

引用格式:陈泓位,王时林,和源,等.四川盆地中北部DB1井区灯影组四段沉积相及储层特征[J].油气地质与采收率,2024,31(3):31-41.

CHEN Hongwei, WANG Shilin, HE Yuan, et al. Sedimentary facies and reservoir characteristics of fourth Member of Dengying Formation in Well DB1 area, north-central Sichuan Basin[J]. Petroleum Geology and Recovery Efficiency, 2024, 31(3): 31-41.

四川盆地中北部DB1井区灯影组四段 沉积相及储层特征

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摘要:四川盆地中北部(川中北部)灯影组四段(灯四段)储层岩性复杂,非均质性较强,限制了灯影组四段气藏的勘探。为了进一步深化川中北部DB1井区的沉积相及储层特征认识,通过钻井岩心及薄片资料的观察,并结合测井、录井、物性测试以及钻探成果等资料的综合分析,对川中北部DB1井区灯四段沉积相及储层特征进行研究。结果表明:研究区灯四段主要发育台地边缘和局限台地2种沉积亚相,进一步可识别出藻丘、颗粒滩和滩间海等沉积微相,其中藻丘微相主要发育藻凝块云岩和藻叠层云岩,颗粒滩微相主要发育砂屑云岩,滩间海微相主要发育泥晶云岩和粉晶云岩;藻丘和颗粒滩沉积主要发育在台缘一侧,向台内藻丘和颗粒滩沉积逐渐减少,以滩间海沉积为主;藻丘发育呈纵向叠置特征,横向延伸较近,且集中发育在灯四段上亚段,单体厚度较大,下亚段发育较少且厚度较薄;储集岩类型主要为藻凝块云岩、藻叠层云岩和砂屑云岩,储集空间主要为藻黏结格架孔、粒间溶孔和晶间溶孔;研究区岩心孔隙度分布在2.02%~6.03%,总体平均孔隙度为3.11%,岩心渗透率分布在0.007 04~9.78 mD,总体平均渗透率为0.692 64 mD,整体物性具有低孔特低渗透特征,部分样品由于受到裂缝的影响呈现低孔高渗透特征。

关键词:沉积微相;展布特征;储层特征;灯影组四段;四川盆地中北部

文章编号:1009-9603(2024)03-0031-11

DOI:10.13673/j.pgre.202308035

中图分类号:TE122

文献标识码:A

Sedimentary facies and reservoir characteristics of fourth Member of Dengying Formation in Well DB1 area, north-central Sichuan Basin

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Abstract: The reservoir lithology of the fourth Member of Dengying Formation in the north-central Sichuan Basin is complex with strong heterogeneity, which limits the gas reservoir exploration in the fourth Member of Dengying Formation. To further deepen the understanding of sedimentary facies and reservoir characteristics in Well DB1 area in north-central Sichuan, the sedi-

收稿日期:2023-08-17。

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基金项目:中国石油重大专项“风险勘探领域和目标研究、工程技术攻关及现场试验”(2023YQX10104)。

mentary facies and reservoir characteristics of the fourth Member of Dengying Formation in Well DB11 area in the north-central Sichuan were studied based on the data of drilling core, thin section observation, well logging, log, physical property test, and drilling results. The results show that two sedimentary subfacies of platform margin and restricted platform are mainly developed in the fourth Member of Dengying Formation in the study area, and sedimentary microfacies such as algal mound, grain beach, and inter-beach sea were further identified. Among them, algal mound microfacies mainly develop algal clot dolomite and algal stromatolite dolomite, grain beach microfacies mainly develop calcarenite dolomite, and inter-beach sea microfacies mainly develop micritic dolomite and powder crystal dolomite. The algal mounds and grain beaches in the fourth Member of Dengying Formation in the study area are mainly developed on the side of the platform margin, and the deposition of algal mounds and grain beaches in the platform gradually decreases mainly inter-beach sea deposition. The development of algal mounds in the fourth Member of the Dengying Formation in the study area is characterized by longitudinal superposition, and the horizontal extension is relatively close. Meanwhile, the algal mounds are concentrated in the Upper Submember of the fourth Member of Dengying Formation with large monomer thickness, while the Lower Submember of the fourth Member of Dengying Formation is less developed and thinner. The reservoir rock types of the fourth Member of Dengying Formation in the study area are mainly algal clot dolomite, algal stromatolite dolomite, and calcarenite dolomite. The reservoir space is mainly algal binding framework pore, intergranular dissolved pore, and intergranular dissolved pore. The core porosity of the fourth Member of Dengying Formation in the study area is distributed between 2.02% and 6.03% with an overall average porosity of 3.11%, the core permeability is distributed between 0.007 04 and 9.78 mD, and the overall average permeability is 0.692 64 mD. The overall physical properties are characterized by low porosity and ultra-low permeability, and some samples show low porosity and high permeability due to the influence of fractures.

Key words: sedimentary microfacies; distribution characteristic; reservoir characteristic; fourth Member of Dengying Formation; north-central Sichuan Basin

碳酸盐岩储层作为重要的油气储集类型,受到了众多学者的广泛重视^[1-3],四川盆地震旦系灯影组发育厚层的碳酸盐岩,是重要的油气富集层,在近年来的天然气勘探过程中取得了重大突破,其中威远气田和安岳气田高产气井的相继出现,展示了灯影组具有高演化天然气藏的巨大勘探潜力^[4-5]。前人对于灯影组的研究主要集中于四川盆地西南部的威远地区和中部的高石梯—磨溪地区,而对于其他地区灯影组的研究则相对较少,限制了在盆地范围内对灯影组的进一步勘探^[6-10]。

四川盆地中北部(川中北部)DB1井区灯影组四段(灯四段)位于德阳—安岳裂陷槽的东部台缘带丘滩相发育有利区,灯四段沉积早期水体整体贫藻,沉积以泥晶白云岩为主,灯四段沉积晚期伴随沉积水体变浅,十分适合各类菌藻的生长,藻丘大量发育,大面积发育的丘滩相有利于后期建设性成岩作用的改造,为灯四段大面积发育优质储层奠定了物质基础^[11-12];研究区PS1井位于川中地区龙女寺构造北斜坡,该井在钻至灯四段时见到了良好的油气显示,同时其录井及岩心显示灯四段白云岩溶孔储层发育,经酸化试气后获得高产,证实了DB1井区灯四段台缘带发育大型气藏。随后在该地区构造高部位钻探的DB1井酸化试气也获得了高产,进一步证明了研究区灯四段的含气性和勘探潜力。

前人研究成果表明,灯影组储层发育受到沉积环境、构造运动等众多因素的影响,其中沉积相带的分布控制着区域上储层的分布格局,沉积相类型为储集空间的形成提供了岩性基础^[13-15]。以钻井岩心、岩心薄片、物性测试、成像测井、常规测井、录井资料和钻探成果等资料分析为基础,结合区域地质背景及前期勘探认识,精细研究了川中北部DB1井区灯四段的沉积相和储层特征,以期为该区域灯四段的下一步勘探提供研究支撑。

1 区域地质概况

DB1井区位于四川省遂宁市境内,区域构造位置隶属于川中古隆起平缓构造带的西北部,该构造带北邻大巴山前缘川北古中坳陷低缓带,南接川西南古隆中斜低褶带,东以华蓥山断裂为界与川东古斜中隆高陡断褶带连接,西以龙泉山断裂与川西中新坳陷低陡带相隔(图1a)。

研究区灯影组由于受到两幕桐湾运动的控制,自下而上可分为灯一段—灯四段,上震旦统灯影组与上部的下寒武统筇竹寺组呈不整合接触,与下部的下震旦统陡山沱组呈整合接触。灯四段的岩性以藻云岩为主,夹有部分的泥晶云岩和砂屑云岩,依据其沉积旋回、岩性和电性特征可以将灯四段细

胶结物已经由泥晶重结晶为粉晶或细晶白云石(图2f)。颗粒滩微相的自然伽马曲线总体表现为低值锯齿状,电阻率曲线整体表现为中幅锯齿状,是储层发育较为有利的沉积相带,其沉积环境具有水体浅,水动力环境相对较强的特征。

2.1.3 滩间海微相

滩间海微相的岩性主要由泥晶云岩、粉晶云岩、泥质云岩和细-中晶云岩等细粒沉积组成,泥晶云岩在成像测井上通常表现为规则或不规则线状,岩心上表现为灰白色或者深灰色,无颗粒感,较为光滑细腻,偶见明显的黑色斑点,这些黑色斑点通常是与泥晶云岩相邻或伴生的藻凝块云岩,在显微镜下可见含有暗色的陆源黏土矿物斑点(图2g)。粉晶云岩在成像测井上通常呈现为黑色条带状,岩心上主要表现为灰白色或者浅黄色,稍有颗粒感,晶洞不发育,仅见少量细小的晶洞(图2h),显微镜下见半自形到它形的白云石晶体,类似于假亮晶白云石,发育晶洞(图2i)。滩间海微相的自然伽马曲线总体呈中高值的齿状,电阻率曲线总体表现为高幅齿状,为非储层相带,以静水沉积为主,环境能量

较低。

2.2 沉积相展布特征

2.2.1 纵向展布特征

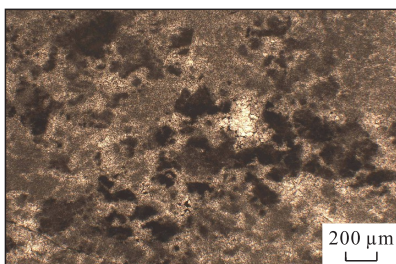
通过对研究区单井沉积相分析,结合实钻资料,研究区灯四段的藻丘发育主要集中在上亚段,其规模巨大,在纵向上多个藻丘呈叠置分布,从藻丘单体的发育规模来看,上亚段藻丘的形成是一个向上加积的过程,这种加积型的藻丘发育致使藻丘在垂向上形成巨厚的丘滩体,从而形成厚层的储层,但由于藻丘是垂向加积发育,致使藻丘在侧向上延伸不远,使得藻丘的横向连通性较差,各藻丘呈孤立发育分布,藻丘与藻丘沉积之间被滩间海所形成的致密带所分隔;颗粒滩主要发育在下亚段,其整体沉积厚度较小,在上亚段零星分布,夹杂在藻丘的纵向叠置间;下亚段的藻丘发育极少,呈零星的点状分布,以滩间海沉积为主,颗粒滩较为发育(图3)。

2.2.2 平面展布特征

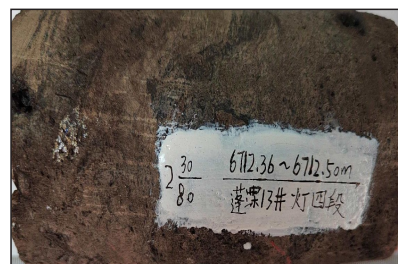
在研究区沉积微相识别的基础上,结合研究区的地震解释成果,通过对DB1、PS1和PS13井的单



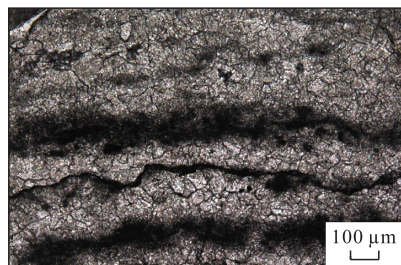
a—PS13井,藻凝块云岩,6714.03~6714.23 m



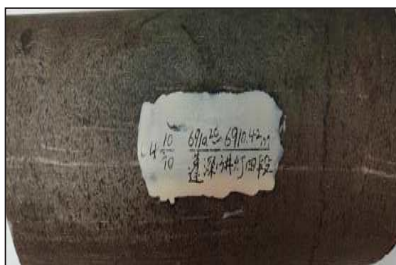
b—PS13井,藻凝块云岩,6714.08 m



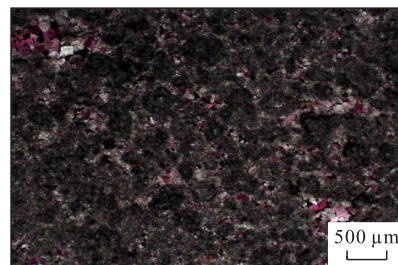
c—PS13井,藻叠层云岩,6712.36~6712.50 m



d—DB1井,藻叠层云岩,6517.43 m



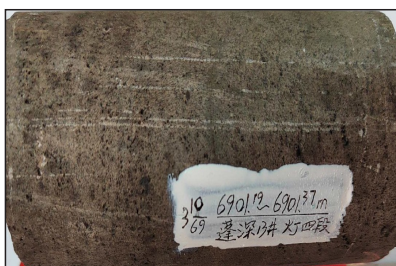
e—PS13井,砂屑云岩,6910.20~6910.42 m



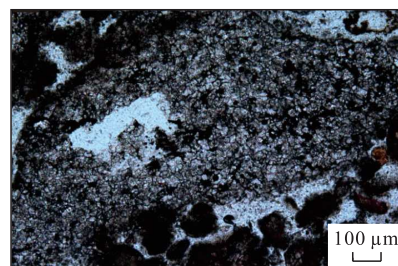
f—PS1井,砂屑云岩,7261.9 m



g—PS13井,泥晶云岩,6708.03 m



h—S13井,粉晶云岩,6901.12~6901.37 m



i—PS1井,粉晶云岩,7511.72 m

图2 DB1井区灯四段典型岩心与薄片照片

Fig.2 Typical core and section photos of fourth Member of Dengying Formation in Well DB1 area

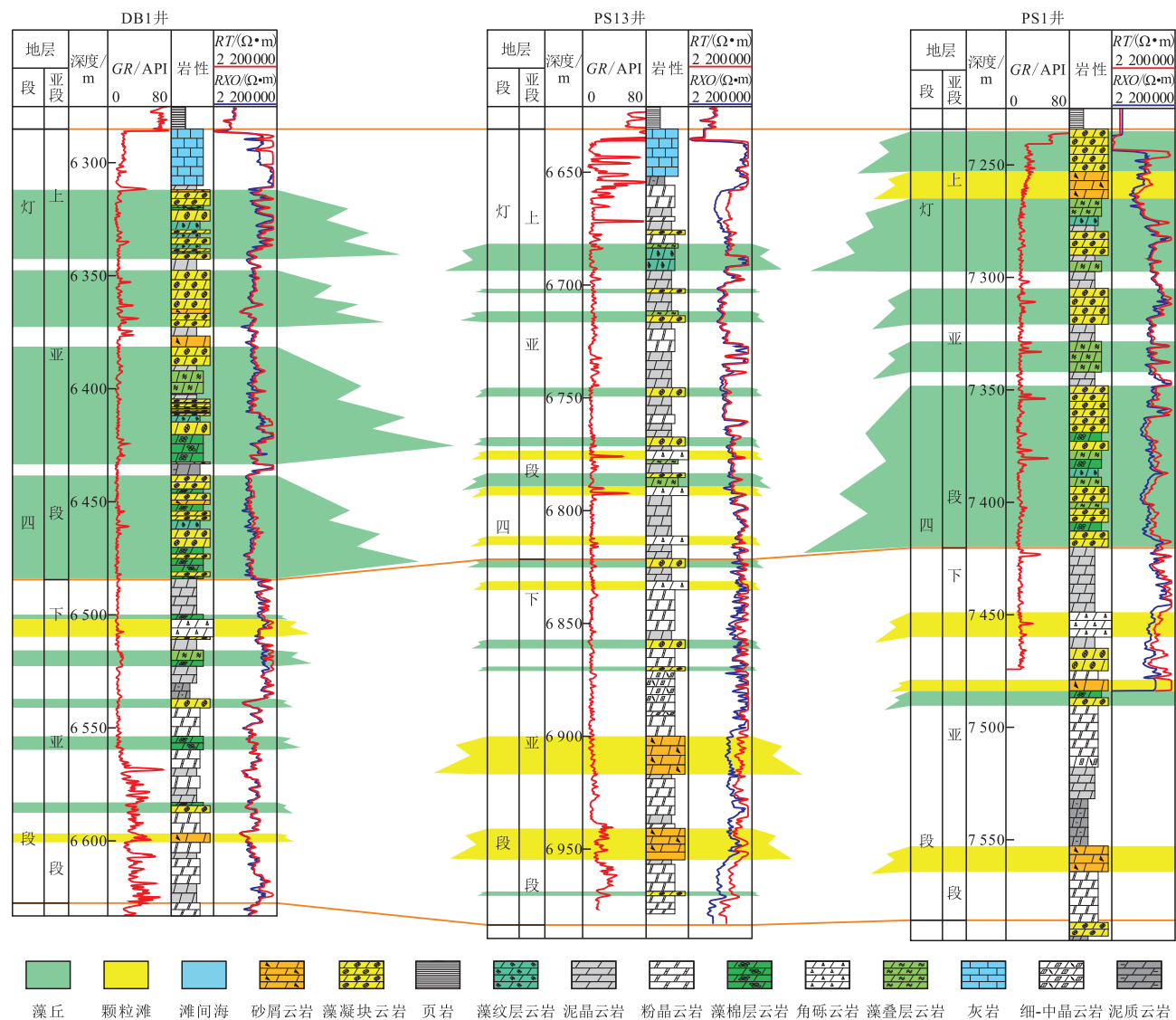


图3 DB1井区灯四段沉积相纵向展布
Fig.3 Longitudinal sedimentary facies distribution of fourth Member of Dengying Formation in Well DB1 area

井有利沉积相精细标定,明确各井的有利相带在地震解释成果上的反射特征,进而以3口井的地震相特征分析为基础,结合实钻资料、地震属性资料,分析认为研究区在灯四段沉积时期由于海平面快速下降,造成该区域水动力变弱,在台缘区迅速形成大规模独立的藻丘或颗粒滩沉积(图4),随着沉积的不断演化,台缘的独立藻丘体、颗粒滩逐渐生长形成连片的藻丘和颗粒滩,在台缘藻丘、颗粒滩之后还发育了连片的颗粒滩、藻丘沉积及其之间的滩间海沉积。

3 储层特征

3.1 储集空间类型

研究区灯四段的储集空间由于受到了多种因

素的控制,导致其类型多样^[23-24],通过对研究区灯四段岩心及薄片等资料的详细观察,根据其形成机理和形态特征,将研究区灯四段储集空间分为孔隙、溶洞和裂缝3大类。

3.1.1 孔隙

DB1井区灯四段的孔隙主要包括藻黏结格架孔、粒间溶孔、晶间溶孔以及少量的残余粒间孔和晶间孔。藻黏结格架孔是灯四段主要的储集空间之一,主要出现在藻凝块云岩和藻叠层云岩中,孔径通常大于1 mm,呈条带状、网格状或斑点状分布(图5a),部分被沥青等充填或半充填。粒间溶孔是对颗粒间胶结物选择性溶解形成的孔隙,也是研究区灯四段主要的储集空间之一,主要分布于砂屑云岩和角砾云岩中,孔隙形态不规则,孔隙边缘通常呈现为不规则溶蚀港湾状(图5b),孔径介于0.05 ~

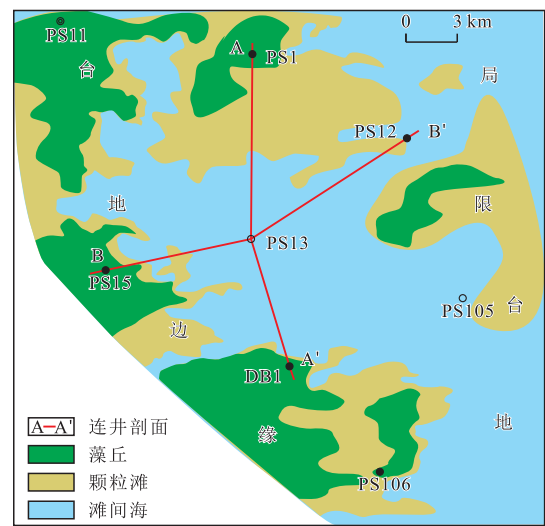


图4 DB1井区灯四段沉积相平面展布

Fig.4 Planar distribution of sedimentary facies of fourth Member of Dengying Formation in Well DB1 area

0.40 mm,部分被沥青等充填或半充填,当溶蚀作用很强烈时,可以形成超大孔隙。晶间溶孔主要发育在研究区灯四段的砂屑云岩和细-中晶云岩中,孔隙形态较为规则(图 5c),孔隙边缘平直,部分发生溶蚀形成晶间溶孔,孔径为0.01 ~ 0.10 mm。

3.1.2 溶洞

研究区灯影组由于在沉积之后经历了漫长的成岩改造作用,发育了各种成因的溶洞^[25],灯四段的溶洞分布不均匀,洞径通常介于2 ~ 20 mm,最大超过40 mm,以中小溶洞为主,大溶洞发育较少,受到溶蚀作用的影响,灯四段发育的溶洞多呈层状或沿裂缝、溶缝呈串珠状分布,也有围绕岩溶角砾分布,发育有扁圆形、椭圆形、条带状、水滴形、裂隙形及不规则形状,部分溶洞被硅质及沥青等充填或半充填(图 5d—5f)。

3.1.3 裂缝

裂缝不仅可以作为流体的渗流通道,还可以直接作为储层重要的储集空间^[26]。据岩心观察可知,研究区灯四段裂缝发育程度总体较高(图 5g—5i),其宽度介于1 ~ 5 mm,形态不规则,裂缝产状以水平层间缝和高角度缝为主,局部出现错乱交织形成的网状缝(图 5i),部分裂缝与孔隙连通(图 5g),按其成因可分为构造缝、压溶缝和溶蚀缝,构造缝断面通常比较平直,多以高角度缝出现,通常被沥青等半充填;压溶缝以平缝和低角度缝为主,普遍被泥

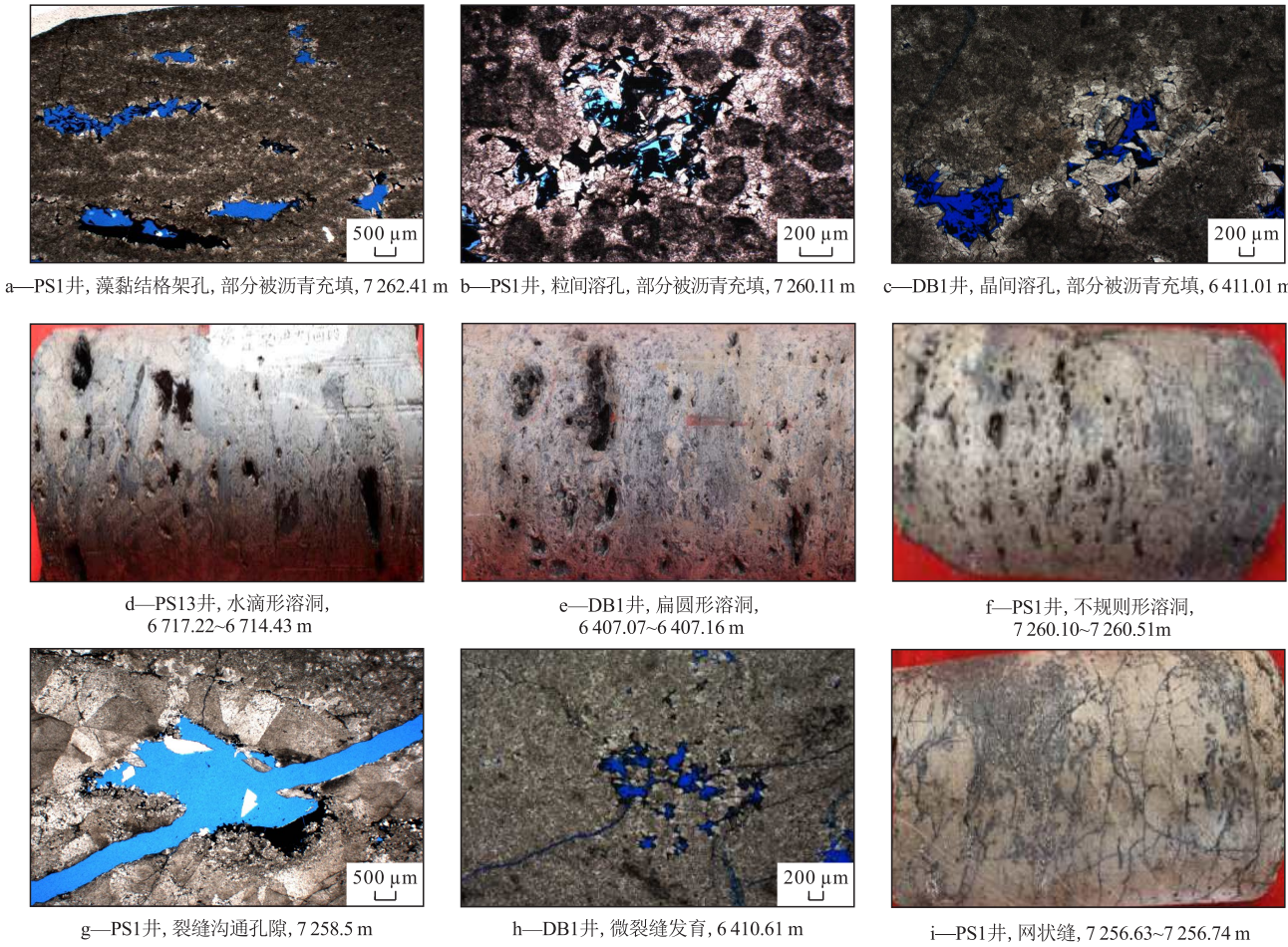


图5 DB1井区灯四段主要储集空间类型

Fig.5 Main reservoir space types of fourth Member of Dengying Formation in Well DB1 area

质充填,对渗流贡献小;溶蚀缝由于经过淡水或地下水的溶蚀,缝壁通常不平直且以港湾状呈现,部分溶蚀缝甚至与孔隙连通,增强了一定的渗透性,但溶蚀缝普遍被沥青或白云石半充填。

3.2 储集物性特征

对研究区取心井段的物性测试可以明确储集岩的储渗能力^[27]。通过对研究区灯四段岩心样品的物性测试资料分析可知,灯四段岩心孔隙度分布在2.02%~6.03%(图6a),总体平均孔隙度为3.11%,中值孔隙度为2.71%,频率分布主体为2%~3%,占62.22%。岩心渗透率分布在0.007 04~9.78 mD(图6b),总体平均渗透率为0.692 64 mD,中值渗透率为0.321 mD,频率分布主体为0.1~1 mD,占59.62%。基于物性测试资料的分析成果,并结合DB1、PS1和PS13井的孔隙度和渗透率测井曲线分

析,灯四段藻丘微相的孔隙度分布介于2.34%~6.98%,总体平均孔隙度为4.55%,渗透率分布介于0.016~9.78 mD,总体平均渗透率为0.753 61 mD。颗粒滩微相的孔隙度分布介于2.01%~4.82%,总体平均孔隙度为3.51%,渗透率分布介于0.182~3.223 mD,总体平均渗透率为0.662 76 mD。滩间海微相的孔隙度分布介于0.61%~2.64%,总体平均孔隙度为1.76%,渗透率分布介于0.003~0.021 mD,总体平均渗透率为0.01 mD。研究区灯四段储层非均质性较强,总体体现为低孔特低渗透特征,局部出现高孔渗段。从渗透率与孔隙度交会图中可以看出(图6c),大部分样品孔隙度和渗透率呈现出正相关关系,表现出孔洞型储集体特征,部分样品呈现为渗透率异常高值,是受到裂缝发育的影响,增强了孔隙之间的连通性,表现出了低孔高渗透的特征,研究区灯四段储层的储集类型主要为裂缝-孔洞型。

3.3 储层分布特征

通过研究区的物性测试资料及测井孔隙度和渗透率分析对灯四段储层进行分类评价(表1),研究区灯四段储层厚度为35.4~160.6 m,占地层厚度比例为10.18%~44.66%,其中DB1井发育I类储层10.2 m,PS1井发育I类储层7.0 m,PS12井发育I类储层2.8 m,PS13井和PS15井不发育I类储层,DB1井发育II类储层18.5 m,PS1井发育II类储层12.2 m,PS12井发育II类储层5.8 m,PS13井发育II类储层4.5 m,PS15井发育II类储层11.5 m,DB1井发育III类储层131.9 m,PS1井发育III类储层100.7 m,PS12井发育III类储层33.8 m,PS13井发育III类储层30.9 m,PS15井发育III类储层72.6 m。

表1 DB1井区灯四段储层分类评价

Table1 Reservoir classification evaluation of fourth Member of Dengying Formation in WELL DB1 area

储层分类	孔隙度/%	渗透率/mD
I	≥6	≥5
II	4~6	0.42~5
III	2~4	<2
IV(非储层)	0.01~0.42	<0.01

通过钻探成果分析,结合研究区的测井解释成果,研究区灯四段的储层主要发育在上亚段,具有层数多、部分单层厚度大且整体厚度大的特征。从研究区南北向储层剖面(图7)可以看出,研究区储层南北厚度大,中间厚度薄。从东西向储层剖面(图8)可以看出,研究区台缘一侧储层厚度较

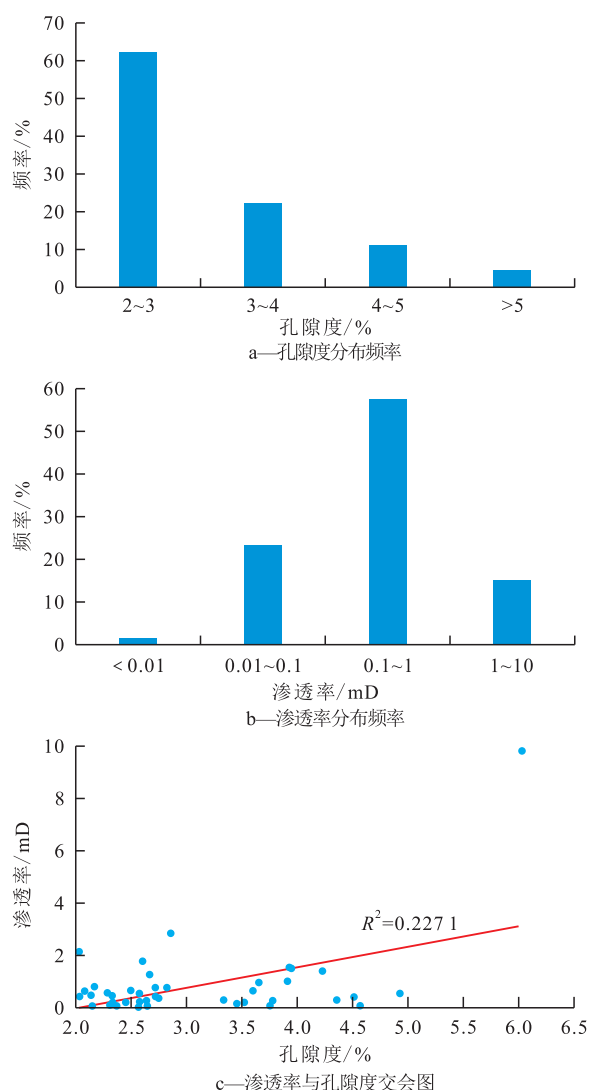


图6 DB1井区灯四段储层孔隙度、渗透率分布及其交会图
Fig.6 Reservoir porosity, permeability, and their intersection of fourth Member of Dengying Formation in Well DB1 area

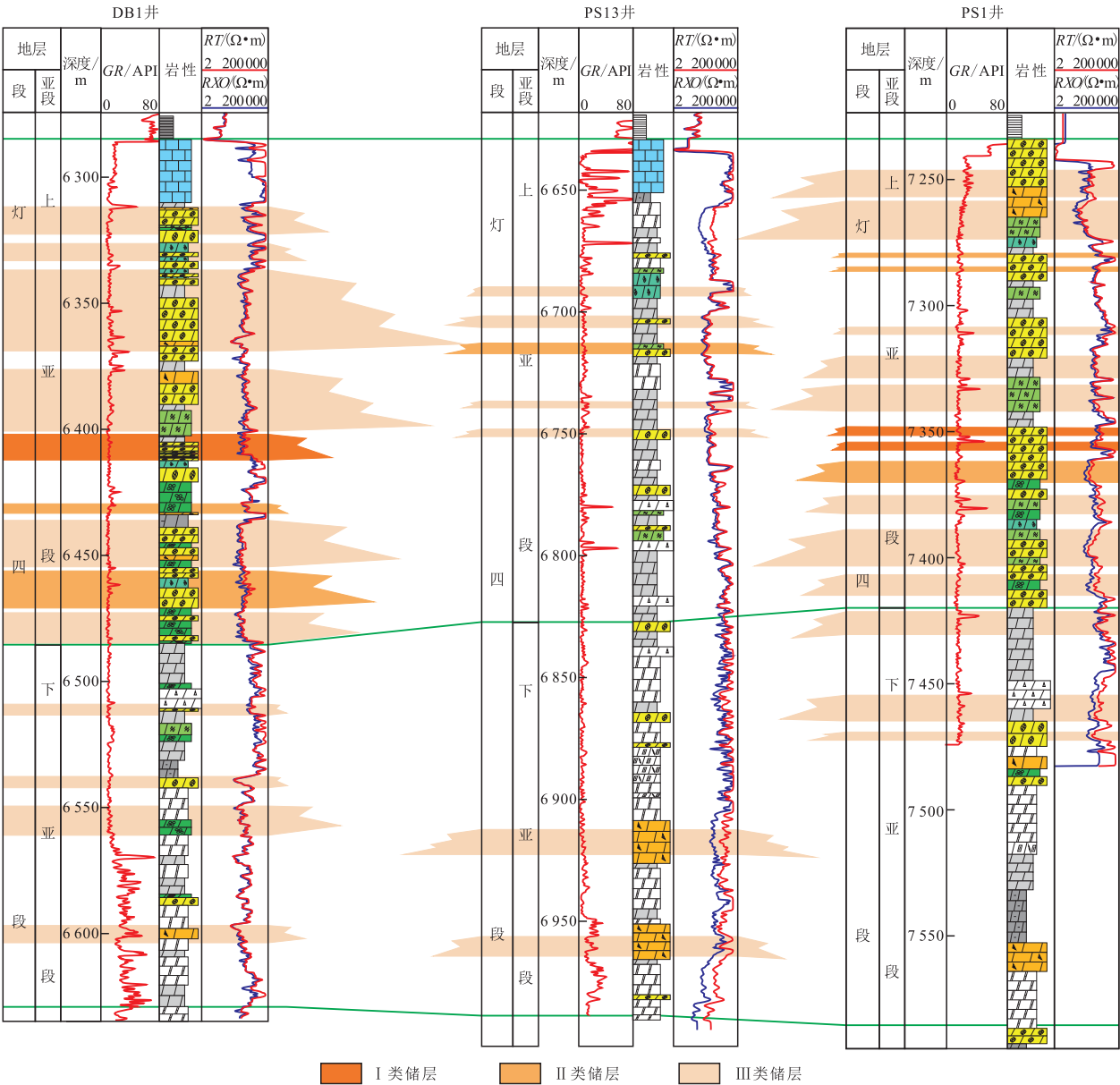


图7 DB1井区南北向储层剖面(剖面位置见图4)
Fig.7 South-north reservoir profile in Well DB1 area (well locations in Fig.4)

大,从台缘向台内具有逐渐减薄的趋势,结合前述的研究区灯四段沉积相展布(图3,图4),研究区藻丘和颗粒滩微相发育的区域,对应着储层也较为发育,储集空间类型发育多样,局部具有低孔高渗透的特征;研究区沉积相带的分布控制着储层的发育情况。

4 结论

(1)川中北部DB1井区灯四段主要发育藻丘、颗粒滩和滩间海3种沉积微相,上亚段广泛发育藻丘沉积,颗粒滩沉积较少,藻丘呈垂向叠加分布,储层发育较好,下亚段藻丘沉积较少,呈零星点状分

布,颗粒滩较为发育,储层发育较差。
(2)川中北部DB1井区灯四段藻丘和颗粒滩主要发育在台缘一侧,向台内逐渐减薄,藻丘和颗粒滩控制着储层的发育分布,呈现为南北厚中间薄、从台缘向台内减薄的分布特征;灯四段的储层发育以Ⅲ类储层为主,Ⅰ类储层和Ⅱ类储层发育较少。
(3)川中北部DB1井区灯四段主要的储集岩类型为与微生物丘建造相关的藻凝块云岩、藻叠层云岩和与颗粒滩建造相关的砂屑云岩,储集空间以藻黏结格架孔、粒间溶孔和晶间溶孔为主,发育不同规模的溶洞和裂缝,但由于孔、洞、缝均被不同程度地充填,整体表现为低孔特低渗透储层,储集类型主要为裂缝-孔洞型。

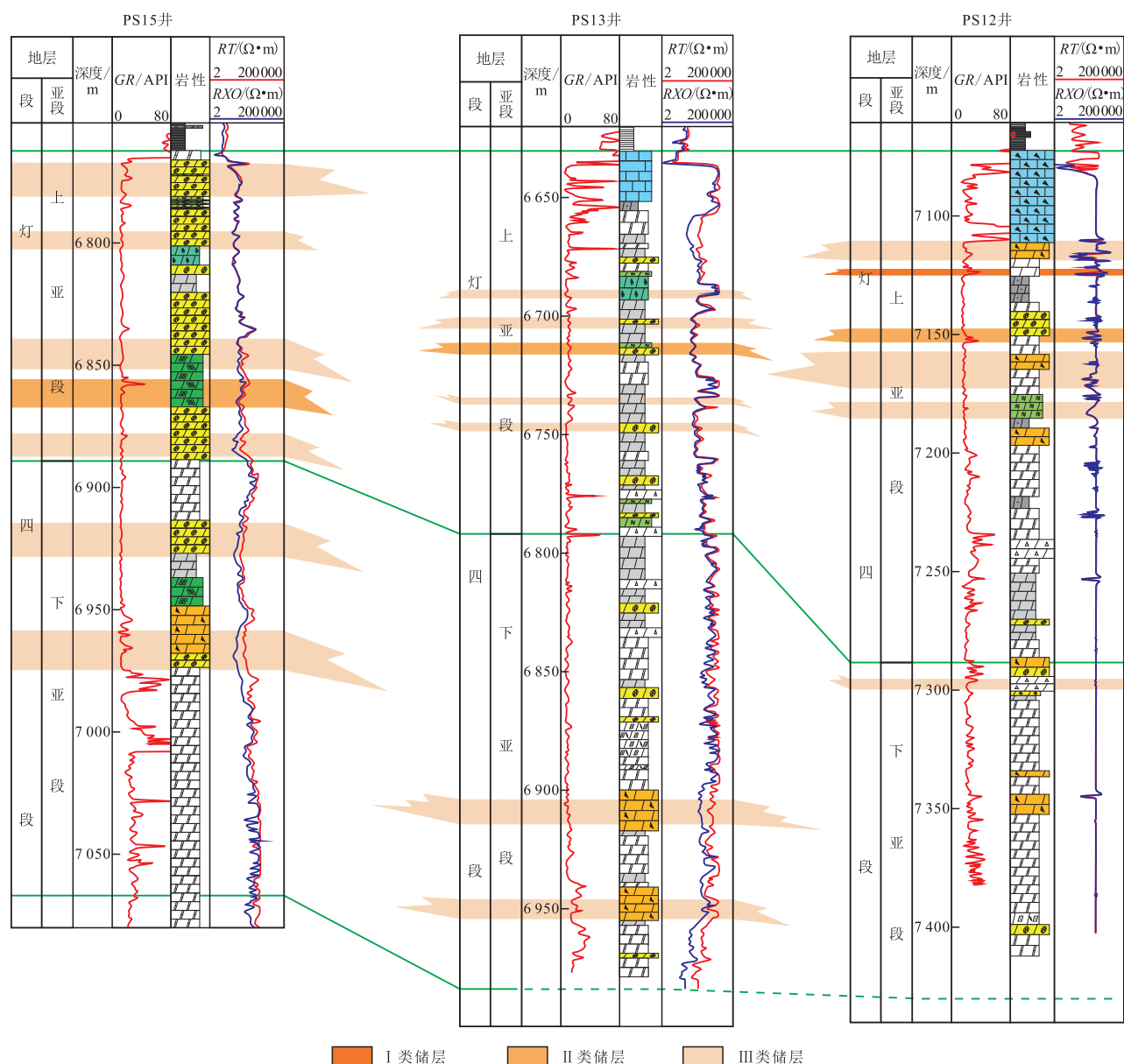


图8 DB1井区东西向储层剖面(剖面位置见图4)
Fig.8 East-west reservoir profile of Well DB1 area (well locations in Fig.4)

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编辑 单体珍