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塔北西部一间房组碳酸盐岩礁滩体同生期暴露溶蚀作用模式

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提要: 在详细的钻井资料和岩心的宏观及微观特征研究的基础上, 通过对塔北隆起西部奥陶系中统一间房组礁滩体沉积相特征及展布规律的分析, 结合礁滩体储层同生期溶蚀作用特征研究, 按照古沉积地貌单元结合岩相的方法建立了一间房组礁滩体同生期溶蚀作用模式。研究认为一间房组开阔台地相包括台内滩、滩间海和台内点礁 3 个亚相, 沉积相平面分布稳定; 一间房组的同生期暴露溶蚀作用明显, 普遍反映出滩体的间歇性暴露的特征: 生物钻孔和溶蚀孔洞内充填礁滩体暴露形成的古土壤泥; 发育潮间带的化石碎片堆积和软体生物活动遗迹; 岩心观察和成像测井可以识别出渗流−潜流带溶蚀作用旋回。按照礁滩相沉积地貌结合岩相的模式, 将一间房组开阔台地的浅滩和点礁沉积划分出潮上长期暴露滩、潮间间歇暴露滩、潮下高能滩、瓶筐石障积礁、潮汐水道等地貌单元。

关　键　词: 塔里木盆地; 奥陶系; 一间房组; 礁滩体; 同生期溶蚀作用
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Syn−sedimentary corrosion mode of carbonate reef−banks in the middle Ordovician Yijianfang Formation within the western Tabei uplift of Tarim Basin

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Abstract: On the basis of the detailed drilling data and the core characteristics at the macro and micro level, by means of analyses

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about characteristics and distribution rules of sedimentary facies, in combination with reef−banks syn−sedimentary corrosion reservoir characteristics,and according to the ancient sedimentary geomorphic units combined with lithofacies, the authors established the syn−sedimentary corrosion model of reef−banks in the Middle Ordovician Yijianfang Formation in the western Tabei uplift of Tarim Basin. According to the results obtained, first, the open platform facies of Yijianfang Formation contain platform−interbank, interbank sea and platform−inter patch reef, and the plane distribution of facies is stable; second, Yijianfang Formation exhibits obvious characteristics of the syn−sedimentary corrosion and widely reflects the characteristics of the intermittent exposure of bank: boring pores and corrosion pores are filled with ancient mud soil formed by the exposure of reef banks, the intertidal zone fossil fragment accumulation and traces of soft−bodied organisms activities are common, the corrosion cycle from seepage to undercurrent belt can be identified by core observation and Image Logging. According to the model, the banks and patch reefs of Yijianfang Formation are classified into five geomorphic units, i.e., supralittoral long−term exposure bank, intertidal intermittent exposure bank, subtidal high−energy bank, Calathium baffles tone and tideway.

Key words: Tarim Basin; Ordovician; Yijianfang Formation; reef−banks; syn−sedimentary corrosion

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1 引 言

碳酸盐岩礁滩体不但具有良好生油环境, 也是优质的储集空间。通过几十年的勘探与开发, 塔里木奥陶系礁滩体不但已成为中国碳酸盐岩油气储量的重要区块之一, 也是国内外礁滩体相关的科学研究的重要区域[1−4]。塔北隆起区中奥陶统一间房组(O_2yj)发育大量的浅水开阔台地的礁滩体, 是塔里木盆地油气勘探的重点层系之一[5−12], 其西部地区(塔北西部地区)中奥陶统一间房组沉积相为开阔台地的浅滩和点礁, 这种环境下礁滩体会时常暴露于海平面之上, 形成海岛、砂洲、砂滩等正地貌单元, 在大气淡水淋滤下经历同生期溶蚀作用作用, 形成非常发育的溶蚀孔洞层[13−16]。本文通过对一间房组开阔台地相沉积特征、相展布研究, 结合同生期溶蚀作用特征, 按照古沉积地貌单元结合岩相的方法建立一间房组开阔台地溶蚀作用模式。本文的研究不但为塔北西部地区中奥陶统一间房组的油气勘探提供地质基础, 同时为探索礁滩体溶蚀储层研究提供另外一种思路和方法。

2 区域地质概况

塔北隆起是塔里木盆地的一个一级构造单元, 呈近东西向展布[17−20], 研究区位于隆起西部, 包括YM地区、HL地区和HD地区(图1), 其奥陶纪地层有下奥陶统蓬莱坝组(O_1p), 中下奥陶统鹰山组($O_{1-2}y$), 中奥陶

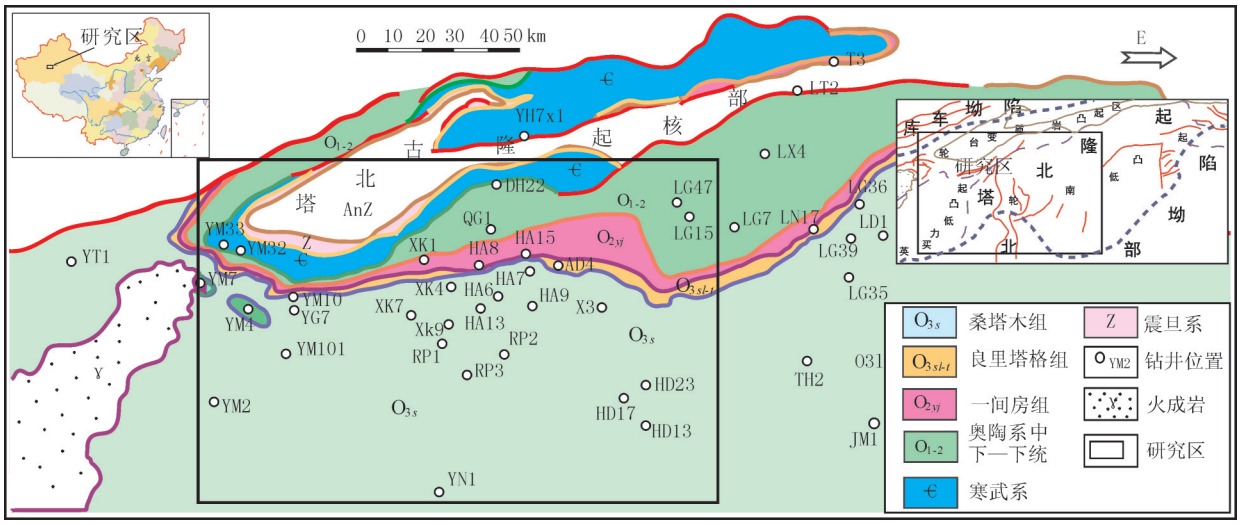

图1 塔北地区奥陶系地层分布图

Fig.1 Distribution of Ordovician carbonate in northern Tarim Basin

统一间房组(O_2yj), 上奥陶统吐木休克组(O_3t)、良里塔格组(O_3l)和桑塔木组(O_3s)[8, 21, 22]。从区域奥陶系分布情况看, 北部区域遭到强烈剥蚀, 南部地区保存较全。中奥陶统一间房组岩性稳定, 主要为亮晶鲕粒灰岩、亮晶砂屑灰岩、亮晶砂砾屑灰岩、塌积角砾岩、瓶筐石生物灰岩、藻粘结岩等。由于其与下伏鹰山组的分层界线较难准确划定, 因此厚度方面有一定的差异, 在HD23井区和YM2井区一间房组稍厚, 有120~160 m, 而在H6区块相对较薄, 一般在110 m以内。

研究认为塔北隆起西部一间房组沉积为开阔台地相[8, 22−24], 此时水深几米~数十米, 沉积物从砾屑到灰泥。海水循环好, 盐度正常; 生物种类多, 丰度高, 以正常盐度生物为主, 多见棘皮、腕足、海绵、苔藓虫、三叶虫、托盘类及藻类, 同时见少量广盐度生物, 如瓣鳃、介形虫。根据研究区内钻井岩心的精细观察描述, 结合镜下薄片微观特征, 综合地震、测井资料分析及区域沉积格局研究, 认为塔北隆起西部一间房组开阔台地相包括台内滩、滩间海和台内点礁3个亚相(图2)。

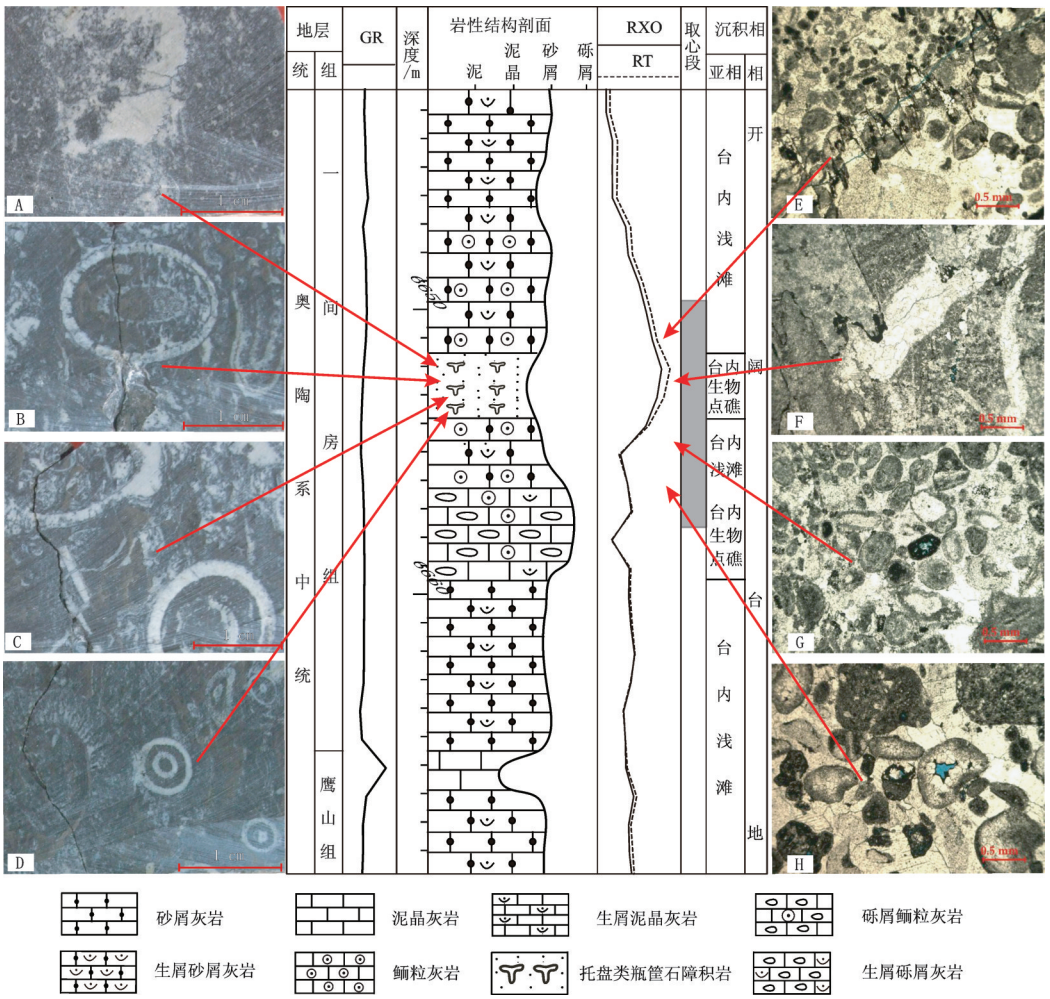

图2 H601−4井奥陶系一间房—鹰山组开阔台地台内浅滩、点礁取心段沉积相精细描述图

A~D—岩心照片; E~H—铸体薄片; A—灰色生屑砂屑灰岩, 粒内溶孔发育; B~D—瓶筐石障积岩; E—亮晶棘屑鲕粒灰岩, 黑色为溶孔; F—藻凝块石灰岩; G—亮晶表鲕粒灰岩, 黑色为溶孔; H—亮晶砂屑灰岩, 粒内溶孔

Fig.2 Fine description of Ordovician platform−interbank, interbank sea and platform−inter patch reef sediments in the H601−4 Well cores

A−D−Photograph of cores; E~H−Casting thin sections; A−Sand−clastic limestone, with well developed intragranular dissolution pores; B−D−Receptaculites calathium bafflestone; E−Sparry calcite echinoderm debris oolitic limestone, black color indicating dissolution pore; F−Algae grumose limestone; G−Sparry calcite surface oolitic limestone, black color indicating dissolution pore; H−Parry calcites and−clastic limestone, with well developed intragranular dissolution pores

3 一间房组礁滩体暴露溶蚀作用特征

同生期溶蚀作用石油界普遍称之为同生期岩溶, 也将其称沉积(期) 岩溶(depositional karst)[3, 25, 26], 主要发生于同生(或者准同生)大气成岩环境中。受次级沉积旋回和海平面升降变化的控制, 颗粒滩、生物礁等浅水碳酸盐沉积体, 尤其是在海退和向上变浅的沉积序列中, 伴随海平面暂时性相对下降, 时而出露海面或处于淡水透镜体内[14, 27, 28], 受大气淡水淋溶作用的影响, 暴露滩体内部多形成大小不一、形态多样的各种孔隙。

同生期溶蚀作用标志主要有溶孔、粒间充填物、胶结方解石等[3, 25, 26, 29−33], 其中粒间充填物渗流粉砂常见[3]。据岩心观察和铸体薄片显示, 研究区同生期溶蚀作用形成的粒内溶孔和粒内微孔隙、铸模孔、平底晶洞、示底构造及孔洞充填渗流粉砂大量发育, 悬垂型、新月型方解石胶结物比较常见(图3−A、B)。如图3−A, H9井, 6623.6 m砂屑灰岩中, 粒内溶孔发育, 为早成岩大气淡水溶蚀作用所致; 一间房组上部岩心中生物钻孔或溶蚀孔洞内普遍充填泥质, 或岩心被褐色泥质侵染, 褐色泥质为滩体暴露形成的古土壤泥(图3−F), 可以推测为早期滩体暴露大气水溶蚀成因。

还有一类早期滩体暴露的重要标志是大气淡水方解石胶结物。这类方解石胶结物可分为2类: 一类是如图3−C所示的颗粒灰岩中, 在第1期海底纤状环边胶结物之后形成的叶片状、马牙状和细柱状粉−细晶方解石胶结物, 另一类是如图3−D所示充填溶洞的环带方解石, 反映了其形成环境在短期暴露和浅埋藏的区域地下水作用环境中的交替变换。

本区多口井一间房组取心见大量瓶筐石化石碎片堆积, 分析认为这些瓶筐石造礁生物主要生长在滩体暴露时期滩体边缘相对静水区域。此外, 岩心观察显示一间房组内还发育有大量的生物觅食迹、生物钻孔、生物扰动构造等软体生物活动遗迹(图3−E), 此类生物活动遗迹主要发育于潮间带以亮−泥晶藻屑藻团块沉积为主的滩体中。

岩心观察和钻井成像测井也显示出, 暴露带和潜流带成岩变化的差异性。H7−1井, 6580.29 m岩心岩性为深灰色、灰色砂砾屑灰岩(图3−G), 上部黑色部位为充满沥青的粒(砾)内溶孔发育区, 为渗流−上部潜流带; 下部白色部位为胶结作用带, 孔隙均被方解石胶结物大量充填, 粒内溶孔不发育区, 为下部潜流带。

由于礁滩体暴露会造成短时间地层缺失, 因此会造成塔北地区奥陶系一间房组内部缺失个别牙形石化石带现象, 形成局部平行不整合现象。

4 暴露溶蚀礁滩发育分布特征

4.1 暴露溶蚀作用发育分布特征

同生期溶蚀作用主要受次级沉积旋回和海平面变化的控制[34, 35]。根据同生期溶蚀作用各环境中的识别标志[36−39], 认为研究区早成岩大气淡水溶蚀作用发育层位的岩性主要为亮晶砂屑灰岩、亮晶砂砾屑灰岩、生屑灰岩、含砾生屑灰岩、藻凝块灰岩、藻泥晶灰岩等, 主要沉积相类型为台内浅滩。随着这些相对高能的浅水沉积体不断向上营建、海平面的相对下降、构造抬升等各种因素的作用, 浅滩的上部会出露于海平面, 在湿润气候情况下, 形成大气淡水透镜体。而且这种暴露溶蚀作用具有明显的旋回性, 研究区多数井自下而上可识别出4个溶蚀作用旋回, 这种溶蚀作用旋回明显受沉积体和海平面变化影响, 如HA10井(图4)。

HA10井一间房组可识别出4个孔隙发育段, 自下而上为6731.0~6718.0 m、6713.5~6703.5 m、6687.0~6679.5 m、6677.5~6667.0 m, 就早成岩大气淡水溶蚀作用而言, 单个孔隙发育段在几米到几十米之间。顶部发育大套的孔隙发育段, 与后期溶蚀作用改造作用有关; 下部孔隙发育段受早成岩大气淡水溶蚀作用控制作用比较明显, 后期改造较弱。

4.2 礁滩发育分布特征

本次研究在岩心观察的基础上, 依据研究区内钻测井资料, 结合区域地震资料, 重点对中奥陶统一间房组沉积相平面展布进行分析和判断, 详细刻画了塔北西部一间房组的沉积相展布特征(图5)。

塔北地区在早中奥陶世沉积期间整体处于碳酸盐台地相区内, 斜坡−盆地相区处于草湖中部—满加尔东部地区[40−42], 因此塔北西部地区在早中奥陶世处于稳定的开阔台地沉积环境中, 沉积的地层基本等厚[8]。在鹰山组鹰一段沉积期间基本处于开阔台地环境中, 为开阔台地台内洼地夹台内滩沉

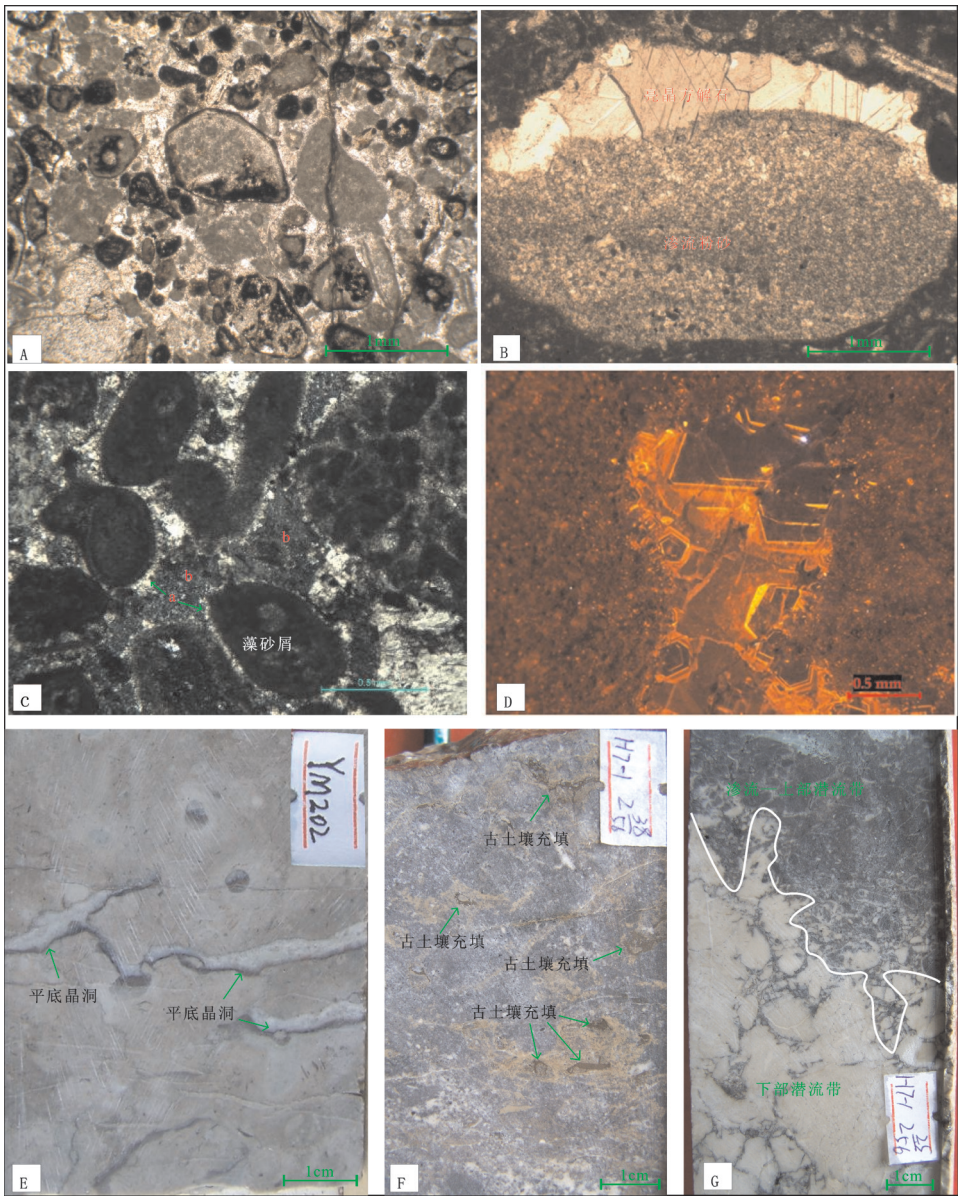

图3 塔北西部中奥陶统一间房组礁滩相同生期溶蚀作用特征

A—亮晶砂屑砾屑灰岩, 粒内溶孔、铸模孔和不规则溶孔, 见新月形方解石胶结, 镜下薄片, H9井, 6623.6 m; B—示顶底构造, 下部为渗流粉砂, 上部亮晶方解石充填, 镜下薄片, YM201井, 5855.25 m; C—亮晶藻砂屑灰岩, 两期亮晶方解石, 第1期(a)呈栉壳状分布于颗粒边缘, 第2期(b)呈半自形和他形晶粒状充填颗粒间孔隙中, 镜下薄片, XK101井, 6810.93 m; D—藻凝块石灰岩, 凝块间空腔由亮晶方解石充填, 藻凝块发暗桔红色光, 空腔中的亮晶方解石环带较发育, 有数十环, 宽窄不均, 不发光−桔红−桔黄, 荧光薄片, H601−4井, 6652.78 m; E—灰褐色泥晶藻粘结灰岩, 平底晶洞发育, 岩心照片, YM202井, 5853.74 m; F—深灰色砂屑灰岩, 溶蚀孔洞发育, 被褐色古土壤充填和侵染, 岩心照片, H7−1井, 6582 m; G—深灰色、灰色砂砾屑灰岩, 上下部同为砾屑但显示两种颜色, 上部深灰色砾屑为粒内溶孔和沥青侵染, 下部浅灰色砾屑为致密胶结, 岩心照片, H7−1井, 6580.29 m

Fig.3 Syn−sedimentary corrosion characteristics of the reef−banks in the middle Ordovician Yijianfang Formation in western Tabei

A−Sparry calcite sand−clastic calcirudite limestone, intragranular dissolution pores, mold pores and irregular dissolution pores, crescent calcite cementation observed, microscopic thin section, H9 well, 6623.6 m; B−Geopetal structure, the lower part filled with silt flow, the upper part filled with sparry calcite, microscopic thin section, YM201 well, 5855.25 m; C−Sparry calcite algae sand−clastic limestone, two−stage sparry calcite observed, the first distributed at the edge of grain with comb −shaped shell, the second filling the pore among the grains with subhedral and xenomorphic crystalline grain, microscopic thin section, XK101 well, 6810.93 m; D −algae grumose limestone, cavity within grume filled with sparry calcite, algae grume exhibiting dark orange light, parry calcite in cavity with well developed luminescence zones, which have tens of zones and uneven width, nonluminescence−orange−orange yellow, fluorescence thin sections, H601−4 well, 6652.78 m; E−Taupe micritic algal boundstone, with well developed flat geode, photograph of core, YM202 well, 5853.74 m; F−Dark gray calcarenite, with well developed corrosion pores filled or polluted with brown ancient soil, photograph of core, H7−1 well, 6582 m; G−Dark gray, gray gravel crumbs limestone, the upper dark part indicates that intragranular dissolution pores polluted by pitch, the lower gray part indicates density cementing

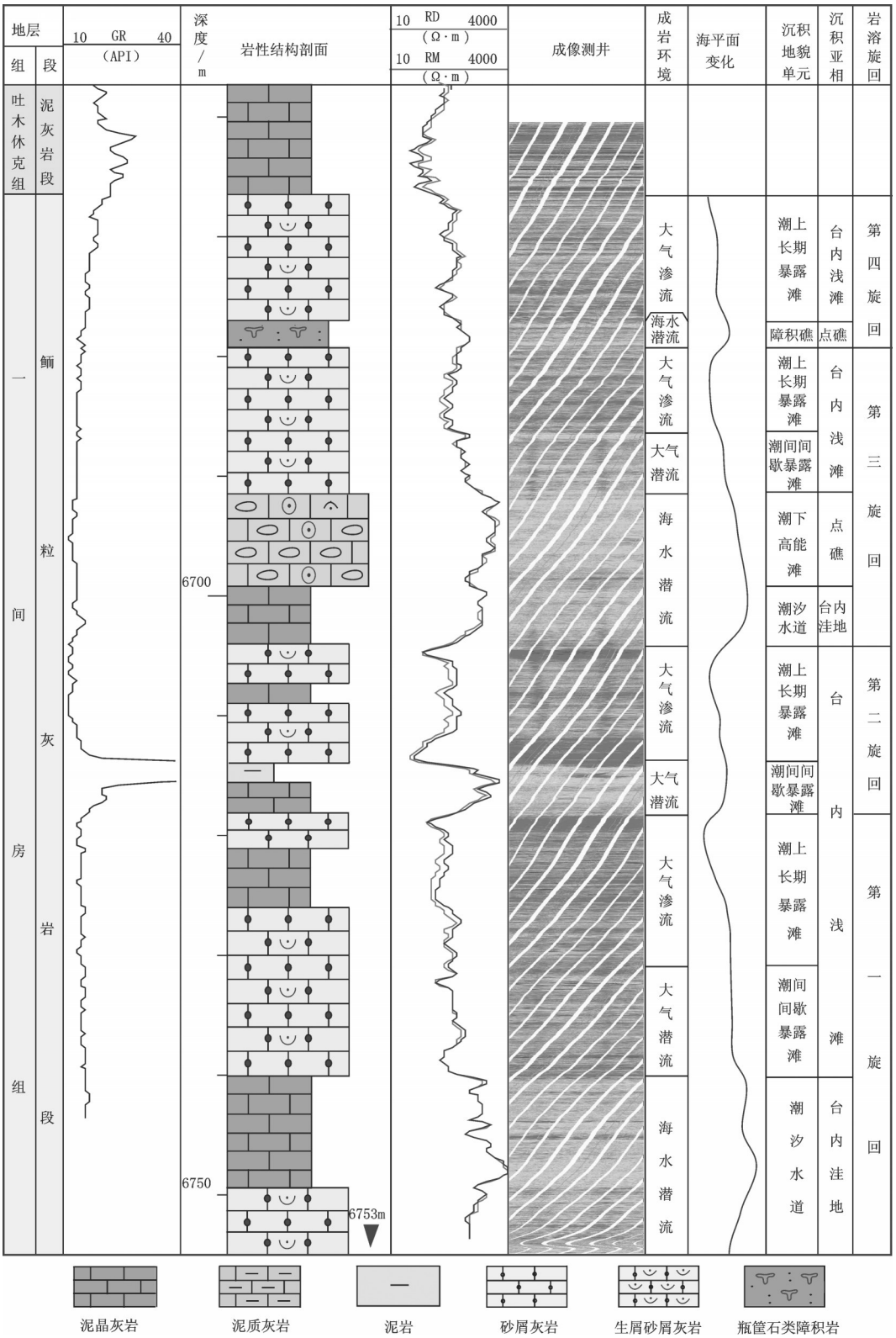

图4 HA10井奥陶系一间房组同生期溶蚀作用发育特征

Fig.4 Syn-sedimentary corrosion characteristics of the middle Ordovician Yijianfang Formation in HA10 Well

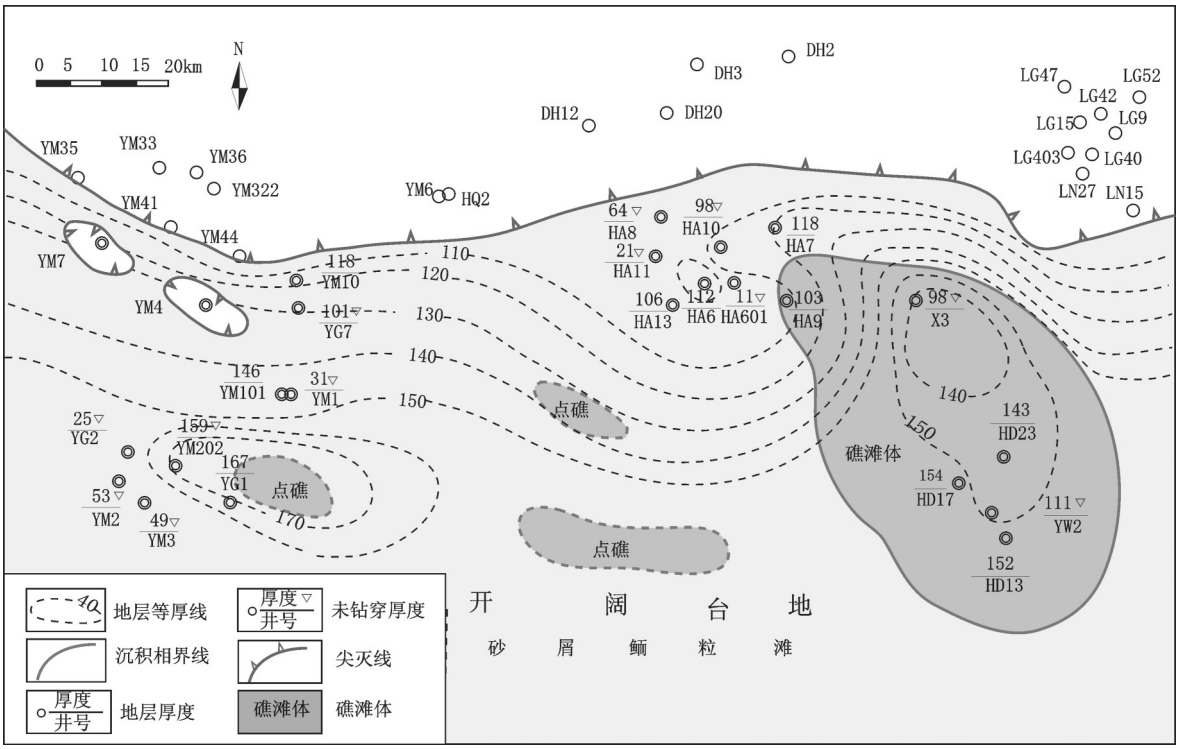

图5 塔北西部中奥陶世一间房组沉积相平面展布图(位置见图1)

Fig.5 Sedimentary faces plane distribution of Middle−Ordovician Yijianfang Formation in western Tabei (for the location see Fig. 1)

积, 沉积相平面分布稳定。一间房组沉积时期基本继承鹰一段的沉积格局, 属于鹰一段水体深度向上变浅的极端沉积事件, 全区域出现开阔台地鲕粒砂屑浅滩粗粒沉积物, 沉积厚度稳定并夹有台内生物点礁沉积(图5)。

H6井区和YM2井区一间房组沉积时期处于开阔台地台内浅滩相区内, 以沉积厚层状亮晶颗粒灰岩为主, 托盘类生物礁以台内点礁形式分布。HD23井区—X3井—H9井在一间房组沉积时期较特殊, 处于开阔台地浅滩和生物礁叠加相区内, 以沉积厚层、巨厚层滩相的灰色、褐灰色亮晶砂屑灰岩、鲕粒灰岩、藻砂屑灰岩、砂砾屑灰岩为特征, 间夹生物礁灰岩和礁前塌积角砾灰岩、泥晶灰岩薄层。

5 一间房组礁滩体暴露溶蚀作用模式

暴露溶蚀作用模式通常根据地下水循环情况, 划分出潜水面之上的渗流带和之下的潜流带各带中成岩变化的差异性[25, 26], 这种溶蚀作用模式通常能体现出溶蚀作用带的垂向上的变化特征。然而, 研究区的沉积相为开阔台地的浅滩和点礁, 这种环境下礁滩体会时常暴露于海平面之上[43−45], 形成海岛、砂洲、砂滩等正地貌单元, 在大气淡水淋滤下经历同生期溶蚀作用, 形成非常发育的溶蚀孔洞层, 因此, 按照古沉积地貌单元结合岩相进行沉积相划分对溶蚀作用储层的研究意义更大。通过前述的一间房组开阔台地相沉积特征、相展布的研究, 结合同生期溶蚀作用特征, 按照古沉积地貌单元结合岩相的方法, 本次研究建立了一间房组开阔台地溶蚀作用模式, 认为塔北西部中奥陶世一间房组可划分出潮上长期暴露滩、潮间间歇暴露滩、潮下高能滩、瓶筐石障积礁、潮汐水道等地貌单元(图6)。

(1)潮上长期暴露滩

位于平均高潮线之上的海岛和砂洲, 只有风暴潮才能影响。沉积物主要为砂砾屑灰岩、瓶筐石砂砾屑灰岩、砂屑灰岩夹泥晶灰岩。暴露滩长期暴露在海平面之上, 在大气淡水的淋滤作用下, 文石、高镁方解石以及不稳定的盐类矿物, 在淡水作用下会发生溶解, 通常产生粒内溶孔、铸模孔和粒间溶孔; 同时大气淡水或淡水−海水混合水所携带来的碳酸

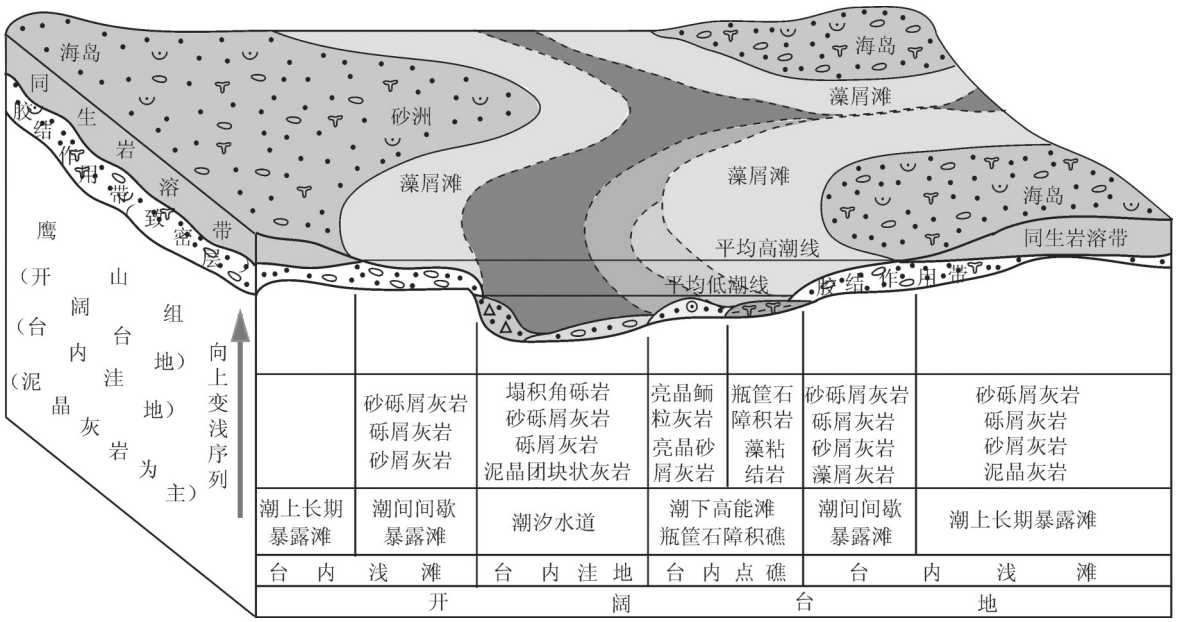

图6 塔北西部地区中奥陶统一间房组礁滩相体沉积及溶蚀作用模式图

Fig.6 Sedimentary facies and corrosion mode of the reef−banks in the middle Ordovician Yijianfang Formation in western Tabei

盐灰泥、粉屑, 充填于生屑(如棘屑等) 的粒(砾) 间或生物体腔孔、格架孔中而形成渗流粉砂, 以及溶蚀孔洞洞底充填渗流灰泥粉砂, 洞顶充填亮晶方解石, 形成平底晶洞等同生期溶蚀作用特征。

(2)潮间间歇暴露滩

位于平均高潮线和平均低潮线之间的海滩区域, 沉积物主要为砂砾屑灰岩, 含瓶筐石砂砾屑灰岩、亮晶砂屑灰岩。潮间间歇暴露滩体处于同生期溶蚀作用带内, 与长期暴露滩不同, 具有溶蚀作用和胶结作用伴生的特点; 暴露时期, 在大气淡水淋滤溶蚀下会形成非常发育的孔洞层, 高潮期间, 在海水作用下发生胶结作用, 孔洞多结晶方解石充填。

(3)潮下高能滩

位于平均低潮线以下的区域, 波浪作用较强, 沉积物以亮晶鲕粒灰岩和亮晶砂屑灰岩为主, 虽然也为滩相沉积, 但由于没有暴露, 储层发育极差, 测井曲线为低伽玛和高电阻特征。

(4)瓶筐石障积礁

位于平均低潮线以下高能滩体之间的相对静水区, 瓶筐石构成抗浪格架, 其间充填灰泥。

(5)潮汐水道

位于潮间带或平均低潮线以下的相对低洼的区域, 沉积物为砂砾屑灰岩、砂屑灰岩、泥晶团块状灰岩和塌积角砾岩。

6 结 论

(1)塔北隆起西部一间房组的开阔台地相包括台内滩、滩间海和台内点礁3个亚相, 沉积相平面分布稳定; 全区域具有开阔台地鲕粒砂屑浅滩粗粒沉积物, 沉积厚度稳定并夹有台内生物点礁沉积。

(2)岩心观察和铸体薄片显示, 一间房组所发育的同生期溶蚀作用特征明显; 生物钻孔或溶洞内充填体暴露形成的古土壤泥; 发育潮间带的化石碎片堆积和软体生物活动遗迹; 岩心观察和成像测井可以识别出暴露溶蚀作用旋回, 反映滩体的间歇性暴露的特征。

(3)按照礁滩相沉积地貌结合岩相的原则, 可将塔北西部地区中奥陶统一间房组开阔台地的浅滩和点礁沉积划分出潮上长期暴露滩、潮间间歇暴露滩、潮下高能滩、瓶筐石障积礁、潮汐水道等地貌单元。

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