

煤层气向斜控气论^{*}

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摘 要 煤层气富集规律的研究贯穿着煤层气勘探开发的始终, 融合了煤田地质学、天然气地质学、流体力学等学科。文章从向斜部位煤层气富集的实例研究出发, 深入分析了向斜部位煤层水对煤层气的作用机理以及应力性质在褶皱部位的表现特征对煤层气赋存的影响, 向斜部位的煤层水具有向心流动机制, 流速缓慢, 溶解气不因水的流动而大量散失; 另一方面, 向斜部位煤层水矿化度高, 减小了煤层气在水中的溶解度, 从而对煤层气起到一定的封堵作用; 向斜构造的两翼与轴部中和面以上表现为压应力, 顶板与煤层断裂或裂隙不发育, 阻止了煤层气向上逸散, 有利于煤层气在此部位的富集。最后从煤田生产资料实践证实了向斜部位煤层气富集这一理论, 对煤层气勘探具有一定的指导意义。

主题词 煤成气 成藏 富集 向斜 构造控制 理论 研究 实例

煤层气成藏是指煤层甲烷依靠压力作用(主要是水压), 以吸附作用为主, 在具有相近地质条件、含气特征的煤层中富集成含气层, 若干相近的含气层构成煤层气藏。煤层气的富集、成藏受多种因素的影响, 主要有含气性因素、煤储层因素、盖层因素、控气地质背景因素等。煤层气能否成藏直接关系到煤层气的勘探与开发。理论和实践研究表明, 向斜为煤层气富集的主要构造控制因素。

一、向斜富气的实例

大量的褶皱构造与含气量关系研究表明, 煤层气的赋存在褶皱构造部位具有明显的规律: 向斜轴部富气, 煤层含气量高; 背斜轴部贫气, 煤层含气量相对较低。晋城矿区 3 号煤层和 15 号煤层含气量与褶皱有明显的上述关系(图 1); 晋城矿务局^[1]勘探资料表明, 潘庄井田内的南沟向斜、磨掌向斜、前长城岭向斜以及襄庄向斜的轴部, 煤层气含量均大于

20 m³/t, 这些向斜的翼部较低部位, 煤层气含量为 (15~20) m³/t, 较高部位煤层气含量为 (10~15) m³/t, 背斜轴部, 含气量一般为 (5~10) m³/t, 其中马庄背斜、郑庄背斜、鹿底背斜轴部煤层气含量小于 5 m³/t^[2]。沁水盆地东北部的阳泉矿区, 区内构造特征与 3 号煤层煤层气的局部富集规律密切相关, 煤层气在次级短轴向斜部位相对富集, 而在短轴背斜部位相对逸散^[3]; 阜新煤田的刘家区向斜两翼倾角较缓, 向斜影响宽度较大, 在向斜轴部煤层气含量高, 而在两翼较低^[4]; 淮北矿区宿东向斜区内, 由向斜的两个仰起端向向斜中部延伸, 8 号煤层含气量亦呈明显增大趋势, 至向斜轴部大致在芦岭矿四采区附近达到最大值^[5]; 平顶山矿区白石山背斜部位煤层存在一个小于 4 m³/t 的低含气量带, 而在两侧的李口向斜和灵武山向斜部位则大于 8 m³/t^[6]; 韩城矿区褶皱构造对煤层气含量的影响由大到小排序依次为: 向斜轴部, 缓倾斜带, 挠曲背斜, 背斜轴部, 边浅部陡斜带^[7]。

二、向斜富气的理论依据

传统的油气地质理论认为背斜是良好的油气聚集构造, 向斜一般不作为储油气地质构造。然而, 大量事实证明, 煤层在向斜构造部位富气。

1. 向斜部位煤层水对煤层气的作用机理

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煤层气富集于地层高压区,煤层气能储存在煤层中主要靠地层压力吸附在煤基质中,对于一定煤阶的煤层,只要能维持一定的地层压力,煤层气就可以吸附在煤层中。地层压力主要体现在流体的势,Hubbert将地下单位质量流体具有的机械能的总和定义为流体势()。^[8]

$$= gZ + \int_0^p \frac{dp}{\rho} + \frac{q^2}{2}$$

式中: Z为测点高程; g为重力加速度; p为测点压力; ρ为流体密度; q为流速;上式等号右端第 1项表示重力引起的位能,第 2项表示流体的压能(或弹性能),第 3项表示动能。

一般情况下,可认为油、水是不可压缩的,即密度不随压力变化,在流体保持动态平衡条件下,压力不变或变化不大,气的密度也可视为常数。因此水势、气势分别写为:

$$w = gZ + p/\rho_w; \quad g = gZ + p/\rho_g$$

水势 w 可用测压水头 h_w 来表示。因为测压水头为测点的高程与测点的压力水头之和

$$h_w = Z + p/\rho_w$$

水势可改写为:

$$w = gZ + p/\rho_w = g(h_w - p/\rho_w) + p/\rho_w = gh_w$$

因此,向斜部位煤层气的势为水势和气势之和:

$$= gh_w + gh_g$$

式中: gh_g 为游离气在饱和状态下的势,在非饱和状态下其值为 0。

值得指出的是,煤层气在水中的溶解度很小,向斜部位具有地层水的向心流动机制,并且水流动较为缓慢,一方面煤层气不容易因水的流动而大量散失;另一方面,煤层中的水流经向斜部位时,水中的各种离子在此富集,致使水的矿化度增大,煤层气在水中的溶解度进一步减小^[9],矿化度较大的水对煤层气起到一定的封堵作用。再者,向斜部位上覆地层厚度较大,有利于维持地层压力。

2 褶皱构造部位应力性质对煤层气赋存的影响

向斜构造的两翼与轴部中和面以上表现为压应力,中和面以上表现为明显的应力集中(图 2),为高

压区,煤层以及顶板的裂隙和孔隙不甚发育,阻止了煤层气向上的逸散,为保存下部的煤层气提供了良好的盖层,有利于煤层气的富集;中和面以下表现为拉张应力,由于煤层往往埋深较大,只产生少量开放性裂隙,释放部分应力,形成相对低压区^[10]。因此,向斜的两翼和轴部中和面以上是有利于煤层气封存和聚集的部位,特别是向斜的轴部是煤层气含量高异常区。背斜构造的两翼与轴部中和面以下表现为压应力,特别是中和面以下出现明显的应力集中,这些部位为高压区。背斜轴部中和面以上表现为拉张应力,产生大量的张性裂隙或正断层,应力快速释放,为低压区。煤层气在背斜的两翼能较好地封存,在轴部由于裂隙较为发育,煤层气逸散。

3. 向斜富气的验证

通过对韩城矿区下峪口燎原井田生产矿井实际揭露的各种构造类型与 3 号煤层含气量进行分析,研究表明,在煤层含气量总体随煤层埋藏深度增大而增加的前提下,对含气量起控制性的主要因素为大中型褶皱构造及挠曲构造,按照褶皱构造与挠曲构造的具体类型及部位不同,其对煤层含气量的影响不同:向斜轴部煤层含气量最高,平均为 12.65 m³/t 缓倾斜带与挠曲背斜部位含气量较高,平均分别为 9.62 m³/t 和 9.38 m³/t,背斜轴部含气量最低,平均为 7.31 m³/t(表 1)。

表 1 韩城矿区下峪口燎原井田 3 号煤层不同构造部位
甲烷含量实测值

构造部位	钻孔号	甲烷含量实测值 (m ³ /t)	甲烷含量平均值 (m ³ /t)
挠曲背斜	L16	9.28	9.38
	P23	9.47	
向斜轴部	341	13.64	12.65
	339	11.56	
	X24	10.15	
	X22	14.26	
	X30	15.52	
	X40	10.76	
背斜轴部	344	6.94	7.31
	L1	7.67	
缓倾斜带	343	7.28	9.62
	X31	10.83	
	X41	10.70	

注:据王生全,2002。

二、认识与结论

(1)大量的褶皱构造与含气量的关系研究表明,

向斜轴部是煤层气富集的重要构造部位。

(2)向斜部位煤层中的水具有向心流动的机制,且流速缓慢,水中的溶解气不易大量散失;另外,向斜部位水的矿化度高,进一步减小了水对煤层气的溶解度,对煤层气起到一定的封堵作用。

(3)向斜轴部的应力性质表现为压应力,煤层及其上覆地层中的裂隙或断层不发育,阻止了煤层气的向上逸散,有利于煤层气的富集。

(4)矿井生产实践与试验测试进一步证实了煤层向斜富气这一褶皱构造控气理论。

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西气东输正式全线商业运营 120亿立方米年商品气量已全部售出

2004年12月29日,记者从北京人民大会堂召开的西气东输工程新闻发布会上获悉,经过数万名参战将士3年多的努力,西气东输工程将于12月30日正式全线投产。这标志着西气东输工程正式进入商业运营。发布会上,国家西气东输工程建设领导小组、中国石油天然气集团公司的有关领导,就“西气”价格、天然气资源、安全运营等问题回答了记者现场的提问。

在回答本报记者提问时,中国石油天然气集团公司有关领导说,西气东输工程被称为新世纪我国四大基础设施项目之一。通过建设西气东输工程,中国石油积累了六大宝贵经验:用“三个代表”重要思想和科学发展观统揽工程建设;用高新技术铸就西气东输工程;建立了一套先进的项目组织管理体系;以科学决策为前提,保证工程顺利建成投产;建设了一条安全、绿色、环保管道;为实现工程建设目标提供了坚强的政治思想保证和强大的精神动力。在发布会前几个小时,国家西气东输工程建设领导小组还召开了第七次也是最后一次工作会议。会议由国家发改委会副主任、国家西气东输工程建设领导小组组长张国宝主持,西气东输工程建设领导小组成员单位和各有关部门的负责人出席了会议。

会议听取了中国石油关于工程建设情况的汇报,听取了国家安全生产监督管理局和中国石油关于管道保护和安全检查工作的通报,审议了西气东输工程建设先进集体和先进个人名单,并举行了供气双方合同签字仪式。中国石油分别与望亭电厂、戚墅堰电厂、华能金陵电厂、张家港电厂、扬子石化股份有限公司等12家天然气用户签订了《天然气销售协议》。至此,中国石油已先后与43家用户签订了《天然气销售协议》,西气东输120亿立方米/年商品气量已全部售出。这为提高管道经济效益,促进西气东输工程尽快达到设计输量奠定了基础。

(蒋静萍 摘自《中国石油报》)

ences). *NATURAL GAS IND.* v. 25, no. 1, pp. 19—21, 1/25/2005. (ISSN 1000 - 0976; **In Chinese**)

ABSTRACT: Coal rank is one of the main factors of controlling coalbed methane formation and coal adsorption capacity, playing an important role in coalbed methane content. According to relevant literatures and measured data, the relation between coal rank and coal adsorption capacity at equilibrium water content is systematically discussed in the paper. It is pointed that the coal adsorption capacity experiences four stages with the rise of coal rank: early or late, i.e. rapid increase stage ($R_o < 1.3\%$), slow increase stage ($R_o = 1.3\% - 2.5\%$), maximum stage ($R_o = 2.5\% - 4.0\%$) and decrease stage ($R_o > 4.0\%$). This change is fully corresponding to the coalification jump. The coalification controlled the porosity and surface physicochemical property of coal, then controlled the occurrence space of coalbed methane and the coal's affinity for methane. (Financed by the National Basic Research Program Project, No. 2002CB211705)

SUBJECT HEADINGS: Coal rank, Coalbed methane, Adsorption capacity, Coalification, Jump

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DISCUSSION ON THE DIVISION OF COAL-BED METHANE-ENRICHED UNITS IN CHINA

Zhao Jingzhou and Shi Baohong (Department of Resource Engineering, Xi'an Shiyou University). *NATURAL GAS IND.* v. 25, no. 1, pp. 22—25, 1/25/2005. (ISSN 1000 - 0976; **In Chinese**)

ABSTRACT: The division of coalbed methane-enriched units is the basis of probing coalbed methane reservoir formation law, carrying out coalbed methane resource and area-selection evaluation, making up scientific coalbed methane exploration program and raising coalbed methane exploration success ratio. The formation conditions and distribution environments of coalbed methane in China are very complicated, so that it is very important for the coalbed methane exploration evaluation to investigate its enrichment units. According to the particularity, complexity and distribution law of coalbed methane in China,

its enrichment units were divided into five grades, i.e. methane-bearing province, methane-bearing basin, methane-rich region, methane-rich zone and methane reservoir (field). (Financed by the National Basic Research Program Project: Basic studies on the formation and economic exploitation of coalbed gas reservoirs in China, No. 2002CB211706)

SUBJECT HEADINGS: Coalbed methane, Enrichment unit, Sequence, Division, Probing

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THEORY OF SYNCLINE-CONTROLLED COALBED METHANE

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ABSTRACT: The research on coalbed methane enrichment law permeates through the whole process of coalbed methane exploration and development, and is merged with these disciplines as coalfield geology, natural gas geology and fluid mechanics. Proceeding from the cases of syncline-enriched coalbed methane, the authors analyze thoroughly the mechanism of the effect of coalbed water at syncline portion upon coalbed methane and investigate the influence of the stress property at fold portion on coalbed methane occurrence. Because of the centripetal flowing mechanism and low flow velocity of the coalbed water at syncline portion, the dissolved methane couldn't be largely dissipated owing to water flow; and on the other hand, because of high salinity of the water, the solubility of coalbed methane in the water decreased, thus playing the role of sealing coalbed methane. The compressive stresses existed in the two flanks and axis above neutral plane of synclinal fold, and the faults and fractures are undeveloped in coal bed and its roof, thus preventing the coalbed methane from being upward dissipated, which is favorable to coalbed methane's being enriched at the syncline portion. Therefore, the theory of syncline-controlled coalbed methane is of a certain guiding significance for coalbed methane exploration, having been proved by

the production practice (**Financed by the National Basic Research Program Projects, Nos 2002CB211705 and 2002CB211704**)

SUBJECT HEADINGS: Coalbed methane, Reservoir ring, Syncline-controlled gas theory, Enrichment law

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INFLUENCE OF THE TECTONIC THERMAL EVENTS IN YANSHAN EPOCH ON COALBED METHANE ENRICHMENT AND HIGH-PRODUCTIVITY IN XISHAN COAL FIELD IN TAIYUAN

Liu Honglin, Wang Hongyan, Zhao Guoliang, Li Guizhong, Yang Fan and Liu Hongjian (Langfang Branch, Research Institute of Petroleum Exploration and Development, CNPC). *NATURAL GAS IND.* v. 25, no. 1, pp. 29—32, 1/25/2005. (ISSN 1000 - 0976; **In Chinese**)

ABSTRACT: Xishan coal field in Taiyuan is located in northwest Qinshui basin and composed of Carboniferous—Permian coal beds. An abnormal paleogeothermal field was formed owing to the occurrence of magma intrusion in Yanshan epoch, which caused the coal rank in the field to be rapidly increased in a short geological time limit. The coal beds in the field had experienced two hydrocarbon-generation stages and the main gas-generation course finished during the second stage. The tectonic thermal events had greatly raised the gas generating amount in the coal beds, thus creating a beneficial gas-source condition for coalbed methane enrichment. Meanwhile, the Mesozoic geothermal field was characterized by large terrestrial heat flow rate and its instantaneity, and a great number of magma-caused coal cleats were formed, thus enhancing coal reservoir permeability. Therefore, the coalbed methane resources in this region are of great exploration potential (**Financed by the National Basic Research Program Project, No. 2002CB211702**)

SUBJECT HEADINGS: Xishan coal field, Coalbed methane, Tectonic thermal event, Influence, Permeability

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HYDROGEOLOGICAL CONDITION ANALYSIS OF CONTROLLING COALBED METHANE AT SHOUYANG—YANGQUAN COAL MINE DISTRICT

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ABSTRACT: In the paper, the regional distribution laws of coalbed methane content in the main coal beds at Shouyang—Yangquan coal mine district and the characteristics of the hydrodynamic fields and hydrochemical fields of the formation water in Middle Ordovician limestones, Taiyuan Formation limestones and Shanxi Formation sandstones were analyzed on the basis of the data on coalfield geological exploration; the coupling relation between coalbed methane content and formation water potential or salinity is discussed; and it is concluded that the formation water at stagnant area is of the characteristics of high salinity and high coalbed methane content (**Financed by the National Basic Research Program Project, No. 2002CB211700**)

SUBJECT HEADINGS: Shouyang—Yangquan coal mine district, Coalbed methane, Hydrogeological condition

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MAIN CONTROL FACTOR AFFECTING PORE DIFFERENTIAL DEVELOPMENT OF THE COAL RESERVOIRS IN QINSHUI BASIN