

蜀南地区天然气地质特征及勘探方向

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李其荣等. 蜀南地区天然气地质特征及勘探方向. 天然气工业, 2009, 29(10): 21-23.

摘 要 为寻找四川盆地南部老探区(以下简称蜀南地区)下 1 步勘探有利区带, 系统分析确认该区基本地质特征, 具有: 多期构造旋回发展演化, 沉积层系相对完整, 多源供烃、多储层层系及圈闭类型、多期成藏及多个含油气系统等特点。通过对老井重新认识, 结合勘探成效及研究成果, 认为近期蜀南地区研究和勘探的重点是: ①深化二叠系、三叠系勘探是目前“增储、上产”的关键; ②主攻上三叠统须家河组气藏是近期天然气储量大幅度增加的重点; ③古隆起外围雷口坡组是近期找气的重点层系; ④下古生界及震旦系是寻找天然气发现的新领域; ⑤页岩气藏将是蜀南地区非常规油气勘探开发的新领域。

关键词 四川盆地 南部 天然气 地质特征 勘探方向 晚三叠世 深层 页岩气

DOI: 10. 3787/j. issn. 1000-0976. 2009. 10. 006

蜀南地区位于四川盆地南部, 西起四川省乐山市—云南省绥江市, 东至重庆市綦江县, 北接简阳市—乐至县, 南抵贵州省赤水市, 勘探开发面积达 $4.99 \times 10^4 \text{ km}^2$ 。大地构造位置属于川东南断褶带西南段和川中古隆平缓构造带西南段, 地层发育较全, 出露最新地层为侏罗系及白垩系, 基底为前震旦系板溪群变质岩系, 震旦纪至中三叠世为海相沉积, 缺失泥盆系, 厚达 6 000 m, 晚三叠世至白垩纪为陆相沉积, 厚约 4 000 m, 沉积总厚度达万米^[1,2]。

1 基本地质特征

1.1 烃源岩层系多, 厚度大, 分布广

本区内经钻井揭示的烃源岩具多层系和多类型特点, 有机质含量丰富。生油母质类型有腐泥型、腐殖型和二者混合型。烃源层在古生界和中生界均有发育, 主要以下寒武统、下志留统及上二叠统泥质岩为主。下寒武统为黑色碳质页岩, 厚 200~300 m, 有机质主要为腐泥型, 丰度 0.5%~1.0%, 主要分布于泸州古隆起北西斜坡。下志留统龙马溪组为黑色页岩, 平均厚度 550 m 左右, I 级生油岩最大厚度可达 847 m(阳深 1 井), 有机质主要为腐泥型, 丰度为 0.4%~6.3%, 主要分布在泸州古隆起区。上二叠统龙潭组为泥岩夹煤层, 泥岩厚 30~70 m, 煤层厚 1~5 m, 有机质主要为偏腐泥混合型及腐殖型, 丰度

为 1.5%~11.5%^[3], 主要分布在泸州古隆起北西斜坡。

上三叠统须家河组为黑色页岩夹煤层, 泥岩厚度 100~150 m, 煤厚度为 1~5 m, 有机质主要为腐殖型, 丰度 0.55%~10.68%, 主要沿古隆起西北斜坡分布。

1.2 储层层系及类型多, 但产层集中, 以裂缝—孔隙(洞)型为主

蜀南地区历经多期构造旋回发展演化, 形成多套生储盖组合。已钻资料揭示获工业气层 20 个, 其中海相碳酸盐岩 14 个, 陆相碎屑岩 6 个, 具多产层特点。但主要产气层集中在三叠系嘉陵江组、二叠系茅口组和震旦系灯影组, 形成了蜀南地区目前主力生产气藏(见图 1)。

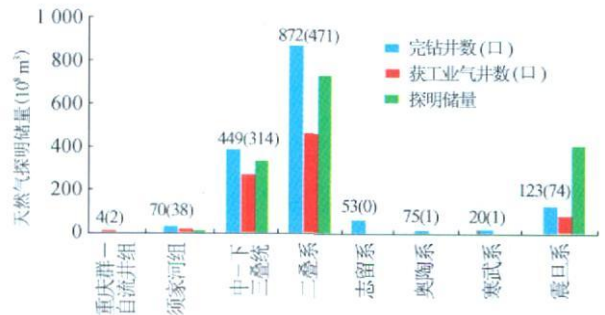


图 1 蜀南地区各层系勘探成效简图

(数据截至 2008 年底, 括号外为完钻井数, 括号内为获气井数)

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目前已发现的主力气层,其储层类型主要是裂缝—孔隙型、孔隙型、裂缝—洞穴型和裂缝型。据大量物性资料统计,以碳酸盐岩占主导地位的三叠系、二叠系储层,岩石平均孔隙度极低,下二叠统平均孔隙度约 0.8%,嘉陵江组稍高,大于 1%,孔隙(洞)是主要储集空间。此外,据上三叠统须家河组物性统计分析,储层孔隙度主要分布在 5%~8%,渗透率主要分布在 $(0.1\sim 1)\times 10^{-3}\mu\text{m}^2$,部分地区(如河包场)孔隙度为 5%~11%,具有低孔、低渗透的储层特征。

1.3 圈闭类型多,以构造和岩性圈闭为主

蜀南地区已发现的气藏圈闭类型多样,除以构造和岩性圈闭为主外,尚有地层及复合类圈闭等多种类型。如威远震旦系灯影组为有底水的块状背斜圈闭气藏,宋家场二叠系茅口组为有边水的层状背斜构造圈闭气藏;自流井地区嘉陵江组主要是岩性一背斜复合圈闭气藏,花果山嘉陵江组二段气藏表现为岩性圈闭气藏,阳高寺嘉一段受控于构造裂缝的圈闭气藏。近年来,在区内须家河组发现了多个岩性圈闭气藏和岩性—构造复合圈闭气藏,如河包场、安岳及丹凤场气田。

1.4 继承性古隆起控制油气多期运聚成藏

勘探实践证明,油气运聚、成藏与古隆起之间有密切关系,并具有多期构造活动、多期运聚成藏的特点^[4]。蜀南地区在地史时期曾发生过加里东、东吴及印支运动,相互叠合并继承发展,具有相当大的规模,为油气多期运聚创造了条件^[57]。如在乐山—龙女寺古隆起南斜坡上发现了威远震旦系灯影组气藏,探明储量达 $400\times 10^8\text{ m}^3$;在泸州—开江古隆起及其缓斜坡上发现了二叠、三叠系油气藏。此外,印支期末中三叠统侵蚀面古残丘构造及其附近,须家河组储层孔隙明显高于其他地区。因此,古隆起(古构造)对油气的运聚、成藏起着重要的作用。

1.5 现今构造控制气藏分布

经燕山运动中幕,本区盖层全面褶皱,喜山运动使该区进一步强烈抬升和褶皱,构成了现今的构造面貌,使古隆起构造富集的油气重新调整、分配,形成现今各类油气藏的分布格局。如泸州古隆起南部的长垣坝串珠状气藏富集带,东侧的塘河、合江、庙高寺、朱沱、鹿角场、榕山、李子坝气田富集带,西北侧的宋家场、牟家坪、广福坪、桐梓园气田富集带,顶部的阳高寺、纳溪、古佛山、南井气田富集带;自流井凹陷中的自流井、黄家场、圣灯山等为代表的以低背斜为主体的挤压背斜气藏富集带。这些气藏(田)富集带的组合,构成了现今的蜀南气区。

2 勘探方向预测

2.1 深化二叠系、三叠系勘探是目前“增储、上产”的关键

二叠系茅口组、三叠系嘉陵江组历来都是蜀南地区的主力产气层,2008 年其产气量分别占区内的 41.1%、49.2%。近年,地质深化研究和钻探实践表明其仍应是滚动勘探开发的主要对象,其潜力表现在:①天然气资源丰富,据张奇等^[89]研究认为区内嘉陵江组油气资源量为 $3\,925\times 10^8\text{ m}^3$,资源转化率仅 13.53%,按照世界富气盆地的平均转化率(35%)计算,仍有超过 $800\times 10^8\text{ m}^3$ 的储量有待发现,近期对茅口组 51 个裂缝系统动态储量复核新增上百亿天然气资源量;②成藏条件优越,区内继承性古隆起的持续演化,为嘉陵江组孔隙型储层和茅口组岩溶型储层的形成奠定了基础,形成了大面积的溶蚀岩性圈闭气藏,如麻柳场、同福场及花果山嘉陵江组气藏,以自流井地区自 2 井为代表的下二叠统气藏;③勘探面积广阔,已钻探的构造主体面积不足蜀南探矿面积的 25%;④近年来的钻探表明,嘉陵江组和茅口组仍是蜀南地区钻探成效最佳的层系(表 1)。

表 1 1998~2008 年蜀南地区钻探成效统计表

项 目	上三 叠统	中一下 三叠统	二叠系 茅口组	寒武系	震旦系
完成井(口)	43	86	42	7	2
获气井(口)	20	50	26	1	2
平均单井测试产量 ($10^4\text{ m}^3/\text{d}$)	2.32	15.27	21.10	10.92	2.02

随着地质认识的不断深化和勘探技术的提高,寻找构造勘探程度低、构造主体之外的隐蔽气藏以及古岩溶与古断裂控制的隐伏气藏是深化勘探的主攻方向^[10]。现有研究认为泸州古隆起东南斜坡以及泸州古隆起核部众多向斜是嘉陵江组有利勘探区带;沿华蓥山断裂带、古井断裂带分布的众多构造及低缓凹陷地区、泸州古隆起区构造斜坡及向斜、威远—安岳等古岩溶发育区是茅口组有利的勘探区带。

此外,蜀南东部及川中、川南过渡带南部长兴—飞仙关组也是二叠、三叠系具有勘探潜力的区域。

2.2 主攻须家河组气藏是近期天然气储量大幅度增加的重点

以前陆盆地、岩性油气藏勘探等新理论为指导,

结合新提出的四川盆地须家河期宽浅型敞流湖盆沉积概念模式、岩相古地理编图新方法和技术,在本区须家河组勘探取得了阶段的成果。据须家河组钻探,已在丹凤场、安岳及河包场地区获得了一批工业性气井,具备形成天然气储量资源的地质基础。以大面岩性圈闭为重点勘探对象,在河包场和安岳地区获天然气控制+探明储量上千亿立方米;自流井凹陷西南部有利区内的观音场构造,以构造圈闭面积为含气面积,有效储层的平均孔隙度按 4.86% 计算,天然气资源量为 $600 \times 10^8 \text{ m}^3$;泸州古隆起东部有利岩相区内的丹凤场岩性—构造圈闭气藏,以含气面积为 53.6 km^2 、平均孔隙度 5.77% 计算,天然气资源量为 $220 \times 10^8 \text{ m}^3$ 。以高精度二维地震资料为核心,地震和地质相结合筛选天然气富集区带及井位优选技术;完善储层改造技术,在河包场—界石场、观音—瓦市、通贤—安岳、牟家坪—九奎山、丹凤场—梁董庙地区将成为扩大储量规模的重点领域。

2.3 古隆起外围雷口坡组是近期找气的重点层系

中三叠统雷口坡组主要沿泸州古隆起外围呈环带分布,受印支期侵蚀面影响,雷口坡组风化剥蚀残留厚度变化较大。据钻探资料表明,本区雷口坡组残厚为 0~300 m,厚度由核部向外围斜坡带增大;储层以雷口坡组雷¹亚段岩溶型为主,其岩性为针孔白云岩,具有连片分布特征;北部在音 2、音 8、威东 6、包 20、包 6、孔 7 及孔 22 井已获工业气井,南面在旺 7 井获天然气 $2.8 \times 10^4 \text{ m}^3/\text{d}$ 。近期研究认为雷口坡组在威东—资阳、大塔—观音地区以及川中、川南过渡带和泸州古隆起外围一些构造上形成一定的含气面积,具有较好的勘探前景。

2.4 下古生界及震旦系是寻找天然气发现的新领域

乐山—龙女寺古隆起东南斜坡下古生界及震旦系灯影组有利勘探领域^[1],现已发现 4 个产气层,获威远气田 1 个,资阳含气构造 1 个,高石梯构造也见到气显示,钻达下古生界的井储层均发育。古隆起层序储集岩主要有 4 套:①震旦系灯影组,藻白云岩达 250 m,桐湾运动的抬升使其溶蚀孔洞发育;②下寒武统龙王庙组,威寒 1 井粉晶云岩储层厚 32.6 m,孔隙度 4.03%,盘 1 井粉晶云岩储层厚 58.4 m,孔隙度 6.51%;③中上寒武系洗象池群为潮坪沉积,白云岩厚达 200 m,溶蚀孔洞发育,阳深 1 井 4 128~4 131 m 岩心针孔云岩发育,局部呈蜂窝状,孔隙度 2.76%~6.14%;④下奥陶统罗汉坡组,粒屑溶孔白云岩厚 30~50 m,威寒 1 井岩心分析孔隙度 3.04%。寒武—奥陶系主要发育海相陆源碎屑和海相碳酸盐

两种不同的沉积体系,洗象池群和龙王庙组有利的台内滩相和潮坪相储集岩主要分布于乐山—龙女寺古隆起南斜坡的峨边—威远—大足—合川一带(见图 2),沿着这一有利沉积相带分布着众多现今构造圈闭,如老龙坝、威远、磨溪、螺观山、阳高寺、东山、西山等。据近期研究分析认为,乐山—龙女寺古隆起剩余天然气资源量达 $5\,000 \times 10^8 \text{ m}^3$,加强岩溶发育规律研究、成藏条件与区带评价、地震攻关与风险井目标优选,寻找发育良好组合的储层,是获得孔隙型整装大中型气田的有利目标。

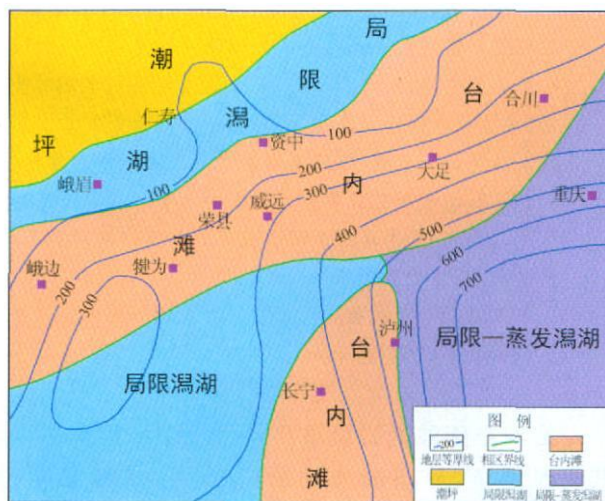


图 2 蜀南地区早寒武世龙王庙岩相古地理图

2.5 页岩气藏将是蜀南地区非常规油气勘探开发的新领域

蜀南地区拥有丰富的泥页岩。主要发育有上二叠统龙潭组、下志留统龙马溪组、下寒武统筇竹寺组 3 套。据初步统计,龙潭组页岩钻井中,在 19 个构造上有 27 口井见气显示;志留系龙马溪组页岩在 8 个构造上,有 16 井次见气显示;寒武系筇竹寺组在 5 个构造上就有 29 井次见气显示。目前蜀南地区对 2 口页岩显示井(均为威远构造筇竹寺组)进行了完井测试,其中威 5 井中途测试产气 $2.46 \times 10^4 \text{ m}^3/\text{d}$ 。与美国页岩气藏相比较,蜀南地区这些暗色页岩发育的地区和层位是值得重点研究和开发的领域,预测广泛分布区中页岩气的开发前景将很乐观。

3 结论

1) 蜀南地区经历多期构造旋回发展演化,地层沉积相对完整,生、储、盖层系多,储层及圈闭类型多样,油气沿古隆起分布明显。已发现的气藏主要集中在二叠系、三叠系及震旦系。(下转第 27 页)

区主要分布于西部靠近良里塔格组尖灭线附近;图 3-d 表明,一间房组溶洞较发育,Ⅰ类和Ⅱ类区主要分布于研究区西部和北部靠近一间房组地层尖灭线附近的弧形地带内,研究区东南部溶洞不发育。

5 结论

溶洞是塔里木盆地轮古东地区奥陶系碳酸盐岩储层主要的储集空间类型之一,按其形态及产状可以划分为斑点—斑块状溶洞、层状大洞及片状和网状缝洞等类型。70%左右的溶洞发育集中带分布在良里塔格组顶部古岩溶不整合面以下 200 m 深度范围内。主要目的层段中,一间房组溶洞较发育,良里塔格组相对较差。总体上,西部及北部靠近地层尖灭线附近,溶洞较发育,自此往东南方向,溶洞发育程度变差。本项研究为利用高分辨率成像测井资料预测古岩溶储层的分布提供了新的途径。

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(收稿日期 2009- 10- 08 编辑 韩晓渝)

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(修改回稿日期 2009- 08- 20 编辑 罗冬梅)

well, technique, reservoir, play identification, advantage, disadvantage, policy, resource volume

DOI: 10.3787/j.issn.1000-0976.2009.010.004

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Geologic characteristics of Yunánchang structural zone and the targets for future exploration

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NATUR. GAS IND. VOLUME 29, ISSUE 10, pp. 17-20, 10/25/2009. (ISSN 1000-0976; In Chinese)

ABSTRACT: The gas exploration in the Carboniferous in eastern Sichuan Basin is stagnant in recent ten years due to insufficient exploration investment and difficulty in the identification of exploration targets in areas with complex and steep structures. Therefore, the poorly explored Yunánchang structural zone is selected for the study of the structural features, reservoir distribution and structural model in this Carboniferous area, and the dry wells in this zone are the focus of the study. Based on a comprehensive analysis of the sections established according to the drilling data and in combination with a research into the mechanisms of structure formation, the structural model in this zone is believed to be a compressional uplifting and inversion type. A comparative analysis of the structural frameworks in the eastern and western parts of the structure zone reveals that the western part is "a semi anticlinal trap of thrusting type", while the eastern part is "an anticlinal trap of faulted horst type". In the western part, the sealing capacity is comparatively poor and the effective trap is controlled by the spill point. On the contrary, in the eastern segment, the fault sealing capacity is stronger, thus the effective trap is larger in area. This analysis shows that two favorable exploration targets are identified in the Yunánchang structural zone: the structural high of the Baiyangwarr Tianqianping in the eastern part and the Shatang buried structure in the foot wall of fault in the southeastern limb of the structural zone.

KEY WORDS: Sichuan Basin, east, Carboniferous, exploration, Yunánchang, structural model, dry well, exploration target, geologic feature, reservoir distribution, potential block, geologic section, buried structure

DOI: 10.3787/j.issn.1000-0976.2009.010.005

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Geologic characteristics of gas reservoirs and exploration direction in southern Sichuan Basin

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NATUR. GAS IND. VOLUME 29, ISSUE 10, pp. 21-23, 10/25/2009. (ISSN 1000-0976; In Chinese)

ABSTRACT: In order to identify favorable plays for future exploration in the southern Sichuan Basin, a systematic analysis of the basic geologic features in this area shows that it is characterized by multiphase cyclic structural evolution, relatively complete sedimentary sequences, multiple source rocks, multiple reservoirs and trap types, multiphase hydrocarbon pooling and multiple petroleum systems. A restudy of the old well data as well as the exploration and research results show that research and exploration should focus on the following in the near future. ① Strengthening the exploration of the Permian and Triassic is the key to reserves growth and production increase; ② The Xujiahe Formation gas reservoirs are the main targets of exploration to realize a large growth of gas reserves in the near term; ③ The Leikoupo Formation on the periphery of the palaeohigh is the major horizon for gas exploration in near term; ④ The Lower Paleozoic and Sinian are the frontiers for gas exploration; ⑤ Shale gas reservoirs will be the frontier for unconventional gas exploration and development in southern Sichuan Basin.

KEY WORDS: Sichuan Basin, south, natural gas, geologic features, exploration direction, Xujiahe Formation, deep layer, shale gas, source rocks, fracture pore (vug) type, structural trap, lithologic trap, palaeohigh, Lower Paleozoic, Sinian

DOI: 10.3787/j.issn.1000-0976.2009.010.006

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Electrical image logs applied to predict the distribution of Ordovician paleocaves in east Lungu area, Tarim Basin

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NATUR. GAS IND. VOLUME 29, ISSUE 10, pp. 24-27, 10/25/2009. (ISSN 1000-0976; In Chinese)

ABSTRACT: Calibrated by core and traditional well log data, electrical image logs (FMI and EMI) are used to study the types, characteristics and distribution of paleocaves in the Ordovician carbonate reservoirs, including Lianglitage and Yijianfang Formations, in east Lungu area, Tarim Basin, Northwest China. The paleocaves are classified into three classes: speckled to patched caves, layered caves, sheet or reticular fractured caves. The identification of various caves on image logs is also discussed. To characterize the spatial distribution of paleocaves, quantitative parameters, including the thickness and the burial depth relative to paleokarst surface of a paleocave zone, and the distribution density of paleocave zones (defined as the percentage of the thickness of paleocave zones in that of a given stratal unit) are introduced. Results indicate that the thickness of about 90 percent of paleocave zones is less than 10 m, and 70 percent of paleocave zones occur within 200 m beneath the paleokarst surface (top of the Lianglitage Formation). The distribution density of paleocaves in the Yijianfang Formation is obviously much higher than that in the Lianglitage Formation. In lateral, the distribution density of paleocaves increases from southeast to northwest, which suggests that paleokarstification strengthened northwestwards.

KEY WORDS: carbonate rock, paleocaves, paleokarst reservoirs, electrical image logs, Ordovician, Tarim Basin

DOI: 10.3787/j.issn.1000-0976.2009.010.007

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Kaijiang-Liangping Platform and seismic prediction of favorable facies belt

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NATUR. GAS IND. VOLUME 29, ISSUE 10, pp. 28-30, 10/25/2009. (ISSN 1000-0976; In Chinese)

ABSTRACT: The prediction of bioherm in the Upper Permian Changxing Formation in the Sichuan Basin focused on geologic research in the 1980s and 1990s. It was common in the early stage of the study that wells being targeted at bioherm did not encounter bioherm, while wells that were not targeted at bioherm sometimes encountered bioherm. In recent years, a set of methods for identifying seismic facies of platforms at the end of Late Permian have been developed by using seismic facies prediction techniques of regional large section as well as geologic, drilling and log data. Evidences of platform trough seismic facies have been identified, for the first time, on Chuanbei (north Sichuan), Chuanzhong (middle Sichuan) and Chuandong (east Sichuan) regional large seismic sections respectively. Based on these jobs, the favorable facies belts on biogenic buildups (reef facies, beach facies) are identified, the seismic facies prediction techniques of biogenic buildups on platform margin are summarized, and the palaeogeomorphology and sedimentary facies of Kaijiang-Liangping Platform at the end of Late Permian in the Si