



论山东、辽宁炒米店组底部(古丈阶顶部)小凤凰虫 (*Fenghuangella* Yang in Zhou *et al.*, 1977)*

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提要 本文对在山东济南市钢城区九龙山和辽宁东部大连市白家山炒米店组底部报道的小凤凰虫, 进行了详细的描述及修订。根据与小凤凰虫共生的三叶虫对于华北地台区苗岭统与芙蓉统的界线进行了深入探讨, 将产有小凤凰虫的*Liostracina simesi*–*Placosema convexa*组合带作为华北地台区苗岭统古丈阶最上部的一个化石带, 而将*Prochuangia mansuyi*的首现作为华北地台区芙蓉统排碧阶的底界, 对于华南斜坡相区和华北地台区苗岭统和芙蓉统之间界线划分和对比具有重要意义。

关键词 小凤凰虫 炒米店组 苗岭统 古丈阶 华北地台

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On the genus *Fenghuangella* Yang in Zhou *et al.*, 1977 from the lowest Chaumitien Formation (uppermost Guzhangian) from Shandong and eastern Liaoning, North China

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Abstract *Fenghuangella* is here reported from the lowest part of the Chaumitien Formation (uppermost Guzhangian, Miaolingian Series) at the Jiulongshan section, Gangcheng District, Jinan City, Shandong and the Baijiashan section, Dalian City, Liaoning. The diagnosis of *Fenghuangella* is revised. The matching of cranium of *Fenghuangella* with its corresponding pygidium is discussed in detail. The pygidium previously assigned to *Fenghuangella subtriangularis* Lin and Zhou in Lin *et al.*, 1983 is better grouped within the genus *Gaoloupingia*

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Yuan and Yin because of its shorter, and narrower pygidial axis, wider pleural field, well developed pleural and interpleural furrows, and ornamentation of dense and coarse granules. The pygidia assigned to *Fenghuangella coniforma* Yang in Zhou *et al.*, 1977 are here transferred to the genus *Pseudomapania* owing to its wider pleural field (tr.), deeper pleural furrows, shallower but distinct interpleural furrows, more convex anterior band of pleural ribs, and narrower pygidial border. The pygidia recognized as *Fenghuangella laevis* Park and Choi, 2011 are here considered as a juvenile ceratopygid trilobite. The pygidia of *Fenghuangella laevis* are correctly matched with their cranidia for the first time. The boundary between Miaolingian and Furongian in North China Platform is also discussed in detail. The lower boundary of the Paibian Stage (Furongian Series) is defined by the first appearance datum (FAD) of *Prochuangia mansuyi* Kobayashi, 1935. The *Liostracina simesi*–*Placosema convexa* Zone bearing *Fenghuangella laevis* Park and Choi, 2011 is placed within the uppermost Guzhangian of the Miaolingian Series. This placement is of great significance for the correlation of the boundaries of Miaolingian and Furongian in Jiangnan Slope and North China Platform.

Key words *Fenghuangella*, Chaumitien Formation, Miaolingian Series, Guzhangian, North China Platform

SYSTEMATIC PALAEONTOLOGY

The morphological terms employed here generally follow those of Whittington and Kelly (1997). All specimens described in the present paper are cataloged using prefix NIGP and are housed in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing, Jiangsu Province, China.

Order Ptychopariida Swinnerton, 1915

Family Diceratocephalidae Lu, 1954

Genus *Fenghuangella* Yang in Zhou *et al.*, 1977

- Fenghuangella* Yang, 1977, Zhou *et al.*, p. 170.
Fenghuangella Yang, Yin and Lee, 1978, p. 489.
Fenghuangella Yang, Yang, 1978, p. 44.
Fenghuangella Yang, Liu, 1982, p. 312.
Fenghuangella Yang, Luo, 1982, p. 4.
Fenghuangella Yang, Lin *et al.*, 1983, p. 403.
Fenghuangella Yang, Qian and Zhou 1984, p. 178.
Fenghuangella Yang, Peng, 1987, p. 97.
Fenghuangella Yang, Yang *et al.*, 1991, p. 147.
Fenghuangella Yang, Duan *et al.*, 1999, p. 158.
Fenghuangella Yang in Zhou *et al.*, Peng *et al.*, 2001a, p. 104–105; 2001b, p. 141; 2004b, p. 73.
Fenghuangella Yang in Zhou *et al.*, Jell and Adrain, 2003, p. 376, 469.
Fenghuangella Yang in Zhou *et al.*, Yuan and Li, 2008, p. 111, 120, 127.
Fenghuangella Yang in Zhou *et al.*, Peng, 2008b, p. 164, 175, 187.
Fenghuangella Yang in Zhou *et al.*, Park and Choi, 2011, p. 492, 493.
Fenghuangella Yang in Zhou *et al.*, Ren, 2017, p. 118.
Fenghuangella Yang in Zhou *et al.*, Peng, 2020, p. 452.
Fenghuangella Yang in Zhou *et al.*, Ren *et al.*, 2021, p. 6.
Cyclolorezellina Ergaliev, 1980, p. 137.
Cyclolorezellina Ergaliev, Peng, 1987, p. 97.
Cyclolorezellina Ergaliev, Jell and Adain, 2003, p. 362, 469.

Type species *Fenghuangella laochatianensis* Yang in Zhou *et al.*, 1977, from the Middle–Upper Cambrian of the Laochatian Formation, Laochatian, Fenghuang County, Hunan Province.

Revised diagnosis Small; cephalon semicircular to semielliptical in outline, moderately convex; axial furrow deep and wide; a pair of short preglabellar furrows on preglabellar area; glabella conical in outline, with three pairs of very faint glabellar furrows; occipital

ring convex, with a short occipital spine; preglabellar field, preocular area, fixigena and posterolateral projection fused together to form a semi-ring shaped swelling; palpebral lobe very short, located on anterolateral area of the cranidium and in front of glabella; eye ridge fairly faint, almost horizontal or slightly stretching forwards; librigena narrow, strongly sloping downwards, with a very short genal spine; anterior branches of facial sutures strongly convergent from palpebral lobes; posterior branches of facial sutures long, slightly bending outwards and backwards. Thorax with eight segments, axial region wider than pleural area, pleural segments with short pleural spines. Pygidium small, semi-elliptical or inverted triangular in outline; axis convex, wide and long, strongly tapering backwards, almost reaching posterior border, with four to five axial rings, anterior two to three axial ring furrows distinct, connected with axial furrow, posterior two to three axial ring furrows disconnected with axial furrow; pleural furrows deep, interpleural furrows shallow; pygidial border very narrow; surface smooth or bearing fine dense or scatter granules.

Discussion In general configuration and characteristics of the cephalon, cranidium, librigena, and pygidium, *Fenghuangella* shows the closest resemblance to *Torifera* Wolfart, 1974. These characteristics include glabella strongly tapering forward, deep axial furrow, the presence of a pair of short furrows slightly divergent forwards on preglabellar field, wide fixigena, short anteriorly located palpebral lobes, occipital ring with occipital spine, pygidium with long pygidial axis strongly tapering backwards, and narrow pygidial border. However, the latter has a trapezoidal cranidium, a deeper anterior border furrow, distinct convex anterior border, shorter palpebral lobe located more posteriorly, eye ridge stretching horizontal or slightly slanting backwards, a distinct baccula on the genal field adjacent to the base of the glabella, wider (tr.) and narrower (sag.) pygidium.

Occurrences South China (Hunan, Guizhou, southern Anhui, southern Jiangsu, Yunnan), North China

(Shandong, Liaoning), Kazakhstan, and Korea; Guzhangian (Miaolingian) and early Paibian (Furongian).

Fenghuangella laevis Park and Choi, 2011

(Fig. 2)

2011 *Fenghuangella laevis* Park and Choi, p. 492–493, Fig. 9 (1–14, non 15–17).

2013 *Fenghuangella laevis*, Park *et al.*, p. 1000.

2016 *Fenghuangella laevis*, Choi *et al.*, 2016, p. 1984.

2017 *Fenghuangella laevis*, Ren, p. 119, pl. 19, fig. 11.

2021 *Fenghuangella laevis*, Ren *et al.*, p. 6, Fig. 2 (A–B, D–F, ?C).

Holotype Cranium (SUNP 4641; Park and Choi, Fig. 9.9–9.12), from the *Fenghuangella laevis* Zone of the Sesong Formation (Paibian Stage, Furongian Series) at the Jikdong section, Korea.

Revised diagnosis Cranium smooth, subtriangular in outline; glabella short, conical. Pygidium semi-elliptical, pygidial axis wide and long, almost extending to the posterior border, with four axial rings, first two rings broad (tr.), axial ring furrows distinct, posterior two rings rapidly narrowing backwards, axial ring furrows short, disconnected with axial furrow; pleural field narrow (tr.), two pairs of anterior pleural furrows deep; border narrow, with irregular ridges along the posterior margin.

Locality and Horizon Jiulongshan, Laiwu, Shandong and Baijiashan, Dalian, Liaoning; *Liostracina simesi–Placosema convexa* Assemblage Zone of the Chaumitien Formation (uppermost Guzhangian, Miaolingian Series).

1 前言

小凤凰虫在中国主要分布在华南斜坡相区, 包括湘西、黔东南、皖南和江苏南部(周天梅等, 1977; 杨家骥, 1978; 尹恭正、李善姬, 1978; 刘义仁, 1982; 林天瑞等, 1983; 钱义元、周泽民, 1984; 姜立富, 1988; 彭善池, 1987, 2020; Peng *et al.*, 2001a, 2001b, 2004a, 2004b; Peng, 2008b; Yuan and Li, 2008); 在云南西部也有报道(罗惠麟, 1982); 在大巴山和东秦岭有零星报道(杨家骥等, 1991; Yang *et al.*, 1993)。另外, 在哈萨克斯坦卡拉套地区也曾被发现(Ergaliev, 1980)。最近在韩国的太白盆地也有发现(Park and Choi, 2011)。本文报道的小凤凰虫产在中国山东济南市钢城区九龙山和辽宁东部大连市白家山的炒米店组底部, 这里属于华北地台的浅水相区。这一重要发现, 对于华北地台上划分苗岭统和芙蓉统的界线以及地台区和斜坡相区生物地层对比具有重要意义。

2 地质背景

小凤凰虫在山东济南市钢城区九龙山剖面(117°44′27.440″E, 36°05′08.313″N)产在炒米店组底部约3–4 cm厚的灰色薄层生物碎屑灰岩中, 与其下伏的崮山组顶部浅灰色至灰白色中薄层竹叶状灰岩呈明显的平行不整合接触, 与上覆的炒米店组下部灰色中薄层灰岩(155层)也有一个不明显的平行不整合接触(任晞营等, 2020, 图4)。小凤凰

虫在辽宁南部大连市金州区复州湾东北部约4.2 km的白家山剖面(121°40′38.585″E, 39°26′26.100″N)产在炒米店组底部约1.2–1.5 m厚的深灰至灰黑色薄层至中层生物碎屑灰岩中(属于 *Liostracina simesi–Placosema convexa*带(任晞营等, 2020), 与其下伏的崮山组顶部浅灰色中薄层灰岩, 生物碎屑灰岩, 和砾屑灰岩呈平行整合接触, 与上覆的炒米店组下部深灰色中层至中薄层灰岩(炒米店组下部约1.8 m厚, 属于 *Prochuangia mansuyi*带)呈整合接触。

3 华北地台寒武系苗岭统与芙蓉统的界线

中国寒武系的4分最早见于西南扬子区(包括地台和斜坡相区), 第四统称为湖南统(Hunanian)(Peng, 2003), 后来才正式命名为芙蓉统(Furongian)(Peng *et al.*, 2004c)。芙蓉统的底界是以球接子 *Glyptagnostus reticulatus* 一种的首现为标准, 然而在华北地台区这种球接子几乎找不到, 所以要精确找到界线的点位是一件非常困难的事情。近年来第三统的研究也取得了长足的进步, 被国际地层委员会命名为苗岭统(Miaolingian)(Zhao *et al.*, 2019)。伴随着碳同位素的演化($\delta^{13}\text{C}$), 层序地层学和事件地层学研究的不断深入, 苗岭统与芙蓉统界线研究在全球范围内已经有了积极的成果和进展(Saltzman *et al.*, 2000; Zhu *et al.*, 2004, 2006; Ahlberg *et al.*, 2009, 2018; Chen *et al.*, 2011; Ng

et al., 2014a, 2014b; Lee *et al.*, 2015; Lim *et al.*, 2015; Li *et al.*, 2018; Zuo *et al.*, 2018; Wang *et al.*, 2020)。

众所周知, 苗岭统与芙蓉统之间有一个生物灭绝事件, 在华北地台上就是在崮山期很繁盛的德氏虫类三叶虫(*Damesellids*)突然消失, 因此长期以来, 往往把寒武系第三统与芙蓉统之间界线置于崮山组的*Neodrepanura* (以往*Drepanura*)带和炒米店组的*Chuangia*带之间(朱兆玲等, 2005; 杜圣贤等, 2007; 左景勋等, 2020; Peng, 2008a; Ng *et al.*, 2014b; Huang *et al.*, 2019; Wu *et al.*, 2020)。近几年来, 生物地层学的研究也取得了一些进展, 如在*Neodrepanura*带之上新增加了*Diceratocephalus armatus*带(朱兆玲等, 2007); 在*Diceratocephalus armatus*带之上和*Prochuangia mansuyi*带之下新建立了*Liostracina simesi-Placosema convexa*带(任晓营等, 2020)。我国华北地区长山阶的下部*Chuangia batia*带之下还有*Prochuangia-Paracoosia*组合带(张梅生, 1988; 郭鸿俊、张梅生, 1992; 彭善池, 2009b, 2020; 朱茂炎等, 2019; Zhang, 1999; Peng, 2009a)。*Prochuangia-Paracoosia*组合带最早由Wittke (1984)所建, 包括以下属种: *Prochuangia levis tenuis* Wittke, 1984、*P. granulosa* Lu, 1956、*Pedinocephalus divergens* Wittke, 1984、*P. aff. divergens* Wittke, 1984、*Pagodia verrucosa* Wittke, 1984、*Stigmatia singularis* Wittke, 1984、*Eokaolishania* ? sp.、*Wuhuia* sp.、*Prochuangia levis levis* Wittke, 1984、*P. cf. mansuyi* Kobayashi, 1935、*Luyanhaoia cribrata* Wittke, 1984、*Eokaolishania constricta* Wittke, 1984、*Paracoosia kingi* Wittke, 1984、*Cheilidonocephalus alifrons preannulatus* (Fortey et Rushton, 1976)和*Abharella magnocula magnocula* Wittke, 1984, Gen. et sp. indet A, 而其中*Prochuangia levis levis* Wittke, 1984、*P. cf. mansuyi* Kobayashi, 1935、*L. cribrata* Wittke, 1984、*E. constricta* Wittke, 1984、*P. kingi* Wittke, 1984和*A. magnocula magnocula* Wittke, 1984, Gen. et sp. indet A等属种可以向下延伸到*Drepanura* (= ?*Palaeadotes*)-*Torifera-Eokaolishania*组合带 (Kushan, 1973; Peng *et al.*, 1999), 很显然在伊朗地区*Prochuangia-*

*Paracoosia*这个组合带跨越苗岭统和芙蓉统。然而在华北地区的*Prochuangia-Paracoosia*组合带与伊朗地区的*Prochuangia-Paracoosia*组合带的含义不完全相同, 这个带内的三叶虫分子, 除了*Prochuangia*和*Paracoosia*外, 还有*Parakotulia*、*Proceratopyge*、*Pseudagnostus*、*Wuhuia*和*Yuepingia*等(张梅生, 1988, 1999; 郭鸿俊、张梅生, 1992), 这些三叶虫都是*Prochuangia mansuyi*带内的常见分子, 应属于芙蓉统。值得一提的是, 产于*Pro chuangia-Paracoosia*组合带上部的*Parakotulia convexa* Guo and Zhang (郭鸿俊、张梅生, 1992, 245页, 图版1, 图4-8), 由于其分布广和层位稳定的特点, 在地层对比上具有重要意义。但这个种与产于祁连山古丈阶的*Taitzia insueta-Poshania poshanensis*带内的模式种*Parakotulia truncata* Chu (朱兆玲, 1960, 图版1, 图9, 10, 21)差异很大, 应归属于*Pseudokotulia* sp. (新属), 此新属的模式种*Pseudokotulia quadrata* (任晓营, 2017, 125-126页, 图版36, 图1-15), 在山东九龙山剖面 and 辽宁白家山剖面上见于*Prochuangia-Paracoosia*组合带(= *Prochuangia mansuyi*带)上部。*Prochuangia mansuyi*带在白家山剖面发育较全, 厚约产于一套厚约1.8 m的深灰色中薄层至中层含海绿石灰岩及生物碎屑灰岩, 自下而上又可以明显分为三个组合: 下组合约50 cm厚, 主要产丰富的*Prochuangia mansuyi* Kobayashi, 1935、*P. granulosa* Lu, 1956、*Paracoosia* Kobayashi, 1936以及从*Liostracina simesi-Placosema convexa*带延伸上来的一些分子, 如: *Parachangshania* Chien, 1958、*Sailoma* Schrank, 1975 (= *Pteroccephalops* Lin and Zhang in Chu *et al.*, 1979, = *Baikadamaspis* Ergaliev, 1980; = *Cathayanella* Yuan and Yin, 1998)、*Liaotrops* Schrank, 1975和*Pseudagnostus* Jaekel, 1909等; 中组合带约70 cm厚, 主要产丰富的球接子类三叶虫, 极少量的多节类三叶虫, 如: *Ceratopygidae*科等三叶虫; 上组合带产在约60 cm厚的中层至中薄层的深灰色灰岩中, 三叶虫的分异度较高, 有: *Paracoosia* Kobayashi, 1936、*Wuhuia* Kobayashi, 1933、*Alataspis* Park and Choi, 2011、*Pseudagnostus* Jaekel, 1909、*Pseudokotulia* gen. nov., 和*Cratopygiidae*科内的*Yuepingia*等。

到目前为止, 在这个带的上部既没有发现 *Prochuangia*, 也没有发现 *Chuangia*。而 *Pseudokotzia* 是一个特征分子, 除了在济南市钢城区九龙山和辽宁东部大连市白家山发现外, 在大连复州湾西山(张梅生, 1988, 图版18, 图1-3; 图版19, 图1-5; 图版20, 图4-5)、大连市金州拉树山(张梅生, 1988, 图版20, 图6)、辽宁本溪营子骆驼岭子(张梅生, 1988, 图版18, 图5-6)、山东济南市莱芜黄羊山(张梅生, 1988, 图版19, 图12; 图版20, 图7); 山东济南市唐王寨(张梅生, 1988, 图版18, 图7; 图版19, 图6-11)和江苏徐州市铜山县大南庄(张梅生, 1988, 图版18, 图8)等地也有发现。在辽宁白家山等地 *Prochuangia mansuyi* 带的下部 *Prochuangia* 这个属很容易被找到; 而在徐州及山东等地几乎找不到, 推测 *Prochuangia mansuyi* 带下部在这些地区很可能也是缺失的, 仅仅这个带的上部分布较广。有关 *Prochuangia mansuyi* 带的三叶虫动物群, 笔者将另文发表。

笔者认为 *Prochuangia-Paracoosia* 组合带内的 *Paracoosia* 虽然在华南斜坡相区最早可出现在 *Proagnostus bulbosus* 带至 *Linguagnostus reconditus* 带(彭善池, 2009b), 但华北地区在鼓山阶就已出现(袁金良等, 2012), 最早可追溯到鼓山阶底部, 在山东费县刘庄镇寺口村 *Paracoosia* 与 *Maotunia*、*Manchuriella*、*Eymekops* 等三叶虫共生(唐永刚、邢立达, 2014)。因此, *Paracoosia* 一属地层上延伸的时限很长, 从鼓山阶底部经古丈阶向上一直到芙蓉统排碧阶都有分布, 在华北地区也可以上延至 *Chuangia* 带(钱义元, 1994), 不宜作为一个带名。因此, 在 *Chuangia* 带之下应该恢复由小林贞 Kobayashi 一提出的 *Prochuangia* 带(Kobayashi, 1935), 或者将卢衍豪和钱义元提出的 *Prochuangia mansuyi* 亚带提升为带(卢衍豪、钱义元, 1983; 钱义元, 1994; Endo, 1944; Park and Choi, 2011)。如果在华北地区将界线置于 *Prochuangia-Paracoosia* 带的中间(彭善池, 2009b, 2020; 朱茂炎等, 2019; Peng, 2009a), 就等于将界线划在 *Prochuangia mansuyi* 带中间, 显然不合适。有人认为 *Prochuangia-Paracoosia* 组合带在华北地区有 6-8 m 厚(郭鸿俊、张梅生, 1992; 彭善池, 2009b; Peng, 2009a), 这是一个

误解, 查阅已经发表的资料不难发现山东地区的唐王寨剖面、黄羊山剖面, 及江苏徐州的大南庄等剖面上炒米店组底部约 2 m 厚的地层不仅包含了 *Prochuangia mansuyi* 带的上部, 而且还包括了 *Chuangia batia* 带(张梅生, 1988)。根据九龙山剖面资料来推测, *Prochuangia mansuyi* 带的厚度在山东地区不会大于 20 cm。而在辽东及太子河流域的复州湾西山剖面、拉树山剖面、火连寨剖面, 厚度也不会大于 3 m; 骆驼岭子剖面厚度要大一些, 炒米店组底部约 4 m 厚的地层中, 也可能包含了 *Prochuangia mansuyi* 带和其下的 *Luotulingia* 带(张梅生, 1988)。而在 *Liostracina simesi-Placosema convexa* 带内常见的一些特征分子, 如: *Liostracina simesi*、*Placosema convexa*、*Fenghuangella* 等, 而它们在 *Prochuangia mansuyi* 带内并未发现(张梅生, 1988)。 *Prochuangia mansuyi* 与 *Paracoosia deprati* 产于同一层内(张梅生, 1988), 因此可以推断在华北地台区 *Prochuangia-Paracoosia* 组合带与 *Prochuangia mansuyi* 带是大致相当的, 如将界线划在 *Prochuangia-Paracoosia* 带的中间(彭善池, 1999, 2020), 就相当于划在 *Prochuangia mansuyi* 带中间, 把 *Prochuangia-Paracoosia* 组合带的底界往下移没有充分依据(图 1)。另需要简单说明的是图 1 内原先的 *Neodrepanura premesnili* 带自下而上分为 *Neodrepanura-Liostracina tangwangzhaiensis* 带, *Neodrepanura premesnili* 带, *Diceratocephalus armatus* 带(任晔营等, 2020)。经初步研究这 3 个带内有不同的三叶虫组合面貌, 例如 *Neodrepanura* 这个属在这 3 个带内的种是不同的, *Neodrepanura premesnili* 一种仅出现在中间那个带内(将另文说明), *Liostracina* 一属 *Liostracina tangwangzhaiensis* 一种出现在最下部那个带, *Liostracina krausei* 一种出现在狭义的 *Neodrepanura premesnili* 带。具有重要对比意义的是在 *Neodrepanura-Liostracina tangwangzhaiensis* 带内发现了大量的 *Clavagnostus spinosus* (Resser, 1938) 一种的标本, 而这个种在王村剖面上仅出现在 *Linguagnostus reconditus* 带的下部(Peng and Robison, 2000), 因此本文将 *Neodrepanura-Liostracina tangwangzhaiensis* 带, *Neodrepanura premesnili* 带与华南斜坡相的 *Lin-*

化石带 / 文献来源 / 地层		朱茂炎等, 2019	Park and Choi, 2011; Ren et al., 2021	彭善池, 2009、2020	本 文
芙蓉统 Furongian	排碧阶 Paibian	Chuangia Zone	Chuangia Zone	Tamagnostus orientalis-Corynexochus plumula Zone	Chuangia batia Zone
				Agnostus inexpectans-Proceratopyge protracta Zone	
苗岭统 Miaolingian	古丈阶 Guzhangian	Prochuangia - Paracoosia Zone	Prochuangia mansuyi Zone	Glyptagnostus reticulatus Zone	Prochuangia mansuyi Zone
			Fenghuangella laevis Zone	Glyptagnostus stolidotus Zone	Liostracina simesi- Placosema convexa Zone
		Neodrepanura premesnili Zone	Liostracina simesi Zone		Diceratocephalus armatus Zone
			Neodrepanura Zone	Linguagnostus reconditus Zone	Neodrepanura premesnili Zone
					Neodrepanura -Liostracina tangwangzhaiensis Zone

图 1 华北地台区苗岭统和芙蓉统界线附近三叶虫分带, 以及与华南斜坡相区的对比

Fig. 1 Trilobite zonation and correlation in the Miaolingian–Furongian boundary interval between North China Platform and Jiangnan Slope
红线代表本文提出的苗岭统和芙蓉统界线; 绿线代表 Park 和 Choi(2011)以及 Ren 等人(2021)文中的苗岭统–芙蓉统界线。
The red line is showing the Miaolingian and Furongian boundary by the present paper; the green line is showing the Miaolingian–Furongian boundary by Park and Choi (2011) and Ren *et al.*, (2021).

guagnostus reconditus 带对比。Diceratocephalus armatus 带以往没有深入研究, 这个带内虽然还有许多新的属种没有描述, 但是有些属种如 Kormagnostella、Pseudagnostus、Ammagnostus、Paraacidaspis 和 Parachangshania 等可以作为与华南地区 Glyptagnostus stolidotus 带对比依据, 有关 Diceratocephalus armatus 带内三叶虫将另文报道。Liostracina simesi–Placosema convexa 带内三叶虫的分异度较高, 除了 Liostracina simesi、Placosema convexa 和 Fenghuangella laevis 等属种可与华南地区 Glyptagnostus stolidotus 带对比外, 还有 Pseudagnostus、Connagnostus、Acmahachis、Sanchennngziella、Sailoma、Parachangshania、Proceratopyge、Paracoosia、Yuepingia、Wenshuia 和 Liotrops 等, 详细的研究将另文报道。

另有一种意见是 Park 和 Choi (2011) 提出来的, 在 Prochuangia mansuyi 带之下新建了 2 个化石带:

Liostracina simesi 带和 Fenghuangella laevis 带, 将苗岭统与芙蓉统之间的界线置于 Fenghuangella laevis 带之底(Park and Choi, 2011; Park *et al.*, 2012; 2013; Lim *et al.*, 2015; Choi *et al.*, 2016; Choi and Park, 2017; Ren *et al.*, 2021)。这个带是以 Placosema bigranulosum (= Placosema convexa) 和 Fenghuangella laevis 的首现点作为底界。Fenghuangella laevis 是一个新种, 其时代很难确定。而 Placosema convexa 的首现点应该在 Glyptagnostus stolidotus 带(Peng *et al.*, 2004a; 2004b; Qi *et al.*, 2006), 虽然它可以上延到 Glyptagnostus reticulatus 带(Peng *et al.*, 2004b)。此外, 在河北唐山丰润区半壁山剖面上 Liostracina simesi 和 Placosema convexa, 前一个种是出现在 Glyptagnostus stolidotus 带(Jago and Cooper, 2005)。更何况在辽宁大连市白家山剖面上 Liostracina simesi 一种与 Fenghuangella laevis 是共生在一起的, 没有上下层位关系。笔者认为 Liostra-

*cina simesi*带和*Fenghuangella laevis*带应该合并为一个组合带(*Liostracina simesi-Plcosema convexa* Assemblage Zone), 如将界线划在*Fenghuangella laevis*带之底, 就是将界线置于*Liostracina simesi-Plcosema convexa*组合带的中间, 显然不太合适。笔者建议将华北地区*Prochuangia mansuyi*带之底作为芙蓉统排碧阶之底, 将*Liostracina simesi-Plcosema convexa*组合带置于古丈阶最上部。此外, 从整个德氏虫类三叶虫的灭绝情况来看, 带尾刺的德氏虫类三叶虫并没有延伸到界线附近——即古丈阶顶部, 而是离开界线有一段距离(Peng et al., 2004a, 2004b, 2004c), 而这段距离在华北地台上就相当于*Liostracina simesi-Plcosema convexa*组合带。但也有个别地区带尾刺的德氏虫类三叶虫的少数属种可以向上延伸到古丈阶顶部, 如南极洲产的*Carrosella alberti* (Jago and Cooper, 2005, p. 673, Fig. 5H–J, M, O, P, R)。

还有一些人将界线划在*Neodrepanura*带中间(Bagnoli et al., 2014), 他们所依据的理由是牙形类生物地层和炭同位素 $\delta^{13}\text{C}$ 的变化曲线, 这显然与三叶虫划分的生物地层是相矛盾的, 不宜采用。

4 小凤凰虫头尾搭配研究

三叶虫头尾搭配是在研究三叶虫过程中经常会遇到的难题, 在一些三叶虫化石富集层里, 特别是灰岩中的富集层, 往往能采集到许多分散保存的头盖、尾部、唇瓣和活动颊, 最多时可以有十几个属种(袁金良等, 2012)。因此在没有发现头胸尾的完整个体时, 想要把所有的属种头尾精准搭配好, 并非易事。这方面曾有个详细的讨论, 可以通过所谓的“筛选法”“分类形态比较法”“数量统计法”来完成搭配(袁金良等, 2012, 52–53页)。三叶虫头尾搭配研究对于确定三叶虫属种的有效性, 高级分类单元位置的合理性和三叶虫的系统演化可靠性又有十分重要意义。自1977年建立小凤凰虫以来, 很长一段时间没有发现其对应的尾部, 这主要是小凤凰虫的头盖本来就很小, 通常为1.5–2.5 mm长, 对应的尾部应该更小, 不易被发现。类似的属种还有很多, 如华北崮山组内的翁氏虫(*Wongia*

Sun, 1924), 当十岭虫(*Tangshihlingia* Chu, 1959), 湘西黔东花桥组所产的*Oculishumardia* Peng, Babcock, Hughes and Lin, 2003、华北地区炒米店组下部的*Elaphraella* Lu and Qian, 1983和*Triangulaspis* Qian, 1994等都是个体很小的三叶虫, 建属时也仅仅依据头盖标本(朱兆玲, 1959; 卢衍豪、钱义元, 1983; 钱义元, 1994; Sun, 1924; Peng et al., 2003), 对于这些属种的深入研究和修订笔者将另文发表。

目前, 大约有3种形态的尾部被认为是属于小凤凰虫。1983年林焕令和周天荣在建立*Fenghuangella subtriangularis* Lin and Zhou in Lin et al., 1983一种时配上了第一种类型的尾部(林天瑞等, 1983, 图版2, 图2)。这个尾部非常特殊, 尾轴较短、较窄, 肋部较宽, 肋沟和间肋沟发育, 其上布满了瘤点装饰。后来又有非常类似的尾部被置于*Fenghuangella laochatianensis laochatianensis* Yang in Zhou et al., 1977 (彭善池, 2020, 图版200, 图6; Peng et al., 2004b, pl. 27, fig. 15)和*Fenghuangella laochatianensis crassa* Peng, Babcock et Lin, 2004b (pl. 27, fig. 16; 彭善池, 2020, 图版200, 图11)。但是这种类型的尾部与双刺头虫的尾部(彭善池, 2020, 图版202, 图6–7)差别很大。因此置于这个属内的结论是有问题的。根据其表面的瘤点装饰, 这种小尾部或许将其与*Gaoloupingia*属的头盖匹配更加合理(袁金良、尹恭正, 1998, 161–163页, 图版5, 图4–10; Peng et al., 2004a, p. 170–171, pl. 2, figs. 10–12)。而真正属于小凤凰虫的尾部错配上了*Pseudomapania*一属头盖, 如*Pseudomapania cylindrica* Yuan and Yin, 1998 (Peng et al., 2004b, pl. 67, figs. 13–17; pl. 68, figs. 7–9)。当然, 这些尾部也可能属于*Fenghuangella*属内不同的种, 以后还需要深入研究。毫无疑问, 小凤凰虫是属于双刺头虫科(*Diceratocephalidae* Lu, 1954), 这个科内三叶虫的尾部共同的特征是尾轴较宽长, 几乎伸达后边缘, 尾轴沟和尾轴节沟向后变得很浅, 肋部较窄, 其上的肋沟和间肋沟很浅或不发育, 尾边缘极窄, 如*Diceratocephalus armatus* Lu的尾部(卢衍豪, 1954, 图版1, 图8–9; 彭善池, 2020, 图版202, 图6–7)。发髻虫属模式种*Torifera triangularis* Wolfart, 1974的

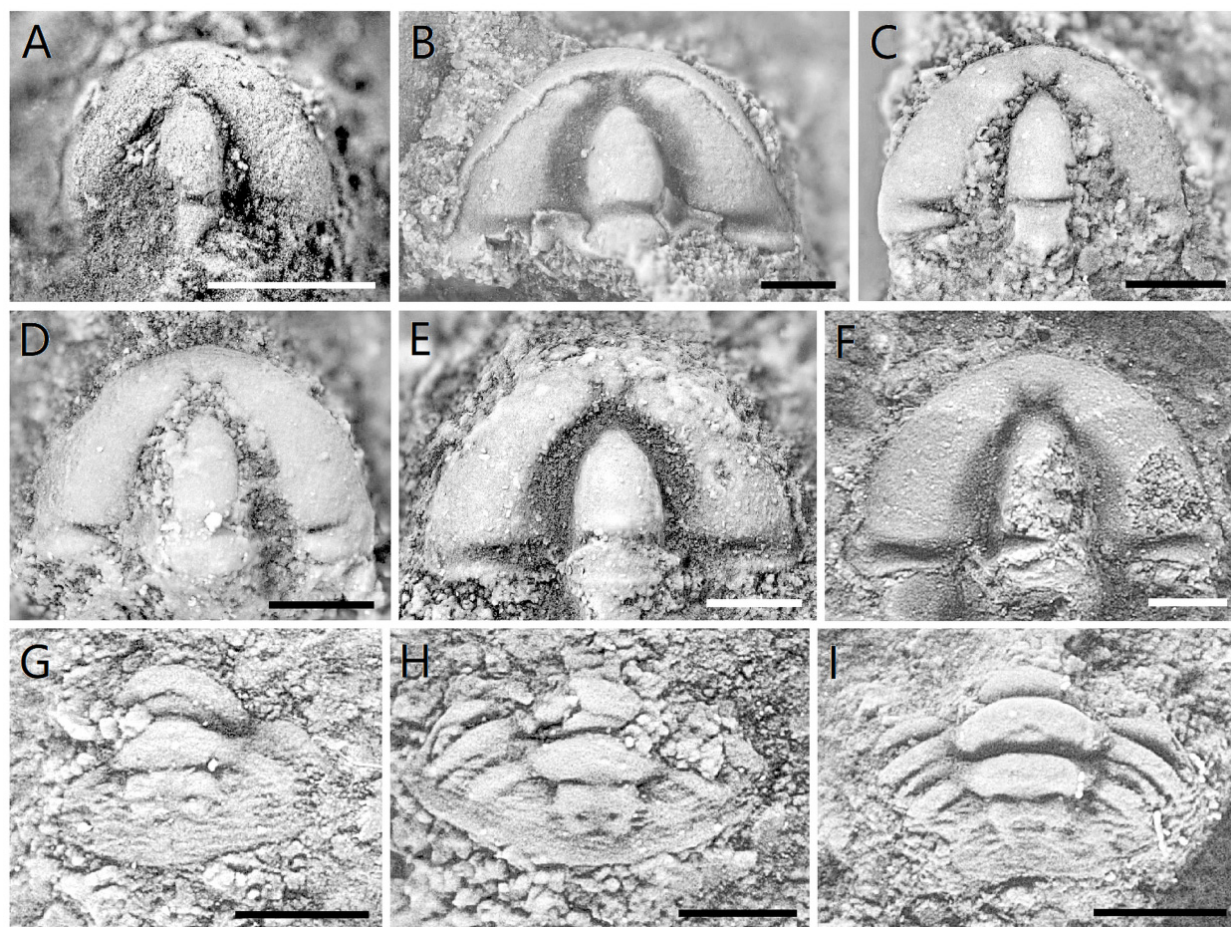


图 2 光滑小凤凰虫

Fig. 2 *Fenghuangella laevis* Park and Choi, 2011

A–F. 头盖(Cranidium); A. 采集号(Collect No.): JLS155, 登记号(Cat.): NIGP 174519; B. BJS 4.85m, NIGP 179695; C. BJS 4.80m, NIGP 179696; D. BJS 4.85m, NIGP 179697; E. BJS 4.85m, NIGP 179698; F. BJS 4.85m, NIGP 174523. G–I. 尾部; G. 采集号(Collect No.): BJS 4.80m, 登记号(Cat.): NIGP 179699; H. BJS 4.80m, NIGP 179700; I. JLS155, NIGP 174522. 标本(A 和 I)采自山东省济南市钢城区九龙山剖面炒米店组底部深灰色薄层灰岩中, 其余标本采自辽宁省大连市白家山剖面炒米店组底部深灰色薄层至中薄层灰岩中。比例尺为 0.5 mm。

Specimens (A, I) were collected from the dark grey thin bedded limestone of the lowermost part of the Chaumitien Formation, at the Jiulongshan section, Gangcheng District, Jinan City, Shandong Province; other specimens were collected from the dark grey thin bedded to medium-bedded limestone of the lowermost part of the Chaumitien Formation, at the Baijiashan section, Dalian City, Liaoning Province. Scale Bars = 0.5 mm.

尾部(Wolfart, 1974, pl. 12, figs. 8–9), 及 *Torifera taoyuanensis* Peng (彭善池, 1987)的尾部(Peng *et al.*, 2004a, pl. 58, figs. 10–11),与 *Diceratocephalus armatus* Lu的尾部(卢衍豪, 1954, 图版1, 图8–9; 彭善池, 2020, 图版202, 图6–7)也都很相似, 因此笔者认为应将其归于双刺头虫科内较合理(Jell and Adrain, 2003; Zhu, 2008)。如果将 *Torifera* 一属置于阿尔萨斯头虫科内(Alsataspididae Turner, 1940), *Torifera* 一属就将置于Asaphida Salter, 1864目内, 因为双刺头虫科和阿尔萨斯头虫科又分别属于两个不同的目: Ptychopariida Swinnerton, 1915 和

Asaphida Salter, 1864, 这种高一级分类单元位置没有充分的依据, 值得商榷(彭善池, 2020; Peng *et al.*, 2004a; Peng, 2008b)。

小凤凰虫第二种形态尾部, 见 *Fenghuangella coniforma* Yang in Zhou *et al.*, 1977一种(Peng *et al.*, 2004b, pl. 29, figs. 15–17)。这种尾部, 尾轴较长, 肋部与尾轴大致等宽(横向), 肋沟较宽深, 间肋沟较窄浅, 有一窄的尾边缘, 而且前肋脊带较宽, 突起较高, 末端往往伸向尾边缘, 这种尾部应该属于 *Pseudomapania* (袁金良, 尹恭正, 1998, 图版4, 图10, 14)。

小凤凰虫第三种形态尾部, 见 *Fenghuangella laevis* Park and Choi, 2011 (Figs. 9.15–17), 此尾部仅有一毫米长, 显然是幼虫标本, 也有可能属于 ceratopygid 某种尾部的幼虫标本。任晔营等 (Ren *et al.*, 2021) 和本文所提供的尾部标本才是 *Fenghuangella laevis* 一种的尾部, 因为和 *Fenghuangella* 头盖共生的尾部仅有一种尾部, 并未发现像 *Gaoloupingia*、*Pseudomapania* 的头盖和尾部。再从已发现的小凤凰虫的头部和胸部完整个体来看, 在通常情况下, 头鞍向前收缩快, 中轴宽, 肋部很窄, 对应的尾轴也应该宽, 向后收缩快 (Peng *et al.*, 2001a, pl. 14, fig. 10; 2004b, pl. 30, fig. 9), 才是一种正确的搭配, 当然也不排除也有些相反的例证。

5 系统古生物学

本文采用的相关系统古生物学术语均依据 Whittington 和 Kelly 等 (1997)。本文所使用标本存放在中国科学院南京地质古生物研究所标本馆, 冠号 NIGP。

三叶虫纲 Class Walch, 1771

褶颊虫目 Order Ptychopariida Swinnerton, 1915

双刺头虫科 Family Diceratocephalidae Lu, 1954

小凤凰虫属 Genus *Fenghuangella* Yang in Zhou *et al.*, 1977

Fenghuangella Yang, 1977, 周天梅等, 170 页。

Fenghuangella Yang, 尹恭正, 李善姬, 1978, 489 页。

Fenghuangella Yang, 杨家骥, 1978, 44 页。

Fenghuangella Yang, 刘义仁, 1982, 312 页。

Fenghuangella Yang, 罗惠麟, 1982, 4 页。

Fenghuangella Yang, 林天瑞等, 1983, 403 页。

Fenghuangella Yang, 钱义元, 周泽民, 1984, 178 页。

Fenghuangella Yang, 彭善池, 1987, 97 页。

Fenghuangella Yang, 杨家骥等, 1991, 147 页。

Fenghuangella Yang, Duan *et al.*, 1999, p. 158.

Fenghuangella Yang in Zhou *et al.*, Peng *et al.*, 2001a, p. 104, 105; 2001b, p. 141; 2004b, p. 73.

Fenghuangella Yang in Zhou *et al.*, Jell and Adrain, 2003, p. 376, 469.

Fenghuangella Yang in Zhou *et al.*, Yuan and Li, 2008, p. 111, 120, 127.

Fenghuangella Yang in Zhou *et al.*, Peng, 2008b, p. 164, 175, 187.

Fenghuangella Yang in Zhou *et al.*, Park and Choi, 2011, p. 492, 493.

Fenghuangella Yang in Zhou *et al.*, 任晔营, 2017, 118 页。

Fenghuangella Yang in Zhou *et al.*, 彭善池, 2020, 452 页。

Fenghuangella Yang in Zhou *et al.*, Ren *et al.*, 2021, p. 6.

Cyclolorezellina Ergaliev, 1980, p. 137.

Cyclolorezellina Ergaliev, 彭善池, 1987, 97 页。

Cyclolorezellina Ergaliev, Jell and Adain, 2003, p. 362, 469.

模式种 *Fenghuangella laochatianensis* Yang in Zhou *et al.*, 1977

产地层位 湖南省凤凰县老茶田, 中上寒武统老茶田组 (周天梅等, 1977)。

属征 (修订) 小型三叶虫, 头部中等突起, 半圆形至半椭圆形; 颈沟和后边缘沟较宽深, 固定颊宽, 与前边缘, 眼前翼, 后侧翼构成半环形突起; 眼叶短小, 位于头鞍相对位置的前侧方。胸部 8 节或更多, 轴部比肋部宽, 肋刺极短。尾部小, 半椭圆形或倒三角形; 尾轴宽长, 几乎伸达尾部后缘, 突起, 向后强烈收缩, 倒锥形, 分 4 至 5 节, 尾边缘极窄。

讨论 就头部, 头盖, 活动颊, 尾部的许多特征来看, 小凤凰虫与发髻虫 (*Torifera* Wolfart, 1974) 较相似, 如头鞍向前收缩较快, 背沟宽深, 头鞍之前有向前分叉斜沟, 固定颊宽, 眼叶短小, 位置靠前, 颈环具颈刺, 尾部尾轴宽长, 向后强烈收缩, 尾边缘窄, 两者的主要区别是发髻虫的头盖呈梯形, 有窄的前边缘和宽而突起的鞍前区, 眼叶位置相对靠后, 眼脊平伸或略向后斜伸, 叶状体发育, 尾部较横宽。

时代分布 寒武系苗岭世古丈期至芙蓉世排碧期早期; 中国华南 (湖南、贵州、皖南、苏南、云南), 中国华北 (山东、辽宁), 哈萨克斯坦和韩国。

光滑小凤凰虫 *Fenghuangella laevis* Park and Choi, 2011

(图 2)

2011 *Fenghuangella laevis* Park and Choi, p. 492–493, Fig. 9 (1–14, non 15–17).

2013 *Fenghuangella laevis*, Park *et al.*, p. 1000.

2016 *Fenghuangella laevis*, Choi *et al.*, 2016, p. 1984.

2017 *Fenghuangella laevis*, 任晔营, 119 页, 图版 19, 图 11.

2021 *Fenghuangella laevis*, Ren *et al.*, p. 6, Fig. 2 (A–B, D–F, ?C).

正模 头盖 SNUP 4641 [Park and Choi, 2011, Fig. 9 (9–12)], 产于韩国织洞剖面细松组 *Fenghuangella laevis* 带。

特征 (修订) 头盖光滑, 次三角形; 颈沟和后边缘沟浅, 具短的颈刺; 头鞍短, 锥形; 眼脊缺失或微弱; 尾部半椭圆形, 尾轴宽而长, 几乎伸达尾部后缘, 分 4 个轴节, 前 2 个轴节宽 (横向) 而长 (纵向), 轴节沟清楚, 后 2 个轴节向后迅速变窄, 轴节

沟不与背沟相连,肋部略窄(横向),前2对肋沟深;尾边缘窄,沿边缘有不规则脊线。

比较 本文标本与韩国所产模式标本相比,背沟和后边缘沟略深宽,在脱皮后的标本上可见到清晰的眼脊。

产地层位 山东莱芜九龙山和辽宁大连市白家山,炒米店组下部 *Liostracina simesi*-*Plcosema convexa* 组合带(古丈阶,苗岭统)。

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