

川西北蓬溪—盐亭地区下三叠统飞仙关组 层序演化及鲕滩展布特征

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摘要 基于钻井、测井及三维地震资料,对川西北蓬溪—盐亭地区下三叠统飞仙关组开展层序特征、层序演化与鲕滩发育规律研究。结果表明:①飞仙关组整体可分为3个三级层序(SQ1—SQ3),层序界面具有特征的岩电与地震响应。②SQ1层序具有高角度S形前积反射结构,受高频层序海平面升降旋回控制,发育高频限制型鲕滩沉积,滩体主要沿各期前积体的上部发育,单期滩体规模较小,横向上呈北西向叠置迁移特征。③SQ2层序为低角度前积反射结构,地形坡度整体较缓,受三级海平面升降旋回控制,层序内发育稳定广覆式鲕滩沉积,滩体厚度较大,平面上分布稳定。④SQ3层序为连续平行反射特征,发育局限—蒸发台地相,以泥岩、白云质膏岩互层为特征,厚度均一。该项成果为川西北飞仙关组台内鲕滩油气藏的精细勘探与高效开发提供了地质依据。

关键词 层序; 碳酸盐岩; 鲕滩; 沉积模式; 飞仙关组; 四川盆地

中图分类号: TE121.3 **文献标识码**: A

引用: 林诚诚, 刘宏, 刘冉, 等. 川西北蓬溪—盐亭地区下三叠统飞仙关组层序演化及鲕滩展布特征[J]. 海相油气地质, 2025, 30(2): 147-156.

LIN Chengcheng, LIU Hong, LIU Ran, et al. Stratigraphic sequence evolution and oolitic shoal distribution of the Lower Triassic Feixianguan Formation in Pengxi-Yanting area, northwestern Sichuan Basin[J]. Marine origin petroleum geology, 2025, 30(2): 147-156.

0 前言

近年来的勘探结果表明,四川盆地下三叠统飞仙关组碳酸盐岩储层油气资源丰富^[1-2]。自20世纪90年代以来,在开江—梁平海槽东侧先后发现了普光^[3]、元坝^[4]、渡口河^[5]等大中型鲕滩气藏,展示了鲕滩储层良好的勘探开发前景。这些鲕滩主要分布于台缘带上,具有多期次、面积广等特征^[6]。总体上,当前针对台内鲕滩的勘探相对较少,这限制了对其油气资源潜力的认识。目前,对川西北台内鲕滩的展布特征已形成一些共识:王一刚等^[7]指出飞仙关组沉积时期呈现出一个持续海退的进程,在此期间深水沉积逐步演变为浅水碳酸盐沉积;谭秀成等^[8]认为鲕滩主要形成于浅水环境,受古地貌和海平面升降的共同控制;还有研究者认为鲕滩储层的形成主要受到区域沉积作用^[9]和后期成岩作用的影

响^[10],其中沉积作用在宏观层面决定了鲕滩储层在空间上的分布状况以及厚度变化,后期成岩作用在微观层面上决定了储层孔隙的形成与演化,并决定了储层的优劣。目前,地震反射剖面分析^[11]、反演技术分析^[12]及地震属性分析^[13]等技术手段常用于鲕滩储层的刻画。陶夏妍等^[13]认为,通过追踪对比不同的地震反射相界面,结合敏感地震属性,可以较好地预测迁移型鲕滩储层。在川西北地区,徐敏等^[11]通过地震剖面解释认为蓬溪—武胜台洼主要在飞仙关组一段(简称飞一段)前积体的顶部发育鲕滩储层,但对鲕滩的平面展布未作详细阐述。

川西北地区探井的主要目的层为上二叠统长兴组及下伏层系,目前飞仙关组缺乏岩心资料。在前期开展与邻区相同沉积环境的岩心、薄片所揭示的沉积特征类比研究的基础上,本文综合测井、三维地震和区域沉积背景资料,识别三级层序界面,

收稿日期:2024-12-20; 改回日期:2025-01-14

本文受中国石油—西南石油大学创新联合体科技合作项目“深层/超深层碳酸盐岩气田勘探开发基础理论与关键技术研究”(编号:2020CX010000)资助

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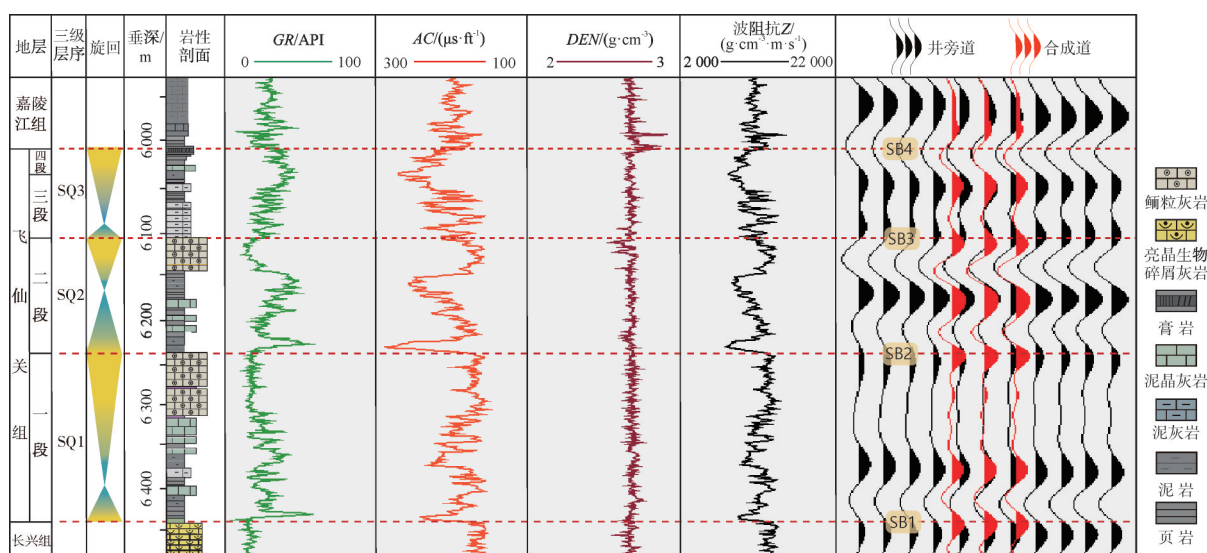


图2 川西北飞仙关组层序界面井-震标定(JT1井)

Fig. 2 Well-seismic calibration for the sequence boundary of Feixianguan Formation in northwestern Sichuan Basin (Well JT1)

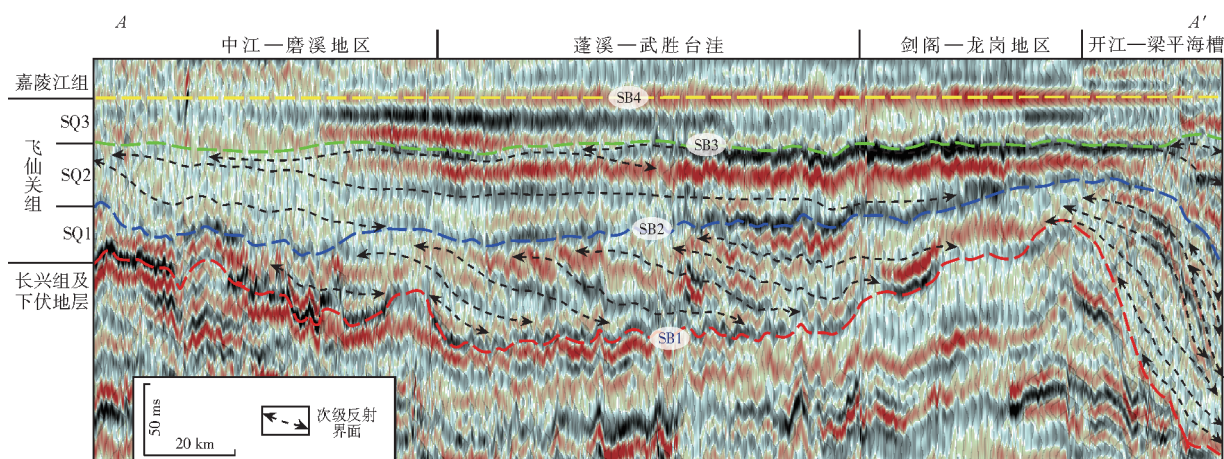


图3 川西北飞仙关组层序A—A'地震解释剖面(拉平嘉陵江组底界。剖面位置见图1a)

Fig. 3 The A-A' seismic interpretation profile of the sequence of Feixianguan Formation in northwestern Sichuan Basin (flatten the bottom of Jialingjiang Formation; the location is shown in Fig. 1a)

晶灰岩、生物碎屑灰岩形成明显的分异。在电性特征方面,长兴组自然伽马曲线呈箱状低值特征,飞一段自然伽马曲线呈齿状中高值特征,AC值由低值向高值突变(图2)。地震剖面上,该界面对应波峰反射,见有清晰的下超反射结构(图3)。

SB2界面,为飞一段与飞二段的分界面。岩性特征表现为飞一段上部泥晶灰岩向飞二段下部泥灰岩过渡。电性特征表现为飞一段自然伽马曲线由相对低值向相对高值过渡,AC值由低值向高值突变(图2)。上述特征反映了由浅水沉积转变为低能的深水沉积的过程。地震反射界面呈波峰反射,见顶超反射结构(图3)。

SB3界面,为飞二段与飞三段的分界面。岩性特

征表现为飞二段上部鲕粒灰岩、泥晶灰岩向飞三段下部泥晶灰岩夹泥灰岩过渡。电性特征表现为自然伽马曲线由箱装低值向齿状中高值转变,AC值由稳定低值向齿状高值转变(图2)。地震反射界面连续性较好,呈现连续中强—强波峰反射特征(图3)。

SB4界面,为飞四段与上覆嘉陵江组的分界面。岩性特征方面,飞四段岩性为紫红色泥晶白云岩和灰白色膏岩互层,嘉陵江组岩性为含泥灰岩、石灰岩,层序界面表现为典型的岩性岩相转换面。电性特征方面,自然伽马表现为飞四段膏岩的箱形、漏斗形中高值向嘉陵江组齿状低值突变(图2)。地震剖面上呈连续的波谷反射特征(图3),反映地层整合接触。

3 层序地层特征

基于精细的井-震层位标定与追踪,通过单井层序划分、连井层序对比,以三级层序为单元进行全区层序地层格架搭建,完成区域性层序综合解释。

3.1 剖面展布特征

基于典型地震剖面层序解释(图4)发现:在SQ1层序框架中,高频海平面升降导致多期小规模沉积单元的堆叠,S形前积反射结构是层序识别的关键;SQ2层序呈现“两谷夹一峰”的特征,层序界面在全

区一致性较好;SQ3层序厚度稳定,地震剖面呈现“一谷两峰”特征,顶界波谷连续性较好,在全区可对比追踪。

如JT1井的合成记录(图2)所示,飞仙关组鲕粒灰岩与上覆泥晶灰岩/泥灰岩之间存在强阻抗差异,鲕滩的地震响应表现为强振幅或亮点反射,能够较好地识别。地震解释剖面显示(图4):SQ1层序内可划分出8个地震前积体,鲕滩主要发育于S形前积体的上部,具有规模小、期次多的特点;SQ2层序内鲕滩分布于层序顶部,具有范围大、稳定沉积的特点。

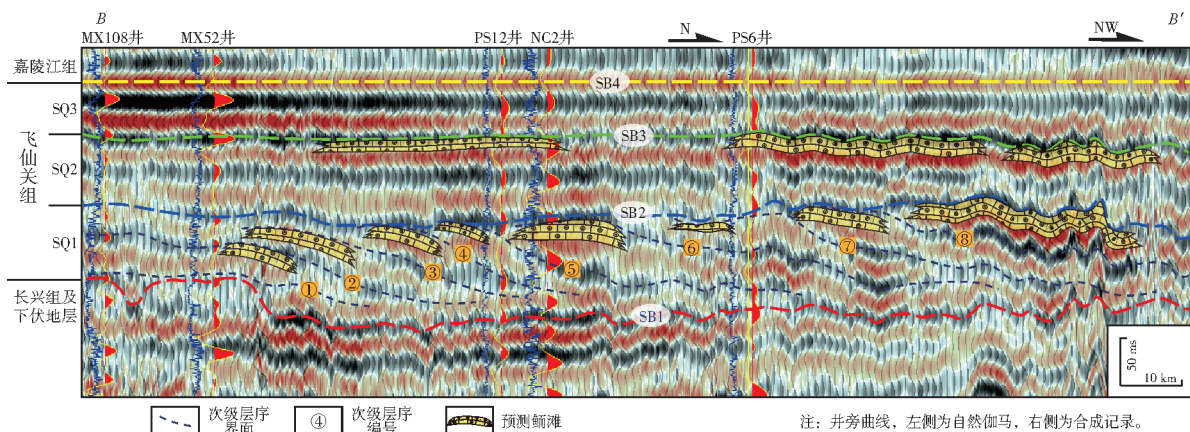


图4 川西北飞仙关组层序B—B'地震解释剖面(拉平嘉陵江组底界。剖面位置见图1a)

Fig. 4 The B—B' seismic interpretation profile of the sequence of Feixianguan Formation in northwestern Sichuan Basin (flatten the bottom of Jialingjiang Formation; the location is shown in Fig. 1a)

在层序界面识别和单井层序划分的基础上,结合区域沉积背景,搭建了垂直于相带展布方向的典型连井层序对比剖面(图5),在层序格架内开展了沉积相对比分析。①SQ1层序充填过程受到下伏长兴组隆凹相间古地理格局的控制,研究区发育开阔台地—台内洼地,PS12井区—NC2井区处于台洼中心部位,从南侧台地往台洼内见到明显的地震前积结构(图4),地层厚度总体上呈现出台洼厚、向南北两侧减薄的特征。SQ1早期以深灰色泥灰岩、泥晶灰岩优势发育为特征;随着相对海退的持续,晚期在台洼的高部位(见于NC2井)、开阔台地(见于JT1井)发育以鲕粒灰岩为主的鲕粒滩,而在南侧MX108井区—MX52井区发育以泥质岩为主的台坪。②SQ2早期随着快速海侵,区内发育以泥质岩为主、泥灰岩夹层的半局限台地,从MX108井区向北一直到NC2井区,分布范围广;北部的PS2井区—CS1井区发育以鲕粒灰岩、泥晶灰岩为主的开阔台地,鲕粒滩的发育呈现出退积特征。层序厚度呈现

出南厚北薄的特征。随着海退的持续,晚期以鲕粒灰岩为特征的开阔台地分布范围扩大,鲕粒滩呈现广覆式发育特征(图4)。③SQ3层序从早期(飞三段)以泥灰岩为主的局限台地,演变为后期(飞四段)以泥岩、白云质膏岩薄互层为特征的蒸发台地,区内该层序分布广,厚度稳定(图4)。

3.2 平面分布特征

对研究区SQ1层序各地震前积体的精细解释表明,该时期的沉积体不断向西北方向进积,从①号到⑧号前积体的平面距离超过140 km(图6a)。受长兴晚期古地貌影响,SQ1层序台洼内可容空间较大,碳酸盐生产率高,平面上地层厚度呈现出中部台洼带厚(150~220 m)、东西两侧台地区薄的特征(图6b)。SQ2层序台洼基本被填平,该时期沉积主要受北东倾向的古地貌影响^[25],平面上地层厚度呈现出西南部厚(150~170 m)、东北部薄的特征(图7)。SQ3层序分布较广,厚度相对稳定(100 m左右)。

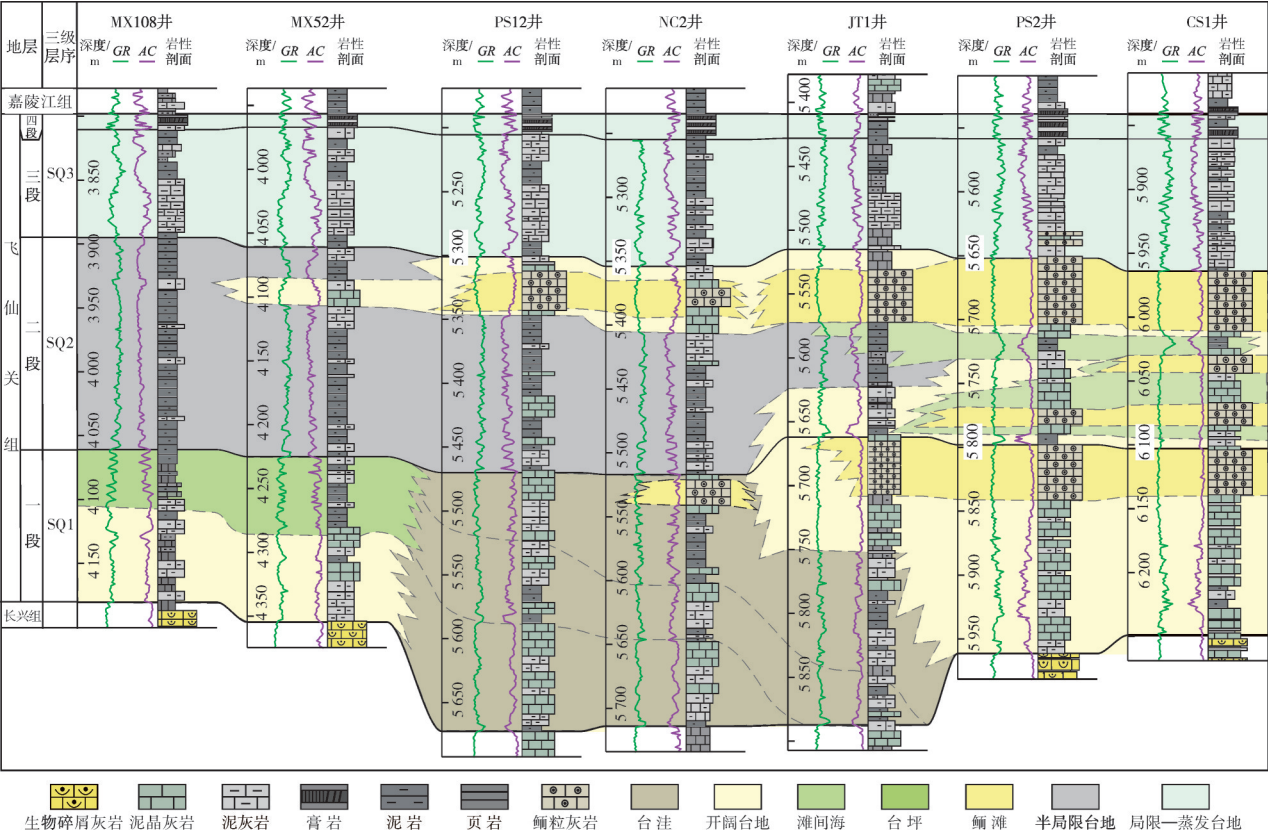
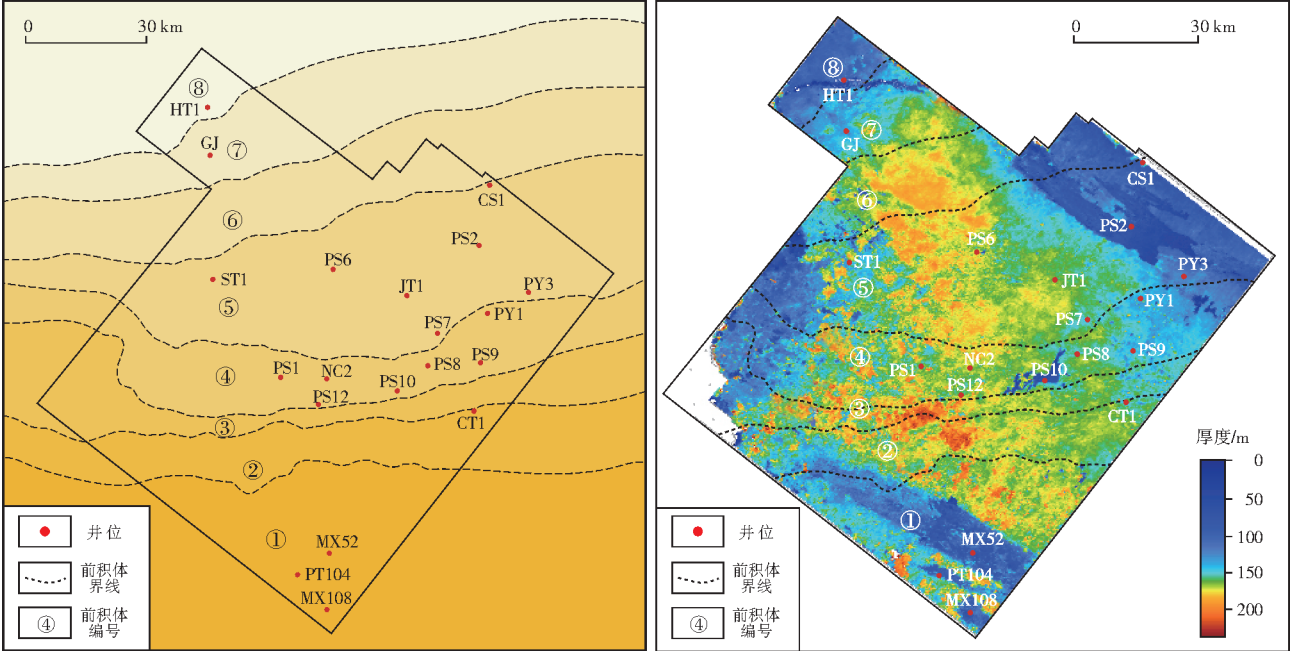


图5 川西北飞仙关组连井沉积相对比图(拉平嘉陵江组底界。剖面位置见图1a)

Fig. 5 Inter-well sedimentary facies comparison section of Feixianguan Formation in northwestern Sichuan Basin (flatten the bottom of Jialingjiang Formation; the location is shown in Fig. 1a)



(a) SQ1层序内前积体平面分布图

(b) SQ1层序厚度平面展布图

图6 川西北飞仙关组SQ1层序前积体平面分布图与层序厚度平面图

Fig. 6 Progradation body distribution plan and thickness map of the SQ1 sequence of Feixianguan Formation in the northwestern Sichuan Basin

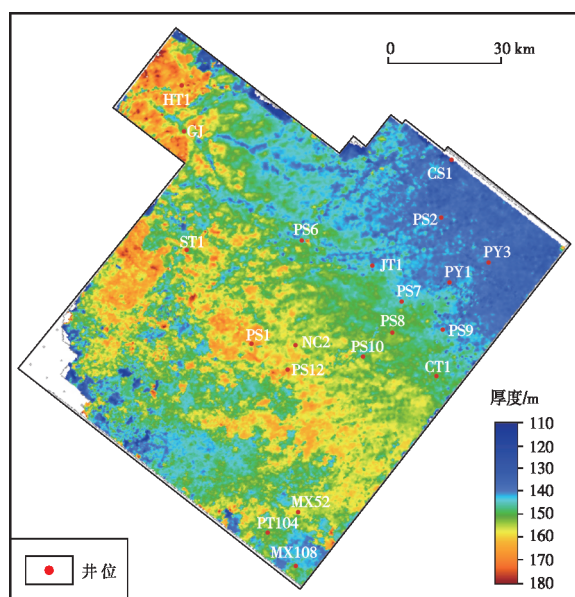


图7 川西北飞仙关组SQ2层序厚度平面图

Fig. 7 Thickness map of the SQ2 sequence of Feixianguan Formation in northwestern Sichuan Basin

4 鲕滩平面展布特征及沉积模式

4.1 鲕滩平面展布特征

基于前述分析, SQ1层序内鲕滩主要发育于S形前积体的顶部, 地震响应呈强振幅(亮点)特征, 而低能相带主要表现为弱振幅特征(图4)。沿SQ1层序内各次级层序的顶界面提取均方根振幅属性, 结果如图8所示。结合图4典型地震解释剖面可知, 每期前积体上部的强振幅区对应鲕粒灰岩发育区, 下部的弱振幅对应泥灰岩发育区; 在平面图上表现出不同岩性分布区从南往北的分异(图8)。整体上看, SQ1层序内鲕滩沿前积体的高部位呈条带状展布, 具有横向快速迁移的特征, 单期鲕滩的规模较小; PS1井区、PS8井区和PY1井区晚期鲕滩均较发育。

沿SB3界面提取均方根振幅(图9), 结果显示SQ2层序内鲕滩主要呈近南北向两个条带稳定分布, 例如东侧PS2井、CS1井揭示鲕滩厚约40 m。

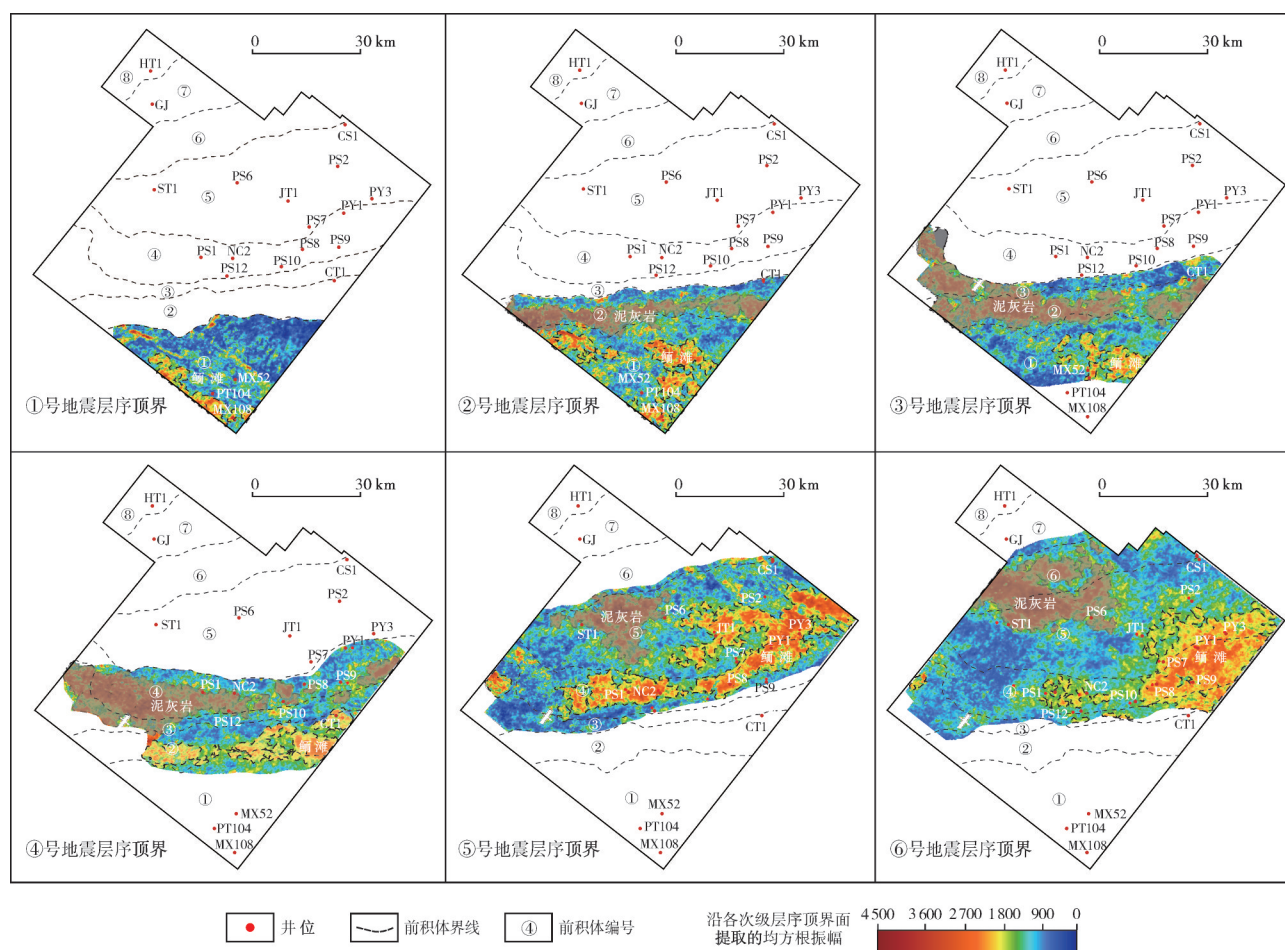


图8 川西北飞仙关组SQ1层序内各次级层序鲕滩预测平面分布图(均方根振幅)

Fig. 8 Oolitic shoal distribution plan predicted by RMS in each secondary sequence of the SQ1 of Feixianguan Formation in northwestern Sichuan Basin

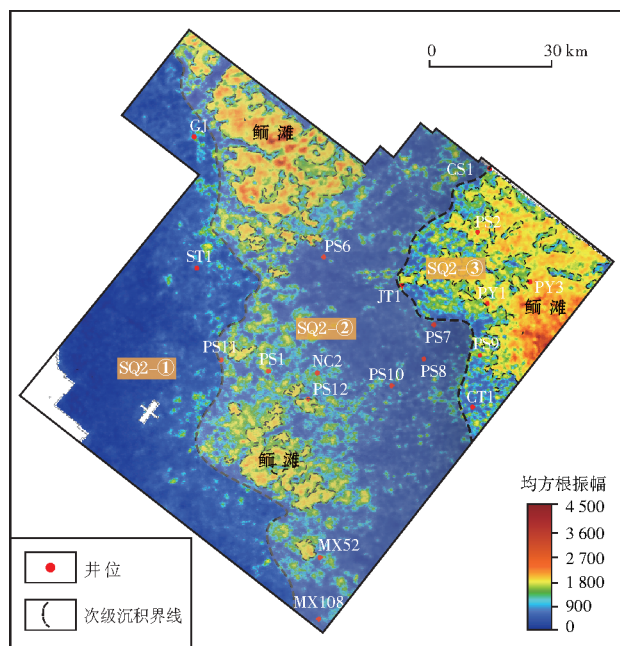


图9 川西北飞仙关组SQ2层序鲕滩预测平面分布图
(均方根振幅)

Fig. 9 Oolitic shoal distribution plan predicted by RMS of the SQ2 sequence of Feixianguan Formation in northwestern Sichuan Basin

4.2 鲕滩沉积模式

综合前述分析,川西北飞仙关组鲕滩存在两类沉积模式:高频限制型鲕滩沉积模式和稳定广覆式鲕滩沉积模式(图10)。

SQ1层序,受二叠纪末期隆凹相间古地理格局控制,在坡折带所围限的台洼内,飞仙关组地层充填模式表现为大规模前积体。鲕滩的发育受到古地貌坡度与海平面变化的影响,主要受到高频海平面升降旋回的控制。海平面上升期,可容纳空间快速增加,水体加深,鲕滩沉积减缓甚至停滞,原有的鲕滩可能遭受侵蚀改造;海平面下降期,可容纳空间减小,碳酸盐生产率相对增加,鲕滩在新的适宜的浅水环境中快速形成并向沉积中心迁移。在SQ1层序内鲕滩呈现横向快速迁移、纵向多期叠置的分布特征(图10);在高频旋回中沉积环境不断变迁,形成了高频限制型鲕滩沉积(图8)。在东北方向的开江—梁平海槽区,受长兴组海槽坡度较大的古地貌影响,SQ1层序表现为镶边台地沉积,具有进积结构特征(图10)。

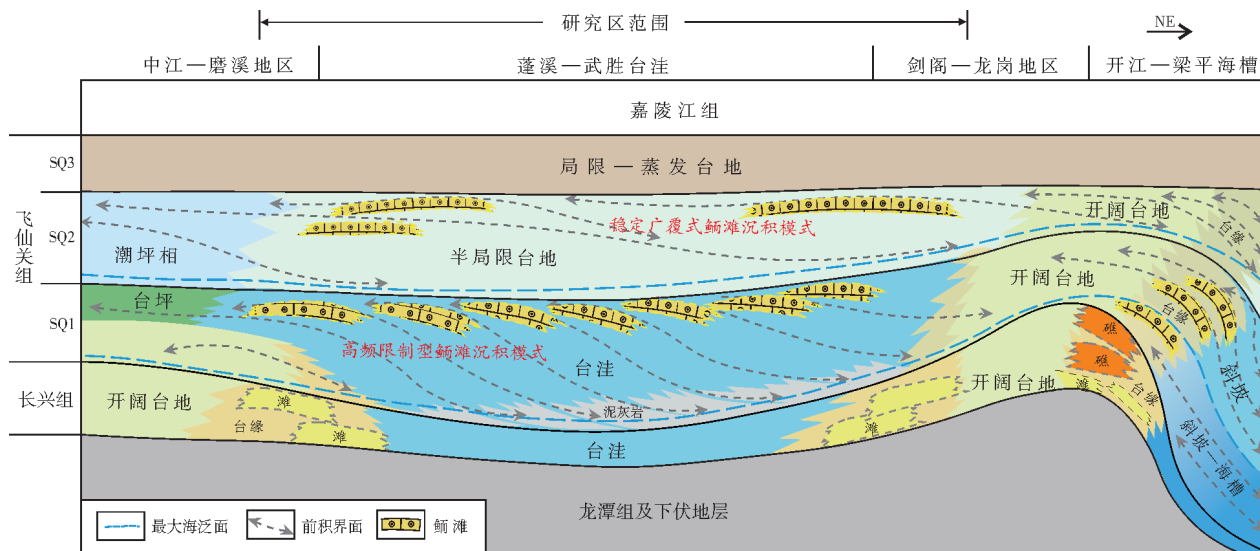


图10 川西北飞仙关组层序及鲕滩发育模式图

Fig. 10 Sequence and oolitic shoal development model of Feixianguan Formation in northwestern Sichuan

SQ2层序,台洼基本被填平,地形整体较缓,地层呈低角度前积反射结构。在三级海平面升降旋回及整体北东倾向的古地貌格局影响下,正地貌区的相对浅水沉积环境为鲕滩发育提供了有利条件,形成稳定的广覆式鲕滩沉积(图10),具有厚度大、范围广的特征。在开江—梁平海槽区,SQ2层序表现为继承性镶边台地沉积,保持进积特征(图10)。

5 结论

(1)在川西北蓬溪—盐亭地区下三叠统飞仙关组识别出4个层序界面,将其划分为3个三级层序。地震响应上,SQ1层序呈现S形进积反射特征,SQ2层序为低角度进积反射特征,SQ3层序表现为连续平行反射特征。

(2)SQ1层序发育多期条带状鲕滩,主要沿各期前积体的上部平行展布,呈北西向叠置迁移特征;SQ2层序的鲕滩厚度较大、范围较广,沿区内正地貌成片分布;SQ3层序内鲕滩欠发育,以泥岩、白云质膏岩互层为特征。

(3)SQ1层序受长兴组沉积晚期古地貌及高频海平面升降旋回控制,发育高频限制型鲕滩沉积;SQ2层序受三级海平面升降旋回控制,发育稳定广覆式鲕滩沉积。

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Stratigraphic sequence evolution and oolitic shoal distribution of the Lower Triassic Feixianguan Formation in Pengxi–Yanting area, northwestern Sichuan Basin

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Abstract: Abundant oil and gas discoveries have been made in the platform edge oolitic shoals of the Lower Triassic Feixianguan Formation in Sichuan Basin. In order to further promote the research and exploration of the inner platform oolitic shoal, based on drilling, logging, and three-dimension seismic data, the sequence characteristics, sequence evolution and oolitic shoal distribution pattern of the Feixianguan Formation in Pengxi–Yanting area, northwestern Sichuan Basin are studied. The results show that: (1) The Feixianguan Formation can be generally divided into three third-order sequences (SQ1, SQ2, SQ3), with typical rock electrical characteristics and seismic response of each sequence boundary. SB1, SB2, and SB3 are all lithological discontinuity surfaces, corresponding to reflection peaks; SB4 is the lithological conversion surface, corresponding to the reflection trough. The four interfaces exhibit abrupt changes in logging responses such as natural gamma and interval transit time. (2) During the deposition period of SQ1 in the study area, the terrain slope was relatively steep, with a high-angle S-shaped progradational reflection structure. Mainly controlled by the sea-level fluctuation cycle of high-frequency sequences, a high-frequency restricted oolitic shoal sedimentary pattern was developed, in which the deposition scale of a single-stage shoal body was small, and the shoal bodies migrated rapidly in the horizontal direction towards northwest. (3) During the deposition period of the SQ2, the platform depression was basically filled, the overall terrain slope was relatively gentle, and the sequence had a low-angle progradational reflection structure. Controlled by the sea-level fluctuation cycle of third-order sequences, a stable and widely distributed oolitic shoal sedimentary pattern was developed, and the single-stage shoal body had a relatively large thickness and a stable planar distribution. (4) The SQ3 sequence had a continuous parallel reflection structure, and restricted-evaporative platform facies was developed, characterized by interbedded mudstone and dolomite gypsum with uniform thickness. This study could provide a geological basis for the fine exploration and efficient development of oolitic shoal reservoirs within the platform of the Feixianguan Formation in northwestern Sichuan Basin.

Key words: sequence; carbonate rock; oolitic shoal; sedimentary model; Feixianguan Formation; Sichuan Basin

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