川西白马庙地区上侏罗统蓬莱镇组天然气成藏研究

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摘　要　本文通过烃源岩生烃史、油气运移史和成藏史分析,对川西白马庙地区上侏罗统蓬莱镇组天然气成藏进行研究。首先,采用有机相分析、埋藏史分析、TTI 计算和生烃率法,建立了烃源岩生烃史:上三叠统泥质岩和煤为烃源岩,侏罗纪末进入生油门限,早白垩至晚白垩世进入成熟期,晚白垩至今处于高成熟期,总生烃量为 11 506 $\times10^8 m^3$。其次,采用平衡浓度法计算天然气运移量为 2 646.6 $\times10^8 m^3$,且散失量小,分子扩散相运移对蓬莱镇组天然气成藏起决定性作用。然后,结合生排烃史分析,采用流体包裹体分析技术确定关键时刻早第三纪。最后,通过分析蓬莱镇组天然气成藏的基本要素及其时空配置关系,建立了蓬莱镇组天然气的成藏模式,动态地再现了天然气成藏的地史过程。

主题词　四川盆地　西　上侏罗统　天然气　烃源岩　流体包裹体

白马庙区域构造隶属于成都凹陷低缓构造带,整体上是一个北东向倾没的大型潜伏断鼻隆起,南北长 45 km,东西宽 30 km,隆起面积大于 600 km^2。

区内侏罗系地层发育齐全,包括上统的蓬莱镇组、遂宁组,中统的沙溪庙组和下统的自流井组,与上覆白垩系和下伏三叠系呈假整合接触。

烃源岩生烃史

1. 烃源岩有机相分析

根据 TOC、R_o、干酪根显微组分含量、干酪根类型及环境特征,对上三叠统须家河组和中下侏罗统岩层进行了有机相划分。上三叠统须一段:有机碳含量 2.25 %,壳质组含量近 50 %,有机质类型较其它几层好,干酪根类型为 Ⅱ型,沉积环境为浅海陆棚,岩性以黑色页岩、碳质页岩为主,有机相为 B 相;须三段:有机碳和干酪根显微组分含量介于须一和须五之间,沉积环境为三角洲—湖泊,岩性以黑、灰黑色页岩夹煤层,BC 相;须五段:由于碳质含量大,3 529.6 m 及 3 539.4～3 552.2 m 有煤 10 层,共厚 13.5 m。白田坝组煤系亦也可成为须五段的烃源。

须家河组气藏属于煤成气,已往的文献已有论述,该区煤系地层发育,但生烃量需进一步研究。

结　论

由上述分析,思依 1 井须五气藏具有深盆气特征,该井相对低压异常的出现,标示了深盆含气范围。即含气面积不限于思依场构造圈闭。根据四川局地调处 1989 年资料所作的须二顶面构造图,思依场构造圈闭线为 - 4 000 m,而思依 1 井位于 - 4 050 m,在圈闭线以外。认为 - 4 050 m 线以下的苍溪—阆中凹陷均是含气的深盆区。仅苍溪—阆中一线以西的深盆面积有 700 km^2。魏城 1 井出现了相对高压异常,须五段砂体测井解释已属气水层,推测剑阁—绵阳凹陷也可能是含气的深盆区。

深盆气藏具有规模大,地质储量大,产能低的特点。之所以出现工业性气田,是由于致密岩层系中,存在常规储层带。如滩相的砂砾岩带及裂缝带。该区须五下砂岩体是以河流相沉积为主夹河口砂坝相沉积,上砂岩段为河流相沉积。河流相沉积砂体的中下部及河口砂坝砂体的中上部储层物性相对变好。河道砂体底部为滩相砾岩层,裂缝发育。思依 1 井的井漏、井涌显示和主要产气层段就在此位置。要提高该类气藏的单井产量,压裂技术是必需的。

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其有机碳含量达 14.02 %,壳质组和类质组含量低于 20 %,镜质组和丝质组含量较须一、须三高,沉积环境为湖沼,岩性以黑、灰黑色页岩夹煤层,C 相;中下侏罗统:有机碳含量极低,小于 0.1 %,沉积环境为河湖,岩性为紫红色泥岩,氧化环境,D 相(表 1)。

从上三叠统须一至中下侏罗统,有机相类型由

表 1　川西地区南部上三叠统—中侏罗统有机相特征表

地层	TOC (%)	R_o (%)	干酪根显微组分含量(%)			干酪根类型	环境特征	有机相
			壳质+类脂组	镜质组	丝质组			
T_3x^1	2.25 (10)	2.05 (10)	48.57	13.86	37.54	Ⅱ型	浅海陆棚相、黑色页岩、碳质页岩	B 相
T_3x^3	7.77 (15)	1.74 (15)	36.14	20.96	42.9	Ⅲ型	三角洲—湖泊相、黑、灰黑色页岩夹煤层	BC 相
T_3x^5	14.02 (29)	1.21 (29)	18.44	35.24	46.24	Ⅲ型	湖沼相、黑、灰黑色页岩夹煤层	C 相
J_{1+2}	<0.1 (6)	<1.0 (6)	/	/	/	/	河湖相、紫红色泥岩、氧化环境	D 相

注:TOC、R_o 值为平均值,括号中数值为样品数;干酪根显微组成分含量引自关效如,1991 年。

B 相→BC 相→C 相→D 相。有机相反映了各层的生烃条件,B 相条件最好,依次为 BC 相和 C 相,D 相最差。另外,中下侏罗统泥质岩 TOC 一般小于 0.1 %,远低于泥质岩作为烃源岩的最低限值(0.5 %);氯仿沥青"A"含量极低。从而说明中下侏罗统紫红色泥质岩生烃潜力极差。因此,上侏罗统蓬莱镇组的气源岩为上三叠统的泥质岩和煤。

2. 烃源岩埋藏史

上三叠统地层在晚三叠末—早侏罗世初发生轻微抬升,少量地层被剥蚀;整个侏罗纪的大部分时间里,地层一直处于沉降阶段,以晚侏罗世沉降最快,沉降速率为 80 m/Ma,须五底最大埋深近 3 500 m;早白垩世没有沉降;晚白垩世至早第三纪又发生沉降,最大沉降速率达 140 m/Ma,最大埋深近 5 000 m;晚第三纪以后地层又抬升,抬升速率 20 m/Ma,最浅埋深小于 4 000 m,剥蚀地层厚度约 1 400 m;第四纪地层又有轻微沉降。

3. 烃源岩生烃史

根据 TTI 计算结果:侏罗纪末,TTI 达到 15,烃源岩进入生油门限;早白垩世至晚白垩世,TTI 为 15～75,进入成熟期;晚白垩世末,TTI > 75,进入高成熟期。采用生烃率法计算须三—须五段生、排气量,参数选取:地层厚度、泥质岩厚度、煤层厚度、TOC 均取平均值;密度、恢复系数、生气率、排气率参考四川盆地第二轮油气资源评价取值。计算结果:在地史过程中须五段生烃量为 6 240 $\times10^8m^3$,须三段生烃量为 5 266 $\times10^8m^3$,总计 11 506 $\times10^8m^3$(表 2)。

综上所述,上侏罗统蓬莱镇组的烃源岩为上三叠统的泥质岩和煤。上三叠统地层在地史过程中,经历了三叠纪末—早侏罗世初、晚第三纪的两次抬升,早白垩世没有沉降。其它时间为沉降时期。侏罗纪末,烃源岩进入生油门限;早白垩至晚白垩世,进入成熟期;晚白垩至今处于高成熟期。在地史过程中,须五和须三段总生烃量为 11 506 $\times10^8m^3$。

表 2　白马庙地区上三叠统须三—须五生、排气量计算表 *

层位	地层厚度 (km)	泥质岩厚 (km)	煤层厚度 (km)	面积 (km^2)	密度 ($10^8t/km^3$)		TOC (%)	恢复系数	生气率 (m^3/t)		生气量 (10^8m^3)	排气率	排气量 (10^8m^3)
					D1	D2			R1	R2			
T_3x^5	0.85	0.5	0.01	600	26	14.2	3.2	1.07	23.2	14.2	6 240	0.45	2 808
T_3x^3	0.15	0.1	0.005	600	26	14.2	3.2	1.24	83.3	64.7	5 266	0.2	1 053
总计	1.0	0.6	0.015								11 506		3 861

* R1 为干酪根视生气率,R2 为视煤气发生率,D1 为泥质岩密度,D2 为煤岩密度,排气率——相对上侏罗统蓬莱镇组储层而言。

油气运移史

1. 白马庙地区天然气运移模式

天然气一般要经历 4 个运移阶段:水溶相、油溶

相、游离相和分子扩散相运移。各地区只在发生这4个运移阶段的时间上有所不同,以及各阶段在成藏的重要性上有所不同。白马庙地区天然气在侏罗纪以水溶气相运移为主,运移动力为压实、渗析作用等;白垩纪主要以油溶气相、游离相运移为主,运移动力为压实、蒙脱石脱水、有机质生烃作用等;晚白垩纪之后,受强烈构造挤压作用影响,地层已变得致密,天然气主要以扩散相运移为主,运移动力为分子扩散作用等。

2. 利用平衡浓度方法计算天然气扩散量

(1) 原理

在天然气分子从高浓度源岩向相邻低浓度地层扩散的过程中,最终两者的浓度趋于一致,这时地层中的浓度即为平衡浓度。由于扩散是个连续过程,所以它实际上是个理论上的瞬时浓度,在此瞬间可以认为整个地层具有相同的浓度。求得每一地层的平衡浓度后,就可利用费克第二定律解决诸如扩散到每层的时间、扩散量、扩散散失量、扩散速率等问题(具体计算方法见参考文献[2])。

(2) 分子扩散相运移对上侏罗统蓬莱镇组气藏的意义

从模拟结果分析,分子扩散相运移对上侏罗统蓬莱镇组天然气的成藏起了决定性作用。表现在:①天然气运移量大,为2 646.6 $\times10^8 m^3$。若考虑断层、裂缝对扩散运移的促进作用,则运移量会更大;②运移至储层的时间远在盖层形成之后,因此绝大部分天然气都保存在储层之中;③由于断层向上仅断至上侏罗统蓬莱镇组,对盖层没有破坏作用。加上盖层本身的封闭性能好,因此对气藏起了很好的保存作用。通过盖层的散失量仅为7.6 $\times10^8 m^3$。

综上所述:对上侏罗统蓬莱镇组天然气成藏来说,分子扩散相运移起了决定性作用。天然气运移量大,运移至储层的时间远在盖层形成之后,因此绝大部分天然气都保存在储层之中。

表3　白马庙地区天然气扩散量模拟结果表

地层	地层厚度(km)		地层体积(km^3)		含气量/初始浓度	平衡浓度($10^8 m^3/km^3$)	扩散时间(Ma)	扩散量($10^8 m^3$)		扩散速率($10^8 m^3$/Ma)
	单层	累计	单层	累计				单层	累计	
Q	0.12	3.65	72	2 190	3 861/6.435	1.763				
K_2g 盖层	0.35	3.53	210	2 118		1.823	125	7.6	2 654.2	
K_2j	0.25	3.18	150	1 908		2.024	73.32	103.2	2 646.6	20.52
J_3p 储层	0.8	2.93	480	1 758		2.196	68.15	495	2 543.4	24.48
J_3s	0.3	2.13	180	1 278		3.021	47.93	297	2 048.4	30.87
J_2s	0.65	1.83	390	1 098		3.516	38.31	1 162.2	1 751.4	41.79
J_1z	0.18	1.18	108	708		5.453	10.5	589.2	589.2	56.11
$T_3x^{3\sim5}$ 烃源层	1	1	600	600		6.435	0	0	0	

注:地层厚度、地层体积取平均值。

关键时刻的确定

关键时刻是指一个油气系统中烃类生成—运移—聚集的时刻(Leslie B. Magoon 和 Wallace G. Dow, 1994年)。对白马庙地区来说,气藏为构造—岩性气藏,且构造是继承性发展的产物。因此,关键时刻就是大部分油气运移至上侏罗统蓬莱镇组砂岩储层的时刻。

1. 采用流体包裹体确定关键时刻

上侏罗统蓬莱镇组砂岩方解石胶结物中的原生天然气包裹体均一温度93.8～110 ℃,平均100.2 ℃。根据地温梯度2.72 ℃/100 m,推算出其地史时期的深度为3 600 m。考虑地层压实因素,推测流体包裹体的捕获时间为早第三纪。因此,采用流体包裹体确定的关键时刻为早第三纪。

2. 采用天然气扩散时间确定关键时刻

根据前面的计算结果:油气从源岩运移到上侏罗统蓬莱镇组需要68.15 Ma,约在57 Ma前(早第三纪)绝大部分天然气扩散到上侏罗统蓬莱镇组。因此,采用天然气扩散时间确定的关键时刻为早第三纪。

综上所述,采用流体包裹体和采用扩散时间计算的关键时刻互相吻合,都为早第三纪。所以,早第三纪为上侏罗统蓬莱镇组的成藏期。

蓬莱镇组天然气成藏体系

1. 成藏基本要素

蓬莱镇组天然气成藏基本要素如下:①烃源岩:

上三叠统须五段为主要烃源岩,须三段为次要烃源岩;②储层条件:蓬莱镇组储层储集类型属裂缝—孔隙型,平均孔隙度为 11.69%,平均渗透率为 1.46 × $10^{-3}\mu m^2$;③区域盖层为上白垩统灌口组的泥质岩夹石膏;④运移作用:早期油气呈溶解相态运移,中晚期以分子扩散相运移为主;⑤聚集作用:早第三纪,大部分天然气通过分子扩散作用,运移至蓬莱镇组储层,并聚集成藏;⑥保存条件:蓬莱镇组气藏形成后,保存条件不错。断层均未断至盖层,对气藏无破坏作用。

2. 成藏模式

须五段生成的油气在晚白垩达高成熟,以分子扩散相的形式向上运移。须三段生成的油气运移至须五段,对须五段的油气起补充作用。大兴⑤号断层本身是油气垂向运移的良好通道,同时伴随断层"末端效应"和"侧向效应"派生的一系列微裂缝,可改善储层的疏导条件,大大促进了油气的成藏(图 2)。

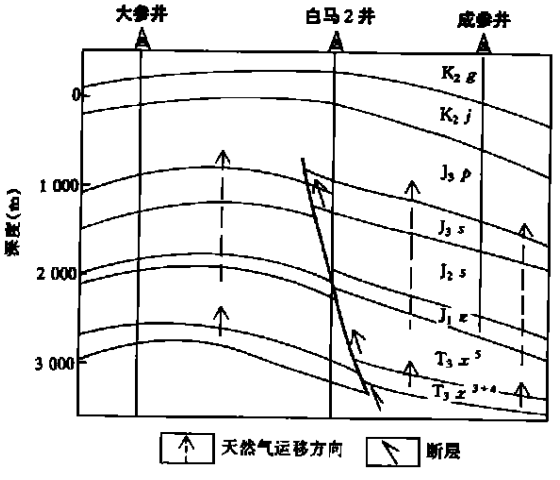

图 2　白马庙地区上侏罗统蓬莱镇组天然气成藏剖面图

综上所述:通过分析蓬莱镇组天然气成藏的基本要素及其时空配置关系,建立了蓬莱镇组天然气的成藏模式,动态地再现了天然气成藏的地史过程。

结　论

川西白马庙地区上侏罗统蓬莱镇组的烃源岩为上三叠统的泥质岩和煤。侏罗纪末,烃源岩进入生油门限;早白垩世至晚白垩世,进入成熟期;晚白垩世至今,处于高成熟期。在地史过程中,须五段和须三段生烃量总计 11 506 × $10^8 m^3$。分子扩散相运移对上侏罗统蓬莱镇组天然气成藏起了决定性作用。早第三纪为上侏罗统蓬莱镇组天然气的成藏期。通过分析蓬莱镇组天然气成藏的基本要素及其时空配置关系,建立了蓬莱镇组天然气的成藏模式。

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ABSTRACTS AND AUTHORS

RECOGNITION OF XUJIAHE FORMATION (T_3x) GAS RESERVOIRS IN WEST SICHUAN DEPRESSION

Wang Jinqi (Southwest Petroleum Bureau of Star Petroleum Corporation, Sinopec). *NATUR. GAS IND.* v. 22, no. 2, pp. 1～6, 3/25/2002. (ISSN1000-0976; **In Chinese)**

ABSTRACT: The source-reservoir-caprock assemblage and early non-structural trap formation are controlled by the basin-structural sedimentary formations over and under T_3x. The superpressures mainly result from sustained hydrocarbon-generation and compaction seal and the current geopressure circumstances are the result caused by late tectonic movements. Because the thick T_3x^3 mudstones are not only the source rocks but also the pressure confining beds, the T_3x^2 sandstones may be rich in gas resources. A theoretical characteristic pattern of T_3x gas reservoir formation in West Sichuan Depression was set up, in which the combination of early accumulation with late structure is emphasized. The key factor is the fissure-formed capacity of the late anticline, because of a general super compactness found in T_3x reservoir. Owing to the fact that the relation between the reservoir formation and the hydrocarbon stagnancy and retrapping was very complicated in geological history, it is not easy to find a gas field with large reserves in T_3x. Therefore it is necessary to make a real development in both gas reservoir formation theory and exploration technology. This paper is written for above purpose.

SUBJECT HEADINGS: Sichuan Basin, West, Xujiahe Formation, Gas reservoir, Structural formation, Superhigh pressure seal, Stress sensitivity damage, Characteristic pattern, Timely accumulation, Late retrapping, Fissure-formed capacity

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CHARACTERISTICS OF DEEP-BASIN GAS IN T_3x^5 RESERVOIR IN NORTHWEST SICHUAN TRACT

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ABSTRACT: The fifth member of Xujiahe Formation of Upper Triassic (T_3x^5) is widely distributed over all the Northwest Sichuan tract and in its lower part, there are up-and-down two sandstone intervals with thicknesses of 24.4～28.4 m and 92.8～145.8 m respectively. According to the comprehensively geological and logging interpretation, the gas found in T_3x^5 reservoir is of the characteristics of deep-basin gas. Tectonically this tract may be divided into three belts, i.e. central uplift belt, east seg belt and west seg belt. Commercial natural gas was found in the well Siyi-1 at the west slope of the east seg and the elevation of the bottom surface of gas-producing interval is below that of the bottom of T_3x^5 in each of the 27 wells at the central uplift belt. In light of log data, the reservoirs in various wells at the central uplift belt are water-bearing strata, being of high porosity, high formation water resistivity and high water saturation; and those at the east and west seg belts are gas-bearing or gas- and water-bearing strata, being of low porosity, low formation water resistivity and low water saturation. The formation pressure coefficients of the central uplift belt range from 1.746 to 1.857, those of the west seg belt are more than 2 and those of the east seg belt near 1, two (high/low) pressure abnormal areas being formed. Because the coal beds are well developed in T_3x^3, T_3x^5 and Baitianba Formation in this tract, the coal-formed gas is the major hydrocarbon source of the gas reservoirs. It is considered that the T_3x^5 gas reservoir found by the well Siyi-1 belongs in a deep-basin gas reservoir; the extensive east seg is a gas-bearing deep-basin area; and the west seg is also possessed of the characteristics of the deep-basin area.

SUBJECT HEADINGS: Sichuan Basin, North, Late Triassic Epoch, Deep basin, Gas reservoir

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RESEARCH ON NATURAL GAS RESERVOIR FORMATION IN PENGLAIZHEN FORMATION

OF UPPER JURASSIC AT BAIMAMIAO REGION IN WEST SICHUAN BASIN

Liu Chenglin (University of Petroleum, Beijing), Li Jingming (Langfang Branch of RIPED) and Men Xiangyong (RIPED). *NATUR. GAS IND.* v. 22, no. 2, pp. 10～13, 2/25/2002. (ISSN1000-0976; **In Chinese)**

ABSTRACT: Through analyzing the history of hydrocarbon generation, oil and gas migration and reservoir formation, the natural gas reservoir formation in Penglaizhen Formation of Upper Jurassic at Baimamiao region in West Sichuan Basin is discussed in the paper. First, in light of organic facies and buried history analyses, TTI calculation and hydrocarbon generation factor method, the hydrocarbon generation history of source rocks is established, i. e. the argillaceous rocks and coal are the source rocks, the oil generation threshold was entered into at the end of Jurassic, the mature stage ranged from Early Cretaceous to Late Cretaceous and the high mature stage began at Late Cretaceous, the hydrocarbon generating quantity being 11 506 × $10^9 m^3$ in total; second, the natural gas migration volume estimated with balance density method was 264.66 × $10^9 m^3$ with a little loss, in which the molecular diffusion migration volume played a decisive role in the gas reservoir formation in Penglaizhen Formation, and the critical moment of hydrocarbon migration was Paleogene according to the research on generating and expelling hydrocarbon histories and fluid inclusion analysis; and third, through analyzing the basic factors of forming gas reservoirs in Penglaizhen Formation and their space-time matching relations, a pattern of natural gas reservoir formation in Penglaizhen Formation is set up, by which the process of geological history of gas reservoir formation is reproduced dynamically.

SUBJECT HEADINGS: Sichuan Basin, West, Late Jurassic Epoch, Natural gas, Organic facies, Critical moment, Fluid inclusion

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PROSPECTS FOR EXPLORING FOR OIL AND GAS IN SHAXIMIAO FORMATION AT JINMA-JUYUAN REGION

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ABSTRACT: Through studying the factors controlling reservoir formation, such as tectonic evolution during Yanshan Epoch, seismic facies distribution and hydrocarbon-preserved conditions, etc., at Jinma-Yazihe region on the basis of analyzing the current situation of oil and gas exploration at this region, it is put forward that the palaeohigh had occurred in Middle-Late Yanshan Epoch at Juyuan-Chonghuo region and there were four beneficial factors of oil and gas reservoir formation in Shaximiao Formation at the region, i. e. ① the early traps timely formed with the palaeohigh in Middle-Late Yanshan Epoch; ② an abundant gas source in Xujiahe Formation and a fair reservoir-seal assemblage of fan delta; ③ structural and lithological preservation function to the early traps; and ④ an improvement on tight reservoirs by the faults and fractures occurred during Himalayan Epoch. For this reason, it is determined finally that the main factor controlling oil and gas reservoir formation in Shaximiao Formation at Juyuan-Chonghuo region is the early trap timely formed with the palaeohigh in Middle-Late Yanshan Epoch, so it is a lithologic-(palaeo) structural combination trap.

SUBJECT HEADINGS: Jinma-Juyuan region, Shaximiao Formation, Middle-Late Yanshan Epoch, Palaeohigh, Exploration prospect

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APPLICATION OF IMPROVED SIMULATED ANNEALING ALGORITHM IN MATERIAL BALANCE CALCULATION OF WATER-DRIVE GAS RESERVOIR

Zeng Yan (Chengdu College of Technology) and Guo Chunhu (Southwest Jiaotong University). *NATUR. GAS IND.* v. 22, no. 2, pp. 18～21, 3/25/2002. (ISSN1000-0976; **In Chinese)**

ABSTRACT: The similarity between solid particle annealing and combined optimization was realized by Kirkpatrick in 1982. Therefore he put forward a simulated annealing algorithm and proved mathematically that an overall optimization solution might be obtained by use of the algorithm. Comparatively, only a partial optimal solution could be got by applying the traditional