and shales are more abundant. The Upper Members show an increasing amount of siltstones. The sections described above are thicker than the Jianjiangping section, whereas the Lower and Middle Members of the Wangjiazei section are particularly thick.

All the three localities are situated on a relatively stable shallow carbonate platform, which was part of the western shelf area of Gondwana (e.g., Scotese & Golonka, 1992) during the Early Ordovician. However, the differences documented by the lithological character of the rocks, as well as the thicknesses of the various members indicate a significant vertical and lateral variation during deposition of the Dawan Formation. This, in the first instance is due to a distinct facies differentiation on the platform itself, and secondly because of a general deepening on the platform, caused by a general transgression up to the Llanvirnian. In the sense of sequence stratigraphy, the two shale-rich intervals at the top of the Lower Member are interpreted as the maximum flooding surface (mfs) within the transgressive cycle, whereas the Upper Member represents the Highstand Systems Tract (HST). Sea level highstand is indicated by several discontinuity surfaces, phosphatic layers and glauconite minerals (Brocke, 1997). Lindström *et al.*, 1991 described this phenomenon as a drowning carbonate platform.

2.2. PREVIOUS ACRITARCH INVESTIGATIONS

Acritarchs from the Dawan Formation of the Upper Yangtze Region, e.g., Hubei Province, have been variously reported in the literature. Zhong Guofang (1981), Lu Lichang (1987), Li Jun (1991) and Yin Leiming (1994) reported acritarch assemblages from the Huanghuachang section, near Yichang. Brocke (1992) presented preliminary results from the Jianjiangping section. Tongiorgi *et al.* (1992, 1995) described a palynological assemblage (sample HD2) of the Daping section, 4 km north of Huanghuachang.

All of these papers concentrated particularly on palynological investigations from layers of the upper *Didymograptus deflexus* graptolite Zone to the *Azygograptus suecicus* graptolite Zone, which yields rich and well preserved acritarch assemblages. Authors studies on the whole Ordovician succession shows that these assemblages are obviously the most prolific of the Yangtze Platform. Therefore, most of the Ordovician acritarch work in South China is focused on this relatively short stratigraphical interval.

For instance, excellent material was described from the *A. suecicus* graptolite Zone of the Meitan Formation (Li Jun, 1987; Li Jun, 1991), Tongzi County, Guizhou Province, and the Jiuxi Formation (Li Jun, 1990; Li Jun, 1991), Jishou, Hunan Province, which belongs to the SE parts of the Upper Yangtze Region (South China Plate).

Lower Ordovician acritarchs are also known from other parts of the Upper Yangtze Region as reported by Xing Yusheng (1980), Dachengsi Formation (upper Tremadocian and Arenigian) of Emeishan, Sichuan Province; Fu Jiayuan (1986), Xiliangsi Formation (Arenigian ?, Llanvirnian) and Jiancaogou Formation (Upper Ordovician) from the Liangjiaqiao area of Zhenba County, Shaanxi Province; Fang Xiaosi (1986), Tangchi Formation (Tremadocian), Hongshiya Formation (Arenigian), and Qiaojia Formation (Llanvirnian) of the Kunming-Luquan region, Yunnan Province; and Gao Lianda (1991), Hongshiya Formation (Arenigian) of Wuding, Yunnan Province.

Lower Ordovician acritarchs from the North China Plate are described by Yin Leiming (1985,

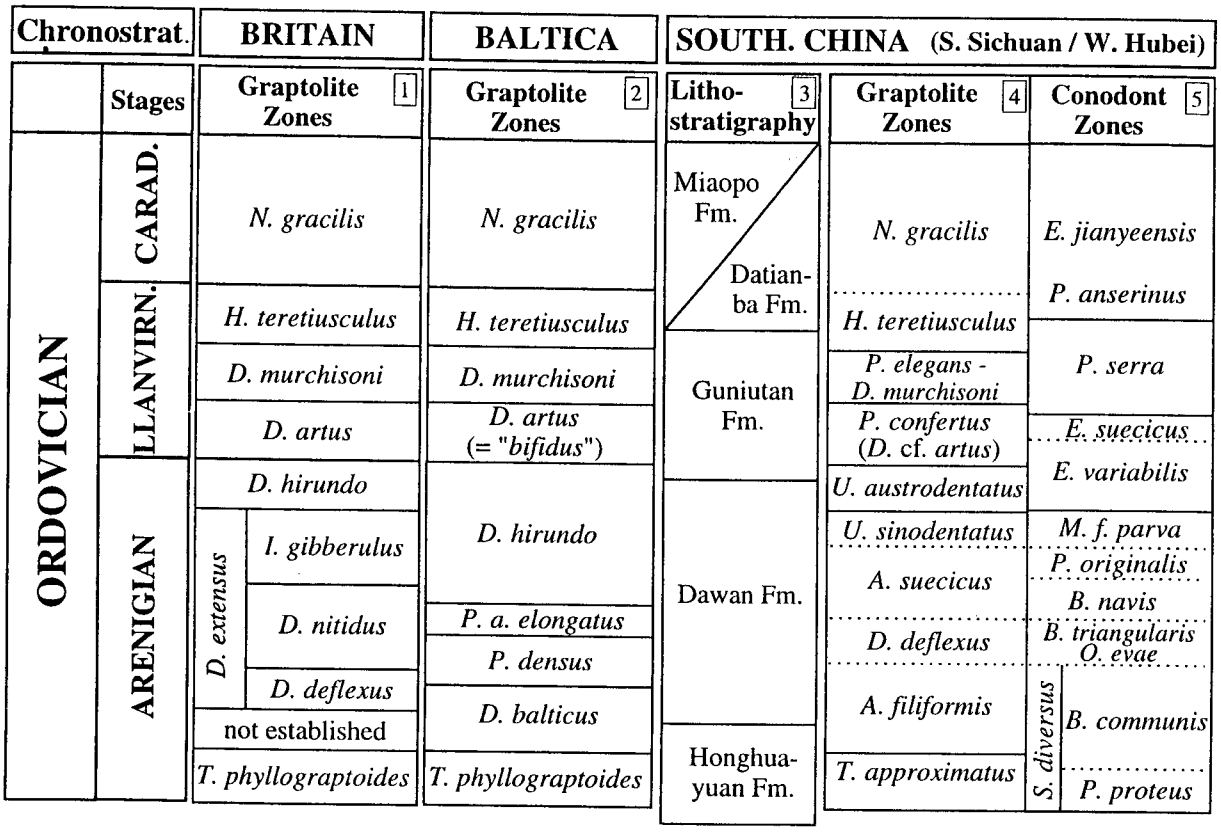

Figure 3. Stratigraphic correlation chart of Arenigian to Caradocian stages in Britain, Baltica and South China. Stratigraphic units and zones are modified from: *Column 1*. Fortey *et al.* (1995); *Column 2*. Nõlvak & Grahn (1993); *Column 3*. this paper; *Column 4*. Wang Xiaofeng *et al.* (1992), VandenBerg & Cooper (1992); *Column 5*. Wang Xiaofeng *et al.* (1992).

1986) and Martin & Yin Leiming (1988), Upper Cambrian -Tremadocian, from Hunjiang, Jilin Province; Li Zaiping (1982), Upper Machiakou Formation (Llanvirnian) from Central Hebei Province; and Hu (1986, cited *in* Li Jun, 1991) from Ziyang, Shaanxi Province.

Up to now, palynological data of the most northern part of the Upper Yangtze Region, the Lower Yangtze Region (northern border of the South China Plate) and of the transition belts to the Sino-Korean Plate and the Tarim Plate are still missing. The whole eastern border of the Yangtze Platform with the transition to the Jiangnan Islands and the Zhuijiang Basin (SE China Sea Trough) have not been studied and would be of great interest for palaeogeographical reconstruction.

2.3. STRATIGRAPHY OF THE DAWAN FORMATION

The studied sections of the Dawan Formation partly contain continuous successions from the underlying Tremadocian Fenxiang and Honghuayuan Formations to the overlying Guniutan Formation, which roughly corresponds to the Llanvirnian. Only the equivalent parts of the upper *Azygograptus filiformis* graptolite Zone to the *Undulograptus austrodentatus* graptolite Zone are discussed and figured within this paper (Fig. 2).

Investigated samples of all sections come from rocks of the middle to upper part of the Lower Member of the Dawan Formation (*A. suecicus* graptolite Zone) and from the lower part of the Upper Member in the Wangjiazei section, dated by conodonts and chitinozoans. The Upper Member is stratigraphically equivalent to the upper part of the *A. suecicus* graptolite Zone or the lower *Undulograptus sinodentatus* Zone. This stratigraphic interval correlates to the upper part of the British *Didymograptus nitidus* Zone and the *Didymograptus hirundo* Zone or to the *D. hirundo* Zone in Scandinavia. However, a clear stratigraphical distinction between the *A. suecicus* graptolite Zone and the *U. sinodentatus* graptolite Zone still remains

● rare ◆ abundant
• very rare ■ common

	DTBDW-14	DTBDW-15	DTBDW-16	DTBDW-17	WJZDW-4	WJZDW-5	WJZDW-7	WJZDW-8	WJZDW-12	WJZDW-14	WJZDW-15	WJZDW-16	JYPD-2	JYPD-3	JYPD-4
Acanthodiacrodium vavrdovae Cramer & Diez 1977	•	•	•						•	•	•	•			
Acanthodiacrodium spp.	•	•	•	•	●	●		•	•	●	●	•	●		●
Ampullula erchunensis (Fang Xiaosi 1986) Brocke, comb. nov., emend.	●	●	●	•	•	•			•	•	•	•	•	•	
Ampullula princeps Brocke, sp. nov.	•	●	●		•					•	•		•	•	•
Ampullula suetica Righi 1991				•											
Arbusculidium filamentosum (Vavrdová 1965) Vavrdová 1972, emend. Fatka & Brocke 1996 (in press)	■	●	●		●	•			•	•	•			•	
Arbusculidium spp.			•	•					•	•	•			●	
Cf. *Arkonia* sp.	•	•	•					•	•	●	●	•		•	•
Aureotesta clathrata var. *clathrata* (Vavrdová 1972) emend. Brocke, Fatka & Servais 1996	•	•	•						•	•			•	•	
A. clathrata var. *simplex* (Cramer *et al.*) comb. nov., emend. Brocke, Fatka & Servais 1996	•	•	•	•					•	•					
Baltisphaeridium sp. cf. *B. coolibahense* Playford & Wicander 1988		•	•	•	•						•	•	•	●	●
Baltisphaeridium klabavense (Vavrdová 1965) Kjellström 1971	•	•	●	•	•	•	•		•	•	•		•		•
Baltisphaeridium spp.	•	•	•	●	•	•	•			•	•	•	●	•	•
Barakella sp.		•	•			•					•		•	•	
Buedingiisphaeridium spp.	•	•										•	•	•	
Coryphidium bohemicum Vavrdová 1972	■	■	■		•	•	•	•	•	●	•	■		•	•
Coryphidium elegans Cramer *et al.* 1974				•						•	•	•			
Coryphidium spp.	●	■	■	•	●	●	•	●	•	•		●	●	■	■
Cristallinium dentatum (Vavrdová 1976) Fensome *et al.* 1990	•	•	•		•									•	
Cymatiogalea aff. cristata (Downie 1958) Rauscher 1973	•	•	•	•	•	•			•	•		•			•
Cymatiogalea granulata Vavrdová 1966	•	●												●	
Cymatiogalea spp.	●	●	●	•	●	●	•	•	•	•	•	•		•	•
Dactylofusa velifera Cocchio 1982	•	•	•	●	•	•			•	●	•	●			
Dactylofusa sp.			•												
Dicrodiacrodium ancoriforme (Burmann 1968) emend. Servais, Brocke & Fatka 1996 (in press)		•	•						•	●					
Ericanthea pollicipes Cramer & Diez 1977										•	•				
Goniosphaeridium/Polygonium group	◆	◆	◆	■	◆	◆	■	■	■	◆	◆	■	◆	◆	◆
Gorgonisphaeridium spp.	•	•	•	•	●	•	•		•	•	•	●	•	■	●
Leiosphaeridia tenuissima Eisenack 1958	•	•	●	•	•			•		•		•		•	•
Loeblichia sp. cf. *L. heterorhabda* Playford & Wicander 1988	•	•	•									•		•	
Micrhystridium acuminosum Cramer & Diez 1977	●	■	◆	•	●	•	•		•	•	•	•	■	◆	◆
Micrhystridium spp.	●	●	●	•	•	•			•	●	●	●	●	●	●
Multiplicisphaeridium rayii Cramer *et al.* 1974			•	●					•			•			
Multiplicisphaeridium spp.	•	•	•	●			•		•	•	•	•	•	•	•
Passalosphaera minuta Playford & Wicander 1988	•	•	•								•				•
Petaloferidium florigerum (Vavrdová 1977) Fensome *et al.* 1990	•	●	•		•	•			•	•	•			•	
Peteinosphaeridium trifurcatum (Eisenack 1931) Eisenack 1969	•	•	●		•	•	•					•	●	●	•
Peteinosphaeridium hymenoferum (Eisenack 1938) Eisenack 1969				•					•		●		•	•	
Peteinosphaeridium spp.	•	•	●	•			•	•	•	•		●	•	•	•
Pirea spp.	•	•	•								•		•	●	•
Pterospermella spp.	•	•	●							•	•	•		•	
Rhopaliophora palmata (Combaz & Peninguel 1972) Playford & Martin 1984	•	●	•		•	•			•	•	•	•	•	•	●
Rhopaliophora spp.	•	•	●							•		•	•	•	●
Stellechinatum spp.	•	●	●	•	•	•				•	•	■	•	●	•
Stelliferidium spp.	•	●	•	●	●	•	■	◆	•	•		•	•		•
Solisphaeridium sp.	•	•	•		•	•		•	•	●	•	•		•	•
Striatotheca rarirrugulata (Cramer *et al.* 1974) Eisenack *et al.* 1976	●	●	●	•	●			•	●	●	●			●	•
Striatotheca principalis parva Burmann 1970	■	◆	◆	•	◆	◆	•	●	■	■	●	•		•	•
Striatotheca spp.	■	●	●	●	•	■	•	●	●	●	■	●		●	•
Veryhachium trispinosum group	◆	◆	◆	●	◆	◆	●	●	●		•		•	●	●
VogtlandialSchizodiacrodium group	•	●	•	•	•					•	•	•			

Table 1. This table contains 51 selected acritarch taxa from the three sections, Datianba (DTBDW), Wangjiazei (WJZDW), and Jianjiangping (JYPD). It shows the semi-quantitative distribution of the taxa.
very rare = <5%; rare = 6-10%; common = 11-25%: abundant = >26%

problematical from the studied sections. The Middle Member of the Dawan Formation has been dated by cephalopods and conodonts. The index conodont of this stratigraphical interval is *Paroistodus originalis*. Figure 3 shows the correlation of the corresponding British, Scandinavian and Australian schemes with the litho- and biostratigraphy from the studied parts of the Yangtze Platform. The lithostratigraphy is based on Zeng *et al.* (1987) and the authors' observations during field work.

2.4. SAMPLES

Forty-nine samples from the Dawan Formation were collected and analyzed from the three sections mentioned above (Fig. 2). The material was processed by standard palynological methods, using HCl and HF treatment and were sieved with 10 µm screen, generally without oxidation of the organic residue. The samples WJZDW-15-17 have been slightly oxidized with HNO_3 to disperse the colloidal complexes of amorphous organic matter (e.g., degraded palynodebris).
The palynological slides are deposited at the Technische Universität Berlin, Institut für Angewandte Geowissenschaften II.

Fifteen samples of parts of the Lower and Upper Members were particularly rich in well-preserved acritarchs whereas the material of the mainly carbonatic successions of the Lower Member are sterile or contain only rare and poorly preserved acritarchs. Fifty-one acritarch genera, species or "groups" from the 15 samples that yielded abundant acritarchs have been selected and listed in Table 1, indicating their semi-quantative occurrences.

The samples JYPD of the Jianjiangping section are composed of lightly carbonitic yellow-green to grey-green shales. The samples of the Datianba (DTBD) and Wangjiazei (WJZDW) sections are composed of grey-green silty shales with mica on the bedding plane (Fig. 2).

Stratigraphically, the samples JYPD-2 - 4 , DTBDW-14 - 16 and WJZDW-4, 5, 7, 8, undoubtely belong to the *A. suecicus* graptolite Zone. The samples DTBDW-17 and WJZDW- 12, 14 - 16 are considered to be part of the upper *A. suecicus* graptolite Zone or lower *U. sinodentatus* graptolite Zone. This time interval corresponds to the upper part of the *P. originalis* conodont Zone.

2.5. COMPOSITION AND PALAEOBIOGEOGRAPHICAL SIGNIFICANCE OF THE ACRITARCH ASSEMBLAGES

Table 1 shows the distribution of 51 selected, easily recognizable taxa in the 15 most prolific samples. All of these samples yielded acritarch assemblages containing more than 70 distinct taxa. The specimens have been assigned to previously described genera and species or to new taxa. This paper will not clarify the numerous taxonomical problems concerning the Ordovician acritarchs, but it will focus on the systematical study of the genus *Ampullula*. The other taxa from these samples will be described in detail in a subsequent paper (Brocke, 1997).

Some acritarch genera are prevailing in the lower to middle Arenigian of South China: cf. *Arkonia*, *Aureotesta* (Vavrdová 1972) emend. Brocke, *et al.* 1996, *Barakella* Cramer & Díez 1977, *Coryphidium* Vavrdová 1972, *Dicrodiacrodium* Burmann 1968, *Pirea* Vavrdová 1972, *Striatotheca* Burmann 1970, *Veryhachium trispinosum* group and specimens of the *Vogtlandia* / *Schizodiacrodium* group. All these genera and some species such as *Acanthodiacrodium vavrdovae* Cramer & Díez 1977, *Arbusculidium filamentosum* (Vavrdová 1965) emend. Fatka & Brocke 1998 (in press), *Baltisphaeridium klabavense* (Vavrdová 1965) Kjellström 1971, *Cymatiogalea granulata* Vavrdová 1966, *Ericanthea pollicipes* Cramer & Díez 1977, *Dactylofusa velifera* Cocchio 1982 (ex. *Eupoikilofusa velifera* Albani *et al.* 1989), *Multiplicisphaeridium rayii* Cramer & Díez 1977, *Petaloferidium florigerum* (Vavrdová 1977) Fensome *et al.* 1990, and *Tongzia meitana* Li Jun 1987, are considered to be distinctive for the cold to temperate Mediterranean (or peri-Gondwanan) acritarch Palaeoprovince which was located at high palaeolatitudes in the Arenigian southern hemisphere. Therefore, all these taxa show a palaeobiogeographical linkage between the Yangtze Platform and peri-Gondwana.

Some other acritarch taxa, which so far have only been reported from the Canning Basin, Western Australia (Combaz & Péniguel, 1972; Playford & Martin, 1984) and the Georgina Basin, Queensland, Australia (Playford & Wicander, 1988) are also present in the Chinese assemblages, including different species of such pylomate forms such as *Peteinosphaeridium* and *Rhopaliophora*. The species cf. *Goniosphaeridium canningianum* Playford & Martin 1984, *Loeblichia heterorhabda*

Playford & Wicander 1988, *Baltisphaeridium coolibahense* Playford & Wicander 1988, *Passalosphaera minuta*, Playford & Wicander 1988, *Pterospermella*, aff. *Pterospermella*. sp. A. Playford & Martin 1984 are partly very common in the Chinese material.

Vavrdová (1974) introduced the terms Mediterranean Province and Baltic Province to describe the differences of acritarch associations from Europe during the Arenigian and Llanvirnian. Her subdivision is based on the presence or absence of certain selected distinctive acritarchs within each of the provinces. Since Vavrdová introduced these terms several workers (e.g., Martin, 1982; Albani, 1989) have followed this concept of two acritarch provinces. The occurrence of taxa which are considered to be of Baltic affinities is documented, for instance, by some baltisphaerids, peteinosphaerids and a great number of specimens which are either assignable to species *Goniosphaeridium* (Eisenack 1969) emend. Turner 1984 or to *Polygonium* Vavrdová 1966. However, because a clear distinction between these two genera is not possible, it is difficult to make a positive identification. In addition, numerous granulated and echinated taxa occur, which indicate transitional forms assignable to the genera *Stellechinatum* Turner 1984 and *Uncinisphaera* Wicander 1974. A distinctive species, *Peteinosphaeridium hymenoferum* (Eisenack 1938) Eisenack 1969 is rare to common in these samples, and may be of palaeobiogeographical value. Several other distinctive peteinosphaerid taxa are tentatively identified herein as *Peteinosphaeridium trifurcatum* (Eisenack 1931) Eisenack 1969 or *Peteinosphaeridium* spp. Some of them may be conspecific with species described by Tongiorgi *et al.* (1995).

As noted earlier (Li Jun, 1990; Gao Lianda, 1991; Brocke, 1992; Yin Leiming, 1994; Tongiorgi *et al.*, 1995) the character of the acritarch assemblages of the Arenigian Dawan Formation indicates biogeographical relations between the subtropical to tropical Yangtze Platform and the cold to cool peri-Gondwanan or Mediterranean so-called Palaeoprovince, with affinities to the Baltic and Australian assemblages. The two latter areas are generally characterized by the dominance of pylomate acanthomorphs and the absence of diacrodians and corymorphids (Playford & Wicander, 1988; Vavrdová, 1990).

Li Jun (1991) and Tongiorgi *et al.* (1992, 1995) discussed the palaeogeographical affinities of acritarchs and pointed out that the influence of cold water currents coming from the high palaeolatitudes of Gondwana, may have led to the dominance of typical peri-Gondwanan taxa in South China during Arenigian-Llanvirnian time. Tongiorgi *et al.* (1995) based their model on the results of one single sample (HD2), of which they described numerous species. Some of them are considered as new and representing a part of an endemic (Chinese) component, distinguished from Mediterranean, Baltic and Australian elements. According to these previous studies, it appears that during the Arenigian the Upper Yangtze Region yielded a mixed palynoflora including an endemic component and elements which have been so far considered as typical for the peri-Gondwanan, Baltic and Australian areas.
It is premature, however, to define an Australian Palaeoprovince, based on only a few published data from this area. Future studies will probably indicate that some of the taxa may also occur elsewhere in the world. Furthermore, the prevalence of the endemic Chinese component in the single sample HD2 of Tongiorgi *et al.* (1995) is not in agreement with the data from the investigated sections in the present study. For instance, some of their new taxa (e.g., species of *Peteinosphaeridium* and *Pirea*) might be included under the concept of a greater variability among the populations.

It is especially important, but partly very difficult to distinguish the palaeobiogeographical factors from local palaeoenvironmental effects (compare also Servais, 1995: 458). The comparison of different sections of the Yangtze Platform already shows major differences in the composition of the acritarch assemblages from samples of an equivelant age but from different localities. The Jianjiangping assemblages are characterized by the prevalance of specimens of the *Goniosphaeridium/Polygonium* group, *Baltisphaeridium*, e.g. cf. *B. coolibahense* Playford & Wicander 1988, *Micrhystridium acuminosum* Cramer & Díez 1977, and a relatively high diversity of species of *Peteinosphaeridium* and *Rhopaliophora*, species which also indicate Australian and Baltic affinities. Typical peri-Gondwanan forms such as *Acanthodiacrodium vavrdovae* Cramer & Díez 1977, *Arbusculidium filamentosum*, (Vavrdová 1965) emend. Fatka & Brocke 1996 (in press), *Aureotesta clathratra* (Vavrdová 1972) emend., Brocke *et al.* 1996,

Dactylofusa velifera Cocchio 1982, *Dicrodiacrodium ancoriforme* (Burmann) emend. Servais *et al.* 1996, *Ericanthea pollicipes* Cramer & Díez 1977, *Multiplicisphaeridium rayii* Cramer *et al.* 1974, and specimens of the *Vogtlandia* / *Schizodiacrodium* group are less represented or are even missing. Altogether the diversity of palynoflora and the number of recorded specimens is lower compared with those of the southern sections.

The latter described acritarch complex is partly represented by high number of specimens in the more southern situated Datianba and Wangjiazei sections, where pylomate forms are relatively less frequent. The composition of the acritarch assemblage and its comparison to equivalent-aged assemblages elsewhere, lead to the conclusion that palaeobiogeographically the present SE part of the Upper Yangtze Region was more closely related to peri-Gondwana, and the NW part was more similar to Australia or even Baltica. However, so far no recent palaeogeographical reconstructions indicate such a position of the South China Plate.
Therefore, based on the above information and data, not yet described from other sections (Brocke, in prep.), it seems to be more convincing to suspect that facies differentation and ecological patterns (physical and chemical oceanic conditions, e.g., energy conditions, input of fines, temperature, salinity, nutrients etc.), are responsible for the local differences among the acritarch assemblages on the Yangtze Platform.

3. SYSTEMATIC PALEONTOLOGY

The genus *Ampullula* Righi 1991 is an easily recognizable Lower Ordovician acritarch, characterized by a spherical central body, which bears a single, calyciform to cylindrical neck-like extension, but without further processes on the vesicle. This tubular, neck-like extension is regarded as the main diagnostic feature of this genus as proposed in the original diagnosis (Righi, 1991).

Up to now, only a single species of *Ampullula*, *A. suetica*, is known. It was orginally recorded from the late Arenigian to Llanvirnian "*Lepidurus* limestone", Hagudden section, Öland (Righi, 1991) and has recently been described from the uppermost Early Arenigian Dawan Formation, Daping section, Yangtze Gorges, Hubei Province, Southern China

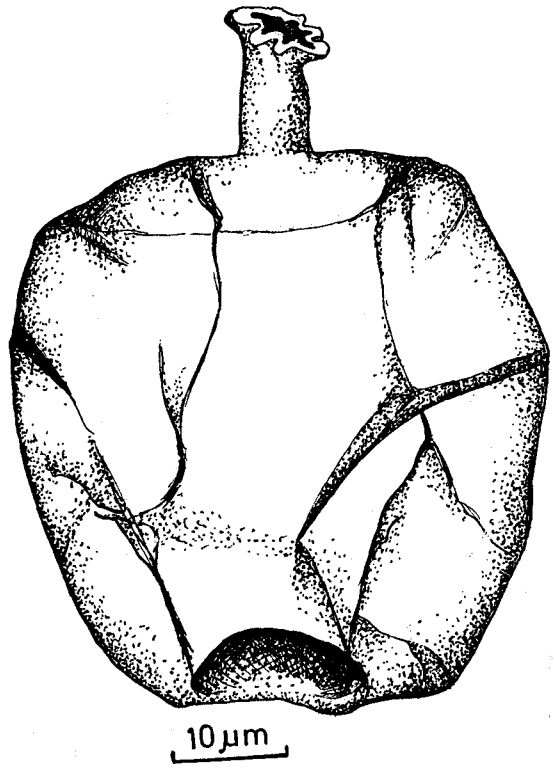

Figure 4. Idealized drawing of a specimen of *Ampullula suetica*, Datianba section, slide DTBDW-17/3, Pl. 1, Fig. F, displaying the typical tubular neck-like extension with the widened and lobed distal termination. The circular pylome is situated on the opposite pole of that bearing the neck.

(Tongiorgi *et al.*, 1995). Unfortunately *A. suetica* was only mentioned but not described in detail or illustrated in this publication.

Fang Xiaosi (1986: 135, 145, 153, Pl. 9, Figs 1, 2) named a new species *Aremoricanium erchunense* from the Arenigian Hongshiya Formation, Kunming-Luquan region, Yunnan Province. The two figured specimens show a more-or-less spherical body with numerous processes and a prominent tubular neck-like extension (prototuberance). Fang Xiaosi (1986) assigned the new species to the genus *Aremoricanium* Deunff 1955, because of its prominent tubular extension.

Yin Leiming (1994: 48, 51, Pl. 1, Figs. 5-7, Pl. 2, Figs. 1-4, 6) erected the new monospecific genus *Stelomorpha* based on the species *A. erchunense* (Fang Xiaosi 1986) from the Huanghuachang section, Yichang, Hubei Province, by a new combination and emendation of Fang Xiaosis' diagnosis. Unfortunately there are no comments remarked about the affinity to the genus *Ampullula*, and it is not clear from discussion, as to which are

the significant differences between *Aremoricanium* and *Stelomorpha*.

Tongiorgi *et al.* (1995: 22, Pl. 1, Figs. 1, 2, 4-7) found specimens of similar morphology to *A. erchunense* in the Daping section and "provisionally and doubtfully" transferred them to *Ampullula* ? *erchunensis* (Fang Xiaosi 1986) Tongiorgi *et al.*, 1995. Their diagnosis is based on the tubular extension, which in their opinion, closely recalls that of *Ampullula* Righi 1991. But the authors pointed out that *Ampullula* is devoid of further processes. They proposed emendation of *Ampullula* or the designation of a new genus very close to *Ampullula*. Remark: Because of the delay of their publication, which was already presented as a talk at the 8th International Palynological Congress, Aix en-Provence in 1992, *A. erchunensis* was transferred to *Stelomorpha erchunensis* Yin Leiming 1994 (Tongiorgi *et al.*, 1995, Addendum: 48).

Vavrdová (1990: 245, Pl. 2, Fig. 1, Fig. 6) described the species *Cymatiogalea crassula* from the late Arenigian Klabava Formation, Myto section near Rokycany, Bohemia. The specimen has very similar processes to the specimens pictured by Fang Xiaosi (1986), Yin Leiming (1994), and Tongiorgi *et al.*, (1995) but without a prominent tubular neck-like extension.

After examination of large populations from several stratigraphically comparable samples (*A. suecicus* graptolite Zone to ? *U. sinodentatus* graptolite Zone) from three different sections, it is obvious that the morphological variability at the specific and even the generic level is significant. The prominent apical "neck" or "tubular extension" considered as diagnostic, is not a sufficiently characteristic morphological feature to classify *Ampullula*. In 18 of the 40 observed specimens of *A. erchunensis* Fang Xiaosi 1986 comb. nov., emend. and 10 of the 25 specimens of *A. princeps* sp. nov. such a process is not observable. This is possibly a matter of preservation or maturity, but seemingly a primary characteristical feature too. Heteromorphic to homomorphic processes are present in a wide range of numbers and patterns of distribution on the vesicle. The type species, *A. suetica*, is regarded here as an extreme pole of the variability within the genus *Ampullula*, because no further processes besides the single neck-like extension exist. Whereas, the species *A. erchunensis*, with numerous processes on the vesicle represents the opposite pople of variation. The new species *A. princeps* may be considered as a linkage between both taxa. However, transitions between *A. suetica* and *A. princeps* have never been observed, while transitions between *A. princeps* and *A. erchunensis* exist (Pl. 1, Fig. G). But, because of numerous specimens observed with a clear bipolar or pseudobipolar orientation of the processes (see diagnosis of *A. princeps*), it seems justifiable to separate the two species.

Algae Incertae Sedis
Acritarcha Evitt 1963
Genus *Ampullula* Righi 1991 nov. emend.
Junior synonym: *Stelomorpha* Yin Leiming 1994
Type species: *Ampullula suetica* Righi 1991, by original designation.

Original diagnosis (Righi 1991: 121). Ellipsoidal to spherical vesicle, with a single calyciform to cylindrical distally widened neck, hollow and proximally not communicating with the vesicle cavity. Vesicle and neck wall relatively thin, seemingly one-layered. Vesicle surface smooth to scabrate or granulated. Distal edge of neck ornamented with protruding tubercles, thin spines, baculae to true distally bulbous to clavate processes of varying lengths. Neck base sometimes ornamented by radiating ridges and / or spines. Excystment observed in form of a pylome situated at the opposite pole of that bearing the neck.

Emended diagnosis. Ellipsoidal to spherical vesicle, seemingly single-layered, psilate to granulate, bearing one or more homomorphic or heteromorphic processes. One of the processes may be developed as a prominent tubular, neck-like extension. Processes, including neck-like extension, hollow, proximally not communicating with the vesicle cavity; closed by plug-like feature or thin layer. Distal end open and mostly widened, sometimes branched, variably shaped and ornamented, often bearing short spines or pinnae. Processes either mainly concentrated on one or two poles and less numerous, or irregularly distributed on the central body and numerous. Excystment observed in form of a pylome.

Discussion. The ellipsoidal to spherical vesicle is relatively thin. It appears to be unilayered and is generally folded, imitating irregular fields. These foldings may form strengthening rods, sometimes occupied by processes, which often stand in a line. The vesicle surface is psilate to granulate. Processes

are often thicker walled than the vesicle, cylindrical, but variably shaped in dimensions and distal terminations. They have no contact with the vesicle interior, and may show plug-like features at the proximal termination, resulting from a local thickening of the wall at the basal part. Additionally, some processes show a dark area around their contact to the vesicle. In some of the specimens observed, a thin layer may seal off the processes from the vesicle interior. In no case a double layered vesicle was clearly observed. Apparently a splitting of the wall into two "layers" is possible on the contact between the vesicle and the processes. Generally the processes seem to be hollow, at least at their distal end. The distal edge of the processes is funnel-like to calyciformly widened. The tip is usually serrated, lobed or irregularly ramified into two to five pinnae, sometimes ramifications are present up to the second order. Rarely they are plain, but sometimes slitted, and bearing spiny to bulbous ornamented terminations.

The "neck" or "tubular extension" or "protuberance" shows similar variable morphological features as the ordinary processes, but it is two to three times larger in its dimensions. However, this tubular extension is not visible in each specimen. Apparently, it is primarily not developed in any case and probably secondarily lost because of preservation conditions. The arrangement of the tubular extension in *A. suetica* and *A. princeps* relates to an "apical" localisation. Additionally, in *A. princeps* a few processes (4-12) are either concentrated on this pole or the opposite one. Processes in the equatorial part are very rare (max. 5). In *A. erchunensis*, the "apical" position of the tubular extension is sometimes marked by rarely distributed processes around it, but usually the processes are numerous and irregularly distributed over the whole vesicle and do not show any favourate localisation of the tubular extension.

Excystment structures occur in the form of a pylome with an operculum ornamented with processes (observed in 2 specimens). They are situated at the opposite pole ("antapical" pole) of that bearing the extension or sometimes grouped processes. In *A. erchunensis*, the existence of the pylome is often more difficult to observe than in *A. suetica* and *A. princeps* because processes are numerous or because the operculum is still closed. The "partial rupture" on specimens described by Yin Leiming (1994) appears to be of secondary origin.

Dimensions. The central body of *Ampullula* ranges between 43 µm ($\mathbf{CB_{min}}$) and 116 µm ($\mathbf{CB_{max}}$). The length of the tubular, neck-like extension ($\mathbf{TP_L}$) is between 9-21 µm. Process lengths ($\mathbf{P_L}$) range from 1 µm to 18 µm.
These data are based on measurements of Fang Xiaosi (1986); Vavrdová (1990); Righi (1991); Yin Leiming (1994); Tongiorgi *et al.* (1995); Paalits (unpubl.) and present studies.

Remarks. The present study on large populations of *Ampullula* in comparison with published data from China (Fang Xiaosi, 1986; Yin Leiming, 1994; Tongiorgi *et al*, 1995), as well as reexamination of materials from Bohemia (Vavrdová, 1990; Fatka, unpubl. data), and investigations of specimens from the Moscow Basin (Paalits, unpubl. data) neccessitate the erection of two additional species in the genus *Ampullula*.

Comparison. The genus *Aremoricanium* Deunff 1955, (type species *A. rigaudae* Deunff 1955) was originally described as being formed of two concentric layers, with the outer layer bears a cylindro-conical expansion. Loeblich & Mac Adam (1971) described six species of *Aremoricanium* from North America with neck-like extensions, which terminate in a pylome. An operculum or a second pylome on the opposite side of the pole bearing the tubular extension has never been observed. Morphologically the neck of *Ampullula* differs from that of *Aremoricanium* by being always more-or-less funnel-like to calyciform widened at the distal end and by possessing ornamentation.

Leiosphaeridia tubulosa Eisenack 1963 differs from *Ampullula* by having a tube-like extension without any terminal widening and ornamention. Eisenack described this feature as a pylome! The opposite pole of that bearing the extension clearly shows a circular opening. However, only two specimens (Eisenack, 1963, 1965) have been published since that time. The description of further specimens could result in an intrageneric relationship to *Ampullula*.

The species *Ammonidium aduncum* Playford & Martin 1984 differs from *Ampullula* by having no tubular extension or excystment structure and typical bifurcate processes. However, heteromorphic processes of *A. aduncum* are within the morphological variety of the processes observed in

Ampullula. Playford & Martin (1984) noted that the process interiors do not communicate with the vesicle cavity. However, this is not according to the type species *Ammonidium microcladum* Lister 1970, where this feature is significant for generic definition. Excystment is characterized by a cryptosuture, apically or near-equatorially situated. Thus, the affinities between *Ammonidium aduncum* and *Ampullula* remain unclear.

The genus *Ordovicidium* Tappan & Loeblich 1971 has hollow processes which do not communicate with the vesicle. It differs from *Ampullula* in having a double-layered vesicle wall, with the hollow processes arising from the outer layer. The processes are not open at their distal end.

Stratigraphical range indicated by graptolites and conodonts. First appearance datum (FAD): upper lower Arenigian, *A. suecicus* graptolite Zone, Lower Member of the Dawan Formation, Datianba and Wangjiazei sections, Sichuan Province; Jianjiangping, Huanghuachang (Yin Leiming, 1994), Daping (Tongiorgi *et al.*, 1995) sections, Hubei Province; Arenigian, Kunming - Luquan Region, Yunnan Province (Fang Xiaosi, 1986). Younger records: upper Arenigian, Upper Member of the Dawan Formation, Wangjiazei section. Stratigraphic position is not clearly verified by graptolites but chitinozoans (Chen Xiaohong, unpublished data) may indicate an age within the upper part of the *A. suecicus* graptolite Zone or equivalent to the lower *U. sinodentatus* graptolite Zone. Uppermost record: Llanvirnian, *Didymograptus bifidus* graptolite Zone, Hagudden section, Öland, Sweden.

Ampullula erchunensis (Fang Xiaosi) Brocke, emend. et comb. nov. Pl. 1, Fig. G, Pl. 2: A, B, E, F, H, K; Fig. 5.

1986 *Aremoricanium erchunense* Fang Xiaosi: 145, Pl.9, Figs. 1, 2.
1990 *Cymatiogalea crassula* Vavrdová: 245, Fig. 6, Pl. 2, Fig. 6.
1994 *Stelomorpha erchunensis* Yin Leiming: 51, Pl. 1, Figs. 5-7, Pl., 2, Figs. 1-4, 6.
1995 *Ampullula ? erchunensis* Tongiorgi *et al.*: 22, Pl. 1, Figs. 1, 2, 4-7.
1995 *Stelomorpha erchunensis* Tongiorgi *et al.*: Addendum:48.

Holotype. Fang Xiaosi 1986: 145, Pl. 9, Fig.1 (2).

Basionym: *Aremoricanium erchunense* Fang Xiaosi 1986.

Original diagnosis. (Fang Xiaosi 1987: 145) translation of the original diagnosis in Chinese, *in*: Tongiorgi *et al.*, 1995: 22.
Vesicle oval with very thin, opaque wall, mostly showing 1-3 strong folds parallel to the longitudinal axis. From the vesicle extends a short, strong, hollow protuberance whose proximal and distal width is the same. Its distal end projects outwards. Around the protuberance, on the vesicle, short, squat processes are evenly distributed, whose bases are a little widened and whose tips are funnel-like and extend into a delicate branching tuft. The vesicle is 68 µm long; the process trunk 2 µm, the whole process 8 µm. The colour is darkish-yellow.

Emended diagnosis. Subspherical to ellipsoidal vesicle, seemingly single-walled, psilate to granulate, bearing homomorphic or heteromorphic processes. One of the processes may be developed as a tubular neck-like extension. Processes, including neck-like extension, hollow and distally open. Proximally processes do not communicate with the vesicle cavity. Processes sealed off from the vesicle sometimes by a plug-like feature or probably by a thin layer. Distal end widened, variably shaped and ornamented, sometimes bearing short spines or pinnae. Processes numerous and irregularly distributed on the central body, sometimes aligned. Excystment observed in form of a pylome with processes on the operculum.

Description. The vesicle is usually subspherical to ellipsoidal with a probably original spherical outline. It is most probably single-walled and usually psilate, sometimes weakly granulate. The processes on the vesicle are heteromorphic to homomorphic, numerous (40 to approximately 100 in number) and irregularly distributed on the central body. Processes are sometimes standing in a line, which is marked by foldings. These folds may imitate irregular fields. A tubular neck-like extension sometimes occur and principally doesn´t differ from the processes, other than in size. Occasionally it is observed that there is an area around the neck which is lacking processes. Proximally there is no contact with the vesicle interior. In some cases a "plug" seems to be developed on the contact between the processes and vesicle, whereas a few specimens may show a thin layer which demarcates the processes from the vesicle interior. The processes are somewhat broadly based with a low angle contact to the

vesicle, but steeply ones also occur. Processes' trunks are thicker walled than the vesicle and varying in length (3,5-11 µm) and width (1,3-5 µm). They are tube-like and tend to widen towards their distal termination. A funnel-like to calyciform outward projecting is widely distributed. Processes are hollow and opened at their distal end. The distal edge is variably shaped: plain, lobed, irregularly ramified or ornamented. Their tips are sometimes bearing short processes and pinnae up to the second order.

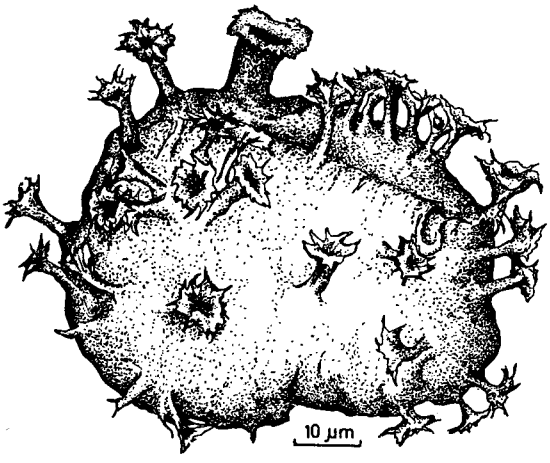

Figure 5. A common representative of *Ampullula erchunensis*, Datianba section, slide DTBDW-16/5, Pl. 2, Fig. A. This specimen shows a prominent tubular extension and relatively long, hollow processes which are distally funnel-like widened and with serrated, partly spiny or filamentouse edges. A few processes are simple or bifurcate.

Dimensions. Table 2 compares the measurement data of *A. erchunensis* from the literature and the 25 specimens studied by the author. The number of measured specimens from Fang Xiaosi and Vavrdová can not clearly verified. Yin Leiming's data are based on 19 specimens, whereas Tongiorgi *et al.* measured 35 specimens. The material from the Moscow Basin (Paalits, unpubl. data) is based on three specimens.

The measured parameters in column 1 are listed as abbrevations in Tables 2, 3 and 4.
CB_{max} - Central Body **max**imum dimension; **CB_{min}** - Central Body **min**imum dimension; **$CB_{\varnothing}$**- Central Body diameter; **TP_L** - Tubular Process Length; **TPW_{prox}** - Tubular Process Width **prox**imal end; **TBW_{dist}** - Tubular Process Width **dist**al end; **P_L** - Process Length; **PW_{prox}** - Process Width **prox**imal end; **PW_{dist}** - Process Width **dist**al end; **PT_W** - Process Trunk Width; **PO_L** - Process Ornamentation Length; **PY_W** - Pylome Width; **N_P** - Number of Processes.

Measured parameters	Fang Xiaosi, 1986	Yin Leiming, 1994	Tongiorgi *et al.*, 1995	+Vavrdová, 1990	*Paalits unpubl.	present study
CB_{max}		57µm	66µm	60µm	81µm	82,7µm
CB_{min}		45µm	43µm	45µm	66µm	60µm
$CB_{\varnothing}$	68µm	51µm	54µm	52,5µm	73,5µm	65µm
TP_L	11µm	9-15µm	9-21µm Ø13,4µm			14-21µm Ø16µm
TPW_{prox}	8µm	6-8µm	5-9µm Ø6,6µm			6-12µm Ø9,3µm
TPW_{dist}						13-17,3µm Ø15,1µm
P_L	8µm	7-9µm	3,5-11µm Ø7,3µm		8-18µm	3,7-10,7µm Ø8,5µm
PW_{prox}		1,5-4,5µm			3,8-5,6µm	1,2-6,7µm Ø5,3µm
PW_{dist}					9-12µm	3,9-9,3µm
PT_W	2µm				2-4µm	1,3-5,0µm Ø2,5µm
PO_L						0-5,3µm Ø1,6µm
PY_W		+12µm				17µm
N_P		30-40 on each face			ca. 25-50	ca. 40-100

* measurements based on three specimens + measurements not verified

Table 2. Comparison of published dimensions of *A. erchunensis* with those of investigated specimens.

Remarks. Studied specimens of *A. erchunensis* include all Chinese representatives (Fang Xiaosi, 1986; Yin Leiming, 1994; Tongiorgi *et al.*, 1995). There is great morphological variability in the observed specimens, including the processes, tubular neck-like extension and the vesicle. The proximal termination of the processes is mostly serrated. But, shapes (Fig. 6), numbers, and dimensions (Tab. 2) are also variable, resulting mostly in heteromorphic processes.

The neck-like extension is not observable in any specimen, which is regarded here as a variation within the species. Observed neck-like extensions are approximately two times larger than the processes, but within the range of variation as described for the processes. The vesicle seems to be originally spherical but it is often deformed and altered by compression folds. Table 2 shows the

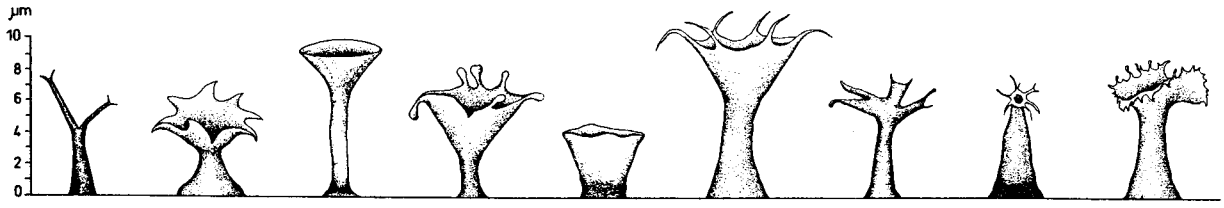

Figure 6. Drawing of different kinds of process types occuring within the genus *Ampullula*. Note the dark basal part occurring in some processes which is interpreted as a plug-like feature.

different dimensions of the vesicle.
The specimen described as *Cymatiogalea crassula* Vavrdová 1990 shows similar morphology and dimensions of the vesicle and the processes. Vavrdová (1990) mentioned a questionable fine striation on the process stems. Restudy of the original material by the present author is in agreement to the protologue that this feature is uncertain and therefore should be regarded as of minor taxonomical value. A striation has never been observed in the Chinese material, but was described for the base of the neck of some rare specimens of *A. suetica* (Righi, 1991). A prominent tubular extension is missing in *C. crassula* but this corresponds to the morphological variability observed within the Chinese populations.

Three specimens from core material of the Moscow Basin (Paalits, unpublished data) are seemingly conspecific with *A. erchunensis*, but a prominent tubular extension has not been observed. The age of the samples is not verified by macrofossils, but an Arenigian age is supposed.

Comparison. *A. erchunensis* differs from *A. suetica* in having numerous processes, a prominent tubular neck occasionally occurs.

Stratigraphical range indicated by graptolites and conodonts. FAD: upper lower Arenigian, *A. suecicus* graptolite Zone, Lower Member of the Dawan Formation, Datianba and Wangjiazei sections, Sichuan Province; Jianjiangping, Huanghuachang (Yin Leiming, 1994), Daping (Tongiorgi *et al.*, 1995) sections, Hubei Province; Arenigian, Kunming - Luquan Region, Yunnan Province (Fang Xiaosi, 1986). Youngest records are in the Wangjiazei section, upper Arenigian, Upper Member of the Dawan Formation. The stratigraphic position is not clearly verified by graptolites but chitinozoans (Chen Xiaohong, unpublished data) may indicate an age in the upper part of the *A. suecicus* graptolite Zone or equivalent to the lower *U. sinodentatus* graptolite Zone.

Ampullula princeps sp. nov.

Derivation of name. *Princeps* (Latin), prince, in the meaning of emperour, according to the planet with the monkey-bread trees on the cover of the book: Le petit prince from A. de St' Éxupery.
Diagnosis. Vesicle spherical or slightly ellipsoidal, wall thin and seemingly unilayered, psilate to granulate. Homomorphic or heteromorphic processes, cylindrical, distally hollow, funnel-like expanded, sometimes simple or bifurcate and variably shaped. One of the processes may be developed as a prominent tubular extension. Processes proximally clearly demarcated from the vesicle by plug-like feature or thin layer, and do not communicate with the vesicle cavity. Distal termination of the processes widened, and with an irregular serrated edge formed by bulbous to conical spines of varying length and thickness, sometimes furcated. Processes are concentrated on two areas (pseudo-bipolar). A few processes might be irregularly distributed on the vesicle. Excystment aperture observed in form of a pylome with an operculum.

Holotype. Pl. 1, Figs. A, B, Fig. 7.

Material. Slide DTBDW-16cd, England Finder Graticule coordinates: M 48.

Locality and horizon. Datianba section, Sichuan Province, South China, Dawan Formation, Arenigian, *Azygograptus suecicus* graptolite Zone.

Repository. All samples are stored in the collection of the Technische Universität Berlin.

Description. The ellipsoidal to spherical vesicle seems to be unilayered, is relatively thin and generally folded, so that the vesicle appears to be divided into irregular fields. These foldings may form ridges, where processes are sometimes situated in a row. The vesicle surface can be smooth,

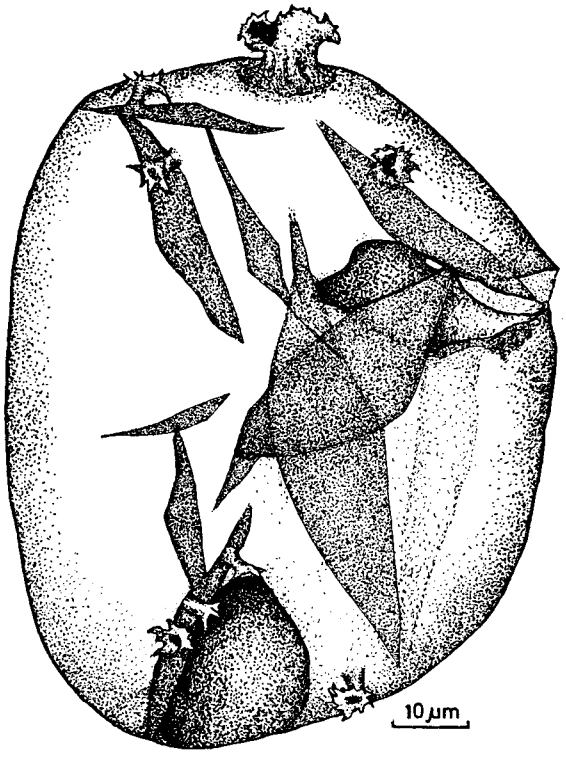

Figure 7. A reconstruction of the holotype of *Ampullula princeps*, Datianba section, slide DTBDW-16cd, Pl. 1, Fig. A, B. On one pole of the holotype a prominent tubular extension occurs, whereas on the opposite there is a circular opening (pylome) with four hollow processes on the surrounding edges. Only three other processes are present on this face of the vesicle, close to the prominent tubular extension.

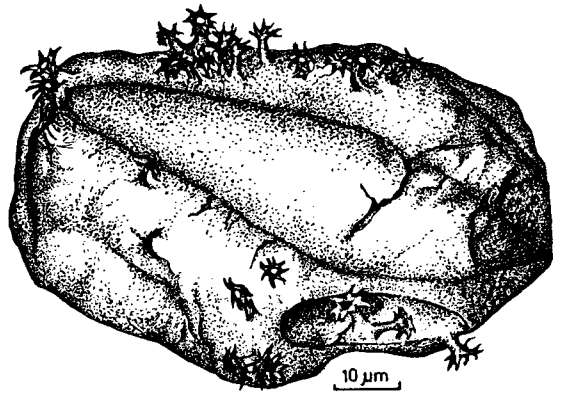

Figure 8. A reconstruction of a different specimen of *A. princeps*, slide DTBDW-16/1, Pl. 1, Fig. H, illustrating the variability of number and arrangement of the processes. The prominent tubular process is not developed in this specimen, but on the opposite side of the pylome processes are more-or-less concentrated in one area.

micrograniulate or unevenly granulate. The process walls are somewhat thicker than that of the vesicle, especially at their proximal part, and visible by an often dark area surrounding the process base. The vesicle bears processes in varying shape, number and arrangement. The processes do not communicate with vesicle interior. Proximally they are generally broad-based and sometimes separated from the vesicle cavity by a plug-like feature, probably resulting from local thickening of the wall. In a few specimens observed, a thin layer may separate the processes from the vesicle cavity. The processes are hollow, at least at their distal part, and some specimens bear thick-walled processes with a small cavity. The presence of solid forms of processes is questionable. The processes are predominantly funnel-shaped, widened towards their distal termination, and probably always distally opened. However, the distal edge shows variety in their contours, ranging from smooth to simply furcated. Most of the specimens show a crown-like denticulate margin, formed by tubercles, spiny ornaments and thin bulbous, to conical processes with occasionally filamentouse elements.

The distinguishing feature of this species is the arrangement and the relatively low number of the processes. They may either be concentrated in two areas, so that the symmetry is homomorphic or they are not directly situated at opposite poles rendering them pseudohomomorphic. Sometimes the processes are closely arranged next to each other on both poles. Besides that a few processes (between 4 and 10) may be irregularly distributed on the vesicle. The total number of processes ranges between 10 and approximately 25.

Dimensions. $\mathbf{CB_W}$ 46-103 µm, $\mathbf{TP_L}$ 11,6-17,7 µm, $\mathbf{P_L}$ 1,0-6,7 µm, $\mathbf{N_P}$ 4-20.
Measurements of *A. princeps* are figured in detail in Table 3.

Remarks. *Ampullula princeps* sp. nov. displays great variation in the arrangement and the type of the processes on the vesicle. On one specimen may be found short, stout and thin simple furcating processes as well as long, wide, funnel-like forms with variably shaped edges, as well transitional forms between them.

Comparison. *A. suetica* is characterized by only one apical, prominent, neck-like extension without further processes on the vesicle. However, the neck is assigned to be principally homomorphic with the

Measured parameters	present study	Measured parameters	present study
CB_{max}	103µm	P_{Wprox}	1,9-4,0µm Ø 2,9µm
CB_{min}	46µm	P_{Wdist}	2,3-7,1µm Ø 4,8µm
$CB_{Ø}$	73µm	PT_W	1,0-2,3µm Ø 1,5µm
TP_L	11,6-17,7µm Ø14,2µm	PO_L	0-5,1µm Ø 1,4µm
TP_{Wprox}	5,3-10,7µm Ø 7,5µm	PY_W	17-27,7µm Ø 21µm
$TP_{Wdistal}$	12-20µm Ø 15µm	N_P on each pole	ca. 4-20
P_L	1,0-6,7µm Ø5,4µm	N_P between the poles	ca. 0-12

Table 3. Dimensions of *A. princeps* are based on 17 specimens. A total of 28 specimens has been observed.

ordinary processes of the two other species, becausewe don't know about the origin and meaning of such an elongated feature.

A. princeps differs from *A. erchunensis* in having a somewhat larger vesicle, thinner vesicle wall that is generally psilate to microgranulate and by having a small number of processes which are predominatly arranged on two poles, suggesting a separation into an "apical" and an "antapical" pole. If a prominent neck-like extension is developed it is situated at the "apical" position, whereas the pylom is on the opposite one. The pylome is usually distinctly visible. Transitional forms between *A. princeps* and *A. erchunensis* rarely occur. Probably because of the small amount of specimens in the Chinese samples transitionals between *A. princeps* and *A. suetica* have not yet been observed .

Stratigraphical range indicated by graptolites and conodonts. FAD: upper lower Arenigian, *A. suecicus* Zone, Lower Member of the Dawan Formation, Datianba and Wangjiazei sections, Sichuan Province; Jianjiangping section, Hubei Province. Youngest records: upper Arenigian, Upper Dawan Formation, Wangjiazei section. Stratigraphic position of the youngest occurrence is not clearly verified by graptolites, but chitinozoans (Chen Xiaohong, unpublished data) indicate the age of the higher part of the *A. suecicus* graptolite Zone to be probably equivalent to the *U. sinodentatus* graptolite Zone.

Ampullula suetica Righi 1991, Pl. 1, Fig. F, Pl. 2, Fig. I, Fig. 4

1991 *Ampullula suetica* Righi: 123, Pl. 1, Figs. 1-6, Pl. 2, Figs. 1-10, Pl. 3, Figs. 1-2.
*1995 *Ampullula suetica* Righi 1991, Tongiorgi *et al.*: 15, 16, Tab. 1.
* no specimen pictured

Diagnosis. By original designation.

Holotype. Righi 1991: Pl. 1, Figs. 1 & 2.

Description. Observations by optical microscopy of the Chinese specimens show the specific features as described by Righi, 1991. No SEM studies have been done because of its rare occurrence.

Dimensions. CB_W 37-116 µm, TP_L 9,3-18 µm, TB_{Wprox} 3,5-6,5 µm, O_L 0-4 µm. Measurements of *A. suetica* are figured in detail in Table 4.

Measured parameters	Righi, 1991	present study
CBWmax	42-116µm Ø 64µm	45,8-81µm Ø 63µm
CBWmin	37-91µm Ø 55µm	44,5-78 Ø 61,3µm
TP_L	Ø 12µm	9,3-18 Ø 13,7µm
TPWbase	3,5-12µm Ø 6µm	5-8µm Ø 6,5µm
O_L	≤ 4µm	0-3µm

Table 4. Measurements of *A. suetica*. Righi's data are based on 79 specimens. Present measurements are based on three specimens.

Remarks. The present author fully agree with the original diagnosis of *A. suetica* Righi (1991). *A. suetica* is rarely present in Chinese material and

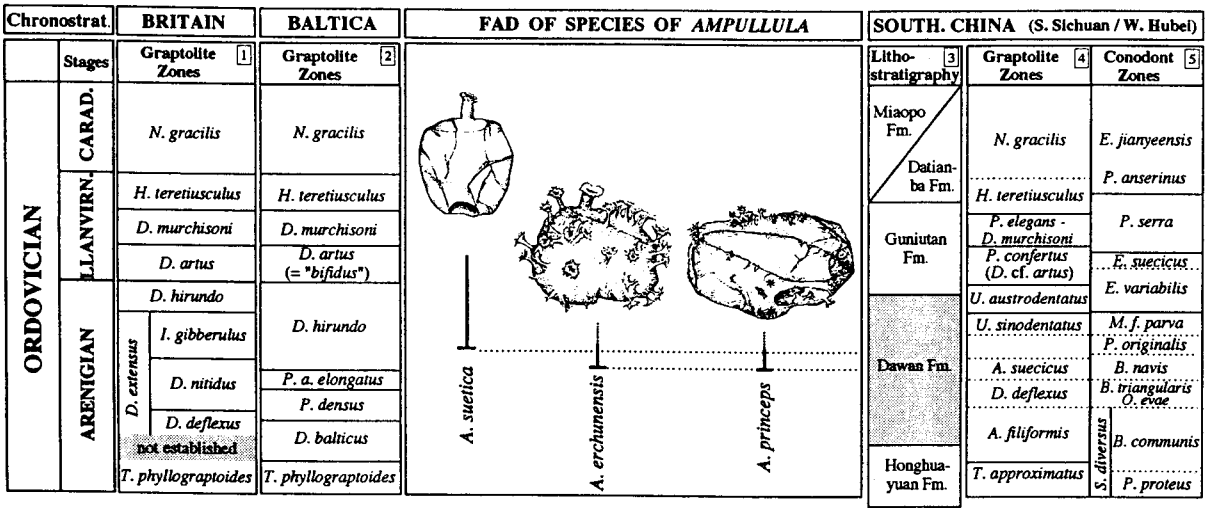

Figure 9. The first appearance datum (FAD) of the three species of *Ampullula*. According to Tongiorgi *et al.* (1995) the FAD of *A. suetica* is in the *Azygograptus suecicus* graptolite Zone. However, it occurs in the Wangjiazei section in the upper part of this zone or probably in the lower part of the *Undulograptus sinodentatus* graptolite Zone. *A. erchunensis* (Fang Xiaosi) comb. nov., emend. and *A. princeps* sp. nov. appear in the *A. suecicus* Zone.

only occurs in sample DTBDW-17 (three specimens). The rare occurrence of *A. suetica* is also in agreement with the observation of Tongiorgi *et al.* (1995) from their sample HD2 from the Daping section.

Stratigraphical range indicated by graptolites and conodonts. FAD: uppermost lower Arenigian, *A. suecicus* Zone, Lower Member of the Dawan Formation, Daping section, Yichang region, Hubei Province (Tongiorgi *et al.*, 1995); Younger records in China: upper Arenigian, approximately *U. sinodentatus* Zone, Upper Dawan Formation, Datianba section, Sichuan Province (here). Uppermost record: Llanvirnian, *D. bifidus* Zone, Hagudden section, Öland, Sweden (Righi, 1991).

4. CONCLUSIONS

Three sections of the Lower Ordovician Dawan Formation from South China have been palynologically investigated. The former monospecific acritarch genus *Ampullula*, type species *A. suetica*, has been recorded from the Datianba section. Based on the revised diagnosis of *Ampullula*, two additional species, *A. erchunensis* comb. nov., emend. and *A. princeps* sp. nov., are now included in the genus. Specimens of *A. erchunensis* are also present in Bohemia and the Moscow Basin. However, *A. suetica* occurs only in Sweden and South China, but so far has not been reported from the cold to temperate peri-Gondwanan region. It is therefore supposed, that *A. suetica* seems to be more typical for warmer, shallow water carbonate environments as they are documented in Sweden and on the Yangtze Platform during the Arenigian.

The first appearance datum (FAD) of the three species of *Ampullula* is illustrated in Fig. 9. *A. suetica* first appears in the Daping section (Tongiorgi *et al.*, 1995) within the *Azygograptus suecicus* graptolite Zone, whereas it occurs later in the Datianba section, in the upper part of the *A. suecicus* graptolite Zone or probably the lower *Undulograptus sinodentatus* graptolite Zone. *A. erchunensis* and *A. princeps* already appear in the lower part of the *A. suecicus* graptolite Zone.

The close palaeobiogeographical relationship between the Upper Yangtze Region and the peri-Gondwanan area during the Arenigian is indicated by the predominance of typical representatives of the peri-Gondwanan acritarch Palaeoprovince, whereas Baltic elements and representatives from Australia are less common but may be of regional increasing frequency (e.g., the Jianjiangping section). Endemic taxa are represented by relatively few species.

The studied acritarch assemblages of the Arenigian *A. suecicus* graptolite Zone shows distinct numbers of specimens and diversity of species from different areas in the Upper Yangtze Region. This result reflects facies differences on the carbonate

platform and sea-level fluctuations during a transgressive cycle from the Tremadocian to the Arenigian, which is also supported by sedimentological data. In addition, these primary environmental conditions are probably secondarily influenced by cold or cooler currents, coming from the high palaeolatitudes of peri-Gondwana, to the more temperate or even tropical South China Plate, as it was proposed by Tongiorgi *et al.*, (1995). However, the reconstruction of such complicated oceanic circulation patterns for the Arenigian remains uncertain, as long as the palaeogeographical position of palaeoplates, for instance, South China and Baltica is still under discussion (e.g., Scotese & McKerrow, 1990, 1991, Scotese & Golonka, 1992, Torsvik & Trench, 1991).

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PLATE 1

A - E ; G - I *Ampullula princeps* sp. nov.

A, B. Slide DTBDW-16cd, England Finder Graticule coordinates M48; holotype. magnification x 750.
C DTBDW-15xy, F38/2. x 750.
D DTBDW-15xy, B49/4. x 750.
E DTBDW-16xy, S25/4; x 750
G DTBDW-16cd, F48; black arrow shows the tubular extension. x 750.
H DTBDW-16/1, Y56/4; x 1000.
I DTBDW-16/1, V44/3 - V44/1; x 1000.
F *Ampullula suetica* Righi 1991, DTBDW-17/3, E49; x 750.

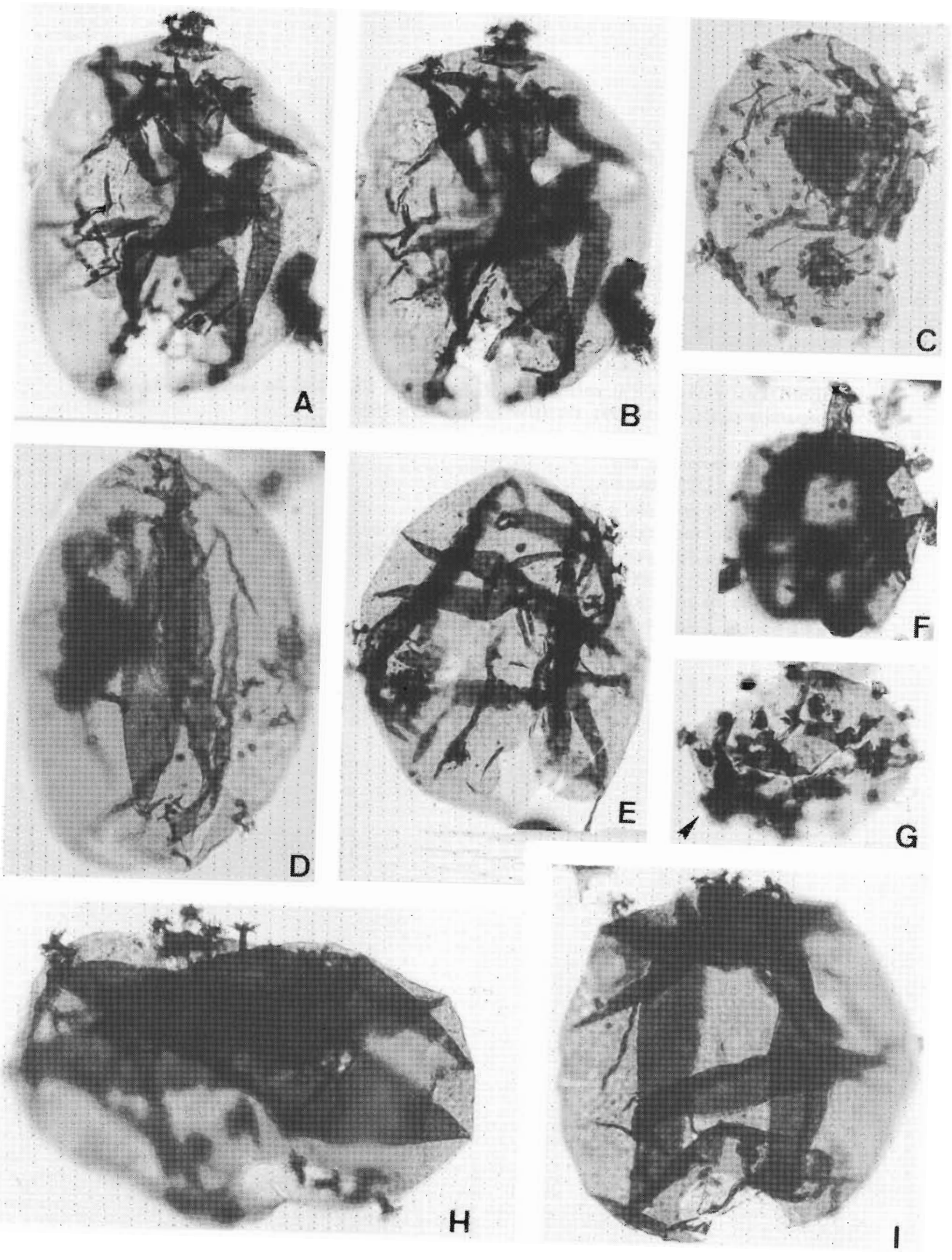
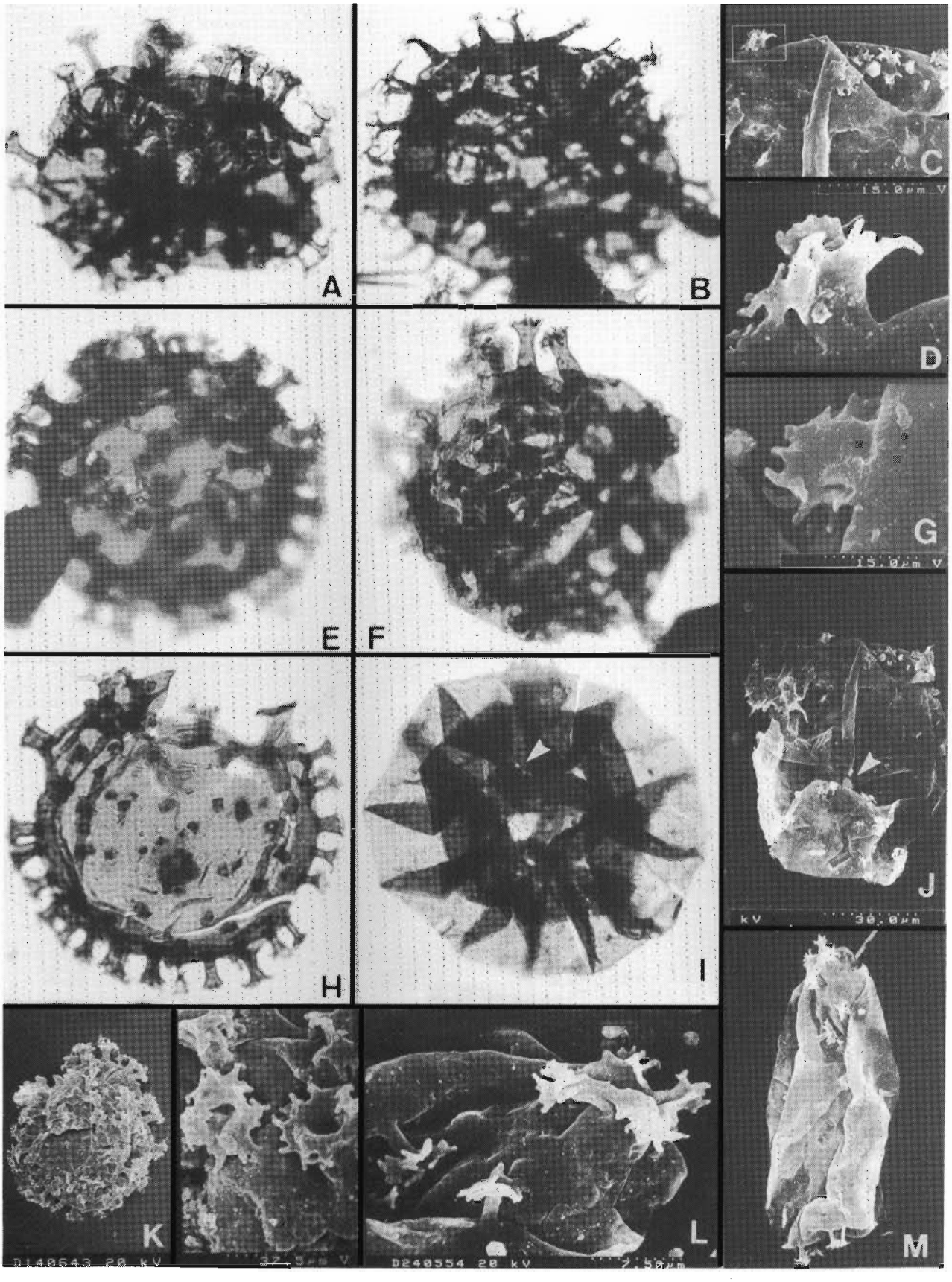

A
B
C
D
E
F
G
H
I

PLATE 2

A, B, E, F, H, K
Ampullula erchunensis (Fang Xiaosi 1986) comb. nov., emend.

A Slide DTBDW-16/5, England Finder Graticule coordinates P54/2; magnification x 750.
B DTBDW-16cd, Y45/2; x 750.
E DTBDW-15xy, D25/4; x 750.
F DTBDW-14xy, E43-E43/3; x 750.
H DTBDW-14cd, R25/2-R26/1; x 800.
K SEM DTBDW-14-2; x 750, enlargement of processes; x 4000, note the distal opening.
I *Ampullula suetica* Righi 1991, DTBDW 17-2, C 64; x 750.

C, D, G, J, L, M,
Ampullula princeps sp. nov.
C, D, G, J SEM DTBDW-14-A.
C Enlargement of one pole; x 2000
D Enlargement of the process (white rectangle, Fig C.); x 10.000.
G Enlargement of the process (white arrow, Fig. J); x 10.000.
J Whole specimen; x 1000
M SEM JYPD-3B-2; x 1300
L Enlargement of the tubular extension; x 4000


A
B
C
D
E
F
G
H
I
J
K
L
M