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Draft

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Abstract: The present paper reviews all investigations of Silurian acritarchs of China. Since Silurian acritarchs were first reported from China in 1978, significant progress has been made in Chinese Silurian acritarch research. A total of 30 scientific articles and theses have been published on Silurian acritarchs from China. A majority of these papers recorded acritarchs from South China and most Silurian acritarch studies concentrated on the Llandovery. Two papers describing material thought to be Silurian have since been shown to be Ordovician acritarch assemblages. We have updated the systematics of the taxa in these reported assemblages and documented their biostratigraphic distribution within China. Investigations of Silurian acritarchs, however, are still very limited and more research is needed for systematic, biostratigraphic, and palaeoecological interpretations.

Keywords: acritarchs, Silurian, China

45 **Introduction**

46 Although the Silurian is the shortest period of the Palaeozoic, it is a fascinating
47 interval for geology, biostratigraphy, biogeography, palaeoecology, geochemistry and
48 tectonics (Rong and Chen 2000). After the End-Ordovician extinction event, a rapid
49 recovery in biodiversity occurred during the Silurian. The Silurian is also important in
50 the history of the colonization of land by plants, the closure of the Iapetus Ocean, and
51 the narrowing of the Rheic Ocean (Melchin et al. 2012). Compared to the Ordovician,
52 biotic provincialism during the Silurian was relatively low (Melchin et al. 2012), but
53 the diversity of acritarchs was still high (e.g., Tappan and Loeblich 1973; Strother
54 1996). As the primary producers, the acritarchs played an important role in the
55 Silurian oceans, and data from China thus make a significant contribution to the
56 understanding of Silurian phytoplankton.

57 Silurian acritarch research in China started relatively recently. The first article was
58 published in 1978 (Zhong 1978). Since then, 30 papers have concentrated on Silurian
59 acritarch assemblages in China. Compared with the Ordovician, Silurian research
60 intensity is fairly low, but it is still important for biostratigraphic correlation,
61 palaeoecological interpretations, and global palaeobiogeographic scenarios of the
62 Silurian. Most Silurian acritarch research in China was published in Chinese and
63 papers were rarely submitted to international journals. Although Li et al. (2002)
64 reviewed the Palaeozoic acritarch research in China, specialists outside of China have
65 still largely ignored Chinese Silurian data. The objective of the present paper is to
66 review the progress of Silurian acritarch studies from China in more detail and to

67 bring this work to the attention of the international community.

68

69 **Silurian geology of China**

70 The research on the Silurian of China can be traced back to the 1880s (Rong and Chen
71 1990). After this initial period of investigation, Silurian studies have been focused
72 mainly on palaeontology, stratigraphy and palaeogeography. Yin (1949) published the
73 first Early Silurian palaeogeographic maps of South China, and a large number of
74 researchers followed by publishing Silurian palaeogeographic maps from almost all
75 regions of China. Rong and Chen (1990) provided the first overview of Chinese
76 Silurian research and its history. In the 1990s, new data on the Silurian of China and
77 new regional or local palaeogeographic maps for different Silurian epochs have been
78 published (Rong et al. 2003; Rong and Chen 2003). Subsequently, Rong et al. (2003)
79 and Rong and Chen (2003) summarized Silurian studies on lithofacies, biofacies,
80 biostratigraphy and palaeogeography from China and provided a palaeogeographic
81 map to illustrate the division of tectonic units and their development in the Silurian of
82 China based on previous studies.

83 Many specialists have noted that the tectonic framework of Silurian China is complex
84 (e.g., Mu et al. 1986). As in the Ordovician, at least eight palaeoplates existed within
85 the Silurian of China (Rong and Chen 2003), including South China, North China,
86 Tarim, Tibet, Sibumasu, Indochina, Qaidam, the Hinggan-Altai Block, Kazakhstan
87 (including the Jungar Block), the Yunkai Block, the Song-Gan Block, and the Alxa
88 Block (Rong and Chen 2003) (Fig.1). Torsvik and Cocks (2013) published more

recent global palaeogeographical reconstructions for the Cambrian to lower Devonian.

The reader is referred to Rong et al. (2003) and Torsvik and Cocks (2013) to

understand the palaeogeographical development of China during the Silurian.

Silurian stratigraphy of China

The Chinese Silurian stratigraphic correlation frameworks have been established

based on graptolite and conodont biostratigraphy (Rong et al. 2003). Other fossil

groups, such as chitinozoans and acritarchs, are also used for correlation. Figure 2

shows a simplified stratigraphic framework that we use herein for correlation.

Silurian acritarch investigations in China

General introduction

Thirty reports of Chinese Silurian acritarchs have been published since 1978. From

the late 1970s to the 1990s, the number of publications increased to 11, but only five

appeared during the 2000s. Since 2010, five papers have documented Silurian

acritarchs in China. In addition, several unpublished theses reported Silurian

acritarchs in China, although most of them just provided taxonomy lists, and only two

theses provided plates of acritarch assemblages (e.g., Guo 2012; Zhou 2014).

The published papers have reported Chinese acritarchs from the Silurian of South

China, the Hainan Block, North China, the Sibumasu and Tarim palaeoplates and the

Junggar Block (Fig 1). As is the case for the rest of the Palaeozoic (Li et al. 2002),

most researchers focused their studies on the Silurian acritarch assemblages from

111 South China, with 22 papers reporting acritarch assemblages from this part of the
112 country. Three papers describe acritarch assemblages from the Tarim Palaeoplate.
113 Two publications concern the material from the Junggar Block, only one paper deals
114 with the acritarchs of Sibumasu, one paper deals with acritarchs of the North China
115 Palaeoplate, and another one with those of the Hainan Block. Most papers are
116 concentrated on biostratigraphy, and only eight papers provide some systematic
117 investigations with photographic plates (Fang 1989; Fang and He 1988; Gao and Ye
118 1987; Li and Wang 1997; Li et al. 1997; Xing and Liu 1985; Ye 1984; Zhong 1978);
119 seven papers just provide a list of acritarch assemblages without photomicrographs
120 (Fang and Hou 1988; Liu 1993; Wang and Zhang 1985; Wang et al. 1988; Yan 1991,
121 1992; Yao et al. 2006); and two papers only mentioned acritarchs without a taxon list
122 (Li 1990; Wang and Ouyang 1997). Some papers only recognized one or two
123 acritarch taxa (e.g., Wang et al. 2005; Tang et al. 2015).

124 In terms of time intervals, 18 papers reported acritarchs from the Llandovery, one
125 from the Wenlock, four from the Ludlow, five from the Pridoli (Fig. 3) and two
126 papers have since been shown to document acritarchs from Ordovician. Because some
127 papers reported Silurian acritarch assemblages in China without independent
128 biostratigraphic control, new evidence has provided more accurate biostratigraphic
129 correlation, and we will discuss these in the following sections pertaining to different
130 regions.

131

132 Biostratigraphy

133 We revise all acritarch taxa reported from Chinese Silurian literature, following
134 Fensome et al. (1990), to remove the invalid taxa and combine taxonomic synonyms.
135 Sixty-eight genera and 226 species have been reported and their stratigraphic
136 distributions are shown in the Appendix. General biostratigraphic studies of the
137 Silurian of China were reviewed in detail by Rong et al. (2003) and this is helpful for
138 acritarch specialists for correlation of Silurian acritarch stratigraphy in China. Most
139 Silurian palynology researchers in China have correlated their acritarch assemblages
140 to each other and to those in Europe and North America. Although several acritarch
141 taxa have been shown to be useful for Silurian biostratigraphic correlation in China,
142 study of the Silurian acritarch biostratigraphic sequence of China is still far from
143 complete. Some taxa are distributed in the strata of both the Ordovician and Silurian,
144 such as *Dactylofusa cabottii*, *Leiofusa tanaocyta*, *Leiosphaeridia laevigata*, *L.*
145 *microcystis*, *L. wenlockia*, and *Strophomorpha ovata*. Although *Dactylofusa cabottii*
146 was first found in the Late Ordovician, it is the most common taxon present in the
147 Silurian of China, and has been used as an index taxon of the Silurian along with
148 other evidence, such as chitinozoans and spores. Some acritarch taxa discussed for
149 stratigraphic correlation are restricted to the Silurian, such as *Deunffia*, *Domasia*,
150 *Elektoriskos pogonius*, *Helosphaeridium clavispinulosum*, *Micrhystridium stellatum*,
151 and *Tylotopalla caelamenicutis*.
152
153 Biogeography and palaeoenvironment
154 Cramer (1971) and Cramer & Díez (1972, 1974a, b) provided a model for the

155 distribution of Silurian acritarchs, represented by six principal acritarch biofacies. Le
156 Hérissé and Gourvennec (1995) re-evaluated four principal acritarch biofacies (the
157 *Neoveryhachium carminae* facies, the *Deunffia* facies, the *Domasia* facies and the
158 *Pulvinosphaeridium–Estiastra* facies) of Cramer’s model, and subsequently Le
159 Hérissé et al. (1997) analysed the acritarch biogeography of the late Silurian. More
160 recently, Molyneux et al. (2013) reviewed Silurian acritarch biogeographical studies,
161 and pointed out that the distribution of mid Silurian acritarch biofacies were
162 controlled by palaeoenvironment rather than biogeography. According to Le Hérissé
163 and Gourvennec (1995), the acritarch assemblage from South China (based on Fang
164 1989) was similar to that of Libya and Jordan because of the presence of *Dactylofusa*
165 *estillis*. *Deunffia* and *Domasia* were important in Cramer’s model and were
166 considered to be representative of outer-shelf environments. *Deunffia* was reported in
167 South China (Location 1 and 4) and Junggar (Location 18), and *Domasia* was
168 reported in South China (Location 1 and 4). *Dactylofusa cabottii* was the most
169 common taxon present in the Silurian of China (Location 1, 4, 6, 9, 10, 11, 13, and
170 16), and it is considered to be an index taxon of shallow water (Li et al. 2006). As an
171 example of a palaeoenvironmental application, a regressive sequence was reported by
172 Yan et al. (2011) based on acritarch assemblage changes.

173

174 South China

175 The Silurian of South China can be palaeogeographically divided into the Yangtze
176 Platform, the Jiangnan Belt, and the Cathaysian Land. The Yangtze Platform consists

177 of the Upper Yangtze and Lower Yangtze regions (Rong and Chen 2003). A large
178 majority of the papers on Silurian acritarchs have focused on the assemblages from
179 South China. Therefore, Silurian acritarchs from the Yangtze Platform are much better
180 known than those of any other region of China.

181 Five papers have described the Silurian acritarch assemblages from the Jiangnan Belt
182 in Zhejiang Province (Fig 1, Location 1). Yin and He (2000) identified 37 genera of
183 acritarchs, including 40 species and 16 additional species in open nomenclature from
184 the latest Ordovician to early Silurian in Zhejiang. Fang and He (1988) and Yan (1991,
185 1992) reported an acritarch assemblage from the Tangjiawu Formation in Zhejiang,
186 which is dominated by *Dactylofusa cabottii* and *Leiosphaeridia wenlockia*. Yan et al.
187 (2011) summarized their Early Palaeozoic palynomorph (including acritarchs and
188 cryptospores) study from Zhejiang and established nine palynomorph assemblages
189 from the Cambrian to the Silurian. Four of their palynomorph assemblages were
190 considered Silurian: the *Retisphaeridium-Dyadospora-Tetrahedraletes* assemblage in
191 the Xiaxiang Formation; the *Nodospora-Tetrahedraletes-Baltisphaeridium*
192 assemblage in the Helixi Formation; the *Tetrahedraletes-Dactylofusa-Leprotolypa* in
193 the Kangshan Formation; and the *Dactylofusa-Strophomorpha-Leiofusa* in the
194 Tangjiawu Formation.

195 Three papers reported acritarchs from the Lower Yangtze region. Li et al. (2000) and
196 Wang and Li (2001) described palynomorph assemblages with acritarchs, dominated
197 by *Dactylofusa cabottii*, trilete spores, plant fragments, chitinozoans and scolecodonts,
198 and referred it to the late Ludlow-early Pridoli (Fig 1, Location 11). Zhou et al. (2013)

199 found some poorly preserved acritarchs, including *Leiosphaeridia*,
200 *Multiplicisphaeridium* and *Solisphaeridium*, in the Xikeng Formation from Jiujiang,
201 Jiangxi (Fig 1, Location 7).

202 Zhong (1978) first reported acritarchs from the Silurian of China and described some
203 sphaeromorphs in Zigui, Hubei (Fig 1, Location 2). Subsequently, Xing and Liu (1985)
204 described an acritarch assemblage in the Lungmachi and Lojoping formations from
205 the same area.

206 Wang and Zhang (1985) and Wang et al. (1988) described the Xiushan and Xiaoxiyu
207 formations and discussed their geological age (Fig 1, Location 6). They listed all taxa
208 that they found, including 15 genera of acritarchs. They interpreted the ages of the
209 Xiushan and the Xiaoxiyu formations as Telychian and Wenlock respectively. Wang et
210 al. (2010) revised the Xiaoxiyu Formation and subdivided it into two parts: the Xiaoxi
211 Formation (the original name of the Xiaoxiyu Formation) in the upper part and the
212 Huixingshao Formation in the lower part. They also indicated that the Xiaoxi
213 Formation is of Ludlow-Pridoli age, and the Huixingshao Formation is late Telychian
214 in age.

215 The Silurian acritarch assemblages from Qijiang area (Chongqing) were described by
216 Fang and Hou (1988) and Fang (1989) (Fig 1, Location 4). Twenty-eight genera and
217 21 species were identified from the Lungmachi, Shihniulan and Hanchiatien
218 formations, indicating a Llandovery age. *Dactylofusa cabottii* was the only acritach
219 taxon found in the Xiaoxi Formation in Xiushan, Chongqing (Wang et al. 2011) (Fig 1,
220 Location 10) and Guangyuan, Sichuan (Wang et al. 2005) (Fig 1, Location 9).

221 Eleven genera and 21 species of acritarchs were described from the Ningqiang
222 Formation from Ningqiang, Shaanxi (Li and Wang 1997) (Fig 1, Location 5).
223 Recently, Tang et al. (2015) reported some graphitized specimens of *Synsphaeridium*
224 from the Wuxiahe Formation in the Ziyang-Langao Region, Shaanxi (Fig 1, Location
225 8).
226 Silurian-Devonian boundary palynomorphs from Qujing were recorded by Tian et al.
227 (2011) (Fig 1, Location 13). Fourteen species assigned to 11 genera of acritarchs from
228 the upper Yulongssu Formation, Xiaxishancun Formation, and the lower-middle parts
229 of the Xitun Formation were recognized and attributed to the Silurian.
230 On the western margin of the South China Palaeoplate, Gao and Ye (1987) described a
231 palynomorph assemblage from the upper Silurian to Middle Devonian in Zoige and
232 Tawo of the West Qinling Mountains (Fig 1, Location 12). This assemblage is
233 dominated by spores, and contains 7 genera and 8 species of acritarchs.
234 Some papers reported Silurian acritarchs from South China with photomicrographs,
235 but no taxon names were provided (Li 1990; Wang and Ouyang 1997).
236
237 Hainan Block
238 The Hainan Block has been considered as a part of Indochina Palaeoplate (Rong et al.
239 2003). Silurian acritarchs were found in Hainan block, with assemblages dominated
240 by sphaeromorphs and acanthomorphs (Liu 1993) (Fig 1, Location 3).
241
242 Sibumasu

243 The Yunnan Province includes three palaeoplates during the Silurian: South China,
244 Sibumasu and Indochina. One paper reported an acritarch assemblage from the
245 Silurian of Sibumasu (Gao 1996) (Fig 1, Location 14). Three spore assemblage zones
246 were recognized from the late Silurian to the Early Devonian of Shidian (Gao 1996)
247 and these assemblages also include acritarchs. The SN (*Apiculiretusispora*
248 *spicula-Emphanisporites neglectus*) Zone was considered to be a late Silurian spore
249 assemblage zone and it is accompanied by acritarch taxa, including *Leiosphaeridia*,
250 *Micrhystridium* and *Lophosphaeridium*.

251
252 North China

253 No Silurian strata have been found in the North China platform, but some were
254 recorded on the margin of the North China Palaeoplate (Rong and Chen 2003). Only a
255 single paper has described an acritarch assemblage from North China, from the
256 southeast margin of the Ordos basin (Yin et al. 1993) (Fig 1, Location 15). The
257 assemblage, which is from the Dongzhuang Shale, includes 20 genera and 26 species
258 and is dominated by *Dactylofusa cabottii* and *Leiosphaeridia*, which have been
259 considered to be indicative of a Llandovery to Wenlock age. However, more recent,
260 unpublished studies by ourselves and other researchers, including U-Pb zircon
261 chronostratigraphy, acritarch and chitinozoan analyses from the same section, imply
262 that the Dongzhuang Shale is of Late Ordovician age.

263

264 Tarim

265 Silurian strata occur on the margin of the Tarim Basin (Rong and Chen 2003) and the
266 Karakum Region is considered to have been united with the Tarim Palaeoplate during
267 the Silurian (Rong et al. 2003). Tarim is considered to be close to South China during
268 the Silurian because their shelly faunas were similar (Rong and Chen 2003). Three
269 papers mentioned Silurian acritarch assemblages in the Tarim Palaeoplate. Li et al.
270 (1997) described an acritarch assemblage together with scolecodonts and cryptospores
271 from the Tataertage Formation in the Dawangou section, Kalping (Fig 1, Location 16).
272 The assemblage contains the acritarchs *Dactylofusa cabottii*, *Gloeocapsomorpha*
273 *prisca*, *Leiofusa tanaocyta*, *Leiosphaeridia laevigata*, *L. microcystis* and *L. wenlockia*,
274 some scolecodonts, the cryptospore *Tetrahedraletes medinensis* and cuticles (Li et al.
275 1997). Xing and Fang (1999) reported acritarch assemblages in the Qilang and lower
276 Kalpingtag formations. They attributed the Qilang Formation to the Upper Ordovician
277 and the lower Kalpingtag Formation to the Silurian (Xing and Fang 1999). The lower
278 member of the Kalpingtag Formation was distinguished and renamed as the
279 Tierenkeawati Formation (Huang et al. 2009). Later, the Tierenkeawati Formation was
280 confined to the lower and middle parts of the lower member of the former Kalpingtag
281 Formation, and was assigned to the Upper Ordovician (Tang et al. 2012). Therefore,
282 the acritarch assemblage described in Xing and Fang (1999) is not considered to be
283 Silurian, but of Ordovician age. Yao et al. (2006) reported the acritarchs
284 *Leiosphaeridia*, *Priscogalea* and *Florisphaeridium*, as well as chitinozoans, in the
285 lower to middle part of the Wenquangou Group from the West Kunlun Mountains and
286 attributed this palynomorph assemblage to the 'Early Silurian' (Fig 1, Location 17).

287

288 Junggar

289 The Junggar Block is a part of the Kazakhstan Palaeoplate and two papers reported
290 Silurian acritarch assemblages in that area. Ye (1984) described a late Llandovery to
291 Wenlock palynomorph assemblage including acritarchs, spores, chitinozoans and
292 scolecodonts. *Deunffia*, *Mutiplicisphaeridium*, *Baltisphaeridium* and *Micrhystridium*
293 were found, and attributed to the *Deunffia-Domasia* assemblage (Fig 1, Location 18).
294 Gao (1993) recognized four spore zones in the late Silurian-Early Devonian from the
295 Sharburti Mountains, western Junggar (Fig 1, Location 19). The first spore zone, DS
296 (*Synorisporites dittonensis-apiculiretusispora spicula*) Zone, was referred to the late
297 Silurian. The palynomorph assemblage corresponding to the DS Zone mainly consists
298 of spores, and about 25% acritarchs, including 15 genera and 18 species. The other
299 spore zones are Devonian.

300

301 Conclusions

302 Thirty papers have been published describing Silurian acritarchs from China
303 from six palaeoplates or blocks, although two of them have since been confirmed to
304 be Ordovician assemblages. Most research has focused on acritarchs from South
305 China and from the Llandovery period. We have updated the systematics of the taxa
306 in these reported assemblages and documented their biostratigraphic distribution
307 within China. Silurian acritarch studies in China are far from being comprehensive;
308 more investigations on Silurian acritarch assemblages in China are needed for

309 systematic, biostratigraphic, and palaeoecological interpretations.

310

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316

317 **Appendix**

318 Chinese Silurian acritarch stratigraphic distribution. The number shows in the right
319 column refer to the location in figure 1. All acritarch taxa have been revised following
320 Fensome et al., 1990 to remove the invalid taxa and combine taxonomic synonym.

321

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495

496 **Figure caption**

497 Figure 1 Map of Silurian tectonic units of China with boundaries of various
498 palaeoplates or blocks. Black dots show sections from which acritarchs have been
499 reported. Modified from Rong and Chen, 2003.

500 1. Anji, Chun'an, Fuyang, Lin'an, Tonglu, Xiaoshan, Zhejiang (Fang and He, 1988;
501 Yan, 1991, 1992; Yan et al., 2011; Yin and He, 2000); 2. Zigui, Hubei (Zhong, 1978;
502 Xing and Liu, 1985); 3. Hainan (Liu, 1993); 4. Qijiang, Chongqing (Fang and
503 Hou, 1988; Fang, 1989); 5. Ningqiang, Shaanxi (Li and Wang, 1997); 6. Baojing,
504 Sangzhi, Zhangjiajie, Hunan (Wang and Zhang, 1985; Wang et al., 1988); 7. Jiujiang,
505 Jiangxi (Zhou et al., 2013); 8. Ziyang, Shaanxi (Tang et al., 2015); 9. Guangyuan,
506 Sichuan (Wang et al., 2005); 10. Xiushan, Chongqing (Wang et al., 2011); 11. Dafeng,

507 Jiangsu (Li et al., 2000; Wang and Li, 2001); 12. Tawo, Gansu; Zouge, Sichuan (Gao
508 and Ye, 1987); 13. Qujing, Yunnan (Tian et al. 2011); 14. Shidian, Yunnan (Gao, 1996);
509 15. Liqun, Shaanxi (Yin et al., 1993); 16. Kalpin, Xinjiang (Li et al., 1997; Xing and
510 Fang, 1999); 17. West Kunlun, Xinjiang (Yao et al., 2006); 18. Toli, Xinjiang (Ye,
511 1984); 19. Sharburti Mountains, Xinjiang (Gao, 1993)

512

513 Figure 2. Silurian stratigraphic framework in China (Modified from Rong et al., 2003;
514 Wang et al., 2010). 1. Cuijiagou Formation; 2. Xitun Formation; 3. Xiaoxishancun
515 Formation.

516

517 Figure 3. Overview of Chinese localities and stratigraphy from which Silurian
518 acritarchs have been reported. Numbers referring to acritarch assemblages are the
519 same as in Fig. 1.

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