

柴达木盆地第四系生物气藏的地震反射特征

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摘要 通过对柴达木盆地第四系含气区地震反射资料的描述, 阐述了该区第四系含气地层的“地震异常反射特征”, 并通过异常反射与探明气藏空间分布的相关性和异常幅度与含气丰度一致性的对比分析, 对地震剖面上各种不同级别的异常反射赋予了明确的地质意义。同时, 根据波动反射理论, 结合该区第四系沉积疏松、埋藏浅的特殊地质条件, 对该区第四系含气地震异常的形成机理进行了探讨, 并明确指出: 沉积疏松、整体低速的地质背景, 正是形成该区第四系特殊“含气地震异常”的特殊地质条件。

主题词 柴达木盆地 第四纪 气层 地震异常 地震反射 特征 形成 机理

对柴达木盆地三湖地区的地震勘探始于五十年代末, 先后经历了光点记录、模拟磁带及数字地震三个发展阶段。虽然含气地震异常在不同阶段的地震剖面上都有发现, 但由于这种物理异常在国内外油气勘探领域很少见到, 缺乏有关的研究理论和参考资料, 对本区第四系普遍存在的含气地震异常的研究过程, 实际上就是一个从发现到理解, 从理解到认识, 从认识再到应用的过程。

第四系含气地震异常的反射特征

在柴达木盆地已知的第四系气田区, 地震剖面分辨率普遍较低, 但同相轴连续性却普遍较好, 且多为平行状反射结构。反射波振幅在构造翼部较强, 构造顶部则相对较弱, 主频范围在构造翼部为 25 Hz 左右, 而在构造顶部则为 10~15 Hz。除此而外, 本区的第四系含气地层还普遍具有如下地震反射特征。

1) 构造主体部位在常规地震剖面 and 特殊处理剖面上常会出现低频、低速、中高振幅的“两低一高”反射特征(图 1)。在特殊处理剖面上, 各种异常的分布范围各不相同: 低频异常范围最大, 大致相当于气田的含气边界范围, 振幅异常范围最小, 可大致指示气田的高丰度气区范围, 而低速异常范围则介于两者之间。

2) 在含气构造的主体部位, 地震剖面通常都存在程度不同的同相轴下拉现象, 且拐点部位常有极

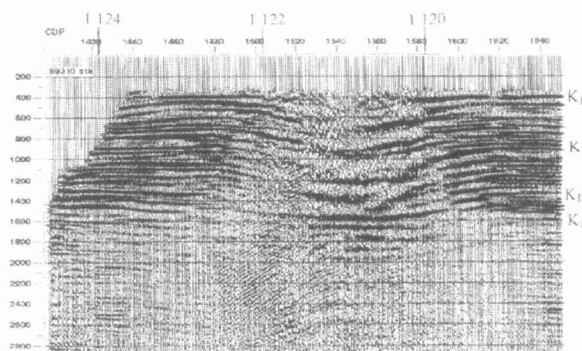


图 1 含气地震异常反射特征示意图

性反转现象。下拉部位相当于含气部位, 下拉反射的最低点对应含气构造的最高点, 下拉反射的斜坡带相当于含气构造的翼部, 下拉反射的拐点部位则相当于含气构造的气水边界。

3) 对于构造气藏, 地震异常的平面分布范围往往浅层小于中深层, 同相轴的下拉幅度也是浅层小于中深层(图 2)。含气地震异常在纵向上的强弱变化, 取决于地震波穿过含气层段的厚度和数量。地震波每穿过一个含气层段, 剖面上的同相轴下拉幅度就会增大一次, 厚度越大增幅越大, 往往在异常区两侧形成“喇叭形”反射, 地震波穿过的含气层段厚度越大或数量越多, 所造成的同相轴下拉幅度就越大, 剖面上相应的“喇叭形”反射数量就越多, 规模就越大(图 3)。

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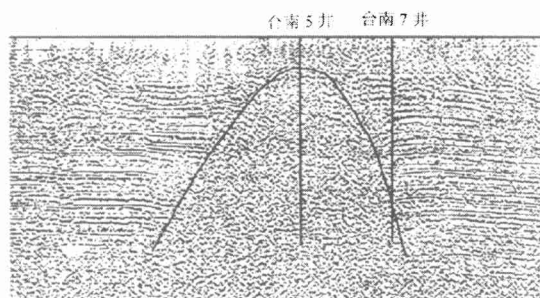


图 2 含气地震弱振幅异常特征示意图

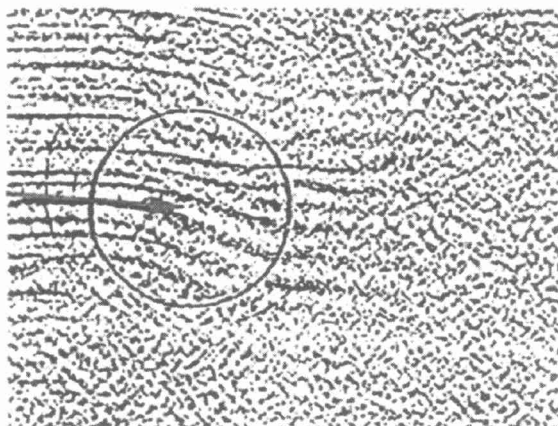


图 3 含气地层“喇叭形”反射特征示意图

4) 含气异常在地震剖面上有“高频—中频—低频—中频—高频”的明显分段对称性,并且这种对称反射基本上能够与气田“边部—腰部—中心—腰部—边部”相对应(图 4)。

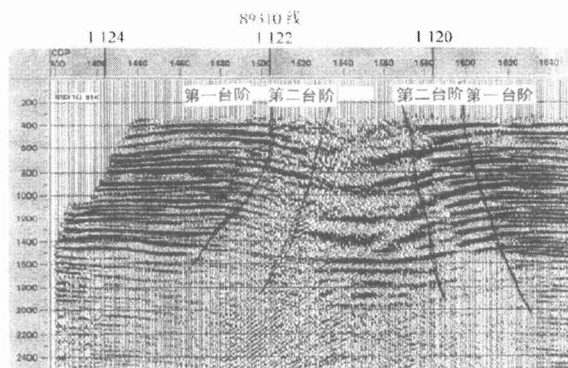


图 4 含气地震异常阶梯状结构示意图

第四系含气地震异常的形成机理

本区地表均为未成岩的晚更新统、全新统甚至现代沉积所覆盖,下伏的早更新统即为主力含气层

段。本套地层虽有较大的沉积厚度,但由于沉积时间短,压实作用和胶结作用微弱,沉积地层非常疏松。据已知气田的岩心分析结果,储层孔隙度均在 26% 以上,且普遍具有高孔、高渗的物性特征。

据地震时间剖面、合成记录及有关处理资料反映,本区第四系含气地层底界的反射时间一般均在 1.40 s 以上,并且合成声波测井剖面、AVO 振幅包络差剖面以及 SLIM 处理层速度剖面所反映的含气部位与录井、测井和测试结果非常吻合。已知台南气田的最大气藏埋深为 1 738 m,按地震最大反射时间 1.40 s 计算,地表到气藏底界的地震平均反射速度为 2 480 m/s。这样低的反射速度,在国内外含油气盆地中都是罕见的。

据有关文献介绍,层速度降低所产生的层间 Δt 增量与层速度的关系式为:

$$\Delta t = H \times [1/(v - \Delta v) - 1/v]$$

式中: Δt 表示层速度降低所产生的反射时间增加量; H 表示地层厚度; Δv 表示层速度降低量; v 表示地层层速度。由上述关系式不难看出:当 $v < 2\ 400$ m/s 后, Δt 将随 v 的降低而明显增大,并且 v 越低,相同层速度降低量所产生的 Δt 增量越大。

结构松散的本区第四系,地层速度较之盆地其它地区一般要低 300~900 m/s,而第四系含气层段的层速度,较之 2 480 m/s 的地层平均速度无疑会更低。研究表明,在本区第四系整体低速的地质背景下,地层含气后会导致层速度的进一步降低,当含气饱和度接近 70% 时,层速度便可达到 15% 的最大降低量。含气地层层速度的降低,无疑会导致地震反射时间的延迟,从而在时间剖面上形成“锅底反射”,也就是人们常说的“同相轴下拉现象”,区域地层速度越低,下拉幅度就越大。如本区台南气田与涩北气田,尽管含气丰度相当,但由于含气地层埋深和厚度的差异,台南气田含气地层的平均速度要高于涩北气田,因而台南气田的地震异常强度及同相轴下拉幅度都不及涩北气田。由此可见:整体低速的地质背景,是形成本区第四系含气地层“低频、低速、同相轴下拉”异常反射的主要原因。地震剖面上程度不同的同相轴下拉,对地下构造的真实形态造成了一定程度的歪曲,不仅会降低地震剖面上的构造幅度或者使小幅度构造从剖面上消失,含气丰度较高时甚至可能使正向构造表现为负向构造。因此,在异常反射剖面的构造解释过程中,必须对异常部位予以恢复。传统的异常恢复方法有趋势面恢复法、同心圆横剖面恢复法、回归法和二维模型法,但目前

最为常用的还是趋势面恢复法。

多年的勘探实践证明,并非所有的地震异常都是地层含气的标志。研究表明:本区第四系已知气田的气藏都集中分布于埋深 300 m 以下的 $K_1 \sim K_{10}$ 标准层之间,埋深 300 m 以上则基本上没有气层发育,但在埋深 300 m 以上的地震剖面上,却同样发现有地震异常存在。

分析认为,在区域低速背景下,表层软泥带和表层分散气的发育,也会导致地层层速度的降低,同样可能在地震剖面上形成异常反射。对于单纯由表层散失气或地表软泥带引起的异常反射,一般都可根据剖面反射特征加以识别。

由表层气引起的地震异常,一般存在于构造顶部的浅层,在地震剖面上表现为反射变差或反射杂乱,异常区虽然具有一定的构造背景,但异常范围很小且多呈上大下小的“V”字形;由表层软泥带引起的地震异常,往往分布范围较广,在剖面上表现为大面积或全剖面的杂乱反射甚至无反射,纵向上既没有“V”字形的结构特征,也不存在背斜隆起的构造背景。

由此可见:低速异常的形成既可能与地下气藏有关,也可能与地表条件有关,第四系气田区的异常地震反射往往也是地下气藏和表层条件的叠加效应。在异常反射地震剖面的解释研究中,必须注意区分真假含气地震异常,即使地震剖面上存在明显的异常反射,有时也不一定是地层含气的反映。

第四系含气地震异常的识别标志

利用地震剖面上的各种异常信息,不仅能够区分含气构造和非含气构造,确定气藏的发育位置和分布范围,而且可以大致判断气藏的含气丰度,从而实现了对地下气藏的定性识别。根据对已知气田地震资料的研究与认识,本区第四系的含气地震异常,一般可从以下 6 个方面加以识别:①含气层段的主频范围应在 10~20 Hz 之间;②工业气区的层速度降低量应大于 250 m/s,高产工业气区的层速度降低量应大于 400 m/s;③当地层背景体密度在 $1.72 \sim 1.77 \text{ g/cm}^3$ 时,含气地层的密度降低量应大于 0.1 g/cm^3 ;④工业气藏的同相轴下拉幅度大于 30 ms,高产工业气藏的同相轴下拉幅度应大于 50 ms;⑤含气地层的反射系数应在 $-0.16 \sim -0.19$ 之间;⑥含气地层的“AVO”包络异常级别应大于 III,并能在平面上圈出 I、II 级异常范围。

地震特殊处理技术的应用

1. 地震模型技术的应用

通过对台南气田地震模型的演算和平面分析,证实气田部位所出现的下陷反射,是富含天然气导致地层层速度降低的产物。当层速度降低 250 m/s 时,在地震剖面上就会出现层间时差增大和反射同相轴下拉现象。模型剖面上反射同相轴下拉的最低部位,正是构造的最高部位,亦即含气层段最厚、含气丰度最高、层速度降低幅度最大的部位。平面分析认为,当气藏埋深在 1 000~2 000 m 时,低速异常值大于 200 m/s 便可见到气显示,大于 400 m/s 为高丰度含气区,推算气水边界附近的低速异常值应在 250 m/s 左右。因此,低速异常值大于 250 m/s 便应具有工业产能,且产能的高低随低速异常值的变化而变化。

2. 合成声波测井技术的应用

通过对台南气田合成声波测井剖面的解释研究,发现垂向上所出现的 3 个低速层段,深度和层位都分别与台南气田的 3 个含气层段相对应,证明砂岩层富含天然气后层速度会有明显的降低。平面分析认为,相对层速度大于 2 650 m/s 时,地层不含气;相对层速度在 2 650~2 350 m/s 时地层含气但不具工业价值;当相对层速度小于 2 350 m/s 时,含气丰度便已具备工业开采价值。

3. AVO 技术的应用

据台南气田 265 剖面的角度道集选排记录,随着角度道的增大($6^\circ \sim 35^\circ$),在 0.9~1.0 s 和 1.3~1.4 s 处的反射振幅明显增强。分别用 10° 和 25° 的中间角度对 265 剖面进行叠加显示,在 85.05~86.675 桩号间的 0.9~1.0 s 和 1.3~1.4 s 处, 10° 中间角叠加剖面上来自地下的是弱反射,在 25° 中间角叠加剖面上来自地下的却是强反射,尤其 1.3~1.4 s 处的强反射更为突出。由此可见,随着角度道的增大,出现了反射振幅明显增强的异常现象。

对比发现,85.05~86.675 桩号 0.9~1.0 s 和 1.3~1.4 s 所出现的 AVO 异常,分别相当于台南气田 $K_3 \sim K_4$ 和 $K_5 \sim K_6$ 含气层段。台南 3 井 AVO 异常消失,钻探中也只见到了微弱的气显示,没有解释气层。根据 AVO 异常部署钻探的台南 6 井,经试气证实,1.3~1.4 s 的强异常部位,正是该井的主力产气层段,说明异常强度与含气丰度存在着明显的相关性和良好的一致性。

4. SLIM 技术的应用

台南气田 265 测线的 SLIM 处理资料, 81.5~86.5 桩号是台南气田的地震异常区, $K_5 \sim K_6$ 含气层段相当于 SLIM 处理剖面的 1.32~1.33 s 反射层段。对比发现, 台南 3 井所在的 80.9 桩号已位于异常范围之外, $K_5 \sim K_6$ 层段虽然也存在较好的储集层, 但因含气丰度太低, 仍然保持着相对较高的地层速度。

含气地震预测技术的应用效果

含气地震预测技术的成功运用, 在本区第四系天然气勘探中有过三次。

第一次是八十年代末, 在台吉乃尔湖以南的地震精细解释中, 由于对地震异常含气性的正确认识, 通过含气地震预测解释发现了新的含气构造。通过全区地震资料的联片解释, 在东台吉乃尔湖以南地区的地震剖面上发现了较为明显的“台南异常反射区”。对比涩北一号、涩北二号气田的地震剖面, 发现这种“异常反射”与探明气田存在明显的相关性和一致性。经过对含气区与非含气区地震剖面的反复对比, 首先确认“台南异常反射”为含气地震异常, 然后采用“趋势面恢复法”, 成功地完成了“同相轴下拉”区的同相轴恢复, 解释发现了“台南潜伏背斜”构造, 经过钻探, 台南中 1 井喜获高产工业气流, 发现了继涩北一号和涩北二号之后的又一个高压高产气田, 新增天然气探明地质储量 $198.91 \times 10^8 \text{ m}^3$, 使柴达木盆地的天然气探明储量由七十年代的 $88.59 \times 10^8 \text{ m}^3$ 增长为 $287.50 \times 10^8 \text{ m}^3$, 增长幅度 224.53%, 实现了天然气勘探的第一次飞跃。

第二次是九十年代初, 根据台南气田的勘探经

验, 通过地震资料的对比研究、特殊处理和含气地震预测, 在涩北一号、涩北二号气田解释发现了新的含气层系。根据台南气田的勘探经验, 通过对涩北一号、涩北二号气田区地震资料的反复对比, 根据相似的地震剖面异常反射特征, 推测两个气田都可能存在新的含气层段。通过对部分测线的特殊处理, 进一步确认了涩北一号、涩北二号气田有新气藏发育的认识, 随即在涩北一号、涩北二号气田先后部署钻探了 9 口评价井, 不仅全部获得了高产工业气流, 而且解释发现了 4 个新的气层组, 累计新增天然气探明地质储量 $184.03 \times 10^8 \text{ m}^3$, 使东部的天然气探明储量由八十年代的 $287.50 \times 10^8 \text{ m}^3$ 增长为 $471.53 \times 10^8 \text{ m}^3$, 增长幅度 64.01%, 实现了天然气勘探的第二次飞跃。

第三次是 1997 年, 通过对涩北二号地震资料的统一处理和连片解释, 利用含气地震预测技术, 在气田东北端解释发现了新的含气区块。为配合已知气田的储量研究工作, 在涩北二号气田西北端部署施工了少量的加密地震测线, 并在含气范围以外的地震剖面上发现了新的含气异常。通过对气田区新老地震剖面的连片解释, 确认上述异常为涩北二号气田含气范围的外延部分, 根据地震反射特征, 结合业已探明的气田边界, 重新圈定了含气范围, 扩大含气面积 12.1 km^2 , 在 1997 年储量地质评价的基础上新增天然气探明地质储量 $128.57 \times 10^8 \text{ m}^3$, 为实现柴达木盆地天然气勘探的第三次飞跃起到了积极的推动作用。

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ABSTRACTS AND AUTHORS

THE ESSENTIAL CONDITIONS AND CONTROLLING FACTORS OF FORMATION OF QUATERNARY BIOGENIC GAS RESERVOIRS

Guan Zhiqiang, Xu Zhiyuan, Zhou Ruinian and Jiang Guifeng (Research Institute of Exploration and Development of Qinghai Oilfield, PetroChina). *NATUR. GAS IND.* v. 21, no. 6. pp. 1 ~ 5, 11/25/2001. (ISSN1000 - 0976; In Chinese)

ABSTRACT: This article presents the formation environments and accumulation conditions of Quaternary biogenic methane gas from palaeoclimate, palaeocurrents, source rocks, reservoirs, seals, trapping conditions and preservation conditions. There also emphasizes that the preconditions of biogenic gas accumulating are sufficient sources, perfect combination of reservoir-and-seals and proper preparations of traps, and the late well-preserved conditions are the guarantee of successful exploration of biogenic gas. According to data statistics and researches of known oilfields, as well as researches of trap development and sedimentary faces, the dynamic accumulating model of Quaternary biogenic gas is founded. This article discusses the vertical and horizontal distribution regularities and controlling factors of biogenic gas pools, expounds that the vertical distribution of biogenic gas pools is controlled by source rocks and seals and the horizontal distribution is strictly controlled by trap structure.

SUBJECT HEADINGS: Quaternary, Trap, Preservation, Accumulation, Dynamic accumulation, Controlling factors

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WELL LOGGING DISTINGUISHING AND TEST OF GAS WELL VERIFYING OF MODERATE-AND-LOW PAY ZONE IN QUATERNARY

Xu Ziyuan, Jiang Guifeng, Zhang Daowei and Wang Jingpeng (Research Institute of Exploration and Development of Qinghai Oil Field, PetroChina). *NATUR. GAS IND.* v. 21, no. 6. pp. 5 ~ 9, 11/25/

2001. (ISSN1000 - 0976; In Chinese)

ABSTRACT: This article sets up the criterion for distinguishing gas bearing formation in Quaternary by analyzing quantities of old well materials, and presents formation mechanism and characteristics of four property of moderate-and-low pay zone. Through test of gas well verifying in a large scope, we not only prove distinguishing criterion and the reliability of explaining gas pay zone, but also make a great leap in natural gas reservoirs in Caidam Basin. Furtherly, research conclusions of drilling mud influence on well-logging environments and well-logging materials of loose stuff are proved. All of this set a foundation for compound of drilling mud, researches of drilling technique, selection of well-logging serials and explaining methods.

SUBJECT HEADINGS: Caidamu Basin, Quaternary, Gas reservoir, Gas formation, Classification, Formation, Mechanism, Gas test

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THE CHARACTERISTICS OF SEISMIC REFLECTIONS OF QUATERNARY BIOGENIC GAS POOLS

Liu Mingde, Liu Zhiqiang, Xu Ziyuan and Si Xiugeng (Research Institute of Exploration and Development of Qinghai Oilfield, PetroChina). *NATUR. GAS IND.* v. 21, no. 6. pp. 10 ~ 13, 11/25/2001. (ISSN1000 - 0976; In Chinese)

ABSTRACT: According to the description of seismic reflections of Quaternary petroliferous area, this article presents characteristics of seismic anomalous reflection of Quaternary petroliferous strata. The anomalous reflections of different grades on the seismic sections are endowed with clear geologic meaning by analysing the correlation between relevance of anomalous reflection and proven reservoirs distributions and conformity of anomalous extent and petroliferous abundance. Meanwhile, considering the special geologic condition, loose sediments and low buried depth, in Quaternary, we effectively discussed the formation mechanism of petroliferous seismic anomaly with the theory of wave reflection. It is clearly concluded that the geologic environment of loose sediments and the whole low velocity is the unique geologic condition of formation of special petroliferous seismic anomaly in Sanhu Quaternary.

SUBJECT HEADINGS: Caidamu Basin, Quaternary, Gas formation, Petroliferous seismic anomaly, Characteristics, For-

mation, Mechanism

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RESEARCH ON BIOGENETIC GAS RESERVOIR FORMATION OF SHIZIGOU FM ON PLIOCENE IN YILIPING OF THE CAIDAM BASIN

Liu Chengliu(Petroleum University of Beijing), Jiang Zhusheng, Li Jian, Xie Zengye (Langfang Branch of RIPED), Jiang Guifeng and Wang Jinpeng (Qinghai Branch of CNPC). *NATUR. GAS IND.* v. 21, no. 6. pp. 14 ~ 16, 11/25/2001. (ISSN1000 - 0976; In Chinese)

ABSTRACT: The forming history of biogenetic gas reservoir is discussed at Shizigou FM on Pliocene in Yiliping of the Caidam Basin. Firstly, natural gas of Shizigou FM is testified as biogenetic gas by the biogenetic gas simulating experiment. Secondly, producing mechanism of biogenetic gas is different from that of conventional natural gas. Through analyzing sedimentary facies, ancient climate, and temperature, the producing conditions of biogenetic gas are clear and higher salinity and lower temperature make it possible for biogenetic gas to appear on the deeper formation. Next, the reservoir and cap conditions are fine on Shizigou FM of Pliocene in Yiliping. There are two kinds of preserving mechanism, one is reservoirs physical property variation preservation, the other is hydrocarbon density preservation. In the end, the model of reservoir forming is constructed and biogenetic gas reservoir formation process is divided into four phases, which are free gas escaping phase, water-soluble gas reservoir phase, water-soluble gas containing net gas reservoir phase, and net gas water-containing soluble gas reservoir phase.

SUBJECT HEADINGS: Caidam Basin, Pliocene, Biogenetic gas, Sedimentary facies, Reservoir rock, Cap rock, Reservoir forming

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PECULIARITIES OF CHINA CBM RESERVOIRS AND THEIR DICTATION ON CBM PRODUCTION TECHNOLOGY

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ABSTRACT: CBM exploration and production test have been conducted in about 18 major coal-bearing basins in China since the introduction of surface vertical hole gas recovery technology in the late 1980's. But almost none of the test wells could encourage us with a stable high gas production rate. This phenomenon seems to demonstrate a very dark future of China CBM industry. The authors analyzed geological backgrounds and engineering history of China CBM reservoir development, and pointed out that the poor well performance in China CBM reservoir peculiarities. The authors believe that there are five entrances of us to get on the way of increasing our well production rate. And under balance drilling technology is strongly recommended. Three series of production technology are created to fit various China CBM reservoir.

SUBJECT HEADINGS: China, Coal-formation reservoir, Development technique

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COAL-BED GAS PRODUCTION PROCESS SIMULATION BY USE OF THERMAL MODEL

Zhang Liehui, Cheng Jun(Southwest Petroleum Institute), Ren Dexiong (Chuan Zhong Oil and Gas Scientific Research Institute of PetroChina) Hu Yong and Tu Zhong (Southwest Oil and Gas Company of PetroChina). *NATUR. GAS IND.* v. 21, no. 6. pp. 20 ~ 22, 11/25/2001. (ISSN1000 - 0976; In Chinese)

ABSTRACT: The transportation of gas through a coal seam includes the desorption of gas from the coal matrix followed by flow through the fractures. If the release of gas from the matrix to the cleats is very rapid compared to the flow of gas and water in the cleats, the desorption kinetics are relatively unimportant in modeling coal-bed methane production. This assumption allows the adsorption of gas on the surface of the coal to be modeled as gas dissolved in an immobile oil. The solution gas-oil ratio of this immobile oil is calculated from the Langmuir adsorption isotherm curve. A conventional reservoir simulator can be used to describe coal-bed methane. No source code modification is required. Based on the thoughts above, this paper simulates coal-bed methane production using conventional thermal model, and the trend is very close compared with the results calculated by coal-bed methane simulation software(COMETPC).

SUBJECT HEADINGS: Thermal model, Coal-bed gas, Simulation, Adsorption, Transportation