doi:10.3799/dqkx.2015.029

黔南地区早二叠世大幅度冰川性海平面下降的沉积学新证据

严雅娟,颜佳新*,武思琴

中国地质大学生物地质与环境地质国家重点实验室,湖北武汉 430074

摘要: 众所周知,石炭纪－二叠纪期间冈瓦纳大陆冰盖的推进和消融在低纬度地区形成了许多高频海平面升降变化和广泛分布的旋回沉积.最新研究表明,石炭纪－二叠纪冰室气候时期的大陆冰盖是由一系列不连续的冰期组成.因此石炭纪－二叠纪期间既存在高频低幅的海平面变化,也发育多次大幅度海平面下降.前者在华南地区已有研究证实,后者仍需要深入研究.描述了贵州龙吟和紫云扁平剖面早二叠世碳酸盐岩地层中古岩溶特征,包括垮塌角砾岩及相关沉积构造,分别对应早二叠世两次冰期导致的显著海平面下降,对深入了解华南地区早二叠世古地理演化具有重要意义.

关键词: 黔南;早二叠世;砾状灰岩;海平面下降;冰期;沉积学.

中图分类号: P588.245　　**文章编号:** 1000－2383(2015)02－0372－09　　**收稿日期:** 2014－11－18

Sedimentary Records of Early Permian Major Glacial Sea-Level Falls in Southern Guizhou Province, China

Yan Yajuan, Yan Jiaxin*, Wu Siqin

State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences, Wuhan 430074, *China*

Abstract: As is well-known, the waxing and waning of the Gondwanan ice sheet contributed to high-frequency glacioeustatic sea level fluctuations and widely distributed cyclothems in the low-latitudes during the Carboniferous-Permian Period. Recent investigations suggest that the Permo-Carboniferous Ice Age is composed of a series of distinct episodes of glaciation and interglaciation. It has been confirmed the glacioeustatic sea-level changes controlled the high frequency and low amplitude sea-level changes in South China during the Carboniferous-Permian Period, but the high amplitude sea level falls still needs further exploration. In this paper we describe the characteristics of paleokarst in the Early Permian in Longyin and Bianping sections at south Guizhou, including solution-collapse breccias and related sedimentary structures, which correlate in time with the two major sea level falls in the Early Permian. This study could facilitate our understanding on the evolution of the Early Permian Palaeogeography of South China.

Key words: South Guizhou; Early Permian; brecciated limestone; sea-level fall; glaciation; sedimentology.

石炭纪－二叠纪冈瓦纳大陆冰盖的发育,使得全球古气候从泥盆纪的"温室地球"进入了石炭纪－二叠纪的"冰室地球"(Veevers and Powell,1987;Crowley and Baum,1992;Isbell *et al.*,2003;Fielding *et al.*,2008a;Frank *et al.*,2008;Heckel,2008).冈瓦纳冰川的扩张和消融导致了全球石炭纪－二叠纪高频率、大振幅的冰川型海平面变化(Heckel,1986;Ross and Ross,1987,1988;Soreghan and Giles,1999;Haq and Schutter,2008;Rygel *et al.*,2008).冰川的明显扩张可以导致全球大规模的海

基金项目:国家自然科学基金项目(Nos.41472087,41072078);国家重点基础研究发展计划"973"项目(No.2011CB8088004).
作者简介:严雅娟(1986－),女,博士研究生,研究方向为碳酸盐岩沉积地质学.E-mail:yajuan_yan@163.com
* **通讯作者:**颜佳新,E-mail:jaxy2008@163.com

引用格式:严雅娟,颜佳新,武思琴,2015.黔南地区早二叠世大幅度冰川性海平面下降的沉积学新证据.地球科学——中国地质大学学报,40(2):372－380.

退,在低纬度碳酸盐台地上表现为暴露或沉积间断,如俄罗斯台地晚古生代地层中的不整合界面和暴露事件(Vennin *et al*.,2002;Vennin,2007);冰川的快速消融可以导致全球性的海侵,如北美中大陆石炭纪—二叠纪地层中的旋回、不整合面和沉积相突变等(Ritter,1995;Olszewski and Patzkowsky,2003).冰川的推进和消融导致了全球性的高频海平面变动和环境变化,在中低纬度地区浅水地台上形成了广泛的旋回性地层记录和生物群的更替,成为同期地层层序识别和对比的基础(Chen *et al*.,1998;Heckel,1999,2008;Kabanov *et al*.,2006;Wang *et al*.,2013).

地层记录、大气二氧化碳含量变化、古水温变化等地球化学数据分析表明(Montañez *et al*.,2007;Frank *et al*.,2008;Grossman *et al*.,2008;Birgenheier *et al*.,2010;Buggisch *et al*.,2011),冈瓦纳冰川发育规模在早二叠世达到顶峰(Fielding *et al*.,2008a,2008b;Isbell *et al*.,2003,2012).此外,冈瓦纳大陆各地冰成岩地层记录的对比还表明,冈瓦纳冰川的发育历史并非一个简单的持续过程,而是经历了一个多阶段的发展过程,由石炭纪 4 个(C_1～C_4)和二叠纪 4 个(P_1～P_4)不连续的冰期组成(Fielding *et al*.,2008a,2008b).随着冈瓦纳大陆冰盖冰量的变化,全球海平面变化的幅度也存在显著差异,如石炭世杜内阶早期一般为 20～25 m,二叠纪早期可达 100～120 m,之后至中二叠世幅度又逐渐变小(Haq and Schutter,2008;Rygel *et al*.,2008).

石炭纪—二叠纪期间的冰川性海平面变化在华南地区碳酸盐台地内部也有清楚的表现,如在黔南地区晚石炭世碳酸盐岩地层中、通过稳定氧碳同位素旋回变化所识别出的 4 级海平面变化(刘本培等,1994;李儒峰等,1997).最近对贵州紫云宗地剖面晚石炭世—早二叠世地层序列的研究清楚地展示了可与北美中大陆旋回层对比的冰川性海平面变化,以及相关的地层暴露标志(Ueno *et al*.,2012;Wang *et al*.,2013).不过这些旋回主要是米级旋回,对应海平面高位期间、可上超至台地内部的高频低幅海平面振动.由于主冰期的发育,早二叠世阿瑟尔阶地层旋回厚度明显增加(Ueno *et al*.,2012).一般认为华南地区二叠纪早期(梁山期)的碎屑含煤地层及之下的不整合面,大体对应全球石炭纪—二叠纪主冰期的大海退,但是由于缺乏系统研究,它们与上述 8 个冰期的确切对比,以及相关的沉积特征仍不清楚.黔南地区发育较为连续的石炭纪—二叠纪地层记录是解读该段海平面变化历史的最佳地区.本文选取贵州紫云扁平剖面和普安龙吟剖面,在前人年代地层研究基础上,侧重描述早二叠世碳酸盐岩地层中(与 P_1、P_2 小冰期相关)大幅度海平面下降形成的沉积学证据.

1　古地理背景和地层沉积序列

黔南地区石炭纪主要为碳酸盐台地沉积.二叠

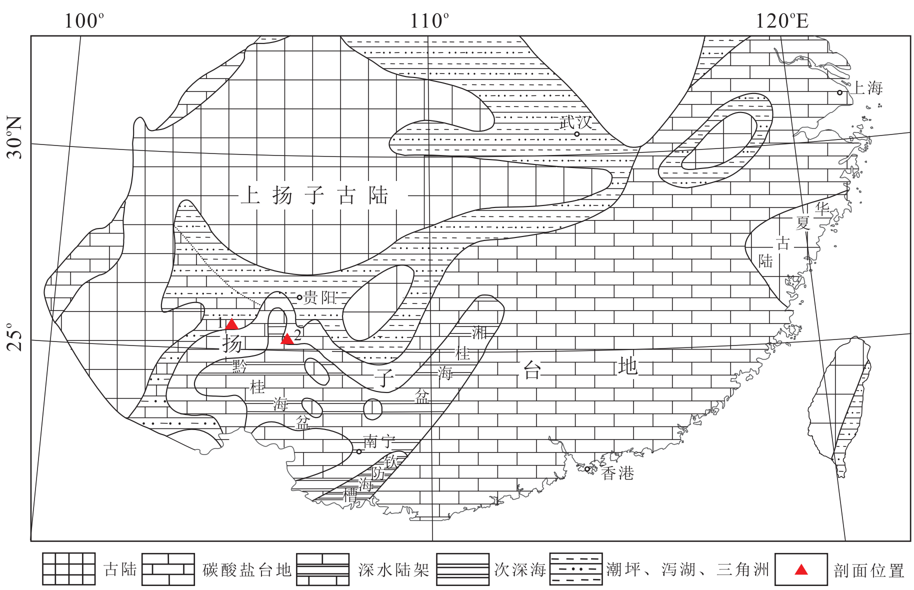

图 1　华南地区早二叠世岩相古地理图

Fig.1　Early Permian Palaeogeography of South China and section location

据刘宝珺和许效松(1994)修改.1.普安龙吟剖面;2.紫云扁平剖面

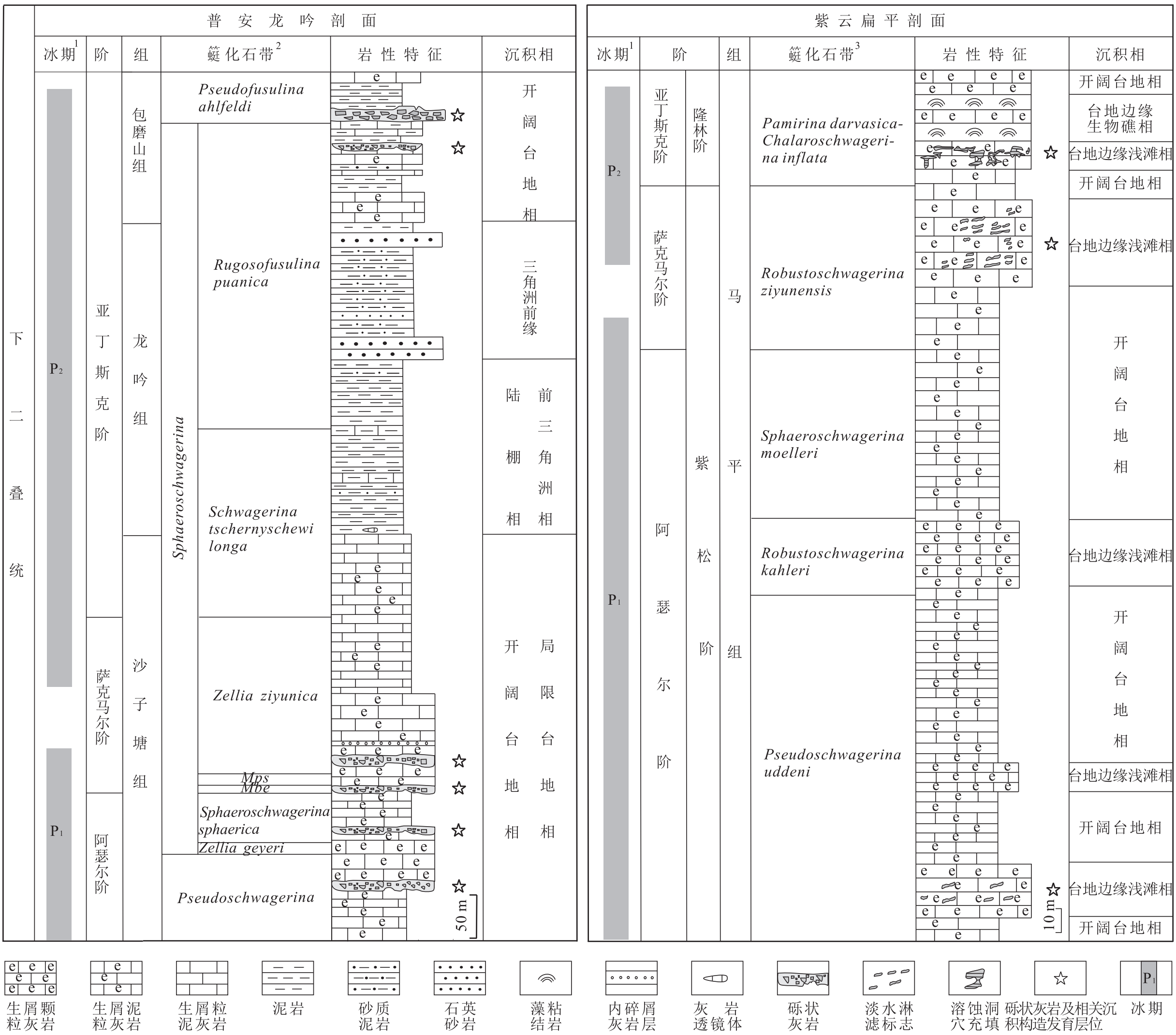

图 2 普安龙吟剖面和紫云扁平剖面生物地层、岩性特征及沉积相

Fig.2 The biostratigraphy, lithologic features and sedimentary facies of Puan Longyin section and Ziyun Bianping section

1.引自 Fielding *et al*.(2008a,2008b);2.引自夏国英等(1994);3.引自肖伟民等(1986);*Mps*. *Mccloudia pseudocontracta*;*Mbe*. *Mccloudia bella*

纪早期的大规模海退使得碳酸盐台地沉积范围向南退缩,在扬子古陆南部边缘石炭纪碳酸盐台地上出现了较为广泛的细粒陆源碎屑沉积,再向南逐渐过渡为碳酸盐台地沉积,直至黔桂盆地.本文研究的普安龙吟剖面正好位于碳酸盐台地与陆源碎屑沉积分布区的交界处;而紫云扁平剖面位于碳酸盐台地边缘高能沉积相带边缘(刘宝珺和许效松,1994),是识别海平面下降的最佳地点(图 1).两剖面均具有很好的生物地层学研究基础(图 2)(吴望始等,1979;肖伟民等,1986;张正华等,1988;丁蕴杰等,1992;夏国英,1995).

普安龙吟剖面位于贵州省普安县龙吟乡.下部沙子塘组出露于沙子塘村至排楼村公路旁,之上的龙吟组、包磨山组和梁山组出露于龙吟村至大岩的简易公路上.沙子塘组地层主要由开阔碳酸盐台地中薄层泥晶灰岩和中厚层生物碎屑灰岩构成,夹少量局限碳酸盐台地纹层状藻灰岩、白云质灰岩.中部发育一层厚约 40 cm 的风暴成因内碎屑灰岩.下部和中部开阔碳酸盐台地相灰岩中发育 4 层"砾状灰岩"(图 2).龙吟组以泥岩为主,夹少量灰岩透镜体,上部出现中细粒石英砂岩,属浅海陆棚-三角洲相沉积.包磨山组下部为泥晶灰岩及生物碎屑灰岩,上部为泥岩和细粒碎屑岩,沉积环境由浅水碳酸盐台地转变到三角洲沉积(图 2).生物碎屑灰岩中发育两层"砾状灰岩".

紫云扁平剖面位于贵州省紫云县猴场镇扁平寨东侧山坡上,为一套连续的浅灰色中厚-厚层生物碎屑灰岩.沉积相包括开阔台地相、台地边缘浅滩相以及生物礁相.开阔台地相岩性主要为生物碎屑泥粒岩和粒泥

岩,台地边缘浅滩相主要由鏟生物碎屑颗粒岩组成,紫松阶下部开阔台地相占优势,上部以浅滩相为主,并发育以生物碎屑颗粒为主的大型交错层理,呈现向上变浅的趋势.上部淡水淋滤和暴露侵蚀构造明显.隆林阶地层中发育薄层藻粘结岩(生物礁相)(图 2).

2　“砾状灰岩”沉积学特征

笔者经详细的野外和室内镜下观察发现,前人描述的“砾状灰岩”中的“灰岩砾石”可能包括多种成因,如断层角砾、风暴成因的内碎屑砾石和与古岩溶有关的垮塌成因砾石,但是主要还是后者,其也是本文研究的重点.现将其沉积学特点及相关沉积构造简述如下:

2.1　粗砾角砾状灰岩

此类型角砾状灰岩发育在龙吟剖面包磨山组下部,角砾岩层厚达 9 m.角砾多呈棱角状,也可见次棱角和次圆状;大小不等,最大直径达 60 cm,小者 1～3 cm;杂乱堆积,也有呈大致顺层分布;角砾成分相对单一,以生物碎屑灰岩和泥晶灰岩为主,部分泥晶化.充填在角砾之间的沉积物主要为土黄色含泥质、粉砂质的灰泥岩(图 3a),局部为镶嵌状粗粒方解石(图 3b).角砾状灰岩与围岩之间为侵蚀面接触.

2.2　细砾角砾状灰岩

这类角砾状灰岩分布在沙子塘组中部的溶蚀洞穴内,大量灰岩角砾分选较差,多呈棱角状,粒径较小从 0.1～1.0 cm 不等,密级堆积在浅土黄色泥质基质当中(图 3c,3d).角砾以生物碎屑灰岩为主,也有少量砾径 1 cm左右的黑色硅质角砾(图 3d).与上述粗砾角砾状灰岩相比,其地层厚度和延伸规模明显较小(图 3d).

2.3　灰黑色砾块状灰岩

此类型灰岩发育在龙吟剖面沙子塘组下部和包磨山组下部,砾石呈灰黑色,边界清楚,圆度相对较好,排列无定向性,砾径 2～10 cm 为主,最大者可达 50 cm,岩性为生物碎屑泥粒岩,以 *Tubiphytes* 和鏟类为主,砾块之间基质为浅灰色泥晶灰岩,可见水平层理,局部基质受差异成岩压实的影响,层理呈现绕砾石弯曲的特征,体现了早期成岩作用过程中同沉积溶蚀作用的特征(图 3e).局部可见燧石角砾.底界为清晰的不整合面,侧向延伸相对较稳定.

2.4　细砾砾屑状灰岩

该类型灰岩主要分布于侵蚀面之上(图 3f).龙吟剖面包磨山组生物碎屑粒泥岩之上发育侵蚀面,以不规则形态延伸,上下波动幅度在 2 cm 范围内.

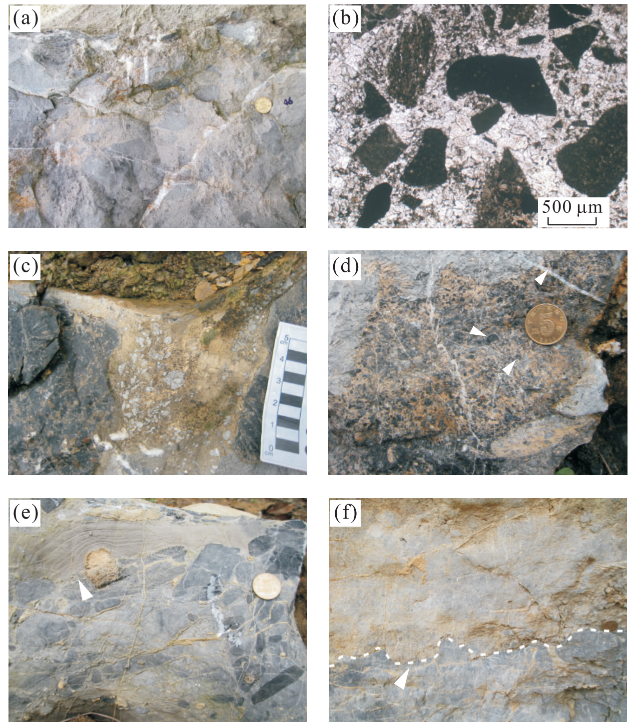

图 3　“砾状灰岩”类型及特征

Fig.3　The types and characteristics of brecciated limestone

a.粗砾角砾状灰岩,角砾呈棱角状,基质为含粉砂质的泥晶;b.角砾部分泥晶化,角砾之间为镶嵌粒状方解石,单偏光;c.角砾状灰岩发育于在溶蚀早期硅质结核的溶洞内,土黄色泥质基质;d.角砾状灰岩中含硅质角砾(箭头所指);e.灰黑色砾块状灰岩,角砾有一定的磨圆,边界清晰,基质为泥晶,局部发育水平纹层(箭头所指);f.侵蚀面之上的砾屑状灰岩

侵蚀面之上含有大量的细小砾屑,砾石细小,直径一般为几毫米,局部生物碎屑丰富,砾屑之间为大量的泥晶基质.

3　“砾状灰岩”相关沉积构造特征

与上述角砾状灰岩和砾块(屑)状灰岩相伴随的,还有一系列溶蚀和沉积构造,现描述如下:

3.1　溶蚀洞穴充填构造

扁平剖面隆林阶底部可见大量溶蚀洞穴,洞穴形态不规则,大小不一,小的洞穴只有十几厘米宽,笔者观察到的最大一个洞穴长度达到 108 cm,高度 70 cm.大多数溶洞近乎垂直层面延伸.洞穴沉积物中紫红色含粘土物质与灰白色岩溶残余物质交替出现,水平层理发育(相对于原始层面)(图 4a);在相对较为狭窄的缝隙中,常可以见到淡紫红色方解石平行洞壁生长,形成环带状(图 4b,4c),整体构成网状(图 4c).有些裂隙充填物全部由粗晶方解石构成,

图4 溶蚀洞穴及沉积物

Fig.4 The solution caves and sediments

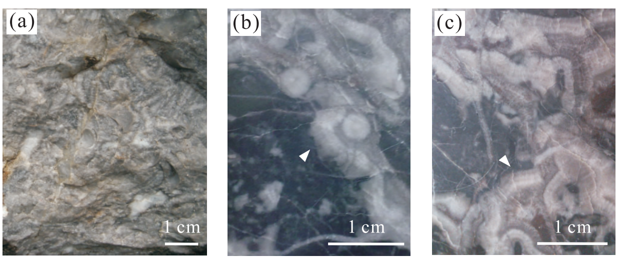

图5 溶蚀孔洞的栉壳构造

Fig.5 The pectinate structures in solution vugs

a.在生物碎屑颗粒岩中发育的栉壳构造;b,c.多世代等厚栉壳状方解石沿不规则洞壁生长(箭头所指),孔洞中心为粒状方解石,光面

呈现厚层栉壳状结构(图4b).

3.2 栉状构造

干净明亮方解石组成的栉状构造较为普遍,常以孔洞形式出现,尤其是在扁平剖面高能沉积相带生物碎屑颗粒岩和泥粒灰岩层中.溶蚀孔洞管径一般较小、直径1～10 cm,孔洞洞壁从光滑平坦状到光滑波浪状.沿洞壁发育多世代等厚栉状排列方解石,向孔洞中央转变为粗晶、镶嵌状(图5).

3.3 渗滤构造

普安龙吟剖面沙子塘中部地层砾状灰岩中发育的渗滤砂充填,在野外露头上也十分明显,主要由与围岩成分相同的砂屑和粉屑(图6d)组成,渗滤砂中有部分溶蚀残余的生物碎屑,可见保存较好的鏟化石,其中片状内碎屑呈定向排列,与层理平行.在渗滤砂沉积的上部,明显发育一期二氧化硅物质的沉积(图6e).

4 "砾状灰岩"等成因解释

综合上述"砾状灰岩"及相伴出现的沉积构造的沉积特征,其成因应该为与古岩溶作用相关的溶蚀和沉积作用.

4.1 "角砾状灰岩"与"砾块(屑)状灰岩"

虽然多种地质作用过程均可以形成类似角砾状灰岩,但是本次描述的砾石成分基本上与围岩一致.粗砾角砾状灰岩中,砾石基本上是大小混杂的,分选和定向性差.但是在细砾角砾状灰岩中笔者有时可以判断出层理,而且层理方向与围岩一致.结合相关沉积构造,这些角砾状灰岩应该为岩溶垮塌成因.相比较而言,较细的角砾状灰岩往往分布在较为狭窄的空间,可能为受地下流水改造的岩溶角砾岩.

灰黑色砾块状灰岩和砾屑状灰岩的底面为清楚的侵蚀面,侧向延伸较稳定,内部缺乏溶蚀淋滤构造,整体沉积成因特征较为清楚,因此砾块状灰岩是由海侵过程中波浪和水流对前期起伏不平地形和砾石的改造形成的,砾屑状灰岩中的砾石有可能是海侵过程中形成的滞留砾石.由此可见上述角砾状和块状两种砾状灰岩形成环境明显不同.

4.2 岩溶垮塌成因角砾和渗滤砂等孔洞充填物

详细的野外露头观察和素描无疑是古岩溶沉积及相关沉积构造成因解释的基础.在龙吟剖面沙子塘组中下部一处露头上,不仅发育与岩溶相关的细砾角砾沉积,而且发育溶蚀孔洞和渗滤砂沉积,为确定不同期次沉积物或者构造形成时间提供了重要依据(图6a).笔者在精细素描和观察的基础上(图6b),可以明显识别出溶蚀及渗滤砂充填在形成时间上晚于土黄色细砾角砾状灰岩(图6c).

4.3 成因模式

综合上述古岩溶特征观察和分析,结合早二叠世期间冰川性海平面升降演化历史,上述沉积构造构成了一个海平面先下降再上升的完整旋回.石炭纪晚期黔南地区处于碳酸盐浅水沉积环境(图7a),二叠纪开始时 P_1 冰期的发展使得海平面迅速下降(Shi and Chen, 2006),黔南碳酸盐台地暴露于地表,地表岩溶作用增强,逐步形成了原地的垮塌岩溶角砾岩层.同时,在地下(层内)则发育了包括大气渗流带和潜流带的岩溶/沉积作用,产生了渗滤砂、溶蚀的溶孔和洞穴,潜流带部分可发育方解石和等厚环边方解石沉淀(图7b).随着海平面的进一步下降,地下水水面也开始下降,早期的溶蚀孔洞进一步扩大,溶洞顶或溶洞壁的垮塌可使溶洞被碎屑部分或完全充填.新形成的溶孔可以切割早期已经大体固结的岩溶角砾(图7c).之后,随着大陆冰盖的消融,海水将逐渐淹没碳酸盐台地,并对各类岩溶地貌

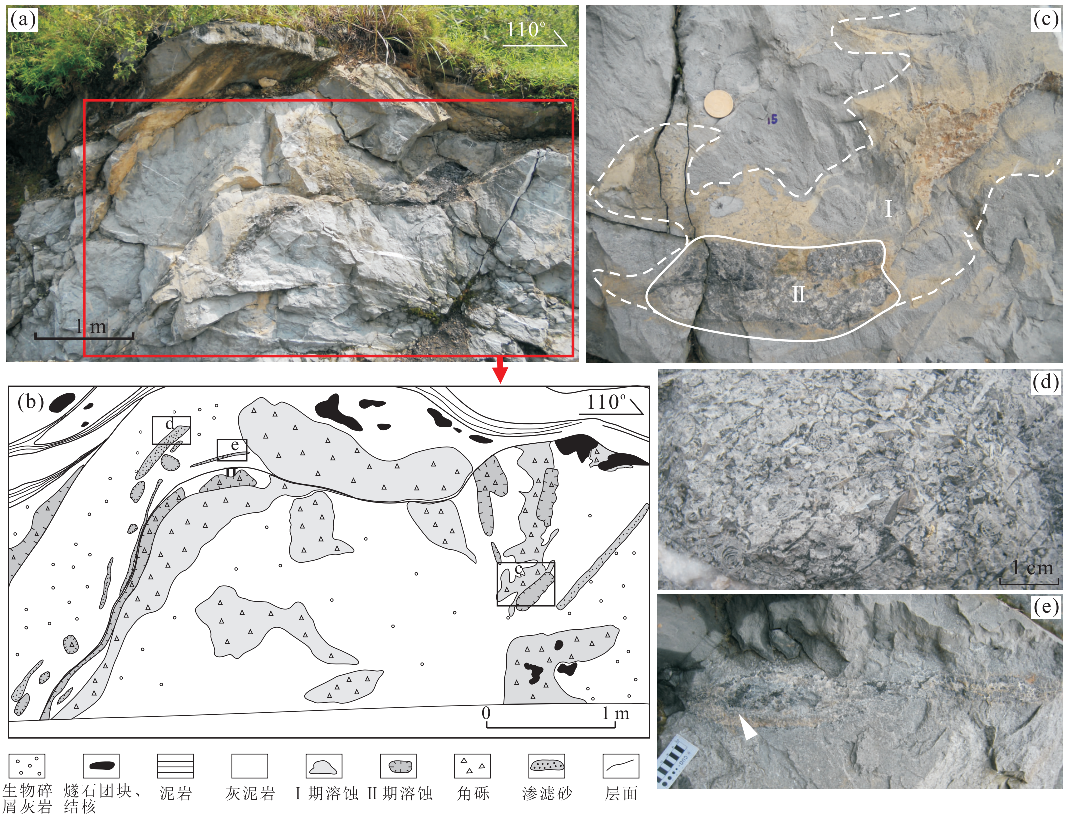

图 6　普安龙吟剖面细砾角砾状灰岩及渗滤砂分布特征

Fig.6　Brecciated limestone and filtrated sands distribution in Puan Longying section

a.普安龙吟剖面细砾角砾及溶蚀孔洞等古岩溶特征发育层位的野外露头;b.野外露头的精细素描;c.沉积时间不同的古岩溶沉积,Ⅰ为土黄色细砾角砾岩,Ⅱ为渗滤砂;d.砂屑和粉屑组成的渗滤砂;e.渗滤砂中的二氧化硅沉积物(箭头所指)

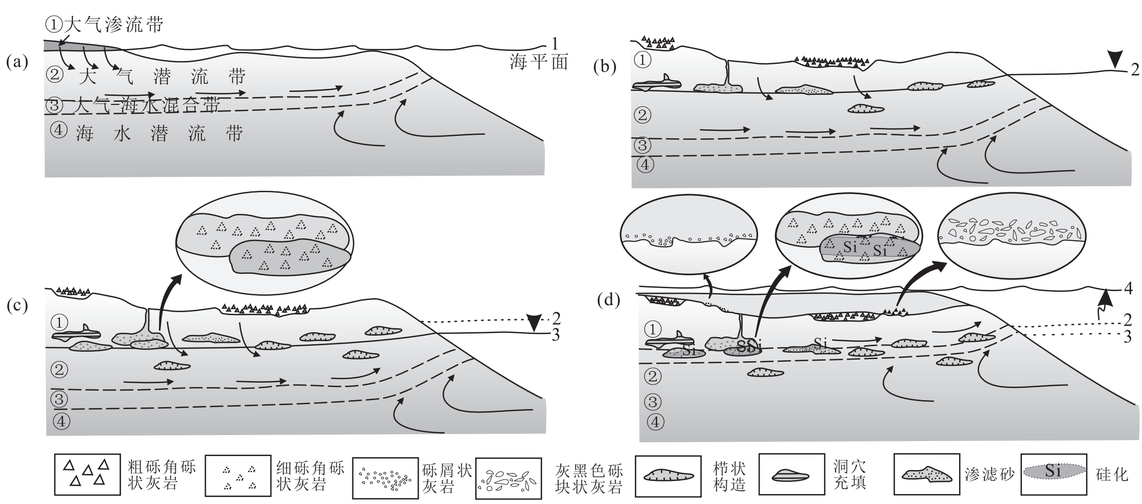

图 7　黔南地区“砾状灰岩”及相关沉积构造成因模式

Fig.7　Schematic diagram illustrating the formation model of the brecciated limestone and related sedimentary structures in south Guizhou

1.黔南碳酸盐台地浅水沉积环境;2.海平面下降,地表形成了垮塌岩溶角砾岩,地下大气渗流带和潜流带产生了渗滤砂,溶蚀的孔洞和洞穴;3.海平面进一步下降,溶蚀孔洞扩大,新形成的孔洞切割早期孔洞;4.海平面上升,形成海侵角砾岩,混合带发生混合水硅化作用

进行改造,形成海侵“砾状灰岩”;地下水水位的提升将使得原先处于潜流带的成岩环境转变为混合水成岩环境,发生混合水硅化作用(图 7d).至此冰川推进、海平面下降导致的岩溶孔隙基本充填完成.海水

再一次下降的时候，将发育新一期的暴露溶蚀构造.

根据"砾状灰岩"及相关沉积构造的古岩溶特征识别，笔者在普安龙吟剖面和紫松扁平剖面阿瑟尔期—萨克马尔早期和萨克马尔晚期—亚丁斯克早期地层识别出两期明显的海平面下降、碳酸盐台地暴露(图 2).地层学和沉积学资料表明，早二叠世中国华南区域构造活动相对稳定，因此本区大幅度海平面下降应与冈瓦纳大陆冰盖增生有关. Fielding *et al*.(2008a，2008b)认为晚古生代冰期在早二叠世有 P_1(阿瑟尔期—萨克马尔早期)和 P_2(萨克马尔晚期—亚丁斯克早期)两个不连续的冰期.本研究描述的砾状灰岩及相关沉积构造在形成时间上正好与此对应，代表了冰川型海平面下降在华南地区的沉积学响应.另外，与其他报道的古岩溶和风化壳相比，本研究剖面上的古土壤层和钙结壳并不发育，可能为快速海平面升降所致，值得今后研究注意.

5 结论

(1)黔南地区普安龙吟剖面和紫云扁平剖面早二叠世发育的"砾状灰岩"及相关沉积构造成因与古岩溶有关，包括岩溶垮塌沉积、岩溶洞穴充填、栉壳构造和淡水淋滤构造.

(2)受相对海平面下降影响，黔南浅水碳酸盐沉积发生了暴露、溶蚀及淡水淋滤.在地表受风化剥蚀作用及岩溶作用的强烈改造，岩层崩塌形成岩溶角砾岩，在大气成岩作用带受淡水渗流和潜流作用及之后海侵改造作用的影响，形成溶蚀孔洞、洞穴及洞穴堆积物等.

(3)本区暴露事件主要发生在阿瑟尔期—萨克马尔早期和萨克马尔晚期—亚丁斯克早期两个时期，对应全球早二叠世两个冰期(P_1 和 P_2)，证实了在早二叠世华南地区存在冰川型大幅度的海平面下降.

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