

北部湾盆地涠西南凹陷 涠洲组二段油气成藏特征分析

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摘要:南海北部湾盆地涠西南凹陷是一个富生烃凹陷,但目前涠洲组二段发现的油气资源规模有限,其成藏特征和规律不清,制约了下一步的勘探方向。通过分析化验、钻井资料和地震资料,对涠洲组二段油气成藏主控因素和成藏规律进行研究,分析表明涠洲组原油主要来自于流沙港组二段中上部厚层优质油页岩,涠洲组二段上层序湖相泥岩是区域上良好盖层。油气主要分布在2号断裂带的沟源断裂附近,沟源断裂是其成藏关键因素;反向断层遮挡的屋脊构造,同时断层断面处断层泥比率(*SGR*)大于0.64、泥岩涂抹系数(*SSF*)小于1.70的断块圈闭成藏概率高,是下一步比较有利的勘探目标和方向。

关键词:断层侧封;沟源断裂;成藏规律;涠洲组二段;涠西南凹陷;北部湾盆地

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Hydrocarbon accumulation characteristics of the 2nd member of Weizhou Formation in the Weixinan Sag, Beibu Gulf Basin

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Abstract: The Weixinan Sag in the Beibu Gulf Basin of the South China Sea is a hydrocarbon-rich sag. However, currently limited oil and gas were found in the 2nd member of Weizhou Formation, and the hydrocarbon accumulation characteristics and laws were unclear, which restricted next exploration direction. The main controlling factors and accumulation rules of oil and gas in the 2nd member of Weizhou Formation were studied based on laboratory tests and drilling and seismic data. The crude oil of Weizhou Formation was mainly originated from the thick oil shale in the central and upper parts of the 2nd member of Liushagang Formation. The lacustrine mudstones in the upper part of the 2nd member of Weizhou Formation provided regional cap rocks. Oil and gas were mainly distributed close to the source rock connected faults of the no.2 fault zone, which were the keys for hydrocarbon accumulation. Fault block traps with roof ridge structures generated by reverse faults and $SGR > 0.64$ and $SSF < 1.70$ at fault sections were favorable for hydrocarbon accumulation, providing an exploration target and direction for the next step.

Key words: lateral sealing of fault; source rock connected fault; hydrocarbon accumulation rules; 2nd member of Weizhou Formation; Beibu Gulf Basin

目前北部湾盆地涠西南凹陷整体已进入高成熟勘探开发阶段^[1],油田开发层位主要为流沙港组一段和涠洲组三段。随着勘探的持续深入,在流沙港组和涠洲组三段寻找优质储量难度越来越大,亟需开阔勘探思路,在新领域、新层位上寻找突破口。而涠洲组二段(以下简称涠二段),由于埋藏深度相对较浅,储层物性较好[孔隙度为15%~35%,渗透率为 $(40 \sim 3\ 000) \times 10^{-3} \mu\text{m}^2$],原油品质也较好(地面密度分布在 $0.807 \sim 0.875 \text{ g/cm}^3$,50℃

动力黏度分布在 $1.58 \sim 9.86 \text{ mPa} \cdot \text{s}$),经济门槛低,开发效果好,是油田内部及周边重要的潜力层,若有发现可借助现有的生产平台或者新平台,将储量快速转化为产量。而目前对涠二段的研究总体上不多,主要集中在构造演化和沉积相上,油气成藏方面的研究程度较低,公开发表的文献也较少。为此,本文通过分析涠二段的油气成藏主控因素,总结其成藏规律和模式,以期指导下一步的勘探方向,最终实现油田的增储上产。

1 区域地质概况

涠西南凹陷位于我国南海北部陆缘北部湾盆地的北部,是一个多层序含油的富生烃凹陷^[2-5],属于典型的“下断上拗”断陷湖盆,构造上总体经历了古近纪断陷期和新近纪拗陷期2大阶段,其中断陷期沉积了长流组、流沙港组和涠洲组陆相地层,拗陷期沉积了下洋组和角尾组等海相地层。涠西南凹陷的主控断层为1号、2号和3号断裂,其中2号断裂位于凹陷中央(图1),在近南北向拉张应力作用下,形成了大量近东西走向的雁列式断层^[6],纵向上发育多套油气组合。研究目的层段涠二段处在湖盆断陷晚期,根据地层特征,涠二段可以分为上、中、下3个层序。其中中层序砂体发育,为主要的储集层;上层序发育大套厚层湖相泥岩,是区域上的盖层,空间上具有良好的储盖组合配置关系。目前涠二段的油气发现主要集中在2号断裂带东段,西段由于涠二段上层序泥岩遭受剥蚀,缺乏盖层,成藏较少。

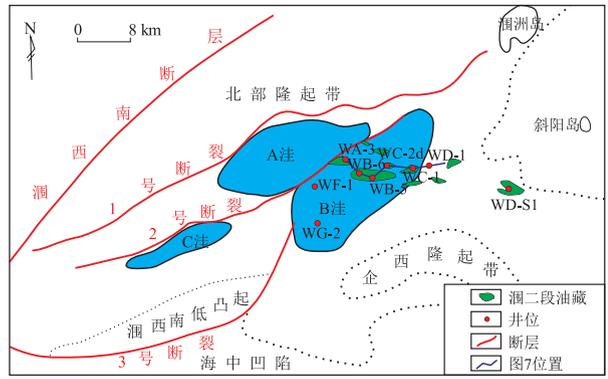


图1 北部湾盆地涠西南凹陷地理位置
Fig.1 Geographic location of Weixinan Sag, Beibu Gulf Basin

2 沉积特征

涠西南凹陷涠二段总体上表现为由水退到水进2个沉积过程,上层序和下层序基本上为高位体系域和湖侵体系域形成的湖相泥岩;而中层序砂体发育,为水退过程中形成的低位体系域三角洲,岩性以细砂岩为主,少量的粉砂岩(图2)。砂岩岩石类型主要为石英砂岩和岩屑石英砂岩,由于涠二段

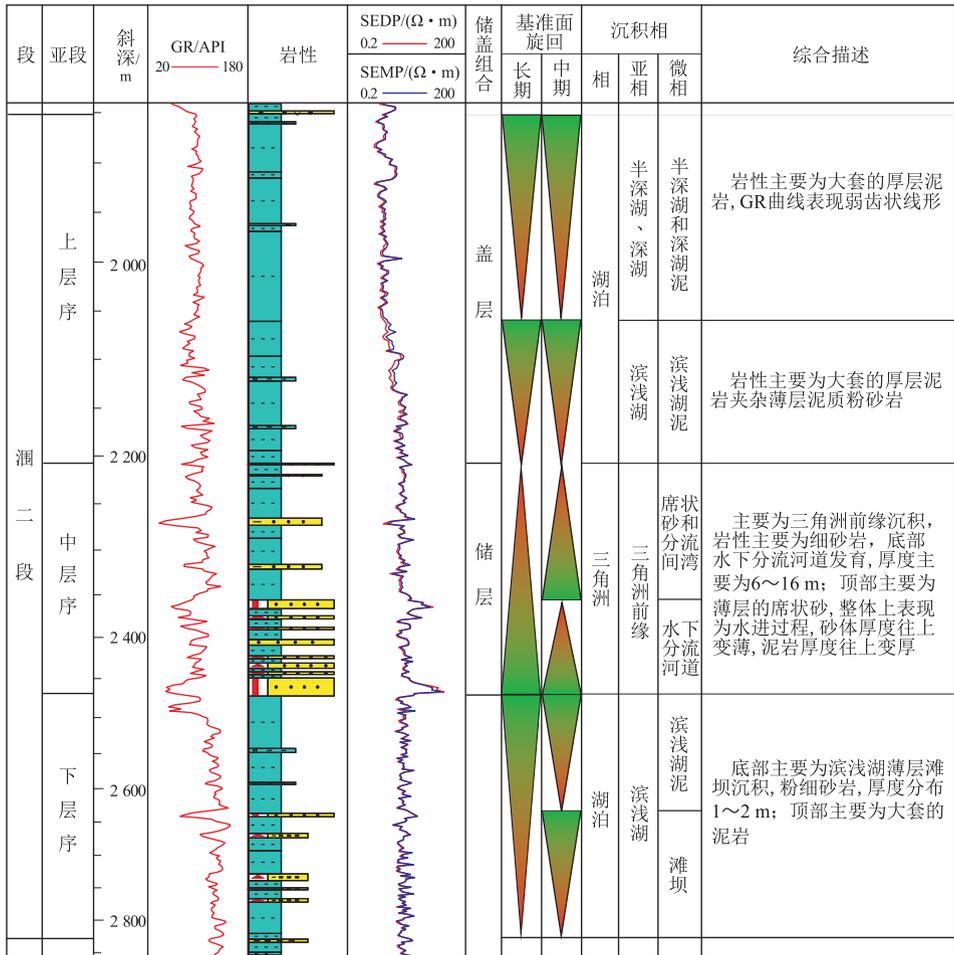


图2 北部湾盆地WB-5单井沉积微相综合柱状图
Fig.2 Single well sedimentary microfacies of well B-5, Beibu Gulf Basin

表 1 北部湾盆地涠西南凹陷涠二段中层序储层特征

Table 1 Reservoir characteristics of the central part of the 2nd member of Weizhou Formation in the Weixinan Sag, Beibu Gulf Basin

油田	井名	砂体厚度 /m	单期河道厚度/m	孔隙度/%	渗透率/ $10^{-3} \mu\text{m}^2$	沉积相
WA	WA-1	41.5	6~19	20.3	516.7	三角洲
	WA-3	52.5	8~13	21.4	677.3	三角洲
WB	WB-5	78.8	7~18	20.0	744.5	三角洲
	WB-6	41.0	10~17	18.7	241.9	三角洲
WC	WC-1	38.4	7~10	24.3	918.6	三角洲
	WC-2d	80.2	9~14	19.1	77.4	三角洲
WD	WD-1	35.9	-	-	-	湖泊
	WD-S1	35.8	5~11	19.2	-	三角洲

沉积期地形坡度较缓,沉积物搬运距离较远,分选磨圆较好,储层物性为中—高孔、中—高渗特征。由于涠二段整体为“泥包砂”沉积环境,砂岩和泥岩波阻抗区分明显,砂体在震上易于识别,表现为强振幅波谷反射特征,泥岩表现为弱振幅反射特征。涠二段中层序分别发育北部(WA 油田)、北东部(WB、WC 和 WD 油田)和南部 3 个三角洲沉积,三角洲分布较广,其中三角洲单期水下分流河道砂体厚度主要分布在 7~13 m(表 1);河道相互切割叠置现象少见,岩心上正粒序、冲刷面和板状交错层理等沉积构造发育。

3 油气成藏主控因素

涠西南凹陷的构造演化特征和沉积背景决定了涠二段油气成藏的主控因素,其油藏类型主要为构造油气藏和构造+岩性隐蔽油气藏。通过油—源对比分析表明,涠二段的油气主要来源于在半咸水—微咸水的中深湖缺氧环境下形成的流二段中厚层湖相富含有机质泥岩和页岩^[7-8]。饱和烃色质实验结果表明,涠二段原油和流二段页岩生物标志物上都表现为:(1)甾烷类化合物,规则甾烷含量较高,重排甾烷含量中等,孕甾烷和升孕甾烷含量

较低,其中规则甾烷中以 C_{27} 、 C_{29} 规则甾烷为主, C_{28} 规则甾烷含量最低,呈“V”型特征(表 2), C_{30} -4 甲基甾烷含量很高,表明其有机质主要来源于藻类等低等水生生物^[9-10]; (2) 萜烷类化合物,以藿烷为主,三环萜烷含量较少,藿烷系列化合物特征与北部湾盆地大多数原油特征类似: $T_s > T_m$, 指征陆源高等植物输入的奥利烷含量低, C_{29} 降藿烷含量高于 $C_{29} T_s$ 含量, C_{30} 藿烷大于 C_{29} 降藿烷, C_{29} 、 C_{30} 莫烷含量也较低,伽马蜡烷含量中—低。Pr/Ph 值达 1.5~1.8,原油成熟度较高,生物标志物显示涠二段原油和流二段页岩具有一定的亲缘关系(图 3)。并且通过原油族组分碳同位素分析也表明,涠二段原油来源于流二段的烃源岩(图 4)。

3.1 盖层

涠二段上层序由于处在大规模湖进沉积过程中,广泛发育大套厚层半深湖—深湖相泥岩,在涠西南凹陷东区沉积的泥岩厚度可达 250~500 m,为中层序的砂体储集层成藏提供了良好的区域性盖层。同时通过正断层错动,使得中层序砂体和上层序泥岩对接,断层的侧封能力较强,有利于油气成藏。

3.2 沟源断裂

沟源断裂通常是油气运移的主要路径,是油气

表 2 北部湾盆地涠西南凹陷涠二段原油和流二段烃源岩抽提物饱和烃色质分析

Table 2 Saturated hydrocarbon GC-MS analysis of crude oil of the 2nd member of Weizhou Formation and source rocks of the 2nd member of Liushagang Formation in the Weixinan Sag, Beibu Gulf Basin

井名	层位	样品类型	深度/m	规则甾烷相对含量/%			Pr/Ph	T_s/T_m	$\alpha\alpha\alpha-C_{29}$ 甾烷 20S/ (20S+20R)
				C_{27}	C_{28}	C_{29}			
WD-S1	涠二段	原油	2 066.5	39.6	16.8	43.5	1.50	1.78	0.47
WD-S1	涠二段	原油	2 100	42.9	16.7	40.4	1.60	1.59	0.43
WB-5	涠二段	原油	2 459	39.3	16.7	44.1	1.64	1.25	0.37
WE-1	流二段	烃源岩	2 813	41.2	15.2	43.6	1.59		0.55
WF-1	流二段	烃源岩	3 344	40.0	13.1	46.9	1.56		0.40
WG-2	流二段	烃源岩	3 352~3 356	45.1	13.2	41.6		1.49	0.61

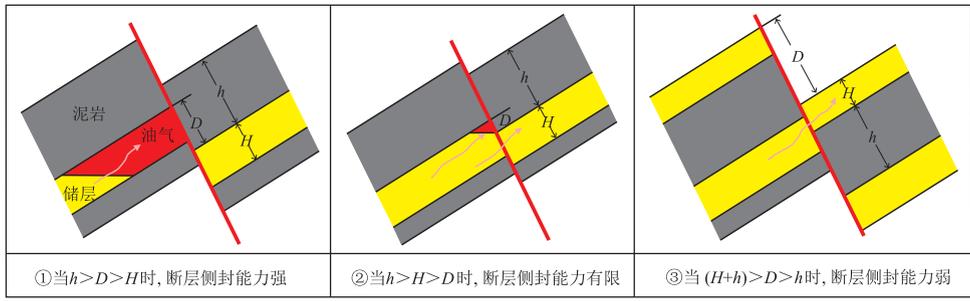


图 5 北部湾盆地涠西南凹陷涠二段侧向封堵能力定性评价

Fig.5 Qualitative evaluation of lateral fault sealing of the 2nd member of Weizhou Formation in the Weixinan Sag, Beibu Gulf Basin

涠西南凹陷涠二段钻探区发现情况的 *SGR* 和 *SSF* 进行统计, 结果表明油层区断面处: $SGR > 0.64$, $SSF < 1.70$; 油水同层区: $0.55 < SGR < 0.64$ 且 $SSF < 2.05$, 或 $SGR > 0.64$, $1.70 < SSF < 2.05$; 水层区: $SGR < 0.55$ 或 $SSF > 2.05$ (图 6)。

4 成藏规律及模式

目前涠西南凹陷涠二段发现的油藏较少, 主要沿着 2 号断裂带附近分布 (图 1), 同时油气充注高度达 30~200 m, 涠二段成藏规律主要表现为:

(1) 油气紧临大型沟源断裂分布, 远离沟源断裂则成藏概率减小。2 号断裂带处于涠西南凹陷 A、B、C 等 3 个富生油洼陷包围中, 是一个凹中隆构造带, 同时 2 号断裂带发育一系列花状和负花状构造, 在涠二段 ($T_7^0-T_7^2$) 形成了大量断鼻和断块圈闭。沟源断裂发育, 有利于直接沟通流二段烃源岩和涠二段中层序发育的低位体系域三角洲储层; 并且 2 号断裂带在新近纪早期停止活动, 前期形成的油藏遭受破坏较少^[24]。当这些沟源断裂发生周期性活动时, 随着断层带压力的释放, 成熟的烃源岩

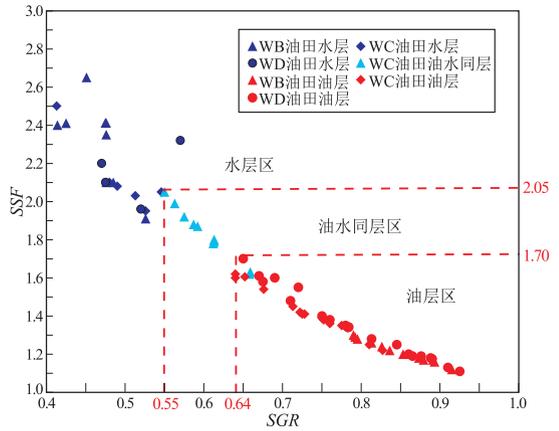


图 6 北部湾盆地涠西南凹陷涠二段侧向封堵能力定量评价图版

Fig.6 Quantitative evaluation of lateral fault sealing of the 2nd member of Weizhou Formation in the Weixinan Sag, Beibu Gulf Basin

排出大量的烃类流体, 沿沟源断裂向上和构造脊运移成藏 (图 7)。由于 $(\alpha\beta\beta - C_{29} \text{ 甾烷 } 20R) / (\alpha\alpha\alpha - C_{29} \text{ 甾烷 } 20R)$ 参数可以表征油气运移距离, 其值多分布在 0.7~0.9, 值小于 1, 表示运移距离较短^[25], 靠近沟源断裂运移成藏。而远离沟源断裂, 由于油

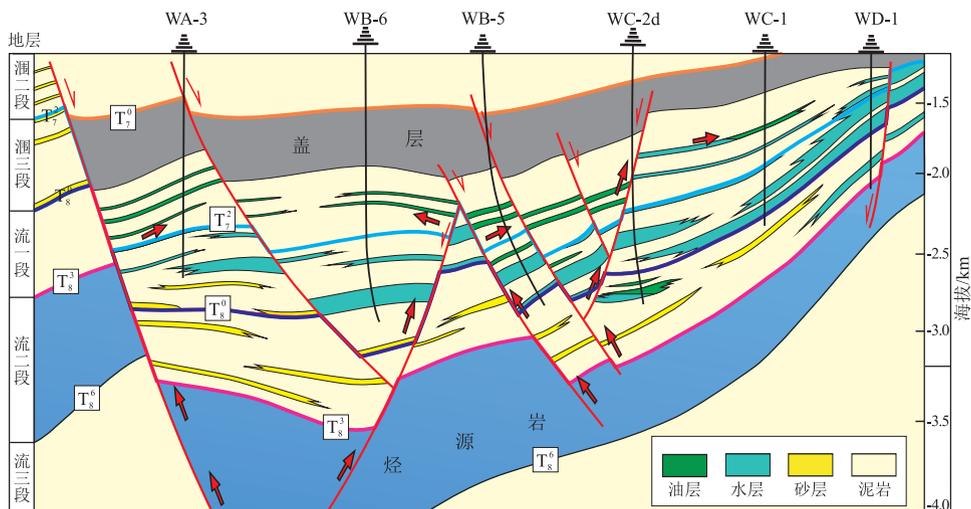


图 7 北部湾盆地涠西南凹陷涠二段成藏模式

Fig.7 Hydrocarbon accumulation model of the 2nd member of Weizhou Formation in the Weixinan Sag, Beibu Gulf Basin

气充足强度和运移通道等原因,成藏概率减小,在WD-1井没有钻遇油层,只有油气显示。

(2)反向断层遮挡的屋脊构造造成藏概率高。这类断块油藏特征就是断层的倾向与储层倾向相反,两者搭在一起,形似“屋脊”。反向断层具有良好的封闭性^[26],主要是因为反向断层与目标盘储层对接的是滑动破碎带,同时遮挡物通常为对接盘的泥岩,侧封能力强;而倾向断层与目标盘储层对接的是诱导裂缝带,遮挡物通常为断层岩,侧封能力稍弱^[27]。涠西南凹陷区域统计结果显示,在涠二段已成藏构造圈闭中,由反向遮挡形成的油藏占95%;断层封堵能力越强,成藏概率越高,同时断层的上升盘比下降盘更容易成藏,可作为重点勘探目标^[28]。通过这种成藏规律和模式,在2016年指导钻探了WC-1井,在涠二段钻遇了7.8 m的优质油层,其孔隙度可达25.4%,渗透率达 $1\ 386.2 \times 10^{-3} \mu\text{m}^2$ 。

5 结论

(1)涠二段可以分为上、中、下3个层序,其中中层序发育低位体系域三角洲砂体,为主要的储集层;上层序发育湖侵和高位体系域厚层湖相泥岩,为区域上的稳定盖层,空间上具有良好的储盖组合特征。涠二段目前油气发现主要集中在2号断裂带东段,西段涠二段上层序泥岩遭受剥蚀,缺乏盖层,成藏较少。

(2)涠二段油藏类型主要为构造和构造+岩性油藏,油气紧临大型沟源断裂分布,远离沟源断裂则成藏概率减小。油气先沿着沟源断裂垂向运移,再沿着构造脊砂体横向运移,高部位断层的侧封能力是圈闭有效性的关键,反向断层遮挡的屋脊构造造成藏概率高。

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