

贵州瓮安—开阳地区陡山沱期含磷岩系 的大型球形绿藻化石*

薛耀松 唐天福 俞从流 周传明

(中国科学院南京地质古生物研究所, 南京 210008)

内 容 提 要

通过对瓮安陡山沱组上段的白云质生物屑磷块岩和磷质白云岩标本进行酸处理和切片后, 获得大量个体硕大的球形绿藻化石, 共鉴定了 7 属 13 种, 其中多数是新属新种。这些绿藻化石与红藻、疑源类及骨骼化石共生, 构成一个特殊的生物群, 其分布与成磷区一致, 显然受到环境因素的控制。南沱冰期后气温上升, 引起海平面升高, 海洋贫氧带扩展和上涌洋流的活跃, 给台缘浅水区带来丰富的磷质和其他营养物质, 促使生物繁盛和成磷作用的发生。

关键词 大型绿藻化石 陡山沱期 中国南方

前寒武纪地层中的球形绿藻化石, 早在 1 900Ma 前的地层中即已发现, 其细胞直径很小, 一般 $< 30\mu\text{m}$ (刘志礼, 1990; Schopf and Blacic, 1971)。尹磊明等曾报道了从宜昌地区上震旦统岩石薄片中发现的较大的球形绿藻化石, 细胞直径 $> 30\mu\text{m}$, 大的可达 $70\text{—}200\mu\text{m}$ (尹磊明、李再平, 1978; Yin Leiming, 1987)。陈孟莪等 (1986) 在瓮安陡山沱组岩石薄片中发现的大型球状化石, 直径达 $500\text{—}800\mu\text{m}$, 被命名为 *Megasphaera inornata*, 怀疑与轮藻有亲缘关系, 但从其图版照片判断, 可能是疑源类球体的切面。

笔者采用醋酸溶液浸泡法从瓮安陡山沱组上段含磷岩系标本中获得大量个体硕大的球形绿藻化石实体标本, 多细胞定形球体的直径通常达 $500\text{—}1\ 200\mu\text{m}$; 在开阳洋水地区洋水组下部碎屑岩薄片中也见到少量磷酸盐化和硅化的球形绿藻化石, 细胞直径都在 $100\mu\text{m}$ 以上。这些大型球状绿藻化石, 与大量大型疑源类、红藻碎屑及少量骨骼化石共存 (薛耀松等, 1992), 成为特殊的瓮安生物群中的重要分子。其中, 磷酸盐化红藻类化石由赵东旭 (1986) 和陈孟莪等 (1986) 最先报道, 定名为 *Solenopora* sp., 之后张昀对其进行了深入的研究, 重新鉴定了 *Thallophyca* 和 *Wengania* 两个属 (Zhang Yun, 1989)。大型疑源类已由尹磊明等 (Yin Leiming and Xue Yaosong, 1993) 作了报道, 详细的研究尚在进行中。

以醋酸浸泡法从晚前寒武纪地层中获得大量可信的磷酸盐化球形绿藻实体化石尚属首次, 可能为晚前寒武纪生物演化和生物成磷作用的解释提供重要依据。

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一、地质背景及化石产出层位

开阳、瓮安、福泉地区是我国南方晚震旦世陡山沱期主要成磷区之一。该区位于晚震旦世川黔滇台地东南边缘,陡山沱期磷矿主要形成于潮间带至风暴浪基面之上的潮下带,地层序列及岩石学性质表明为水动力能量较强、沉积速率较低的沉积环境(薛耀松等,1992)。瓮安磷矿大塘矿段,陡山沱组中部有一显著的岩溶侵蚀面,从而把它分为下段和上段两部分。陡山沱组下段为浅肉红色至灰色含锰白云岩-灰黑至棕黑色砂屑磷块岩-浅灰色白云岩序列;上段则为黑色磷基砾屑磷块岩-磷质白云岩与生物屑磷块岩条带状互层-磷质白云岩夹磷块岩及燧石条带的岩性序列(插图1);下段中部磷块岩称“A”矿层,上段称“B”矿层。向南至福泉高坪地区,“A”矿层相变为硅化层纹状白云岩,甚至完全被硅化而为白色硅岩;向北至玉华一带,“A”矿层亦被层纹状白云岩代替。根据开阳、福泉、上饶等地磷酸盐岩的Sm-Nd同位素年龄测定,陡山沱组顶界年龄值约为640Ma(杨杰东等,1994)。

本文描述的主要化石,大多采自瓮安大塘地区的陡山沱组上段。化石多已磷酸盐化,成为磷块岩和磷质岩中的主要磷质颗粒成分,基质为白云石,并已普遍重结晶,常见保存尚好的小的球型绿藻 *Tetraphycus* sp. 群集分布。对白云质生物屑磷块岩及生物屑磷质白云岩样品作了醋酸溶液的浸泡处理(薛耀松等,1992),除了获得大量大型疑源类实体化石外,还有较丰富的大型球形绿藻化石个体,并对各类岩石标本切制了薄片,观察到很多球形绿藻化石的切面,提供了化石外观形态和内部结构的对照映证。

二、开阳地区洋水组的球形绿藻和地层划分对比

开阳洋水地区灯影组之下的部分震旦纪地层,刘鸿允等(1966)命名为“南沱组”和洋水组,前者分为冰碛砾岩段和紫色页岩段,后者分为下部灰绿色碎屑岩和上部磷块岩;洋水组可与陡山沱组对比。我们在观察洋水沙坝上剖面时发现,灰绿色砂岩顶部有透镜状含锰白云岩及2.05m厚的砂质白云岩,其中常见胶磷矿砂砾屑,并在其中及其下的青灰色岩屑石英砂岩和“紫色页岩段”上部的岩屑石英砂岩夹层的薄片,发现磷酸盐化和硅化的球形绿藻化石 *Protosphearidium* sp. A, *P.* sp. B 和 *Eozygion* sp. (插图2)。它们的直径都 $>100\mu\text{m}$,个体明显比华北蓟县系中发现的同类化石(大小 $20\mu\text{m}$ 左右)(刘志礼,1982)要大得多。据上述岩性特性、化石特征,我们认为,洋水地区的“南沱组”上部“紫色页岩段”与洋水组下部灰绿色碎屑岩一起,相当于瓮安地区的陡山沱组下段;洋水组上部磷块岩层主要为藻层纹与磷质砂屑层纹互层,部分地区叠层石发育,与瓮安地区陡山沱组上段(即“B”矿层)对比;上、下段间为明显的假整合接触关系。因此秦守用等(1984)把洋水组仅限于磷矿层,其下碎屑岩称为马路坪组并与莲沱组对比的方案是不可取的。

三、大型球形绿藻的生态环境分析

瓮安大塘地区陡山沱期含磷岩系厚度较薄,其中风暴及强水流冲刷现象屡见,上段频繁地夹磷酸盐质硬底,表明为水动力强、沉积速率低、陆源碎屑极少的沉积条件。陡山沱早期,大塘地区在南沱期较低洼的地形基础上发展成为面积不大,较局限的陆表小海盆(湾?),以

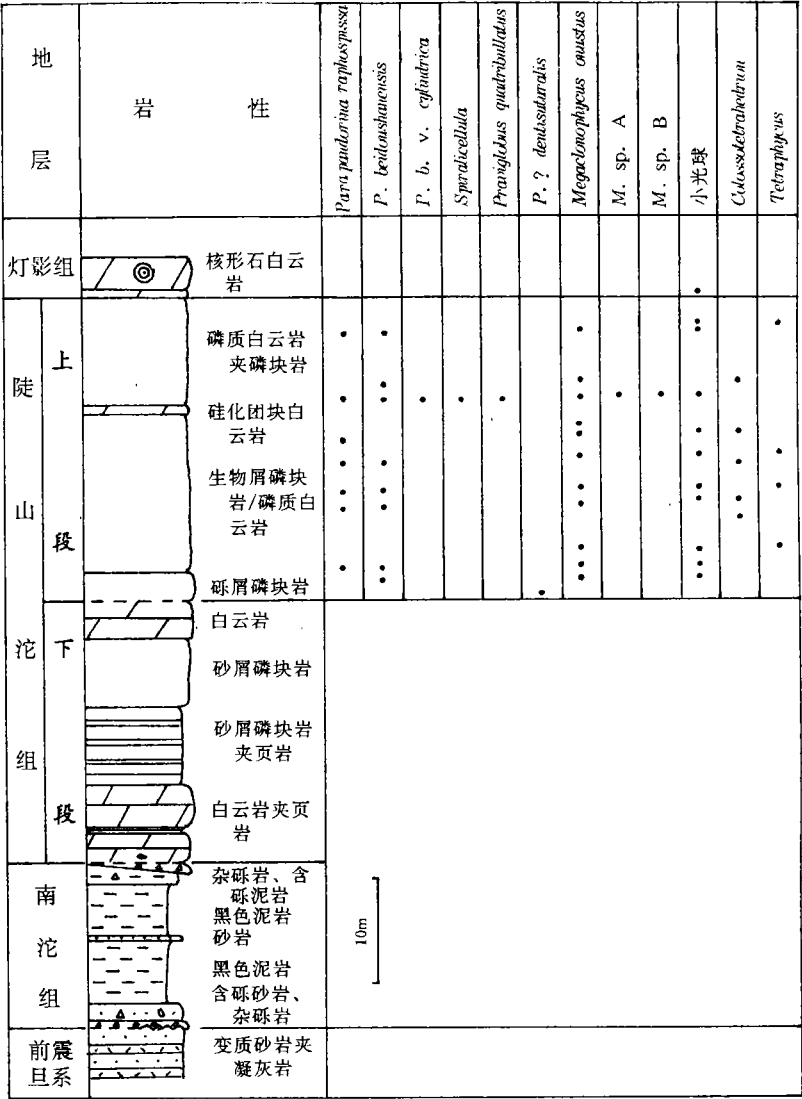


插图 1 瓮安地区陡山沱组大型绿藻化石的分布
Distribution of the large Chlorophyta fossils in the Doushantuo Formation of Weng'an

暗色薄层状砂屑磷块岩为主的“A”矿层在这个小盆地中堆积,其中基本上不含疑源类及绿藻化石;其南面的高坪地区和北面的玉华地区为潮坪环境,藻席发育,沉积层纹状藻白云岩。陡山沱早期末,黔中地区局部上升,露出海面,遭受侵蚀,碳酸盐岩分布区还发育古喀斯特地形。陡山沱晚期,海平面上升,高坪地区迅速从潮坪变为潮下环境,有较厚的潮下红藻滩相磷块岩分布,其他生物很少;大塘至玉华一带成为开敞的潮下-陆架浅海水域,各类生物大量繁盛,并经强水流的冲刷搬运,常常富集成白云质生物屑磷块岩或生物屑磷质白云岩。

大型球形绿藻的发生和繁盛,和与之共生的大型疑源类及其他陡山沱期生物一样,都与

的相当一段时间内,可能随风浪或海流漂浮而分散出去。

四、化石描述

绿藻纲 (Chlorophyceae)

团藻目 (Volvocales)

团藻科 (Volvocaceae)

副实球藻属(新属) *Parapandorina* gen. nov.

模式种 *Parapandorina raphospissa* gen. et sp. nov.

属征 由 4、8、16 个细胞组成球形定形体,群体直径 480—1 200 μm 。细胞倒卵状或倒锥状,向球体中央收缩,紧密集结;球体表面,细胞因紧密贴接而呈多角形,或非紧密集结而呈圆形,外观似足球状。单个细胞的壁薄,无胶质膜;球状定形群体周围有薄的胶质膜层,但在处理出的标本常未被保存。

讨论 细胞结构及在群体中的排列方式,与现代团藻科实球藻属(*Pandorina* Bory, 1824)很相似,其中最常见的是 *P. morum* Bory 可达 80 μm (Fott, 1971)。刘志礼(1982)从雾迷山组中发现并命名的拟实球藻属(*Pandorinopsis* Liu, 1982)也与我们的标本具类似的结构,但该属细胞数目较多,群体直径仅 20 μm 左右。本文的标本主要以 8 个细胞组成,定形体直径特别大,与上述两属不同;但细胞结构及定形体性质上更接近于 *Pandorina* 属的特征。

时代分布 晚震旦世,中国贵州瓮安及湖北保康。

密缝副实球藻(新属、新种) *Parapandorina raphospissa* gen. et sp. nov.

(图版 I, 图 1a, 1b, 2, 3)

材料 以酸处理方法获得实体化石标本数十枚。

描述 由 4—8 个细胞组成定形球形,直径达 700—1 200 μm 。细胞倒锥状,向球心收缩紧密贴接;以 8 个细胞拼成的标本,球体表面细胞呈多角形,酷似足球状。细胞壁薄,表面光滑,无单独的胶质膜。部分定形球体表面保存薄而半透明的胶质膜。

讨论 典型标本未保存胶质膜和细胞壁,局部放大显示细胞内部有许多 5—10 μm 的小球状物,它们是细胞内容物胶磷矿化形成的胶球体,还是细胞变为配子囊而形成的配子? 尚难定论。少数标本的细胞间贴接缝显示强、弱或主、次之分(图版 I, 图 2),主拼接缝(a)清晰,次拼接缝(b)似细胞再分裂之状,与现代实球藻属的无性繁殖方式类似(Fott, 1971)。

产地层位 贵州瓮安陡山沱组上段。

北斗山副实球藻(新属、新种) *Parapandorina beidoushanensis* gen. et sp. nov.

(图版 I, 图 6; 图版 II, 图 1, 3—5b)

材料 酸处理后获实体标本 10 枚以上,少量薄片切面。

描述 由 4、8、16 个倒卵状细胞集结成定形球体,直径 480—560 μm 。细胞间的间隙大,接缝宽 25—40 μm ,故定形圆球体表面上细胞呈圆或亚圆形;外包薄的胶质膜(图版 II, 图 4 中 a 所示)。但单个细胞不具独自の胶质膜。

讨论 倒卵状细胞镶嵌成定形球体的性质符合 *Parapandorina* 属征。个别 4 个细胞的

定形球体,在胶质膜和细胞壁破损以后的低倍扫描照片中显示无数小球体聚集的形状(图版 I,图 5a),但高倍放大后表现为细胞内含物被胶磷矿化而形成的胶球状或葡萄状结构,并不是产生的孢子。

产地层位 贵州瓮安陡山沱组上段及湖北保康陡山沱组下部。

北斗山副实球藻圆锥状变种(新属、新变种)

Parapandorina beidoushanensis var. *cylindrica* gen. et sp. nov.

(图版 I,图 2)

材料 酸处理后获实体标本 1 枚。

描述 由 8 个细胞集结而成群集体,细胞间接缝宽;部分细胞变长变尖,使群体呈锥状。群体锥长 $850\mu\text{m}$ (照片中的锥尖已在制样时损坏),圆头部分直径 $720\mu\text{m}$ 。

讨论 标本圆头部分特征与 *P. beidoushanensis* 特征相同。锥部系部分细胞变形所致,实为前一种的变异,因形态特别,定为变种。

产地层位 贵州瓮安陡山沱组上段。

畸球藻属(新属) *Praviglobus* gen. nov.

模式种 *Praviglobus quadribullatus* gen. et sp. nov.

属征 由若干细胞镶嵌拼接成亚球形群集体,直径 $550\text{--}640\mu\text{m}$;细胞大小不等,形状不规则,具包嵌性质。细胞壁薄,有薄的公共胶质膜包裹。

讨论 细胞向内收缩镶嵌成亚球形体的性质与 *Parapandorina* 属相似,但细胞大小相差悬殊,集合方式及接缝不规则,与 *Parapandorina* 属显著不同。

时代分布 晚震旦世,中国贵州瓮安。

四髻畸球藻(新属、新种) *Praviglobus quadribullatus* gen. et sp. nov.

(图版 I,图 4a,4b)

材料 由酸处理后得实体化石 1 枚。

描述 一个大细胞,四面相对嵌有 4 个小细胞,组成凸球状群集体,群体直径 $640\times 550\mu\text{m}$;被包嵌的 4 个小细胞明显凸出于群球体表面,高达 $50\text{--}80\mu\text{m}$,状如发髻。细胞接缝处有残存的胶质膜(?)。球体表面密布圆形、四边形、三角形小孔,孔径或边长在 $5\text{--}20\mu\text{m}$ 。

讨论 与 *Parapandorina raphospissa* 比较,具有类似的拼接特征,但似乎其中 4 个细胞已联结成一个大细胞而保留相对的另外 4 个细胞。表面小孔的性质还不十分清楚,怀疑其中有的是鞭毛伸出孔(?)。其结构显然比 *P. raphospissa* 复杂。

产地层位 贵州瓮安陡山沱组上段。

齿缝畸球藻?(新属、新种) *Praviglobus? dentisuturalis* gen. et sp. nov.

(图版 I,图 5)

材料 实体标本 1 枚。

描述 4 个(?)不规则细胞犬牙交错包嵌成球形群集体,直径约 $570\mu\text{m}$ 。表面较光滑,未

保留胶质膜。

讨论 以畸形细胞包嵌成球形群集体,类似 *Praviglobus* 属的特征,但其表面无众多的小孔,与 *P. quadribullatus* 显然不同。与由 4 个细胞组成的 *Parapandorina raphospissa* 比较,似乎是其细胞间接缝齿形变异(?)的结果。

产地层位 贵州瓮安陡山沱组上段。

旋胞藻属(新属) *Spirallicellula* gen. nov.

模式种 *Spirallicellula bulbifera* gen. et sp. nov.

属征 由 8 个细胞构成亚球形定形群集体,群体直径 730—1 100 μm 。细胞丝(管?)状,直径 80—100 μm ,右旋而呈倒锥状“团”。在群集体表面,旋纹细胞“团”呈近圆形,直径 600—700 μm ;两细胞“团”间紧密接触,但 3 个细胞“团”间留有三角形孔隙。标本未见胶质膜。

讨论 由 8 个倒锥状细胞“团”构成亚球形定形群体,特征类似 *Parapandorina beidoushanensis*,而且丝状体旋至细胞“团”边缘有向内旋埋趋势(图版 III,图 1b 的 a),显示向内收缩的性质。其外形特征使人联想到与颗石藻类的关系。但颗石藻类是单细胞生物,由原生质分泌一系列碳酸钙晶片组成或胶质膜钙化而成,本文描述的标本显然与它不同。据此,把这个属置于团藻科,可能是 *Parapandorina* 的进化类型(?)。

时代分布 晚震旦世,中国贵州瓮安。

球形旋胞藻(新属、新种) *Spirallicellula bulbifera* gen. et sp. nov.

(图版 III,图 1a,1b 及 2)

材料 酸处理得实体化石 10 余枚,其中部分标本已强烈磨损。

描述 同属征。

产地层位 贵州瓮安陡山沱组上段。

团藻目? 或绿球藻目 Volvicales? 或 Chlorococcales?

大积球藻属(新属) *Megaclonophycus* gen. nov.

模式种 *Megaclonophycus onustus* gen. et sp. nov.

属征 单细胞圆球体或多细胞组成的球形体。单细胞化石具清晰而透明的壁(5—10 μm)和薄的内膜(3—5 μm),故显双层结构;直径 50—330 μm (或更大);胞内具均匀的微粒状内容物,大的个体细胞内容物常已凝缩并胶磷矿化,残余空腔被石英或(和)白云石充填。群集体直径 650—960 μm ,内包成百个球形似亲孢子;似亲孢子直径 30—80 μm ,有薄的壁而无单独的胶质膜。群体有薄的母细胞壁或胶质膜,许多标本无(未保存?)胶质膜。母细胞及子细胞常包含许多黑色粒状内含物。

讨论 作为模式种典型标本的多细胞球形体化石,含有成百个球形似亲孢子,群体表面常常无胶质膜或仅有极薄而透明的膜状残余物。在处理的砂样和岩石切片中,常见 50—200 μm 的光滑球体(图版 IV,图 5,6;图版 V,图 6—9),它们可能就是逸散出的似亲孢子在各生长阶段被保存的化石,而正模标本则是其繁殖阶段的化石。

细胞形态特征的发育阶段,与 *Clonophycus* (Oehler, 1977) Oehler, 1978 相类似,但是

Megaclonophycus 的细胞壁结构、众多的似亲孢子和巨大的直径,与之显著不同,繁殖方式似亦有别(下面讨论),故定为新属。可能是团藻目或绿球藻目的分子。

时代分布 中国贵州、云南、湖北,晚震旦世至早寒武世早期。

密聚大积球藻(新属、新种) *Megaclonophycus onustus* gen. et sp. nov.

(图版Ⅱ,图3a,3b,4;图版Ⅳ,图1a—6;图版Ⅴ,图2,6—9)

1977 *Archaeooides kuanchuanpuensis* Qian, p. 269, pl. Ⅱ, fig. 24.

1984 *Clonophycus inaequimagnus* Wang et Luo, p. 157, pl. Ⅱ, Fig. 3.

1989 *Archaeooides* cf. *granulatus* Qian et Bengtson, p. 135, fig. 90-E.

材料 处理出的实体化石标本数百枚,薄片中的化石切面数十个。

描述 由无数子细胞充填于母细胞内,形成巨大的球形体,直径650—960 μm 。母细胞壁透明、薄,5 μm 左右;常不保存或部分保存(图版Ⅴ,图2),大多已变为薄的胶质膜,甚至无胶质膜。子细胞圆球形,充满母细胞但排列无规律性,大小为30—40 μm 、60—75 μm 或60—80 μm ;每个化石标本中的子细胞大小近相等,与母细胞直径比为1:11至1:20。子细胞有薄的壁,无单独的胶质层;常形成不透明的炭化粒状内容物。

讨论 王福星等(1984)在贵州清镇相当于梅树村阶的地层中发现并命名的 *Clonophycus inaequimagnus* Wang et Luo, 1984, 与本文描述的化石基本相同,只是其球状定形体直径较小(最大为144 μm),子细胞大小变化范围较大(薄片切面中观察)。钱逸在滇东梅树村阶中宜村段发现并命名为 *Archaeooides* cf. *granulatus* (见 Qian and Bengtson, 1989, p. 135, Fig. 90-E) 和陕南下寒武统宽川铺组的 *Archaeooides kuanchuanpuensis* Qian, 1977, 特征与我们的标本一致,实为同种化石。但是,钱逸定为 *Archaeooides* 属的有些标本、包括模式种 *A. granulatus* Qian, 1977 的标本,与瓮安地区陡山沱组发现的某些疑源类相似。*Archaeooides* 可能包含了不同类型的化石,不能作为一个化石属,故本文未采用这一名称。丁莲芳等(1992)建立一球壳新科(Globooidae),包括 *Archaeooides* Qian 和 *Olivoides* Qian 两个属,并认为可能是原生动物门的分子;其实后一属主要是疑源类,有机质壁大多已挤压变形,这个科的建立和归属是有问题的。

瓮安陡山沱组上段的样品经酸泡处理后,常获得直径50—200 μm 的光滑小圆球体,分散分布(图版Ⅳ,图6)或几个集中在一起(图版Ⅳ,图5);岩石薄片中也常见这种球体的切面,显示具明显的壁(5—10 μm)和薄的内膜(约3—5 μm)(图版Ⅴ,图6—9)。其形态和结构特征与 *Megaclonophycus onustus* 的子细胞相同。认为这些分散的小球形细胞就是 *Megaclonophycus onustus* 逸散出的似亲孢子及其生长发育阶段的代表;其成熟阶段的营养细胞直径应更大,但与瘤饰及板饰疑源类表皮剥离后由内膜保存的球体,在形态上难以区分。多细胞的 *Megaclonophycus onustus* 可能只是该类生物繁殖期(似亲孢子已开始形成但尚未逸散)被磷酸盐化而保存为化石的。从其母细胞壁至转变为胶质膜、无胶质膜(已被溶解?),与许多绿球藻目的分子的繁殖方式相同,而与 *Clonophycus* Oehler, 1978 以母细胞壁开口或壁撕裂的繁殖方式不同。巨大的直径及母细胞中形成成百个子细胞,其特点又与现代团藻属的某些分子相似(Fott, 1971)。

产地层位 贵州瓮安陡山沱组上段;湖北保康陡山沱组下部;贵州、云南、陕南下寒武统

梅树村阶。

绿球藻目 *Chlorococcales*

绿球藻科 *Chlorococcaceae*

巨四面球藻属(新属) *Colossotetrahedrion* gen. nov.

模式种 *Colossotetrahedrion ovimpositum* gen. et sp. nov.

属征 4个巨大的球形细胞作四面体紧密堆积,单个细胞直径 335—550 μm ,无胶质膜,群体表面无或有极薄的胶质膜。

讨论 4个球形细胞作四面体堆积,特征类似于 *Eotetrahedrion* Schopf et Blacic, 1971, 但后者直径较小(7.7—12 μm , 平均 9.4 μm)而具较厚的(2.5 μm)鞘状膜,两者有明显区别。球形细胞作四面体堆砌的方式与 *Parapandorina* 的细胞向内收缩集结的性质不同。描述标本也与刘雪娴等(1984)报道的 *Protosphaeridium densum* Tim 的孢子囊中 4个似亲孢子作四面体排列形态相似,但直径要大几十倍,且无明显的母细胞壁。我们的标本未保存母细胞壁,或仅有极薄的胶质(?)膜(图版 V, 图 5), 4个子细胞并未散开,与母细胞开口释放似亲孢子的方式似乎不同。尹磊明记述的 *Xenosphaera liantuensis* 的某些切面,显示 3个紧密排列的细胞直径可达 100—125 μm ,无单独的和公共的胶质膜(Yin Leiming, 1987, pl. 23-8),特征与本文描述的标本十分相似。该种的其他化石切面,如具圆形开口的单细胞球体,似与我们的标本不同,而大小相同或不等的球体成对分布,则不能排除由机械作用所致的可能性,是否同种生物,在薄片中还难以断定。

Schopf 和 Blacic(1971)怀疑 *Eotetrahedrion* 属是绿藻门(?)或红藻门(?)的分子;刘志礼(1982)则认为可能隶属红藻门(?)或褐藻门(?)。瓮安地区陡山沱组上段有较丰富的磷酸盐化红藻化石的分布(Zhang Yun, 1989),但是原叶体均很小(毫米级),不可能产生达 500—1000 μm 的四分孢。根据其四面体排列形态,巨大的细胞直径、胶质膜的缺乏,可能是绿球藻目的分子。

叁卵状巨四面球藻(新属、新种) *Colossotetrahedrion ovimpositum* gen. et sp. nov.

(图版 V, 图 3, 5)

材料 酸处理得实体化石标本 10 余枚。

描述 同属征。

讨论 有的标本 3个“座细胞”可变形成为平面接触,甚至包嵌,可能是机械挤压的结果。

产地层位 贵州瓮安陡山沱组上段。

原始球形藻属 *Protosphaeridium* Timofeev, 1966

原始球形藻(未定种 A) *Protosphaeridium* sp. A

(图版 I, 图 5)

材料 岩石薄片化石切面 1 个。

描述 单细胞,椭球形,150 \times 210 μm ;透明的细胞壁厚 7—10 μm ,表面光滑,胞内有微粒状内容物,细胞及内容物均已胶磷矿化。

讨论 细胞结构与蓟县雾迷山组发现的 *Protosphaeridium* cf. *densum* (刘志礼, 1982) 很相似, 但本文的标本为椭球状, 且个体特别大。

产地层位 贵州开阳沙坝土, 洋水组下段中上部紫红色砂岩(相当于刘鸿允 1966 年划分的南沱组紫色页岩段顶部)。

原始球形藻(未定种 B) *Protosphaeridium* sp. B

(图版 I, 图 6)

材料 岩石薄片化石切面数个。

描述 单细胞, 圆球形, 直径 $140 \times 150 \mu\text{m}$ 。有机质细胞壁厚约 $5 \mu\text{m}$, 表面光滑至微粒状。细胞内有不规则斑点状暗色内容物, 细胞已胶磷矿化和硅化。

产地层位 贵州开阳沙坝土, 洋水组下段顶部青灰色砂质白云岩层(相当刘鸿允, 1966 年的洋水组下部的近顶部)。

古对胞藻属 *Eozygion* Schopf et Blacic, 1971

古对胞藻(未定种) *Eozygion* sp.

(图版 I, 图 7)

材料 岩石薄片化石切面 1 个。

描述 细胞半球形, 成对以一平面拼成椭球形群体, 群体被薄的胶质膜包裹, 大小为 $120 \times 200 \mu\text{m}$ 。群体中两个细胞大小不等。分别为 $110 \times 70 \mu\text{m}$ 和 $100 \times 150 \mu\text{m}$, 不具单独的胶质膜, 细胞壁厚约 $5 \mu\text{m}$, 具均匀微粒状内容物。已胶磷矿化。

讨论 半球状细胞成对包在共胶鞘中, 附合 *Eozygion* 特征。群体胶鞘不均匀, 可能是因成岩作用的结果。本文标本特别大; *Eozygion grande* Schopf et Blacic, 1971 和刘志礼 (1982) 在蓟县雾迷山组发现的 *Eozygion laevis* Liu, 1982, 细胞仅 $4-18.7 \mu\text{m}$ 。Schopf 和 Blacic 最早建立该属, 置于蓝藻门色球藻目色球藻科; 刘志礼 (1982) 则归入绿藻门绿球藻目的栅藻科 (Scenedesmaceae), 但在进行化石藻类总结时仍置蓝藻门色球藻纲 (刘志礼, 1990)。根据巨大的细胞及单个细胞与 *Protosphaeridium* sp. B 类似的结构, 它很可能是绿藻门绿球藻目的分子。

产地层位 贵州开阳沙坝土, 洋水组下段上部青灰色砂岩底部(即刘鸿允, 1966 年的洋水组底部)。

本文描述的个别属种的鉴定, 曾得到刘志礼教授的指教, 成文后尹磊明研究员阅读全文并提出了宝贵的修改意见, 袁留平高级实验师和姜庆玲协助实体化石的扫描摄影。对比, 作者一并致以衷心感谢。

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LARGE SPHEROIDAL CHLOROPHYTA FOSSILS FROM DOUSHANTUO FORMATION PHOSPHORIC SEQUENCE (LATE SINIAN), CENTRAL GUIZHOU, SOUTH CHINA

Xue Yao-song, Tang Tian-fu, Yu Cong-liu and Zhou Chuan-ming
(Nanjing Institute of Geology and Palaeontology, Academia Sinica, Nanjing 210008)

Summary

Spheroidal Chlorophyta fossils have been found from the Precambrian strata, of which the oldest may be about 1 900 Ma, but the cells of these fossils are very small, usually from $n\ \mu\text{m}$ to approximately $30\ \mu\text{m}$ in diameter (Liu Zhili, 1990; Schopf and Blacic, 1971). Some of the fossils, ranging from $30\ \mu\text{m}$ to $200\ \mu\text{m}$ in diameter, were reported by Yin Leiming *et al.* from the Late Sinian strata of Yizhang area, western Hubei (Yin Leiming and Li Zaiping, 1978; Yin Leiming, 1987).

Recently, the authors have got plentiful phosphate fossil bodies of acritarchs and Chlorophyta by means of 20% acetic acid treatment from the phosphorous dolostones and dolomitic phosphorites of the Upper Member of the Doushantuo Formation in Weng'an County, and some sections of the spheroidal Chlorophyta fossils (such as *Protosphaeridium* sp. A, *P.* sp. B and *Eozygion* sp.) from the phosphoric, sandy dolostone and sandstones of the Lower Member of the Yangshui Formation in Yangshui area of Kaiyang County, central Guizhou (Text-figs. 1 and 2). These fossils are characteristically of large spheroids, commonly more than $50\ \mu\text{m}$ in cell's diameter and from $500\ \mu\text{m}$ to $1\ 200\ \mu\text{m}$ in size of the colonies. Some species such as *Parapandorina beidoushanensis* and *Megaclonophycus onustus* also occur in the phosphorite beds of the lower part of the Doushantuo Formation in Baokang County, Hubei, while others such as *M. onustus* occur in the Meishucunian phosphoric strata (early Early Cambrian) in Yunnan, Guizhou and Shaanxi. In addition, *Tetraphycus* sp. can be frequently found in the phosphorites and dolomite matrixes; its cells varying from $12\ \mu\text{m}$ to $20\ \mu\text{m}$ in diameter are larger than those described by Oehler (1978). It is first referred to Chroococcaceae (?) by Oehler (1978), and regarded as Chlorococcales by some others (Liu Zhili, 1982; Liu Xuexian *et al.*, 1984). Besides large acritarch fossils, a great number of Rhodophyta thallophytes including their fragments (Zhang Yun, 1989), and a few of the skeletal fossils (Xue Yaosong *et al.*, 1992) coexist with these Chlorophyta spheroidal fossils, altogether constituting a special biota with a characteristic variety of organisms, high abundance and very large-diameter cells and colonies.

These fossils had been mostly phosphatized as an important component of the phosphorites and phosphoric rocks, suggesting that they have played an important role in phosphogenesis. Based on detailed studies of the Doushantuo Formation phosphoric strata in petrology and geochemistry, it is considered that heightening atmospheric temperature after the Nantuo Ice Age caused the rise of sea level, the extension of marine oxygen minimum zone and the break of upwelling currents, bringing in abundant phosphorus and other nutrients to shallow platform-margin regions, and thus leading to the rapid thriving of plankton organisms, especially acritarchs and algae (Zhou Chuanming, 1993, Master's thesis). Therefore, the Doushantuo age was not only an important phosphogenic stage, but also an age indicating one of the most important organic expansion events in geological histo-

ry.

The evidences of petrology and palaeontology suggest that the Upper (Purple Shale) Member of Liu's Nantuo Formation (Liu Hongyun *et al.*, 1966) should be redelimited as the lower part of the Yangshui Formation corresponding to the Doushantuo Formation (Text-fig. 2).

DESCRIPTION OF FOSSILS

All the fossils described here are large spheroids of new genus and new species belonging in Chlorophyta.

Class Chlorophyceae

Order Volvocales

Family Volvocaceae

Genus *Parapandorina* gen. nov.

Type species: *Parapandorina raphospissa* gen. et sp. nov.

Diagnosis: Spheroidal colony consisting of 4, 8 or 16 cells, ranging from 480 μm to 1 200 μm in diameter, with thin membrane but not preserved in a number of the bodied specimens. Cells with thin walls but without individual gelatinous membranes, inversely pyramidal or inversely oval, contracted inwards and put together, forming a colonial body looking very much like a small football.

Etymology: From *Pandorina* Bory, 1824, the resemblance.

Discussion: In the nature of the colonies this genus resembles the modern genus *Pandorina* Bory and the fossil genus *Pandorinopsis* Liu, 1982, but the specimens described here consist mostly of 8 cells and are especially large in diameter.

Occurrence: Late Sinian, South China.

Parapandorina raphospissa gen. et sp. nov.

(P1. I, figs. 1a, 1b, 2, 3)

Diagnosis: Inversely-pyramidal cells closely inlaid with each other, becoming polygonal in form on the surface of the colony. Colonial spheroids ranging from 700 μm to 1 200 μm in diameter. Other characteristics the same as in genus.

Etymology: With reference to close sutures between the cells.

Type specimen: As illustrated in P1. I, fig. 1a.

Discussion: In a small number of the specimens the sutures between the cells show difference in clearness (P1. I, fig. 2), suggesting a secondary cell division (?).

Distribution: Upper Member of Doushantuo Formation, Weng'an, Guizhou.

***Parapandorina beidoushanensis* gen. et sp. nov.**

(Pl. I, fig. 6; Pl. I, figs. 1, 3—5b)

Diagnosis: Sutures between inversely oval cells relatively broad (25—40 μm), and thus the cells appearing to be spherical on the surface of the colonial spheroids, ranging from 480 μm to 560 μm in diameter. Other characteristics the same as in genus.

Etymology: From Beidoushan the main peak of the fossiliferous locality.

Type specimen: As illustrated in Pl. I, fig. 1.

Distribution: Mainly Upper Member of Doushantuo Formation in Went'an, Guizhou and also lower part of Doushantuo Formation in Baokang, Hubei.

***Parapandorina beidoushanensis* var. *cylindrica* gen. et sp. nov.**

(Pl. I, fig. 2)

Diagnosis: Some of the 8 cells having changed into long-pointed forms gathering together toward one end and thus colony appearing to be a conical body of 850 μm in length and 720 μm in diameter. Other characteristics basically the same as in the preceding species.

Etymology: From "cylindrica" to show a variety of the preceding species.

Distribution: Upper Member of Doushantuo Formation; Weng'an, Guizhou.

Genus *Praviglobus* gen. nov.

Type species: *Praviglobus quadribullatus* gen. et sp. nov.

Diagnosis: A few cells unequal in form and size embracing and embedding each other to constitute a subspheroidal colony, 550—640 μm in size. Sutures between cells irregular.

Etymology: With reference to unequal, irregularly deformed cells.

Discussion: In the cells contracted inwards and inlaid with each other, the new genus is similar to *Parapandorina*, but obviously different from the latter in the size and formation of cells and irregular sutures.

Occurrence: Late Sinian, South China.

***Praviglobus quadribullatus* gen. et sp. nov.**

(Pl. I, figs. 4a, 4b)

Diagnosis: Four smaller cells embedded oppositely in a large cell, forming a convex-spheroidal colony of 640 \times 550 μm in size; smaller cells rather high over the surface of large cell, about 50—80 μm . Cells likely having gelatinous membrane (?) which remains in the close sutures. A considerable number of spherical, triangular or quadrilateral pores densely distributed on the outer surface of colony, ranging from 5 μm to 20 μm in diameter or length of one side.

Etymology: With reference to 4 smaller cells embedded oppositely in a larger cell.

Discussion: In the character of cells contracted inwards, this species is similar to *Parapandorina raphospissa*, but obviously different from the latter in the changeability and porous texture of the cells. It seems that the 4 daughter cells are combined into a larger cell embedded with other 4 remainder cells, and that the pores on the surface of colony are probably some where the flagella stretched out (?).

Distribution: Upper Member of Doushantuo Formation, Weng'an, Guizhou.

***Praviglobus ? dentisuturalis* gen. et sp. nov.**

(P1. 1, fig. 5)

Diagnosis: Four irregular cells embracing and embedding each other in dentiform sutures into a spheroidal colony, about 570 μm in diameter, with psilate surface and without gelatinous membrane to be preserved on the specimen.

Etymology: With reference to the dentiform sutures between the cells.

Discussion: In the deformed cells embracing and embedding each other into a spheroidal colony, this form is analogous to *Praviglobus quadribullatus*, but it is uncertain to be referred to this genus because of the psilate surface without pores. Perhaps, it is a variety of *Parapandorina raphospissa* consisting of 4 daughter cells (P1. 1, fig. 3)(?).

Distribution: Upper Member of Doushantuo Formation, Weng'an, Guizhou.

Genus *Spirallicellula* gen. nov.

Type species: *Spirallicellula bulbifera* gen. et sp. nov.

Diagnosis: Eight filamentous cells (80—100 μm in diameter) spiraled rightwards into masses to constitute a spheroidal colony ranging from 730 μm to 1 100 μm in diameter. Each cell mass appearing contracted inwards and spherical on the surface of the spheroidal colony. No gelatinous membrane seen on the specimens.

Etymology: With reference to the spiral daughter cells.

Discussion: In the inlaid pattern of 8 cell masses contracted inwards (as shown in P1. II, fig. 1b), this genus is analogous to *Parapandorina beidoushanensis*, except for the spiral cells. It may be connected with *Coccolithus*, but the latter is unicellular and different from the multicellular colony of the new genus.

Occurrence: Late Sinian, South China.

***Spirallicellula bulbifera* gen. et sp. nov.**

(P1. II, figs. 1a, 1b, 2)

Diagnosis: The same as for genus.

Etymology: With reference to the spheroidal colony.

Type specimen: P1. II, fig. 1a.

Distribution: Upper Member of Doushantuo Formation, Weng'an, Guizhou.

Order Volvocales ? or Chlorococcales ?

Genus *Megaclonophycus* gen. nov.

Type species: *Megaclonophycus onustus* gen. et sp. nov.

Diagnosis: Unicellular spheroid and multicellular spheroidal colony. Individual cells varying from about 50 μm to more than 330 μm in diameter, with transparent walls (5—10 μm thick) and internal membranes (3—5 μm thick); finely granular inclusions present or absent. Cellular material in larger cell often condensed and then phosphatized in early diagenesis; remainder space pore filled with quartz and/or dolomite. Spheroidal colonies ranging from 650 μm to 960 μm in diameter, including hundreds of spheroidal daughter cells ranging from 30 μm to 80 μm in diameter; cell's walls thin and lacking individual sheaths. Colonies having thin gelatinous membranes, occasionally with partly remaining walls, all of which, however, are not often preserved on the bodied specimens.

Etymology: From mega, large, and *Clonophycus* (Oehler, 1977) Oehler, 1978, a genus with similar formation and texture, which is ten times smaller in diameters of daughter cells and colonies.

Discussion: As the Holotype specimen of the type species, the multicellular colony consists of hundreds of daughter cells; the mother cell lacks wall or gelatinous membrane, but the sections of some specimens appear to be the wall or/and membrane (P1. III, fig. 4; P1. V, fig. 2). A number of small, independent cells with psilate walls, ranging from 50 μm to 200 μm in diameter, can be seen in the sandy samples after acid treatment and in the thin sections of the rocks. It is considered that they are the younger nutrient cells from the daughter cells of *Megaclonophycus onustus* disseminated in the reproductive period. This new genus is obviously different from *Clonophycus* (Oehler, 1977) Oehler, 1978, in wall texture, number of daughter cells, size of colonies and cells, and model of disseminating daughter cells.

Occurrence: Late Sinian—early Early Cambrian, South China.

Megaclonophycus onustus gen. et sp. nov.

(P1. II, figs. 3a, 3b, 4; P1. N, figs. 1a—6; P1. V, figs. 2, 6—9)

1977 *Archaeooides kuanchuanpuensis* Qian, p. 269, pl. II, fig. 24.

1984 *Clonophycus inaequimagnus* Wang et Luo, p. 157, pl. I, fig. 3.

1989 *Archaeooides* cf. *granulatus* Qian et Bengtson, p. 135, Fig. 90-E.

Diagnosis: Spheroidal colony, ranging from 650 μm to 960 μm in diameter, formed by hundreds of spheroidal daughter cells. Wall of mother cell thin (about 5 μm) and transparent, or partly to completely transformed into gelatinous membrane in a number of specimens, which, however, are generally not preserved on the bodied specimens. Daughter cells of each colony ranging from 30 μm to 40 μm , 60 μm to 75 μm or 60 μm to 80 μm in diame-

ter respectively, with psilate, thin walls but without sheaths, distributed densely and irregularly in mother cells.

Etymology: With reference to hundreds of daughter cells densely filling in the mother cell.

Type specimen: As illustrated in P1. N, figs. 1a and 1b.

Discussion: *Clonophycus inaequimagnus* Wang et Luo, 1984, from the Meishucunian strata of Qingzhen County, Guizhou, is basically identical with our specimens, although rather smaller in diameter (at most up to 144 μm), with daughter cells changing in a wider range (determined from the thin section). The fossil discovered by Qian Yi under the name of *Archaeooides* cf. *granulatus* (see Qian and Bengtson, 1989, p. 135, Fig. 90-E) is also very similar to our specimens, and therefore both should be the same species. However, some fossils or the genus *Archaeooides* Qian, 1977, are similar to some of the acritarchs from the Doushantuo Formation of Weng'an, suggesting that the genus probably includes not only one kind of microorganisms.

A number of small, psilate spheroids can be found in the sandy samples and thin sections (P1. N, figs. 5 and 6; P1. V, figs. 6 to 9); they are very much identical in form and texture with the daughter cells of *M. onustus*. The type specimen of *M. onustus* is representative of this microorganism only in the mature period. The dissemination of the daughter cells is through disappearance of the gelatinous membrane transformed from the wall (see P1. V, fig. 2) as in the members of Chlorococcales, but it is obviously different from that of the genus *Clonophycus* through an opening or by rupturing of enclosure (Oehler, 1978).

Distribution: Upper Member of Doushantuo Formation, Weng'an; lower part of Doushantuo Formation, Baokang, Hubei; Meishucunian in Guizhou, Yunnan and Shaanxi.

Order Chlorococcales

Family Chlorococcaceae

Genus *Colossotetrahedron* gen. nov.

Type species: *Colossotetrahedron ovimpositum* gen. et sp. nov.

Diagnosis: Four large spheroidal cells closely stacked into a tetrahedral colony with or without thin envelope. Cells ranging from 335 μm to 550 μm in diameter, with walls but without independent sheath-like membrane.

Etymology: With reference to the arrangement of cells as in *Eotetrahedron* Schopf et Blacic, 1971, but the genus is tens of times larger than the latter in diameter.

Discussion: In the arrangement of cells, this genus is analogous to *Eotetrahedron* Schopf et Blacic, 1971, but the latter shows much smaller cells in diameter and relatively thicker sheath-like membrane. The spheroidal cells are also different from the cells of *Parapandorina* which are contracted inwards in nature. The mother cell of *Protosphaeridium densum* reported by Liu Xuexian et al. (1984) from the Pre-sinian Jiudingshan For-

mation of Suining, northern Jiangsu, includes 4 daughter cells arranging in tetrad, but they are also much smaller in diameter as compared with our specimens.

Schopf and Blacic (1971) refer the genus *Eotetrahedron* to Chlorophyta (?) or Rhodophyta (?), while Liu Zhili (1982) regards it as Rhodophyta (?) or Phaeophyta (?). Although a number of Rhodophyta fossils have been found in the Weng'an area (Zhang Yun, 1989), their prothalli are too small (in mm-size) to produce such quadripartite spores in size as compared with our specimens. Based on the large cells and their arrangement pattern, together with the general absence of a sheath-like membrane, it is considered that the new genus might be a member of Chlorococcaceae.

Occurrence: Late Sinian, South China.

Colossotetrahedron ovimpositum gen. et sp. nov.

(Pl. V, figs. 3, 5)

Diagnosis: As for genus (in some of the specimens, however, the three cells at basic level might contact in a plane or embed each other probably due to process of compression).

Etymology: With reference to the arrangement pattern of the cells like densely stacked eggs.

Type specimen: Pl. V, fig. 5.

Discussion: A section of *Xenosphaera liantuoensis* named by Yin Leiming (1987, Pl. 23, fig. 8) shows the model of 3 large cells, 100—125 μm in diameter, stacking together closely. This species is very analogous to the specimen described in this paper; but other fossils of this species, comprising 2 unequal cells or a spheroidal cell with a spherical opening, are obviously different from it. Since these fossils have been referred to as the same species, they still remain an open question. The genus *Xenosphaera* probably includes various members of Chlorococcales and even acritarchs.

Distribution: Upper Member of Doushantuo Formation, Weng'an, Guizhou.

图 版 说 明

化石标本及岩石薄片均保存在中国科学院南京地质古生物研究所,除注明产地及薄片照相者,均产自瓮安陡山沱组上段,为实体扫描照片。

图 版 I

1a—3. *Parapandorina raphospissa* gen. et sp. nov.

1a. Holotype, 采集号: Z_北-7; 1b 是 1a 的局部放大。2, 3. Paratype, 采集号: Z_斗-53 及 Z_斗-88。

4a, b. *Praviglobus quadribullatus* gen. et sp. nov.

4a. Holotype, 采集号: Z_北-7; 4b 是 4a 的局部放大。

5. *Praviglobus ? dentisuturalis* gen. et sp. nov.

采集号: Z_{GW}-37。

6. *Parapandorina beidoushanensis* 的切面

采集号:Z_白-E;湖北保康白竹,陡山沱组下部;薄片,图中比例尺为 100μm。

图 版 I

1,3—5b. *Parapandorina beidoushanensis* gen. et sp. nov.

1, Holotype, 采集号:Z_北-7, 3—5a. Paratype, 采集号:3 和 5a 是 Z_斗-60, 4 是 Z_斗-88, 5b 是 5a 的局部放大。

2. *Parapandorina beidoushanensis* var. *cylindrica* gen. et sp. nov.

Holotype, 采集号:Z_北-7。

图 版 II

1a—2. *Spirallicellula bulbifera* gen. et sp. nov.

1a. Holotype, 采集号:Z_北-7, 1b 是 1a 的局部放大, 图中 a 示线形细胞向内旋埋。2. Paratype, 采集号:Z_北-7; 1 个螺旋形细胞的正视。

3a—4. *Megaclonophycus onustus* gen. et sp. nov.

Paratype, 3a. 采集号:Z_斗-88, 3b 是 3a 的局部放大。4. 采集号:Z_白-E; 薄片, 示内部结构; 湖北保康白竹, 图中比例尺代表 100μm。

5. *Protosphaeridium* sp. A.

采集号:Z_砂-12; 贵州开阳洋水沙坝土剖面, 洋水组下段; 薄片, 比例同图 4。

6. *Protosphaeridium* sp. B.

采集号:Z_砂-9; 产地同上, 洋水组下段的上部砂质白云岩; 薄片, 比例同图 4。

7. *Eozygion* sp.

采集号:Z_砂-11; 产地同上, 洋水组下段上部青灰色砂岩; 薄片, 比例同图 4。

图 版 IV

1a—6. *Megaclonophycus onustus* gen. et sp. nov.

1. Holotype, 采集号:Z_北-7, 1b 是 1a 的局部放大。2a—4. paratype, 采集号:Z_北-7; 2b 是 2a 的局部放大; 4 是一标本的断面, 示内部似亲孢子的分布。5, 6. *M. onustus* 逸散出来的似亲孢子及生长阶段中的单细胞球形体; 采集号:5 是 Z_北-9, 6 是 Z_斗-41。

图 版 V

1a, b. *Megaclonophycus* sp. A

采集号:Z_北-7; 1b 是 1a 的局部放大。

2. *Megaclonophycus onustus* 的切面, 保存有部分母细胞壁(W), 大部已变为胶质膜。采集号:Z_南-3; 贵州丹寨南皋, 下寒武统底部磷块岩; 薄片, 图中比例尺为 100μm。

3, 5. *Colossotetrahedron ovimpositum* gen. et sp. nov.

3. paratype; 5. Holotype; 采集号:均是 Z_北-7。

4. *Megaclonophycus* sp. B

采集号:Z_北-7。

6—9. *Megaclonophycus onustus* 生长阶段细胞的切面, 示细胞壁结构及内容物性质

6. 采集号:Z_北-9; 图中比例尺为 100μm。7. 采集号:Z_北-8; 图中比例尺为 100μm。8. 采集号:Z_北-6; 9. 采集号:Z_北-10; 它们的比例尺同图 7。