DOI:10.19800/j.cnki.aps.2018.02.007

古生物学报,57(2):212—227(2018年6月)
Acta Palaeontologica Sinica,57(2):212—227(June,2018)

湖北利川二叠纪生物礁的埋藏学特征及其环境意义*

李　阳[1,2,3]　吴亚生[1,2,3]　姜红霞[4]

1)中国科学院油气资源研究重点实验室,中国科学院地质与地球物理研究所,北京 100029,wys@mail.igcas.ac.cn;
2)中国科学院地球科学研究院,北京 100029;
3)中国科学院大学,北京 100049;
4)河北地质大学,石家庄 050031

提要　二叠纪钙质海绵礁的研究已逾百年,但缺乏埋藏学方面的研究。本文选取鄂西利川典型钙质海绵礁剖面,对造架生物的属种组成、保存状态(直立还是倒伏)、个体大小、古石孔藻包壳和泥晶含量进行统计研究。共鉴定出17个属种的钙质海绵和一个属种的水螅;通过统计研究发现,含钙质海绵的灰岩厚98 m,其下部4/5厚度所含钙质海绵以倒伏的为主,上部1/5厚度以直立的为主;含倒伏钙质海绵的灰岩中藻包壳(古石孔藻)不发育,钙质海绵以直立为主的灰岩中,藻包壳发育;钙质海绵的个体大小由海绵灰岩下部而上增大不明显;泥晶基质的含量自海绵灰岩的下部而上明显减少。由此推断:下部的钙质海绵灰岩形成时由于没有藻包壳,大多被风浪打倒。上部具有藻包壳的钙质海绵灰岩,尽管形成时的水动力能量更强,但由于有藻包壳,其抗风浪能力得到加强,所以大多直立保存。

关键词　生物礁　钙质海绵　埋藏学　古石孔藻包壳　泥晶含量　二叠纪　湖北利川

1　前　言

生物礁是良好的油气储层,普光、龙岗和元坝等大型气田的主要储层都包括了二叠纪生物礁储层(马永生等,2006,2014),所以,二叠纪生物礁研究不仅有科学意义而且有重要的经济意义。在我国,目前已经在鄂西利川、贵州紫云、浙江冷坞、湖南慈利、广西隆林、四川东北部和东昆仑山等地发现有良好的二叠纪生物礁露头(范嘉松等,1990;林启祥,1992;范嘉松,1996;王生海等,1996;王永标、徐桂荣,1998;王永标、张克信,1998;吴亚生,1998;田树刚、范嘉松,2001;邱小松等,2011;邓剑等,2014;Wu,1991;Liu *et al.*,2016,2017)。

二叠纪生物礁主要是钙质海绵礁(范嘉松等,1982;Rigby *et al.*,1989a,b)。钙质海绵的造礁作用在中三叠世之后逐渐被六射珊瑚所取代(Stanton and Flügel,1987)。二叠纪还有一些其他类型的生物礁,如苔藓虫礁、叠层石礁、钙藻礁(范嘉松、吴亚生,2005)。本文内容只涉及钙质海绵礁。二叠纪钙质海绵礁的研究始于20世纪初,研究涉及生物礁的特征、造礁生物分类和古生态、生物礁形成过程、微生物作用对生物礁的贡献等(Girty,1908;Fan and Zhang,1985;Senowbari-Daryan and Di Stefano,1988;Senowbari-Daryan and Rigby,1988,1991;Guo and Riding,1992;Rigby *et al.*,1994,1998;Senowbari-Daryan and Ingavat-Helmcke,1994;Rigby and Senowbari-Daryan,1996;Kirkland *et al.*,1998;Fan *et al.*,2001;Flügel and Kiessling,2002;Rigby and Bell Jr,2006;Senowbari-Daryan *et al.*,2007;Wahlman *et al.*,2013;Nakazawa *et al.*,2015)。

中国二叠纪钙质海绵礁研究的开创性工作是范嘉松等(1982)对鄂西利川见天坝钙质海绵生物礁的造礁生物钙质海绵的系统分类、生物礁的沉积相发育和生长发育阶段、成岩作用等诸方面的系统研究。其后许多学者对中国二叠纪的钙质海绵礁开展了多方面的研究(强子同等,1985;张维,1985,1987;张维、张孝林,1992;杨万容等,1995;徐桂荣等,1996;王永标等,1997,2001;柳祖汉等,2001;柳祖汉,

收稿日期:2018-01-29
*国家自然科学基金(41372121)和国家重大专项(2016ZX05004006)联合资助。

2003;胡明毅等,2012;Fan *et al.*,2014)。重要的工作还包括范嘉松等对广西隆林二叠纪生物礁的研究,范嘉松和吴亚生等对钙质海绵的大量古生物学研究工作(范嘉松、张维,1986,1987;范嘉松等,1987,2002,2004;吴亚生,1989,1992,1994,1998;吴亚生、范嘉松,2000,2002;范嘉松、吴亚生,2002;吴亚生等,2007,2015;Fan and Zhang,1985;Wu,1991,2017)。这些研究丰富了人们对二叠纪钙质海绵礁的类型、古地理背景、相带分布、生长控制因素、发育演化、成岩作用的认识。但仍然存在不少问题,例如对同一礁体的相带划分意见不一致。对于湖北利川见天坝的二叠纪钙质海绵礁,范嘉松等(1982)将其划分为礁前、礁核和礁后泻湖亚相,而胡明毅等(2012)将其划分为灰泥丘、礁核和礁顶亚相。另外,对二叠纪钙质海绵生物礁的埋藏学研究几乎没有开展。

埋藏学是地球科学的一个分支学科。前人(Efremov,1940;Behrensmeyer *et al.*,2000)对埋藏学的定义是生物遗骸从生物圈到岩石圈转变过程中发生的所有变化,这些变化可以记录在化石中。我们的理解是:埋藏学主要研究现今和地质历史时期的生物群在死亡后遭受的沉积和成岩改造过程,关键的研究内容是生物在沉积物或地层中的保存状态。生物的保存状态可以反映生物在死亡前后遭受的外力作用,可以反映环境的水动力状况,所以有重要研究意义。化石的埋藏学研究主要包括两部分内容:(1)化石保存学,指生物死亡后到其遗体最终被埋藏这段时间内的一系列环境作用过程(机械过程);(2)化石早期成岩作用,指生物遗体从被埋藏后到变成化石这段时间间隔内所有影响化石化作用的过程(化学过程)(张廷山等,1992)。目前人们对二叠纪钙质海绵礁的沉积相认识还存在很大的局限性,埋藏学的研究也许是提升人们这方面认识深度的途径之一。湖北利川见天坝二叠纪钙质海绵礁是目前所知的二叠纪最典型的生物礁之一,也是研究程度最高的生物礁之一。本文以该礁为首例,开展埋藏学研究的尝试,试图通过对该礁的埋藏学研究,提升对其沉积相和发育环境的认识。

2　区域地质背景

鄂西地区位于中、上扬子结合的部位,包括齐岳山背斜带、利川复向斜带、中央背斜带和花果坪向斜带 4 个次级构造单元(刘富艳等,2009)。见天坝生物礁位于利川复向斜的中北部,距利川市柏杨镇东北方向约 25 km。鄂西地区在晚二叠世吴家坪期主要发育了一套含煤碎屑岩与碳酸盐岩互层的沉积。晚二叠世长兴期,随着相对海平面的上升,大部分地区以开阔台地沉积为主,但在开江-梁平海槽区域发育了一套水体相对台地较深的台棚相沉积(马永生等,2006),而在海槽与碳酸盐岩台地之间发育了台缘礁滩相带。典型的台缘生物礁露头见于四川宣汉盘龙洞和湖北利川见天坝(牟传龙等,2004;吴亚生等,2015)。见天坝地区在长兴期早期发育深水斜坡相沉积,向上逐渐变浅,发育一套台地边缘生物礁相沉积(插图 1),到长兴期末期逐渐变为开阔台地-局限台地相沉积。

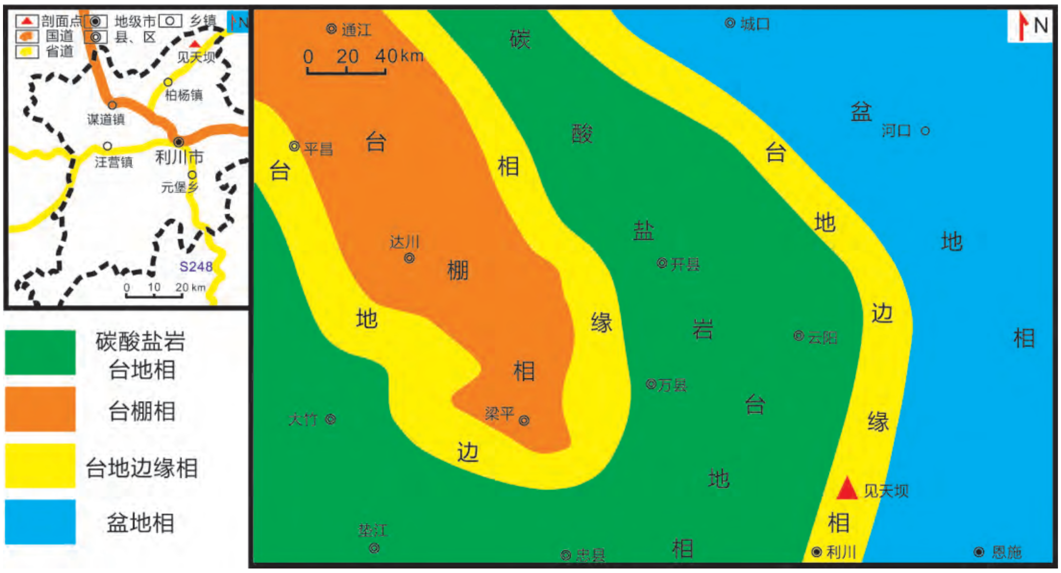

插图 1　鄂西地区上二叠统长兴组古地理及交通位置图(引自胡明毅等,2012)

Paleogeography and location of the Jiantianba section of the upper Permian Changxing Formation in Lichuan, western Hubei Province (Hu *et al.*, 2012)

3 研究材料和方法

首先对鄂西利川见天坝生物礁剖面(插图 2)进行野外工作,测量了剖面,对露头的岩石和古生物特征进行了观察和描述,按照约 2 m 的间隔采集了定向的岩石标本 82 块,对每块标本制作 1—3 个 5 cm×7 cm 大小的古生物大薄片,薄片号对应相应的层号。根据薄片观察,进行了岩性和古生物鉴定,确定剖面可以分为三段。下段是野外分层的 1—7 层,厚度 98.4 m,为深水相的薄层泥质灰岩;中段包括野外分层的 8—10 层,厚度 98 m,为含钙质海绵的生物礁相;上段是野外分层的 11 层,厚 49.9 m,为非礁相的灰岩和白云岩。剖面顶部 12 层为微生物岩,属于 2.5 亿年前蓝藻微囊藻赤潮形成的微生物沉积(Wu *et al.*,2014)。在四川和其他地区,代表三叠纪开始的牙形刺 *Hindeodus parvus* 出现于微生物岩的中部偏下或者底部(姜红霞、吴亚生,2007;Kershaw *et al.*,2002;Ezaki *et al.*,2003)。微生物岩是生物大灭绝之后的沉积。见天坝剖面的二叠纪-三叠纪界线可以暂时放在微生物岩出现的位置。

为了进行埋藏学研究,对 8—10 层 60 张大薄片进行了进一步的研究和统计。首先对钙质海绵进行了属种鉴定;然后,对钙质海绵的保存状态、平均直径、岩石的泥晶含量、古石孔藻包壳含量进行了统计。保存状况分直立和倒伏或倒置两种情况,其判断依据是与层面的关系。层面系在野外取样时根据地层产状在岩石标本上标定,于层面朝上的方向,室内磨制薄片时在薄片上标出垂直于层面朝上的方向,一部分薄片是平行于层面切割和制作的,标注该薄片是平行于层面的。在统计时,根据薄片中钙质海绵的保存方向与层面的关系来判断钙质海绵是直立的还是倒伏或倒置的,分别计数直立的和倒伏与倒置的海绵的个体数量。除了对薄片中全部海绵的保存状况进行统计外,还对最常见的纤维海绵 *Peronidella* 属进行了专门的统计。泥晶含量统计用泥晶占薄片中岩石的面积比表示,通过目估来确定。古石孔藻包壳的含量统计以一张薄片中古石孔藻包覆的长度与薄片中所有钙质海绵和水螅的总周长之比表示。

4 造礁生物埋藏学特征统计结果和意义分析

4.1 造礁生物组成

钙质海绵是见天坝生物礁的主要造架生物,包括纤维海绵、串管海绵和硬海绵,集中分布在 8—10 层,柱状为主。根据钙质海绵的形态和内部结构,共鉴定出 17 个属钙质海绵和三种未知海绵(插图 3—5),分别为串管海绵 *Cystothalamia* sp.,*Parauvanella* sp.,*Polycystothalamia* sp.,*Sollasia* sp.,*Amblysiphonella* sp.,*Girtyocoelia* sp.;纤维海绵 *Peronidella* sp.,*Elasmostoma* sp.,*Flabellisclera* sp.,*Ramospongia* sp.,*Bisiphonella* sp.;硬海绵 *Bauneia ampliata*(皮壳状),*Bauneia epicharis*(皮壳状),*Bauneia ampliata*(柱状),*Bauneia epicharis*(柱状),*Fungispongia* sp.,*Reticulocoelia* sp.,以及纤维海绵未定属、硬海绵未定属、串管海绵未定属。纤维海绵 *Peronidella*(插图 4B)呈柱形,中间有一中央腔,直径 1.8—13.1 mm,分布最广泛,遍布 8—10 层,是丰度最高、最常见的属;纤维海绵未定属(插图 4E)以柱状、扇状和锥状为主,骨纤排列不规则,直径 2.0—15.75 mm,丰度次于 *Peronidella*,分布较广泛。串管海绵 *Polycystothalamia*(插图 3D)呈柱状,房室呈囊状,房室壁相交部位有眼孔,直径 2.0—7.2 mm,是利川生物礁常见的串管海绵,数量第三,在第 8 层中缺失、第 9 层中大量出现、第 10 层中次之。纤维海绵 *Ramospongia* 呈柱状,骨纤较规则,粒状显微结构,直径 1.75—7.43 mm;硬海绵 *Reticulocoelia*(插图 4C)呈柱状,横切面呈圆形或者椭圆形,中间亮晶化,仅边缘放射状排列的小管壁清晰,直径 2.0—6.6 mm。这两个属虽然在 8—10 层均有出现,但丰度较低。其他的海绵属虽有出现,但分布局限,丰度较低。

水螅也是见天坝生物礁的造礁生物之一,这里仅见到 *Tritubulistroma* 属(插图 4D)呈蘑菇状,个体较大,直径为 12—15.3 mm,由规则排列的纤维状骨骼单元组成,内部有 3 种不同宽度的小管,直径分别为 0.66 mm、0.42 mm 和 0.2 mm,含量很少,分布相对局限,仅在第 10 层的顶部有出现。水螅表面通常被藻包壳包覆,也有被泡孔目苔藓虫包覆,苔藓虫再被硬海绵包覆,这种包覆结构被认为可以增强水螅的抗风浪能力,有利于建礁(Kirkland *et al.*,1998;Wahlman *et al.*,2013)。

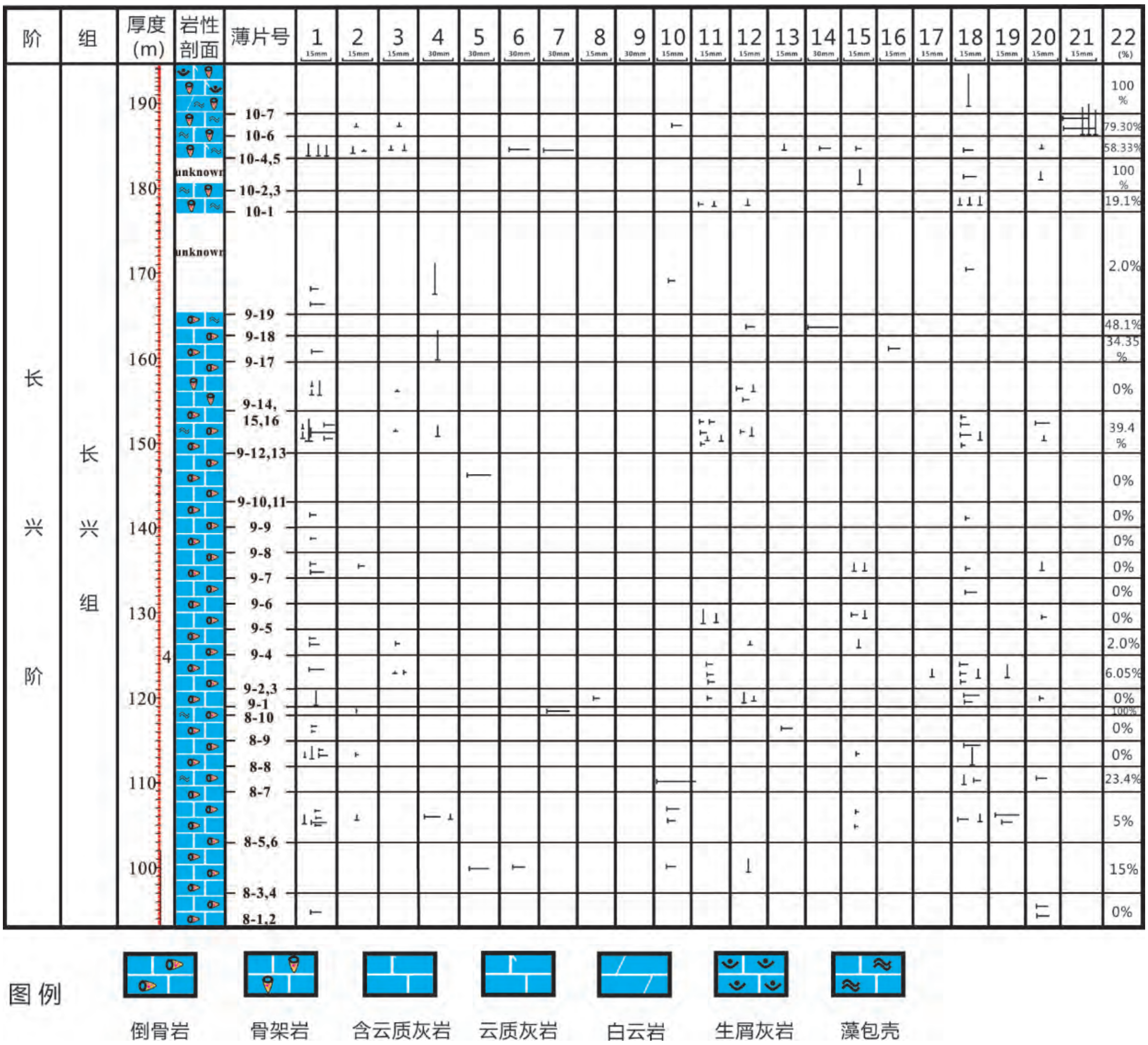

插图 2　钙质海绵和水螅的保存状态(直立与倒伏含量)、平均直径以及古石孔藻包壳含量在含钙质海绵的灰岩中的分布

Preservation status (erect or toppled) and sizes of the main calcisponges and hydrozoans and the content of *Archaeolithoporella* encrustations

其中┻代表直立的钙质海绵或水螅,垂直线的长度代表钙质海绵或水螅的直径大小;┣代表倒伏的钙质海绵或水螅,水平线的长度代表钙质海绵或水螅的直径大小。数字 1—22 分别代表 *Peronidella* sp.、*Bauneia ampliata*(**皮壳状**)、*Bauneia epicharis*(**皮壳状**)、*Bauneia ampliata*(**柱状**)、*Bauneia epicharis*(**柱状**)、*Cystothalamia* sp.、*Elasmostoma* sp.、*Flabellisclera* sp.、*Fungispongia* sp.、*Parauvanella* sp.、*Polycystothalamia* sp.、*Reticulocoelia* sp.、*Sollasia* sp.、*Amblysiphonella* sp.、*Ramospongia* sp.、*Bisiphonella* sp.、*Girtyocoelia* sp.、**纤维海绵未定属、硬海绵未定属、串管海绵未定属**、*Tritubulistroma* sp. **和古石孔藻包壳含量(%)。**

┻ stands for erect calcisponges or hydrozoans and the length of the vertical line represents the diameter of the organism; ┣ stands for toppled calcisponges or hydrozoans and the length of the horizontal line represents the diameter of the organism. The numbers 1-22 respectively represent *Peronidella* sp., *Bauneia ampliata* (encrusting), *Bauneia epicharis* (encrusting), *Bauneia ampliata* (columnar), *Bauneia epicharis* (columnar), *Cystothalamia* sp., *Elasmostoma* sp., *Flabellisclera* sp., *Fungispongia* sp., *Parauvanella* sp., *Polycystothalamia* sp., *Reticulocoelia* sp., *Sollasia* sp., *Amblysiphonella* sp., *Ramospongia* sp., *Bisiphonella* sp., *Girtyocoelia* sp., unknown inozoans, unknown sclerosponges, unknown sphinctozoans, *Tritubulistroma* sp. and the content of *Archaeolithoporella* encrustations.

4.2　埋藏学特征统计结果

通过镜下薄片详细观察,对见天坝生物礁剖面的 8—10 层进行了埋藏学统计,统计每一张薄片内钙质海绵和水螅主要属的保存状况(原地直立的还是倒伏或倒置的),结果见表Ⅰ。参与统计的属种包括串管海绵 *Cystothalamia* sp.,*Parauvanella* sp.,*Polycystothalamia* sp.,*Sollasia* sp.,*Amblysiphonella* sp.,*Girtyocoelia* sp.,纤维海绵 *Peronidella* sp.,*Elasmostoma* sp.,*Flabellisclera* sp.,*Ramospongia* sp.,*Bisiphonella* sp.,硬海绵 *Bauneia ampliata*(皮壳状),*Bauneia epicharis*(皮

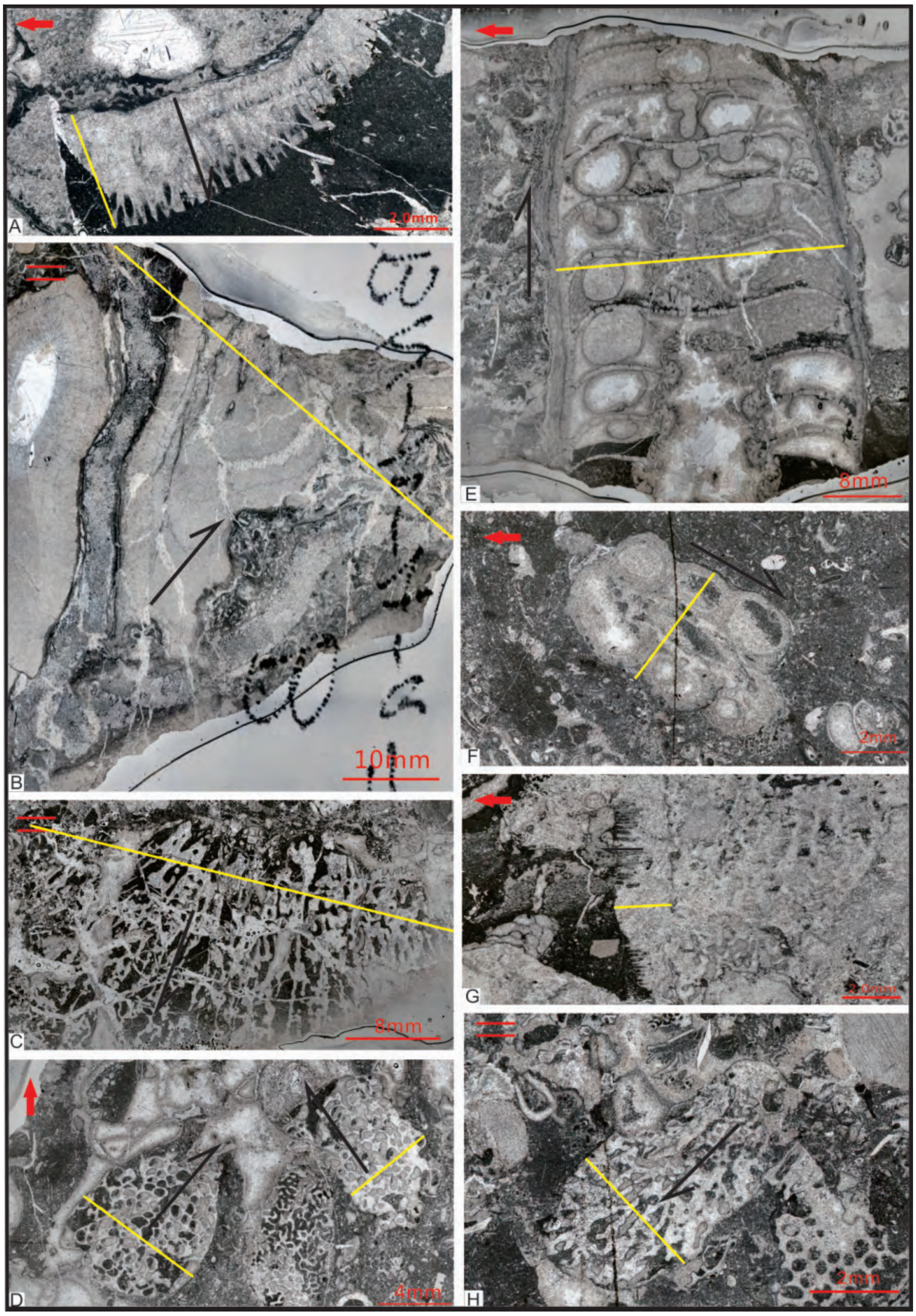

插图 3 湖北利川见天坝剖面钙质海绵礁中钙质海绵的典型分子

The main frame-building organisms in Jiantianba section, Lichuan, Hubei Province

A. *Bauneia ampliata*，最大厚度 3.1 mm，倒伏的，层 9-7；B. *Elasmostoma* sp.，最大直径 28.9 mm，倒伏的，层 10-4B；C. *Fungispongia* sp.，最大直径 38 mm，倒伏的，层 8-7B；D. *Polycystothalamia* sp.，直径左侧 7.2 mm，右侧 4.6 mm，直立的，层 9-5B；E. *Amblysiphonella* sp.，最大直径 29.5 mm，倒伏的，层 9-18；F. *Girtyocoelia* sp.，最大直径 3.94 mm，直立的，层 9-3B；G. *Bauneia epicharis*，最大厚度 1.2 mm，直立的，层 9-13B；H. *Flabellisclera* sp.，最大直径 3.1 mm，倒伏的，层 9-1。红色箭头指向垂直于层面向上的方向，红色双线代表薄片平行于地层层面。黄线代表生物体最大直径的位置，黑色箭头指向海绵体的头部，反向于根部。所有标本均保存于中国科学院地质与地球物理研究所。

A. *Bauneia ampliata*, maximum thickness 3.1 mm, toppled, bed 9-7; B. *Elasmostoma* sp., maximum diameter 28.9 mm, toppled, bed 10-4B; C. *Fungispongia* sp., maximum diameter 38 mm, toppled, bed 8-7B; D. *Polycystothalamia* sp., left diameter 7.2 mm, right diameter 4.6 mm, erect, bed 9-5B; E. *Amblysiphonella* sp., maximum diameter 29.5 mm, toppled, bed 9-18; F. *Girtyocoelia* sp., maximum diameter 3.94 mm, erect, bed 9-3B; G. *Bauneia epicharis*, maximum thickness 1.2 mm, erect, bed 9-13B; H. *Flabellisclera* sp., maximum diameter 3.1 mm, toppled, bed 9-1. The red arrow points to the direction perpendicular to the bedding plane and the red double lines represents the direction parallel to the bedding plane. The yellow lines represent the location of the maximum diameter and the black arrow directs to the head of sponges. All specimens are deposited in Institute of Geology and Geophysics, Chinese Academy of Sciences.

壳状),*Bauneia ampliata*(柱状),*Bauneia epicharis*(柱状),*Fungispongia* sp.,*Reticulocoelia* sp.,以及纤维海绵未定属、硬海绵类未定属、串管海绵未定属,统计结果见插图 2。

除了上述参与统计的属种外,尚有一部分钙质海绵和水螅特征不明显,未做单个属种的埋藏学统计。为此,需要对所有钙质海绵和水螅的埋藏学特征进行统计,统计结果见插图 6。其中绿色代表倒伏造礁生物所占的百分比,红色代表直立造礁生物所占的百分比,两者的和为 100%。

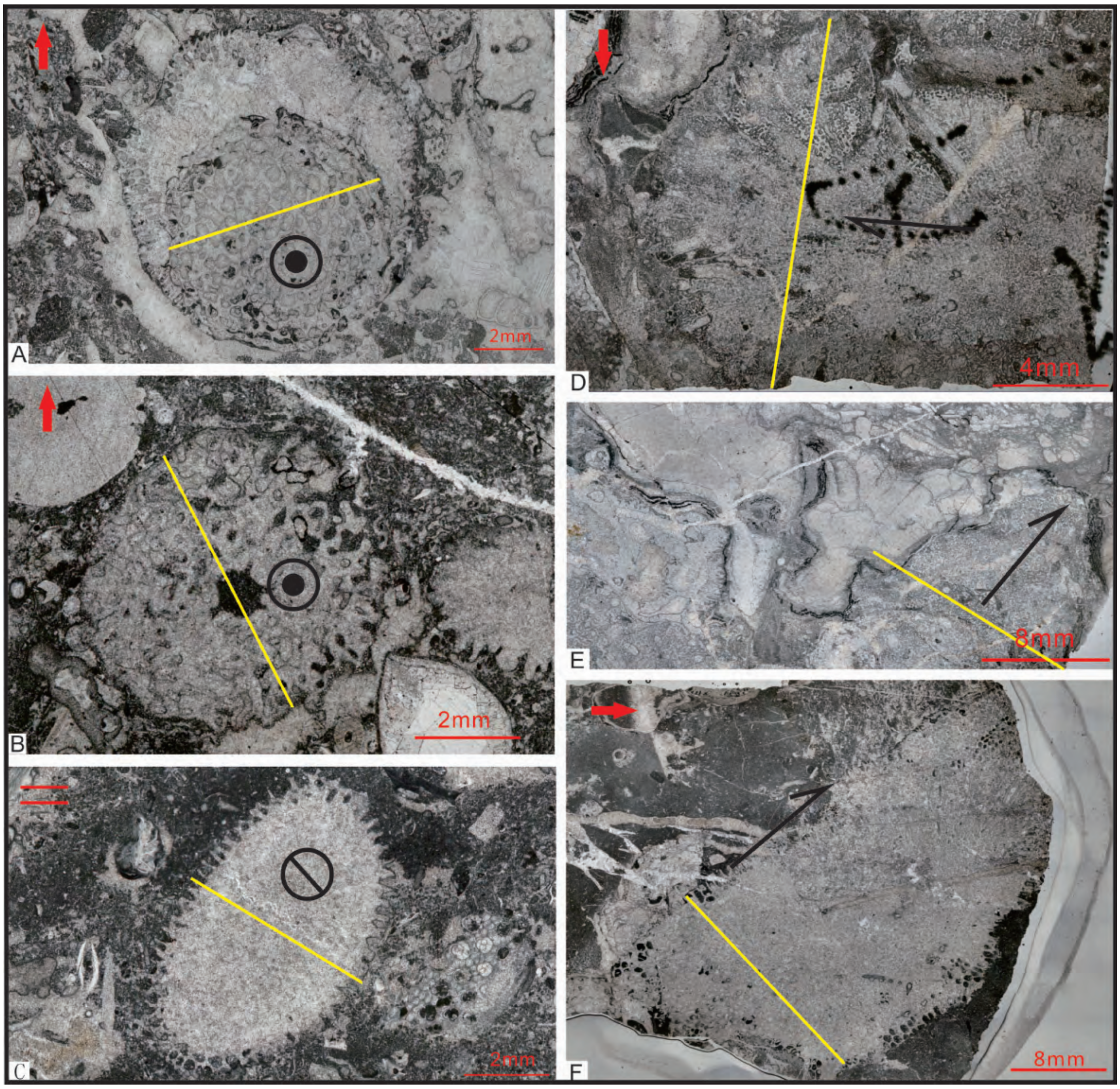

插图 4　湖北利川见天坝剖面二叠纪钙质海绵礁的主要钙质海绵和水螅

The main reef-building calcisponges and hydrozoan in the Permian reef section at Jiantianba, Lichuan, Hubei Province

A. *Parauvanella* sp.,最大直径 6.1 mm,倒伏的,层 8-5B;B. *Peronidella* sp.,最大直径 5.5 mm,倒伏的,层 9-17A;C. *Reticulocoelia* sp.,最大直径 3.5 mm,倒伏的,层 9-14;D. *Tritubulistroma* sp.,最大直径 12.5 mm,倒伏的,层 10-6A;E. 纤维海绵未定属,最大直径 14.54 mm,直立的,层 10-7;F. *Bauneia epicharis*,最大直径 23.0 mm,倒伏的,层 9-11。红色箭头指向垂直于层面向上的方向,红色双线代表薄片平行于地层层面,黄线代表生物体最大直径的位置,黑色箭头指向海绵体或水螅的头部,反向于根部。双圆圈代表海绵的头指向垂直于层面的方向,圈中带一线代表钙质海绵原始生长方向斜交于薄片。所有标本均保存于中国科学院地质与地球物理研究所。

A. *Parauvanella* sp., maximum diameter 6.1 mm, toppled, bed 8-5B; B. *Peronidella* sp., maximum diameter 5.5 mm, toppled, bed 9-17A; C. *Reticulocoelia* sp., maximum diameter 3.5 mm, toppled, bed 9-14; D. *Tritubulistroma* sp., maximum diameter 12.5 mm, toppled, bed 10-6A; E. Unknown calcisponge, maximum diameter 14.54 mm, erect, bed 10-7; F. *Bauneia epicharis*, maximum diameter 23.0 mm, toppled, bed 9-11。The red arrow points to the direction perpendicular to the bedding plane and the red double lines represents the direction parallel to the bedding plane. The yellow lines represent the location of the maximum diameter and the black arrow directs to the head of sponges. The circles mean sponge heads perpendicular to thin sections and the circles with a line mean sponge heads oblique to thin sections. All specimens are deposited in Institute of Geology and Geophysics, Chinese Academy of Sciences.

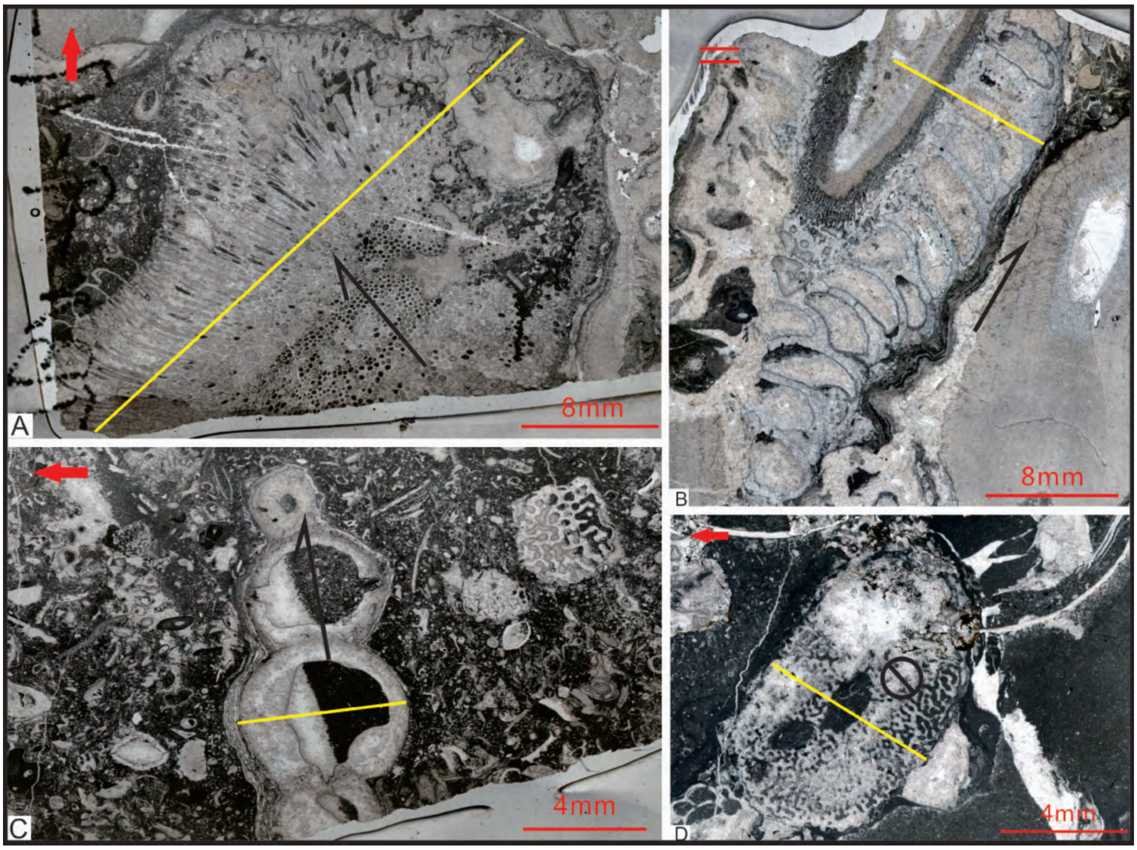

插图 5 湖北利川见天坝剖面钙质海绵礁中钙质海绵的典型分子

The main frame-building organisms in Jiantianba section, Lichuan, Hubei Province

A. *Bauneia ampliata*，最大直径 28.9 mm，直立的，层 9-17A；B. *Cystothalamia* sp.，最大直径 20 mm，倒伏的，层 10-4B；C. *Sollasia* sp.，最大房室直径 5.5 mm，倒伏的，层 8-9；D. *Bisiphonella* sp.，最大直径 5.7mm，倒伏的，层 9-7。红色箭头指向垂直于层面向上的方向。红色双线代表薄片平行于地层层面。黄线代表生物体最大直径的位置。黑色箭头指向海绵体的头部，反向于根部。圈中带一线代表钙质海绵原始生长方向斜交于薄片。所有标本均保存于中国科学院地质与地球物理研究所。

A. *Bauneia ampliata*, maximum diameter 28.9 mm, erect, bed 9-17A; B. *Cystothalamia* sp., maximum diameter 20 mm, toppled, bed 10-4B; C. *Sollasia* sp., maximum chamber diameter 5.5 mm, toppled, bed 8-9; D. *Bisiphonella* sp., maximum diameter 5.7 mm, toppled, bed 9-7. The red arrow points to the direction perpendicular to the bedding plane and the red double lines represent the direction parallel to the bedding plane. The yellow lines represent the location of the maximum diameter and the black arrow directs to the head of sponges. The circles with a line mean sponge heads oblique to thin sections. All specimens are deposited in Institute of Geology and Geophysics, Chinese Academy of Sciences.

表 I 湖北利川见天坝二叠纪生物礁剖面含钙质海绵段全部海绵直立倒伏统计数据

The erect or toppled data of calcisponges in the calcisponge-bearing limestone interval of Jiantianba section in Lichuan, Hubei Province

薄片号	8－2	8－4	8－5	8－7	8－8	8－9	8－10
倒伏	100.00％	75.00％	75.00％	75.00％	62.50％	100.00％	100.00％
直立	0.00％	25.00％	25.00％	25.00％	37.50％	0.00％	0.00％
薄片号	9－1	9－3	9－4	9－5	9－6	9－7	9－8
倒伏	62.50％	66.70％	60.00％	40.00％	100.00％	57.20％	100.00％
直立	37.50％	33.30％	40.00％	60.00％	0.00％	42.80％	0.00％
薄片号	9－9	9－11	9－13	9－14	9－17	9－18	9－19
倒伏	100.00％	100.00％	59.10％	25.00％	66.70％	100.00％	80.00％
直立	0.00％	0.00％	40.90％	75.00％	33.30％	0.00％	20.00％
薄片号	10－1	10－2	10－4､5	10－6	10－7		
倒伏	16.70％	33.30％	35.71％	37.50％	0.00％		
直立	83.30％	66.70％	64.29％	62.50％	100.00％		

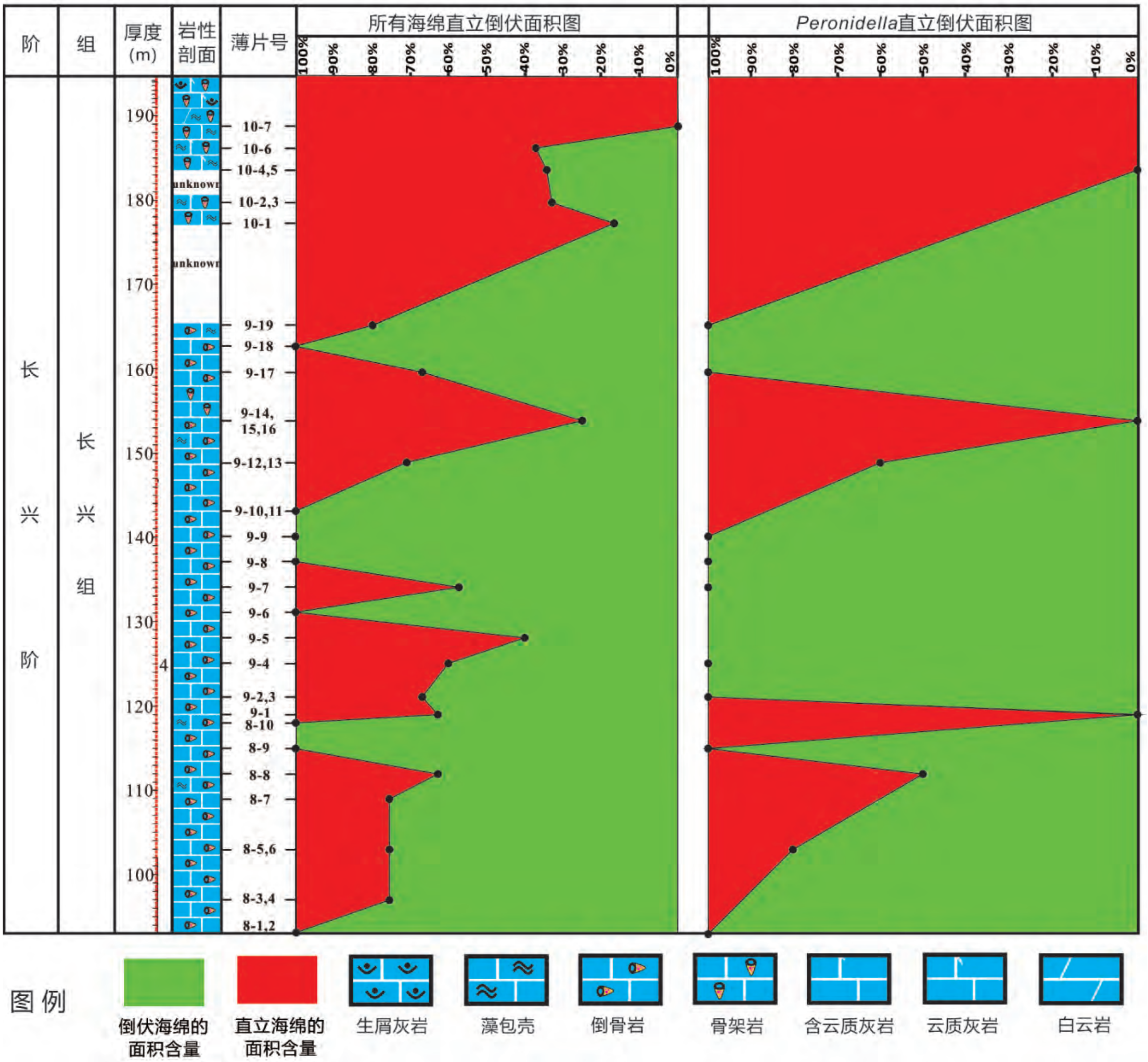

插图 6　湖北利川上二叠统钙质海绵礁剖面含钙质海绵段各层的钙质海绵直立-倒伏含量分布

Aerial percentages of erect to toppled calcisponges in the calcisponge-bearing interval of the Jiantianba section in Lichuan, Hubei Province

为了考察埋藏学特征与钙质海绵和水螅个体大小的关系,还统计了每张薄片内造礁生物直径的平均值,结果见表格Ⅱ;根据所统计的数据,以薄片号为横坐标,大小为纵坐标,作出造礁生物的大小变化趋势图(插图 7),红线代表趋势线。

为了进行对比,还对分布最广、丰度最高的 *Peronidella* 属的保存状况和直径大小进行了专门统计,保存状况数据见表Ⅲ,该属直立-倒伏含量图见插图 6,直径大小数据见表Ⅲ,直径纵向分布见插图 7。

4.3　纵向变化规律

由全部海绵直立-倒伏含量图(插图 6)可见,第 8—9 层倒伏海绵的比例远远大于直立海绵,从第 9 层的顶部开始,直立海绵比例增加,明显大于倒伏海绵所占的比例。

具体而言,第 8 层倒伏海绵含量超过 75%,最高处达 100%,完全以倒伏海绵为主;第 9 层倒伏海绵的含量变化较大,为 25%—100%,但整体来说还是以倒伏海绵为主,仅仅在中上部 154.2—159.6 m 段以直立海绵占优势;第 9 层顶部到第 10 层,直立海绵占据优势,含量大于 70%,在 10 层的顶部倒伏海绵逐渐增加,但总体以直立海绵为主。

由全部海绵大小变化趋势图(插图 7)可见,钙质海绵和水螅直径在纵向上是逐渐增加的,但是增

表Ⅱ 湖北利川见天坝二叠纪生物礁剖面含钙质海绵段全部海绵平均直径统计表

The average diameters of all calcisponges in the calcisponge-bearing limestone interval of Jiantianba section in Lichuan, Hubei Province

薄片号	8—2	8—4	8—5	8—7	8—8	8—9	8—10
大小(mm)	5.70	10.75	5.23	12.84	4.44	3.33	11.50
薄片号	9—1	9—3	9—4	9—5	9—6	9—7	9—8
大小(mm)	4.25	3.71	3.29	4.29	5.69	3.89	2.80
薄片号	9—9	9—11	9—13	9—14	9—17	9—18	9—19
大小(mm)	2.64	23.00	4.49	3.32	13.37	16.95	9.79
薄片号	10—1	10—2	10—4,5	10—6	10—7		
大小(mm)	3.35	5.96	7.12	9.63	15.75		

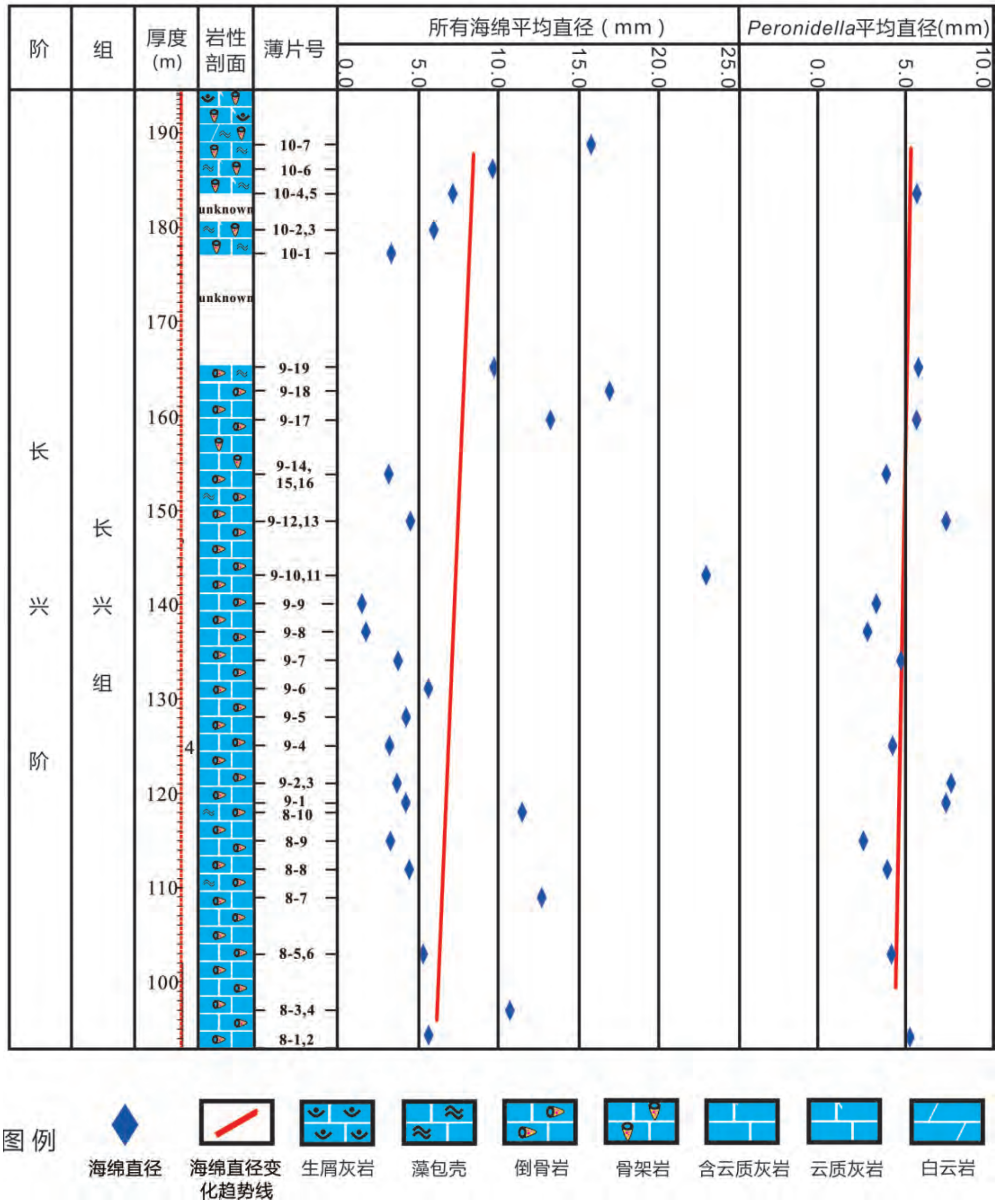

插图 7 湖北利川上二叠统钙质海绵礁剖面含钙质海绵段各层的钙质海绵个体直径平均值

Average diameters of the calcisponges in the calcisponge-bearing interval of the Jiantianba section in Lichuan, Hubei Province

表Ⅲ　湖北利川见天坝二叠纪生物礁剖面含钙质海绵段 *Peronidella* 属直立倒伏和平均直径统计表

The erect or toppled data and average diameters of *Peronidella* in the calcisponge-bearing limestone interval of Jiantianba section in Lichuan, Hubei Province

薄片号	8—2	8—5	8—8	8—9	9—1	9—3	9—4	9—7
倒伏	100.00%	80.00%	50.00%	100.00%	0.00%	100.00%	100.00%	100.00%
直立	0.00%	20.00%	50.00%	0.00%	100.00%	0.00%	0.00%	0.00%
大小(mm)	5.20	4.14	3.88	2.25	7.20	7.44	4.10	4.85
薄片号	9—8	9—9	9—13	9—14	9—17	9—19	10—4、5	
倒伏	100.00%	100.00%	60.00%	0.00%	100.00%	100.00%	0.00%	
直立	0.00%	0.00%	40.00%	100.00%	0.00%	0.00%	100.00%	
大小(mm)	2.80	3.28	7.22	3.88	5.50	5.55	5.67	

大不明显。

由 *Peronidella* 属直立-倒伏含量图(插图6)可见,其直立倒伏情况和全部海绵的统计结果一致:8—9层以倒伏海绵为主,第9层顶部到第10层以直立海绵为主,第9层中上部以直立海绵占据优势,第10层顶部以倒伏海绵占据优势,唯一不同的是第9层底部很窄的范围内直立海绵较多。通过对比可见,单属埋藏学统计结果与全部属的埋藏学统计结果基本一致。

由 *Peronidella* 属的大小变化趋势图(插图7)可见,与全部属的大小统计结果一样,直径在纵向上是逐渐增加的,但是增大的幅度很小。

4.4　统计结果的环境意义

钙质海绵的抗浪性一直是学者关注的热点。吴亚生(1992,1997,1998)在广西隆林、贵州紫云、浙江冷坞、四川盘龙洞等地的二叠纪生物礁中都发现了原地的亮晶骨架岩,这说明钙质海绵有一定的抗浪能力。

此次研究在见天坝生物礁中也发现骨架岩的存在,比如第10层。但在第8—9层,却是由倒伏的钙质海绵所组成。吴亚生和范嘉松(2000)在典型的二叠纪钙质海绵礁中也发现了倒伏海绵的存在。在浙江冷坞中二叠统钙质海绵生物礁中也有倒伏海绵存在,吴亚生(1997)把这种主要由倒伏造礁生物组成的礁岩叫做倒骨岩。造成钙质海绵倒伏的原因可能有3种:(1)不同大小和形态的钙质海绵具有不同的抗浪能力,吴亚生(1989)认为生物个体的大小不同则抗浪性也不同;(2)钙质海绵造礁时处于不同的水动力条件下,即位于不同的水深中;(3)造礁生物表面是否具有古石孔藻包壳(Kirkland *et al.*,1998;Wahlman *et al.*,2013)。

见天坝生物礁的造礁生物以柱状为主,并且钙质海绵的大小在纵向上变化不大,因此可以排除钙质海绵的倒伏与否是由个体大小决定的这种可能性。所以,造成钙质海绵倒伏情况纵向变化的原因可能是不同造礁时期水动力条件发生了变化或者古石孔藻包壳的差异。

由插图2和插图8可见,8—9层的古石孔藻包壳很少,基本小于15%,第10层古石孔藻含量大于70%,不少薄片包覆含量达到100%。具体而言,第8层,整体包壳含量小于15%,仅仅在顶部局限区域包壳含量达到100%;第9层,古石孔藻包壳含量整体小于第8层,大多数在6%以下,局部达到48%,但很少;第10层底部包壳含量很少,仅19.1%,但向上包壳含量很多,基本每个造礁生物都被包覆。

从插图8可以看出,泥晶含量在8—10层普遍较低,平均值为13.5%,但8—9层的泥晶含量(平均值为17.5%)要高于第10层(9.55%)。泥晶含量可以反映水动力条件的变化,通常水动力条件和泥晶含量成反比(排除微生物粘结作用)。

从以上的数据我们可以看出,8—9层的钙质海绵造礁时水深较大,水动力条件较弱,但仍然有较强的水动力能量;造礁生物在造礁时,由于没有古石孔藻的包覆,抗风浪能力较弱,往往被风浪打倒,造成造礁生物的倒伏保存。第10层的造礁生物呈现直立状态,虽然较弱的水动力可以造成这种现象,但由泥晶的含量可以看出第10层的水动力条件更强。尽管如此,由于古石孔藻的包覆作用加强了造礁生物的抗风浪能力,所以第10层的钙质海绵大多处于直立的状态。

5　讨　论

生物礁的早期研究主要是针对生物礁的岩石类型进行的,早期学者把生物礁的岩石类型统称为一

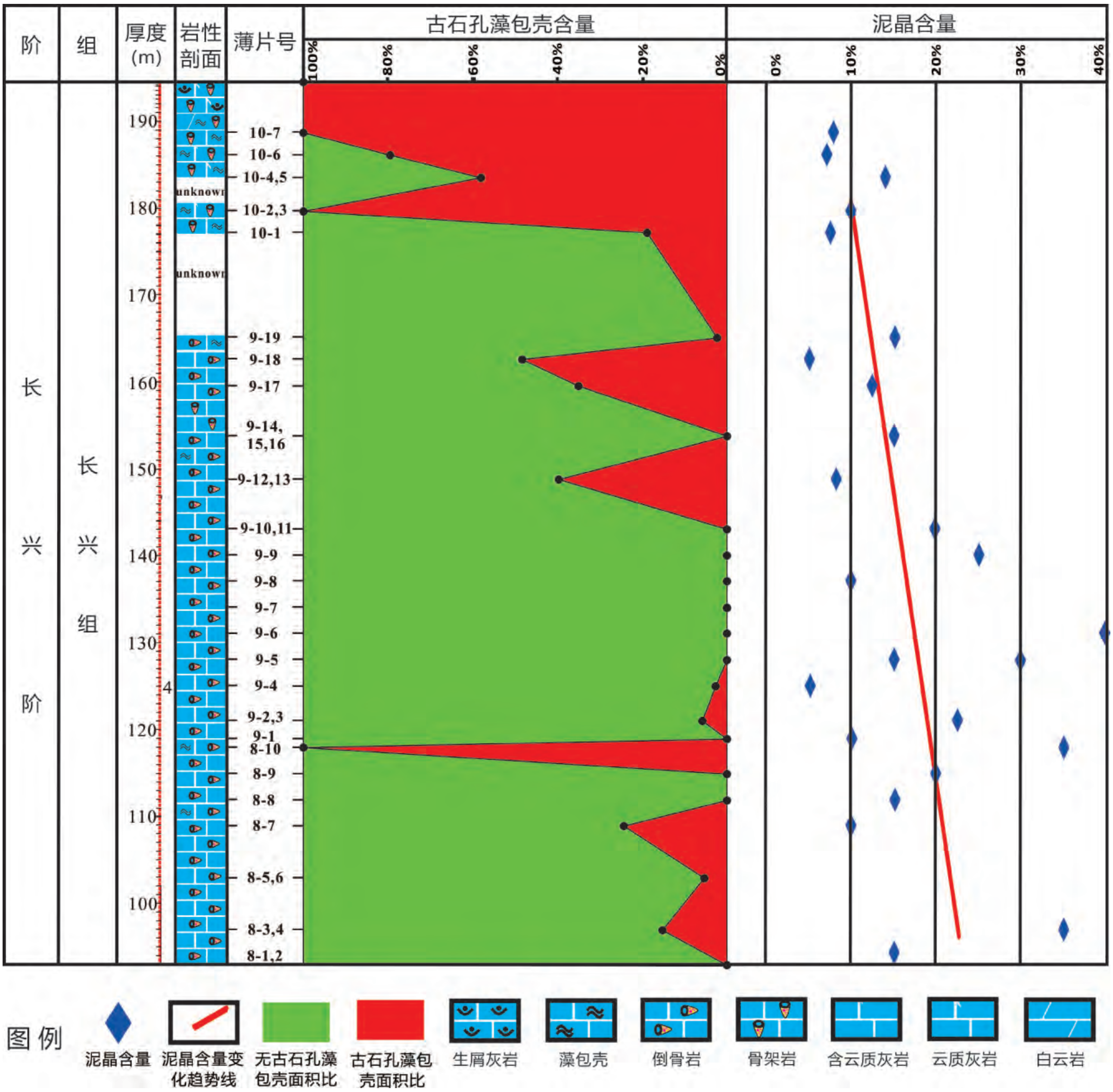

插图 8 湖北利川上二叠统钙质海绵礁剖面含钙质海绵段各层的古石孔藻包壳和泥晶含量

Contents of the *Archaeolithoporella* encrustations and micrites in the calcisponge-bearing interval of the Jiantianba section in Lichuan, Hubei Province

种,比如 Folk(1962)把生物礁的岩石类型统称为生物礁岩(Biolithite);Dunham(1962)把生物礁的岩石类型统称为粘结岩(Boundstone)。直到 Embry 和 Klovan(1971)提出了生物礁岩的系统分类,沿用至今,在这个分类系统中,首先把灰岩分为二类:原地和异地,其中原地的灰岩包括骨架岩、绑结岩(bindstone)和障积岩。Cuffey(1985)提出一个较系统的礁岩分类体系,分类体系基于造礁生物的形态,但因涉及太多的古生态知识而很难被广泛接受。国内学者吴亚生(1992,1997)根据野外和镜下实际观测,提出了一个更为全面的分类,将生物礁岩石类型划分为 12 种,其中骨架岩、障积岩、粘结岩和盖覆岩主要由原地生物生长所形成,并且每一种岩石类型都有自己的结构相。上述分类方案可以看出经典分类以及国内学者吴亚生(1992,1997)的分类方案,都将生物礁岩石类型分为原地的和次生的,其中骨架岩和障积岩都属于原地生物建造形成。本文 8—10 层以浅灰色块状礁灰岩为主,厚 98 m,含有丰富的钙质海绵,与范嘉松等(1982)的 10—16 层相对应。范嘉松研究认为其 10—13 层中存在角砾岩的条带,所以

是礁前亚相,其 14—16 层以骨架岩为主,属于礁核亚相,厚 50 m。此次研究我们没有发现角砾岩的存在。由于角砾岩的存在是划分礁前相的关键依据,此次研究认为角砾岩不存在,所以本文不采纳礁前相的划分。

胡明毅等(2012)对见天坝剖面也进行了研究,其 6—11 层对应本文的 8—10 层。胡明毅等认为其 6—8 层以钙藻的粘结作用为主,海绵化石含量很少,是灰泥丘相;9—11 层以障积岩和骨架岩为主,是礁核亚相,厚 55.8 m。此次研究以 2 m 间距采样,未在见天坝剖面发现钙藻粘结岩,所以本文不采纳灰泥丘的划分。此次研究的 8—9 层以倒伏海绵组成的礁岩为主,厚 84.1 m,因为海绵是倒伏的,不能称为障积岩或骨架岩,而应该归入吴亚生(1997)命名的倒骨岩。第 10 层以原地的骨架岩为主,仅厚 13.9 m。倒骨岩的厚度是骨架岩的 4 倍,说明礁核亚相主要不是由原地的钙质海绵组成,反而更多的以倒伏海绵为主。本文认为可以将礁核亚相进一步划分为两个次一级相:倒骨岩小相和骨架岩小相。

6　结　论

湖北利川见天坝二叠纪钙质海绵礁剖面由 98 m 厚的含钙质海绵礁灰岩段和其上其下的不含海绵的非礁相碳酸盐岩组成。通过对含钙质海绵灰岩段的埋藏学研究,得出以下结论:

1) 造礁生物以钙质海绵为主,一般呈柱状,共鉴定出 17 个属种的海绵和 1 个属种的水螅,分别为 *Peronidella* sp.,*Bauneia ampliata*(皮壳状),*Bauneia epicharis*(皮壳状),*Bauneia ampliata*(柱状),*Bauneia epicharis*(柱状),*Cystothalamia* sp.,*Elasmostoma* sp.,*Flabellisclera* sp.,*Fungispongia* sp.,*Parauvanella* sp.,*Polycystothalamia* sp.,*Reticulocoelia* sp.,*Sollasia* sp.,*Amblysiphonella* sp.,*Ramospongia* sp.,*Bisiphonella* sp.,*Girtyocoelia* sp. 和呈蘑菇状的 *Tritubulistroma* 属水螅。

2) 含钙质海绵段中下部 4/5 厚度是主要由倒伏海绵组成的倒骨岩,只有很少的古石孔藻包壳,说明造礁生物造礁时处于水动力能量较强的环境,钙质海绵易被打倒;含钙质海绵段上部 1/5 厚度内海绵大多呈直立态,几乎所有造礁生物被古石孔藻包覆,而且泥晶含量相对减少,说明此时的水动力更强,但古石孔藻的包覆增强了造礁生物的抗风浪能力,因而海绵大多数是原地保存的。

3) 含钙质海绵段没有发现角砾岩,也没有发现钙藻粘结岩,所以缺乏划分礁前相或灰泥丘的理由。由于大多数含海绵灰岩中的海绵都是倒伏的,以往研究者将礁体描述为主要由障积岩和骨架岩组成,也是欠准确的。

4) 礁核亚相可进一步划分为倒骨岩小相和骨架岩小相。

致谢　参与野外工作的还有刘青松,匿名审稿专家提出宝贵评审意见和建议,在此致以诚挚的感谢!

参 考 文 献 (References)

Behrensmeyer A K, Kidwell S M, Gastaldo R A, 2000. Taphonomy and paleobiology. Paleobiology, **26**: 103—147.

Cuffey R J, 1985. Expanded reef-rock textural classification and the geologic history of bryozoan reefs. Geology, **13**: 307—310.

Deng Jian (邓　剑), Duan Jin-bao (段金宝), Wang Zheng-he (王正和), Wang Ming-fa (王明筏), 2014. Research on the reef characteristic of Changxing Formation in Yuanba area of north-east Sichuan Province. Journal of Southern Petroleum University(Science & Technology Edition) (西南石油大学学报:自然科学版), **36**(4): 63—72 (in Chinese with English abstract).

Dunham R J, 1962. Classification of carbonate rocks according to depositional textures. *In*: Ham W E (ed.), Classification of Carbonate Rocks. A Symposium American Association of Petroleum Geologists, **1**: 108—121.

Efremov I, 1940. Taphonomy: a new branch of paleontology. Pan-American Geologist, **74**(2): 81—93.

Embry III A F, Klovan J E, 1971. A late Devonian reef tract on northeastern Banks Island, NWT. Bulletin of Canadian Petroleum Geology, **19**: 730—781.

Ezaki Y, Liu J, Adachi N, 2003. Earliest Triassic microbialite micro-to megastructures in the Huaying area of Sichuan Province, South China: Implications for the nature of oceanic conditions after the end-Permian extinction. Palaios, **18**(4/5): 388—402.

Fan G H, Wang Y B, Kershaw S, Li G S, Meng Z, Lin Q X, Yuan Z M, 2014. Recurrent breakdown of Late Permian reef communities in response to episodic volcanic activities: evidence from southern Guizhou in South China. Facies, **60**: 603—613.

Fan Jia-song (范嘉松), 1996. The Chinese Organic Reefs and Oil. Beijing: China Ocean Press. 1—329 (in Chinese).

Fan Jia-song (范嘉松), Qi Jing-wen (齐敬文), Zhou Tie-ming (周铁明), Zhang Xiao-lin (张孝林), Zhang Wei (张　维), 1990. The Permian Reefs of Longlin, Guangxi Province. Beijing: Geological Publishing House. 1—128(in Chinese).

Fan Jia-song (范嘉松), Tian Shu-gang (田树刚), Wu Ya-sheng (吴亚生), 2004. Characteristics of the Permian reefs in Aergeshan, eastern Kunlun Mountains and their palaeogeographic and palaeoclimatic significance. Journal of Palaeogeography (古地理学报), **6**(3): 329—338(in Chinese with English abstract).

Fan Jia-song(范嘉松), Wang Yu-mao(王予卯), Wu Ya-sheng(吴亚生), 2002. Calcisponges and hydrozoans from Permian reefs in western Guangxi. Acta Palaeontologica Sinica(古生物学报), **41**(3): 334—348.

Fan Jia-song (范嘉松), Wu Ya-sheng (吴亚生), 2002. On some Permian calcareous algae from Guangxi, Guizhou provinces and East Sichuan, and their paleoecological environments. Acta Micropalaeontologica Sinica (微体古生物学报), **19**(4): 337—347 (in Chinese with English abstract).

Fan Jia-song (范嘉松), Wu Ya-sheng (吴亚生), 2005. Main features of the Permian reefs of world and their palaeogeography distribution. Journal of Palaeogeography (古地理学报), **7**(3): 287—304 (in Chinese with English abstract).

Fan J S, Zhang W, 1985. Sphinctozoans from late Permian reefs of Lichuan, West Hubei,China. Facies, **13**: 1—43.

Fan Jia-song (范嘉松), Zhang Wei (张 维), 1986. On a new Sphinctozoa family-Intrasporeocoe Liidae from Upper Permian reefs in the Lichuan district, West Hubei. Scientia Geologica Sinica (地质科学), **2**: 151—160 (in Chinese with English abstract).

Fan Jia-song (范嘉松), Zhang Wei (张 维), 1987. On some Inozoan, Pharetronida (Clacispongea) and Tabulozoan (Sclerospongiae) from Upper Permian reefs, Lichuan County, West Hubei, China. Scientia Geologica Sinica (地质科学), **4**: 326—333 (in Chinese with English abstract).

Fan Jia-song (范嘉松), Zhang Wei (张 维), Ma Xing (马 行), Zhang Yin-ben (张荫本), Liu Huai-bo (刘怀波), 1982. The Upper Permian reefs in Lichuan district, West Hubei. Scientia Geologica Sinica (地质科学), **3**: 274—282, 343—344 (in Chinese with English abstract).

Fan Jia-song (范嘉松), Zhang Wei (张 维), Qi Jing-wen (齐敬文), Wang Jiong-zhang (王炯章), 1987. On the main feature of Lower Permian reefs in Guangnan County, SE Yunnan Province and their frame-building organisms-sphinctozoans. Scientia Geologica Sinica (地质科学), **1**: 50—60 (in Chinese with English abstract).

Flügel E, Kiessling W, 2002. A new look at ancient reefs. AAPG Bulletin, **72**: 3—9.

Folk R L, 1962. Spectral subdivision of limestone types. *In*: Ham W E (ed.), Classification of Carbonate Rocks. AAPG Memoir, **1**: 62—84.

Girty G H, 1908. The Guadalupian Fauna. United States Geological Survey Professor Paper, **58**: 1—649.

Guo L, Riding R, 1992. Microbial micritic carbonates in uppermost Permian reefs, Sichuan Basin, southern China: some similarities with recent travertines. Sedimentology, **39**: 37—53.

Hu Ming-yi (胡明毅), Wei Huan (魏 欢), Qiu Xiao-song 邱小松), Zhao En-zhang (赵恩璋), 2012. Reef composition and their forming models of Changxing Formation in Jiantianba Section of Lichuan, western Hubei. Acta Sedimentologica Sinica (沉积学报), **30**(1): 33—42 (in Chinese with English abstract).

Jiang Hong-xia (姜红霞), Wu Ya-sheng (吴亚生), 2007. Restudy of the microbialites from the Permian-Triassic boundary section, Chongqing. Acta Petrologica Sinica (岩石学报), **23**(5): 1189—1196 (in Chinese with English abstract).

Kershaw S, Guo L, Swift A, Fan J S, 2002. Microbialites in the Permian-Triassic boundary interval in central China: Structure, age and distribution. Facies, **47**(1): 83—89.

Kirkland B, Dickson J, Wood R, Land L, 1998. Microbialite and microstratigraphy: the origin of encrustations in the middle and upper Capitan Formation, Guadalupe Mountains, Texas and New Mexico, USA. Journal of Sedimentary Research, **68**: 956—969.

Lin Qi-xiang(林启祥), 1992. Nature and evolution of Late Permian reef in Ziyun, Guangxi Province. Earth-Science-Journal of China University of Geosciences (地球科学——中国地质大学学报), **17**(3): 301—307(in Chinese with English abstract).

Liu Fu-yan (刘富艳), Wang Yan-qi (王延奇),Wang Shu (王 书), Song Hai-jing (宋海敬), Xu Wen-qiang (许文强), 2009. Sequence stratigraphy analysis and reservoir evaluation for Jiantianba spongy reef. Special Oil and Gas Reservoirs (特种油气藏), **16** (1): 23—26, 106—107 (in Chinese with English abstract).

Liu L, Wu Y S, Jiang H X, Liu H, 2016. Growth characteristics and sedimentary mode of Permian reefs,Lengwu, Tonglu, Zhejiang Province, southern China. Journal of Palaeogeography, **5**(4): 409—422.

Liu L, Wu Y S, Li Y, Liu Q S, Jiang H X, Liu H, 2017. Microfacies of a Permian calcisponge reef in Lichuan, western Hubei, South China. Palaeoworld, **27**(1):90—106.

Liu Zu-han (柳祖汉), 2003. Communities, palaeogeography and reefs of Middle Permian Qixia Period in Hunan. Chinese Journal of Geology (地质科学), **38**(2): 190—199 (in Chinese with English abstract).

Liu Zu-han(柳祖汉), Yang Meng-da(杨孟达), Yang Rong-feng(杨荣丰), 2001. Permian sponge-alga reef in Xingwuchang of Hunan. Journal of Xiangtan Mining Institute (湘潭矿业学院学报), **16**(4): 20—24 (in Chinese with English abstract).

Ma Yong-sheng (马永生), Cai Xun-yu (蔡勋育), Zhao Pei-rong (赵培荣), 2014. Characteristics and formation mechanisms of reef-shoal carbonate reservoirs of Changxing-Feixianguan formation, Yuanba gas field. Acta Petrolei Sinica(石油学报), **35**(6): 1001—1011 (in Chinese with English abstract).

Ma Yong-sheng (马永生), Mu Chuan-long (牟传龙), Guo Xu-sheng (郭旭生), Tan Qin-yin (谭钦银), Yu Qian (余 谦), 2006. Characteristic and framework of the Changxingian sedimentation in the northeastern Sichuan Basin. Geological Reviews (地质论评), **52**(1): 25—29 (in Chinese with English abstract).

Mu Chuan-long (牟传龙), Tan Qin-yin (谭钦银), Yu Qian (余

谦), Wang Li-quan (王立全), Wang Rui-hua (王瑞华), 2004. The organic reefs and their reef-forming model for the Upper Permian Changxing Formation in northeastern Sichuan. Sedimentary Geology and Tethyan Geology (沉积与特提斯地质), **24**(3): 65—71 (in Chinese with English abstract).

Nakazawa T, Igawa T, Ueno K, Fujikawa M, 2015. Middle Permian sponge-microencruster reefal facies in the mid-Panthalassan Akiyoshi atoll carbonates: observations on a limestone slab. Facies, **61**: 1—14.

Qiang Zi-tong (强子同), Guo Yi-hua (郭一华), Zhang Fan (张帆), Yan Chuan-tai (严传太), Zheng Jia-feng (郑家凤), 1985. The Upper Permian reef and its diagenesis in Sichuan Basin. Oil & Gas Geology(石油与天然气地质), **6**(1): 82—90, 125—128 (in Chinese with English abstract).

Qiu Xiao-song (邱小松), Hu Ming-yi (胡明毅), Hu Zhong-gui (胡忠贵), Zhao En-zhang (赵恩璋), 2011. Analysis on sedimentary facies of Changxing Formation reefs profile of Panlongdong in Xuanhan, northeastern Sichuan Basin. Offshore Oil (海洋石油), **31**(3): 39—44 (in Chinese with English abstract).

Rigby J K, Bell Jr G L, 2006. Sponges from the reef trail member of the Upper Guadalupian (Permian) Bell Canyon Formation, Guadalupe Mountains National Park, Texas. Journal of Paleontology, **80**: 1—42.

Rigby J K, Fan J S, Zhang W, 1989a. Inozoan calcareous Porifera from the Permian reefs in South China. Journal of Paleontology, **63**: 778—800.

Rigby J K, Fan J S, Zhang W, 1989b. Sphinctozoan sponges from the Permian reefs of South China. Journal of Paleontology, **63**: 404—439.

Rigby J K, Fan J S, Zhang W, Wang S H, Zhang X, 1994. Sphinctozoan and inozoan sponges from the Permian reefs of South China. BYU Geology Studies, **40**: 43—109.

Rigby J K, Senowbari-Daryan B, 1996. Upper Permian inozoid, demospongid, and hexactinellid sponges from Djebel Tebaga, Tunisia. University of Kansas Paleontological Contributions, New Series, **7**: 1—130.

Rigby J K, Senowbari-Daryan B, Liu H, 1998. Sponges of the Permian Upper Capitan Limestone Guadalupe Mountains, New Mexico and Texas. Brigham Young University Geology Studies, **43**: 19—89.

Senowbari-Daryan B, Di Stefano P, 1988. Microfacies and sphinctozoan assemblage of some Lower Permian breccias from the Lercara Formation (Sicily). Rivista Italiana di Paleontologia e Stratigrafia, **94**: 3—34.

Senowbari-Daryan B, Hamedani A, Rashidi K, 2007. Sponges from the Permian of Hambast Mountains, south of Abadeh, central Iran. Facies, **53**: 575—614.

Senowbari-Daryan B, Ingavat-Helmcke R, 1994. Sponge assemblage of some Upper Permian reef limestones from Phrae Province (Northern Thailand). Geologija, **36**: 5—59.

Senowbari-Daryan B, Rigby J K, 1988. Upper Permian segmented sponges from Djebel Tebaga, Tunisia. Facies, **19**: 171—249.

Senowbari-Daryan B, Rigby J K, 1991. Three additional thalamid sponges from the Upper Permian reefs of Djebel Tebaga (Tunisia). Journal of Paleontology, **65**: 623—629.

Stanton R J, Flügel E, 1987. Palaeoecology of upper Triassic reefs in the northern Calcareous Alps: Reef communities. Facies, **16**: 157—185.

Tian Shu-gang (田树刚), Fan Jia-song (范嘉松), 2002. Reef-building mechanism in the Early-Middle Permian, the East Kunlun. Acta Geologica Sinica (地质学报), **76**(2): 145—154 (in Chinese with English abstract).

Wahlman G P, Orchard D M, Buijs G J, 2013. Calcisponge-microbialite reef facies, middle Permian (lower Guadalupian), northwest shelf margin of Permian Basin, New Mexico. AAPG Bulletin, **97**: 1895—1919.

Wang Sheng-hai (王生海), Fan Jia-song (范嘉松), Rigby J K, 1996. The characteristics and development of the Permian reefs in Ziyun County, South Guizhou, China. Acta Sedimentologica Sinica (沉积学报), **14**(2): 66—74 (in Chinese with English abstract).

Wang Yong-biao (王永标), Xu Gui-rong (徐桂荣), 1998. Diagenesis and diagenetic facies of the Late Permian reef in Cili, Hunan Province. Acta Sedimentologica Sinica (沉积学报), **16**(1): 132—136 (in Chinese with English abstract).

Wang Yong-biao (王永标), Xu Gui-rong (徐桂荣), Lin Qi-xiang (林启祥), 1997. Paleoecological relations between coral reef and sponge reef of Late Permian in Cili area, West Hunan Province. Earth Science-Journal of China University of Geosciences (地球科学-中国地质大学学报), **22**(2): 135—138 (in Chinese with English abstract).

Wang Yong-biao (王永标), Xu Gui-rong (徐桂荣), Lin Qi-xiang (林启祥), Gong Shu-yun (龚淑云), 2001. Sedimentary models of the Early Permian reef and island ocean in the eastern Kunlun Mountains. Science China (Series D) (中国科学:地球科学), **31**(3): 243—249 (in Chinese with English abstract).

Wang Yong-biao (王永标), Zhang Ke-xin (张克信), 1998. The discovery of Early Permian reefs in the eastern Kunlun Mountains and its significance. Chinese Science Bulletin (科学通报), **43**(6): 630—632 (in Chinese with English abstract).

Wu Ya-sheng (吴亚生), 1989. The Early Permian organic reefs, Longlin County, Guangxi Province. Geological Review (地质论评), **35**(1): 52—59 (in Chinese with English abstract).

Wu Y S, 1991. Organisms and Communities of Permian Reef of Xiangbo, China. Beijing: International Academic Publishers. 1—192.

Wu Ya-sheng (吴亚生), 1992. Fabric facies and fabric rock types of reefs in China. Science in China: Series B (中国科学 B 辑), **35**: 1503—1511 (in Chinese with English abstract).

Wu Ya-sheng (吴亚生), 1994. Paleoecology of Permian reef in Guangxi and Guizhou. Oil & Gas Geology(石油与天然气地质), **15**(3): 201—207 (in Chinese with English abstract).

Wu Ya-sheng (吴亚生), 1997. Classification of reef rocks. Geological Reviews (地质论评), **43**(3): 281—289 (in Chinese with English abstract).

Wu Ya-sheng (吴亚生), 1998. Permian reef development model in Lengwu, Tonglu, Zhejiang. Marine Origin Petroleum Geology (海相油气地质), **3**(2): 11—15 (in Chinese with English abstract).

Wu Y S, 2017. A latest Permian non-reef calcisponge fauna from Laibin, Guangxi, southern China and its significance. Journal of Palaeogeography, **6**(1): 60—68.

Wu Ya-sheng (吴亚生), Fan Jia-song (范嘉松), 2000. Paleoecology of calcisponges (inozoans, thalamid sponges, sclerosponges). Acta Paleontologica Sinica (古生物学报), **39**(4): 544—547 (in Chinese with English abstract).

Wu Ya-sheng (吴亚生), Fan Jia-song (范嘉松), 2002. Permian-Triassis history of reefal thalamid sponges: Evolution and extinction. Acta Paleontologica Sinica (古生物学报), **41**(2): 163—177 (in Chinese with English abstract).

Wu Ya-sheng (吴亚生), Fan Jia-song (范嘉松), Jiang Hong-xia (姜红霞), 2007. The extinction patterns of reef ecosystem at the end of Permian. Chinese Science Bulletin (科学通报), **52**(2): 207—214 (in Chinese).

Wu Ya-sheng (吴亚生), Jiang Hong-xia (姜红霞), Liu Li-jing (刘丽静), Zhao Rui (赵　锐), 2015. Revised sedimentary facies and lithostratigraphy of the Upper Permian Changxing Formation at Panlongdong, Xuanhan, Sichuan Province. Acta Geologica Sinica (地质学报), **89**(2): 412—424 (in Chinese with English abstract).

Wu Y S, Yu G L, Li R H, Song L R, Jiang H X, Riding R, Liu L J, Zhao R, 2014. Cyanobacterial fossils from 252 Ma old microbialites and their environmental significance. Scientific Reports, **4**(1): 3820.

Xu Gui-rong (徐桂荣), Luo Xin-min (罗新民), Huang Shi-ji (黄世骥), Wang Yong-biao (王永标), Lin Qi-xiang (林启祥), Chen Lin-zhou (陈林洲), Xiao Shi-yu (肖诗宇), 1996. On original conditions of Late Permian carbonate building-up in middle Yangtze River area. Acta Geoscientia Sinica (地球学报), **17**: 120—129.

Yang Wan-rong (杨万容), Yang Chang-geng (杨长庚), Li Xun (李迅), Zhang Guo-fang (张国方), 1995. The sedimentary and diagenesis environments of Permian sponge mound in Tonglu, Zhejiang. Journal of Stratigraphy (地层学杂志), **19**(3): 191—198 (in Chinese with English abstract).

Zhang Ting-shan (张廷山), Hou Fang-hao (侯方浩), Fang Shao-xian (方少仙), 1992. Introduction and comment of comparative taphonomy and taphofacies. Acta Sedimentologica Sinica (沉积学报), **10**(1): 36—46(in Chinese with English abstract).

Zhang Wei (张　维), 1985. New findings of Sphinctozoa from late Permian reefs in Lichuan, W. Hubei, China. Scientia Geologica Sinica (地质科学), (4): 364—374, 407—410 (in Chinese with English abstract).

Zhang Wei (张　维), 1987. A new genus *Neoguadalupia* with notes on connections of interrelated genera in Sebargasiidae, Sphinctozoa. Scientia Geologica Sinica (地质科学), (3): 231—238, 300 (in Chinese with English abstract).

Zhang Wei (张　维), Zhang Xiao-lin (张孝林), 1992. Characteristics, distribution and paleoecology of Permian calcisponges in South China. Scientia Geologica Sinica (地质科学), (1): 10—19 (in Chinese with English abstract).

TAPHONOMIC CHARACTERISTICS OF A PERMIAN CALCISPONGE REEF IN LICHUAN, HUBEI PROVINCE AND ITS PALEOENVIRONMENTAL SIGNIFICANCE

LI Yang[1,2,3], WU Ya-sheng[1,2,3] and JIANG Hong-xia[4]

1) *Key Laboratory of Petroleum Research, CAS; Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing* 100029, *China*;

2) *Institutions of Earth Science, Chinese Academy of Sciences, Beijing* 100029, *China*;

3) *University of Chinese Academy of Sciences, Beijing* 100049, *China*;

4) *Hebei GEO University, Shijiazhuang* 050031, *China*

Key words Reef, calcisponge, taphonomy, *Archaeolithoporella* encrustation, micrite content, Permian, Lichuan

Abstract

The calcisponge reefs in Lichuan, western Hubei Province is analyzed for reef-building organism composition, preservation status of calcisponges, size of calcisponges, contents of *Archaeolithoporella* encrustations and micrites. A

total of 17 genera of calcisponges and one genus of hydrozoan are found in the reef-core facies (Layers 8-10). The 8th to 9th layers are mainly composed of toppled sponges and have little content of *Archaeolithoporella* encrustations, while the 10th layer has more contents of erect calcisponges and *Archaeolithoporella* encrustations. The average diameters of the calcisponges in the 8th to 10th layers increase a little, but the content of micrites gradually declines. Thus we infer that the reef-building organisms in the 8th to 9th layers formed under less strong hydrodynamic conditions, and were mostly toppled. For the 10th layer, the hydrodynamic conditions are stronger, but, the *Archaeolithoporella* encrustations enhanced the anti-wave capability of the reef-building organisms, and they were preserved in erect positions.