页岩气成藏机理和分布*

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摘　要　对页岩气成藏机理进行了全面分析, 获得了四个方面的认识。¹ 页岩气成藏机理兼具煤层吸附气和常规圈闭气藏特征, 体现出了复杂的多机理递变特点。º 在页岩气的成藏过程中, 天然气的赋存方式和成藏类型逐渐改变, 含气丰度和富集程度逐渐增加。» 完整的页岩气成藏与演化可分为 3 个主要的作用过程, 自身构成了从吸附聚集、膨胀造隙富集到活塞式推进或置换式运移的机理序列。¼ 相应的成藏条件和成藏机理变化对页岩气的成藏与分布产生了控制和影响作用, 岩性特征变化和裂缝发育状况对页岩气藏中天然气的赋存特征和分布规律具有控制作用。研究了我国的情况, 认为我国的许多盆地存在工业性页岩气藏发育的基本地质条件, 其中, 吐哈盆地吐鲁番坳陷的水西沟群是页岩气发育的重要区域之一。

主题词　页岩气　赋存状态　成藏机理　序列递变

页岩气是指主体位于暗色泥页岩或高碳泥页岩中, 以吸附或游离状态为主要存在方式的天然气聚集。在页岩气藏中, 天然气也存在于夹层状的粉砂岩、粉砂质泥岩、泥质粉砂岩、甚至砂岩地层中, 为天然气生成之后在源岩层内就近聚集的结果, 表现为典型的/ 原地0成藏模式。从某种意义来说, 页岩气藏的形成是天然气在源岩中大规模滞留的结果, 由于储集条件特殊, 天然气在其中以多种相态存在。页岩气是目前经济技术条件下, 天然气工业化勘探的重要领域和目标。

页岩气成藏机理

页岩在地层组成上, 多为暗色泥岩与浅色粉砂岩的薄互层。在页岩中, 天然气的赋存状态多种多样。除极少量的溶解状态天然气以外, 大部分均以吸附状态赋存于岩石颗粒和有机质表面, 或以游离状态赋存于孔隙和裂缝之中。吸附状天然气的赋存与有机质含量密切有关[132], 它与游离状天然气含量之间呈彼此消长关系, 其中吸附状态天然气的含量变化于 20%~ 85% 之间[122]。因此从赋存状态观察, 页岩气介于煤层吸附气(吸附气含量在 85% 以上) 和常规圈闭气(吸附气含量通常忽略为零) 之间。页岩气成藏体现出了非常复杂的多机理递变特点, 除天然气在孔隙水、干酪根有机质以及液态烃类中的溶解作用机理以外, 天然气从生烃初期时的吸附聚集到大量生烃时期的活塞式运聚, 再到生烃高峰时期的置换式运聚, 体现出了页岩气自身所构成的完整性天然气成藏机理序列[1 6]。

上述一系列作用过程的发生使页岩中的天然气赋存相态本身也构成了从典型吸附到常规游离之间的序列过渡, 因而页岩气成藏机理研究具有自身的独特意义, 它至少将煤层气(典型吸附气成藏原理)、根缘气(活塞式气水排驱原理) 和常规气(典型的置换式运聚机理) 的运移、聚集和成藏过程联结在一起。由于页岩气在主体上表现为吸附状态与游离状态天然气之间的递变过渡, 体现为成藏过程中的无运移或极短距离的有限运移, 因此页岩气藏具有典型煤层气、典型根缘气和典型常规圈闭气成藏的多重机理意义, 在表现特征上具有典型的过渡意义。

第一阶段是天然气在页岩中的生成、吸附与溶解逃离(图 1 ¹), 具有与煤层气成藏大致相同的机理过程。在天然气的最初生成阶段, 主要由生物作用所产生的天然气首先满足有机质和岩石颗粒表面吸附的需要, 当吸附气量与溶解的逃逸气量达到饱和时, 富裕的天然气则以游离相或溶解相进行运移逃散, 条件适宜时可为水溶气藏的形成提供丰富气源。

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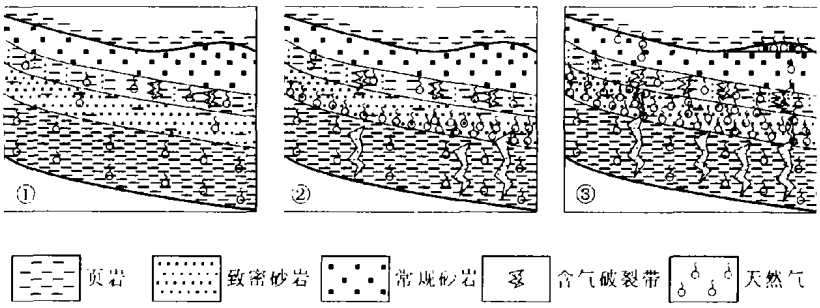

图 1　天然气成藏的三个阶段

(¹ 页岩气成藏阶段; º 根缘气成藏阶段; » 常规圈闭气成藏阶段)

此时所形成的页岩气藏分布限于页岩内部且以吸附状态为主要赋存方式, 总体含气量有限。

在热裂解气大量生成过程中, 由于天然气的生成作用主要来自于热化学能的转化, 它将较高密度的有机母质转换成较低密度的天然气。在相对密闭的系统中, 物质密度的变小导致了体积的膨胀和压力的提高, 天然气的大量生成作用使原有的地层压力得到不断提高, 从而产生原始的高异常地层压力, 即/ 高压锅0原理[172]。由于压力的升高作用, 页岩内部沿应力集中面、岩性接触过渡面或脆性薄弱面产生裂缝, 天然气聚集其中则易于形成以游离相为主的工业性页岩气藏, 此时页岩气藏的形成在主体上表现为由生气膨胀力所促动的成藏过程, 天然气原地或就近分布, 构成了挤压造隙式的运聚成藏特征(图 1º)。在该阶段, 游离相的天然气以裂隙聚集为主, 页岩地层的平均含气量丰度达到较高水平。

随着更多天然气源源不断地生成, 越来越多的游离相天然气无法全部保留于页岩内部, 从而产生以生烃膨胀作用为基本动力的天然气/ 逃逸0作用。在通常情况下, 与页岩间互出现的储层主要为粉-细砂岩类, 具有低孔低渗特点, 它限定了天然气的运移方式为活塞式排水特点, 这种气水排驱方式从页岩开始, 从而在页岩边缘以活塞式推进方式产生根缘气聚集。此时的天然气聚集已经超越了页岩本身, 表现为无边、底水和浮力作用发生的地层含气特点。因此从整套页岩层系考察, 不论是页岩地层本身还是薄互层分布的砂岩储层, 均表现为普遍的饱含气性(图 1»)。若地层中的砂岩含量逐渐增多并逐步转变为以致密砂岩为主, 则页岩气藏逐渐改变为根缘气藏(图 1º)。如果生气量继续增加, 则天然气分布范围进一步扩大, 直到遇常规储层或输导通道后, 天然气受浮力作用而进行置换式运移, 从而导致常规圈闭气藏的大范围出现(图 1»)。

页岩气成藏主控地质因素及分布规律

与根缘气藏的地层普遍含气性机理不同, 页岩气藏普遍含气性的内涵较广, 在岩性上包括了泥页岩、致密的砂岩或砂质细粒岩, 在赋存状态上包容了吸附、游离与溶解, 在成藏机理上则包含了吸附与扩散、溶解与析出、活塞与置换等运聚过程。在通常情况下, 泥页岩与致密砂岩(泥质粉砂岩与粉砂质泥岩等)之间的互层分布为这种多相态、多机理的地层普遍含气性提供了有利条件。

(1)页岩岩性多为沥青质或富含有机质的暗色、黑色泥页岩和高碳泥页岩类, 岩石组成一般为 30%~ 50%的粘土矿物、15%~ 25%的粉砂质(石英颗粒)和 4%~ 30%的有机质。页岩气的工业聚集需要丰富的气源物质基础, 要求生烃有机质含量达到一定标准, 那些/ 肥沃0的黑色泥页岩通常是页岩气成藏的最好岩性, 它们的形成需要较快速的沉积条件和封闭性较好的还原环境。在页岩气藏中, 地层有机碳含量相对较高, 一般大于 2%, 可以达到普通源岩有机碳含量的 10~ 20 倍。天然气的生成可来源于生物作用、热成熟作用或两者的结合, 因此镜质体反射率一般在 0.4%以上。在陆相盆地中, 湖沼相和三角洲相沉积产物一般是页岩气成藏的最好条件, 但通常位于或接近于盆地的沉降) 沉积中心处, 导致页岩气的分布有利区主要集中于盆地中心处。从天然气的生成角度分析, 生物气的产生需要厌氧环境, 而热成因气的产生也需要较高的温度条件, 因此靠近盆地中心方向是页岩气成藏的有利区域。

(2)页岩本身既是气源岩又是储集层, 其总孔隙度一般小于 10%, 而含气的有效孔隙度一般不及总孔隙度的一半, 渗透率则随裂缝的发育程度不同而有较大变化。页岩气虽然为地层普遍含气性特点, 但目前具有工业勘探价值的页岩气藏或甜点主要依

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赖于页岩地层中具有一定规模的裂缝系统。根据有关资料分析[122], 页岩的含气量变化幅度较大, 从 0.4 m^3/t 到 10 m^3/t, 在美国的大约 30000 口钻井中, 钻遇具有自然工业产能的裂缝性甜点的井数只有大约 10%, 表明裂缝系统是提高页岩气钻井工业产能的重要影响因素。除了页岩地层中的自生裂缝系统以外, 构造裂缝系统的规模性发育为页岩含气丰度的提高提供了条件保证。因此, 构造转折带、地应力相对集中带以及褶皱) 断裂发育带通常是页岩气富集的重要场所。

(3) 由于赋存状态的特殊性以及开采效率的局限性, 较大的埋藏深度往往需要更高的成本投入, 对页岩气藏的工业性勘探和开发来说, 首先考虑较浅的埋藏深度尤为必要。从美国的有关资料考察, 目前投入开发生产的页岩气埋深介于 180~ 2600 m (600~ 8500 ft) 之间[122]。同时, 页岩气的大规模发育也需要相当的储集空间, 即页岩发育还需要一定的地层厚度, 一般在 30 m 以上。

(4) 根据成藏机理分析, 页岩气原生的地层压力为高异常特征。但从美国已发现页岩气的统计[122]规律来看, 页岩气藏既有高异常地层压力, 也有低异常地层压力。作者认为, 产生理论分析与统计结果不相符合的主要原因在于构造的抬升或沉降运动, 由于页岩气储层为致密的地层所构成, 其间的孔隙地层水无法进行有效的流动, 因此地层压力的封闭性相对较强。当已经成藏的页岩气发生相对的构造抬升或沉降运动时, 原始的页岩气藏地层压力得到了一定程度的滞留, 从而产生了更高或相对降低的异常地层压力。根据这一特点, 页岩气藏的发育通常与高异常地层压力保持一致, 除非在页岩气成藏后发生了较大幅度的构造沉降运动。但在使用这一原理进行异常地层压力分析时, 需要确准良好的封闭性条件, 否则可能产生恰好相反的分析结果, 统计资料表明, 页岩气藏的地层压力系数可有较大幅度变化。除此之外, 水平方向的构造挤压作用亦对页岩气藏地层压力的发育产生重要影响, 这种作用可以通过势场分析方法予以考虑, 通常情况下, 页岩气藏存在于流体的高势能区。

结论与认识

根据成藏机理分析, 页岩气的成藏及分布具有广泛的地质意义, 不论是在新沉积的年轻盆地还是在经过多次构造影响和改造的古老盆地中, 页岩气的赋存都从天然气的生成开始, 但是否能够成藏或达到工业勘探研究意义则随地质和地理条件的不同而有所变化。

页岩气具有广泛的饱含气性, 资源量潜力大并具有良好的勘探开发前景。吸附作用是天然气生成之后的第一个聚集过程, 因此页岩内部的储集空间具有近水楼台先得月之优势, 是天然气聚集的最优先场所, 只有当页岩内部的储集空间达到饱含气之后, 多余的天然气才能向外继续运移。页岩内部普遍的饱含气状态使其成为资源量大的天然气藏类型之一。页岩气成藏不需要常规圈闭的存在, 页岩内部具有工业价值天然气的聚集(甜点, Sweet Spots) 具有隐蔽性特点。与常规气相比, 页岩随普遍含气但单井产量变化较大, 一般只有钻遇裂缝的页岩气井才具有较大的工业开发价值。

从天然气聚集的有利性和开采的经济性分析, 页岩气位居五大类已开发气藏中的第三位(图 2)。页岩气的采收率变化较大(5%~ 60%)[122], 钻井的产气量相对较低, 但生产周期较长, 在天然气产出的同时伴随有地层水的排出。美国页岩气井的单井总平均产气量约为 1000 m^3/d, 但页岩气产区的单井产率一般介于 2800~ 33000 m^3/d[122] 之间。通常情况下, 盆地的构造较深部位是页岩和页岩气藏发育的有利区, 页岩气成藏和分布的最大范围与有效气源岩面积相当。

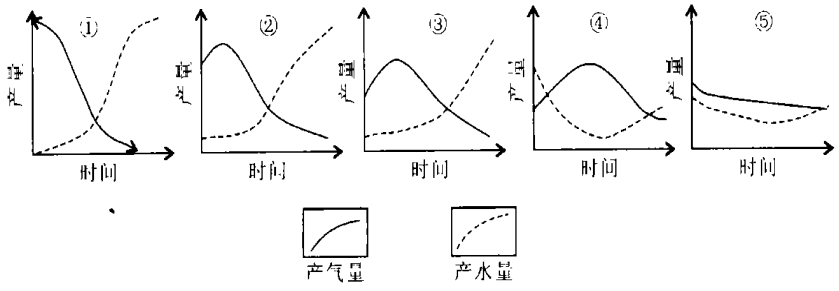

图 2　不同类型天然气藏的生产曲线示意图

(¹ 常规圈闭气藏; ° 根缘气藏; » 页岩气藏; ¼ 煤层气藏; ½ 水溶气藏)

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页岩气在中国具有良好的勘探前景, 对页岩气(泥页岩气)的勘探研究也已经逐步展开[182], 在四川盆地、鄂尔多斯盆地、渤海湾盆地、松辽盆地、吐哈盆地、江汉盆地、吐哈盆地、塔里木盆地、准噶尔盆地等均有页岩气成藏的地质条件, 局部有机碳含量在 30% 以上, 发现了典型页岩层中局部的天然气富集。其中, 暗色页岩发育的地区和层位是需要重点研究的领域和目标。在吐哈盆地, 吐鲁番坳陷水西沟群地层广泛发育了暗色泥岩和炭质泥页岩(图 3), 炭质泥岩累积平均厚度在 30 m 以上, 有机碳含量一般介于 6% ~ 30%; 暗色泥页岩厚度更大, 如八道湾组暗色泥页岩厚度一般大于 100 m, 盆地中北部达到 200 m 以上, 西山窑组暗色泥页岩最大厚度大于 600 m, 有机质的成熟度目前大都处于 0. 4% ~ 1. 5% 之间, 非常有利于页岩气藏的形成和发育。此外, 我国南方志留系广布区中泥页岩气的勘探前景亦不可忽视[182]。

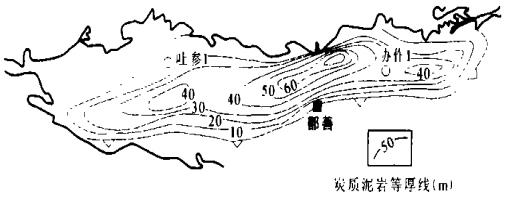

图 3　吐哈盆地吐鲁番坳陷水西沟群炭质泥岩分布等厚图

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(上接第 14 页)注受到极大的限制。依南 2 井以北的依南 4 井区, 断层较发育, 物性普遍变好, 尽管有丰富的气源供给, 但缺少构造圈闭, 天然气向上倾方向好储层及断裂带快速逸散, 形成依南深盆气藏的气水过渡带(图 2)。而北部的依深 4 井虽然储层物性好, 由于天然气的散失更快, 形成水层, 因此依南 2 气藏是一种动态圈闭气藏, 下倾部位是天然气强烈的不断充注, 上倾部位天然气不断散失是天然气的充注与散失形成一种动态平衡的产物。

以上各方面的分析表明, 依南 2 气藏是深盆气藏, 具有可观的经济开发价值。

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gas field is analyzed around the transmission efficiency problem of the effective migration channel connecting gas source rocks and traps in the paper. The fault F_2 under the satl layer was an efficient migration channel for Kela2 structure. The negative pressures caused by the fractures formed in fault activity period might inhale the gas accumulated early in the sands included in hydrocarbon source beds and induce it to be migrated into the fracture zone, i. e. so2called/ seismic pump0 inhaling effect; then, under the driving of tectonic extrusion stresses and overpres2 sures, a vast amount of gas was quickly migrated along the fault zone and charged into the traps; and, because the extensional K2 type fault didnct directly connect with the traps, the gas charged into them wouldnct be lost. After the fault activitycs being end2 ed, the fault F_1 through salt layer was quickly closed. The butted joint of sandstones and mudstones and the good quality cap rocks caused the natural gas to be preserved in the traps.

SUBJECT HEADINGS: Kela2 structure, Main control factor, Effective migration channel, Seismic pump inhaling, Sealing condition

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ANALYZING THE CHARACTERISTICS OF YI2 NAN2 GAS RESERVOIR IN KUCHE DEPRES2 SION OF TALIMU BASIN

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ABSTRACT: / Deep Basin Gas Reservoir0 is an unconven2 tional gas accumulation formed in a special trap with an upside2 down relation of water to gas and its formation conditions in2 clude mainly a gentle structure, a tight reservoir and an unceas2 ingly outputting gas source. Through investiga tion, it was con2 sidered that the Yinan22 gas reservoir of Yiqikelike Structural Belt in Kuche Depression belongs in a/ Deep Basin Gas Reser2 voir0, because its gas2producing interval is composed of tight sandstones, it is situated on the down2dip portion of a west2tilted monocline and there exist massive Jurassic) Triassic coal mea2 sure strata being able to generate a vast amount of gas. Mean2 while, this gas reservoir is characterized by the upside2down re2 lation of water to gas and the high gas saturation and abnormal high formation pressure. When the gas was charged into the tight sandstones, the migration mode was mainly diffusional ef2 fect in the procoss of reservoir formation. To sum up, the Yi2 nan22 trap was of the geological conditions of forming/ Deep Basin Gas Reservoir0.

SUBJECT HEADINGS: Kuche Depression, Yinan22 gas reservoir, Deep basin, Gas reservoir, Feature, Resolution

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RESERVOIRING MECHANISM OF SHALE GAS AND ITS DISTRIBUTION

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ABSTRACT: The reservoiring mechanism of shale gas is of the features of both the coalbed2adsorbed methane and the con2 ventionally trapped gas reservoirs, it showing a complicated mul2 tiple2mechanism gradation character. In the reservoiring process of shale gas, the occurrence manner of the gas and the reservoir2 ing type were gradually changed, and the abundance and enrich2 ment degree of the gas were gradually increased. An whole pro2 cess of the formation and evolution of shale gas reservoir may be divided into three stages, i. e. the absorption and accumulation stage, the expansion and cracking stage and the piston2like driv2 ing or displacement2like migration stage. Relevant change in reservoiring condition and mechanism could control and influ2 ence the formation and distribution of shale gas reservoirs and the lithologic change and fracture development status played a control role in the occurrence and distribution of the gas in shale gas reservoir. The basic geological conditions of forming com2 mercial shale gas reservoirs exist in many basins in China, in which Shuixigou Group in Tulufan Depression of Tuha Basin is one of the important horizons of shale gas generation.

SUBJECT HEADINGS: Shale gas, Occurrence status, Reservoiring mechanism, Sequence gradation

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CHARACTERISTICS OF T_1f_1 RESERVOIRS AT YUDONGLIANG IN THE NORTH PART OF WEST SICHUAN

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ABSTRACT: The first member of Feixianguan Formation, Lower Triassic (T_1f_1) at Yudongliang of Jiangyou County is at the higher portion of high2energy beach body of the platform edge facies, it being composed of a regressive sequence of the sparry oolitic (pisolitic) limestones and silty2fine crystalline granular dolomites on the vertical. It is the result of an ancient oil reservoirc s being destroyed because of its highly2developed and asphalt2filled pores. The diageneses suffered mainly by pore evolution include three stages of cementation and three stages of dissolution. During the early2middle stage of diagenesis, the high porous dolomite reservoirs were formed owing to the reformation of the intensive dolomization of mixed water and the dissolution of meteoric fresh water. The outstanding characteristics of forming the ancient oil reservoir include suffering the dolomization of mixed water in the early diagenetic stage; having the participation of meteoric fresh water in two stages of dissolution; reservoiring during high porous stage; and having an exact time2space matching relation. Such a reservoiring example provides new ideas and new target horizons for oil and gas exploration.

SUBJECT HEADINGS: Yudongliang, First member of Feixianguan Formation, Oolitic beach, Reservoir, Pore evolution, Reservoiring

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CHARACTERISTICS OF THE FORMATION OF SHALLOW OIL AND GAS RESERVOIRS IN NORTH JIANGSU AND THEIR EXPLORATION POTENTIAL

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ABSTRACT: The oil and gas shows were often found in drilling the shallow layers (Neogene) in North Jiangsu. In recent years, through remote sensing imaging, shallow seismic exploration, geochemical exploration and drilling, the characteristics of the formation of shallow oil and gas reservoirs and their control factors were comprehensively studied and discussed, and six oil2and gas2bearing zones were evaluated for shallow oil and gas exploration in North Jiangsu, in which the Xuzhuang, Jiangdu2Wubao and Taixing2Haican regions are the favourable zones and also the mainly experimental areas of shallow oil and gas exploration. The formation of shallow oil and gas reservoir must have a perfect source2reservoir2caprock assemblage, i.e. multiple hydrocarbon source, good petrophysical property and ideal caprocks. The gas reservoirs mainly belong in lithologic traps and low2amplitude structural traps and their burial depths are 500) 1000 m, being about 800 m in general. The shallow hydrocarbon resources predicted initially for North Jiangsu might be up to 39744 @(10^6) 141855 @ 10^6m^3; those for Jiangdu2Wubao region 17754 @ (10^6) 50304 @ 10^6m^3; and those for Taixing2Haican region 13060@(10^6) 60461 @10^6m^3. Therefore the shallow oil and gas reservoirs in North Jiangsu are of good exploration potential.

SUBJECT HEADINGS: Jiangsu, Shallow layer, Oil and gas exploration

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METHODS OF ESTIMATING COALBED METHANE RESERVES AND THEIR APPLICATION

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ABSTRACT: By reference to the methods of estimating

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