鄂尔多斯盆地致密砂岩气层测井评价新技术

杨 双 定

(中国石油集团测井有限公司长庆事业部)

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摘 要 鄂尔多斯盆地上古生界以陆相、海陆交互相碎屑岩为主, 属于低孔、低渗的致密砂岩储集层。由于其低孔、低渗、非均质性强等原因, 使利用常规测井资料正确识别气层的难度增大。文章分析认为, 上古生界气田测井特征受岩性物性作用比较明显, 石英砂岩和岩屑砂岩的测井特征与含气特征不同, 电性上高低电阻率气层共存。在综合利用成象测井新技术提供的新方法及多信息、高精度参数, 在分析储层特征的基础上, 结合实验数据确定了核磁共振变等待时间的测井参数, 提出了对致密气层识别有效的气层识别新方法, 主要为基于核磁共振测井的差谱法、移谱法, 基于交叉偶极声波测井纵波差值法。通过实例分析, 证明了方法的有效性, 较好地解决了低孔、低渗致密气层和低阻砂岩储层的气层识别问题, 提高了测井识别的准确率, 解释符合率达 85% 以上。

主题词 鄂尔多斯盆地　核磁测井　声波测井　致密砂岩　储集层　流体

一、储层特征

鄂尔多斯盆地上古生界以陆相、海陆交互相碎屑岩为主。自下而上发育着石炭系本溪组、太原组、二叠系山西组、石盒子组和石千峰组。其中太原组、山西组、石盒子组是主要储集层, 储集层岩性为浅灰色含砾粗砂岩, 灰—灰白色中粒石英砂岩, 灰绿色岩屑质石英砂岩, 岩屑砂岩等。

上古生界主要储集层砂岩经历了漫长而复杂的成岩后生作用的改造, 储集岩中的原生孔隙大部分遭受破坏, 仅存残余粒间孔、自生溶孔以及高岭石晶间孔, 从而构成了上古生界低孔、低渗砂岩的储集体系。通过 12 口井的岩心分析样品统计, 其物性特征如表 1 所示。

表 1　储层物性统计表

地　层	孔隙度 (%)	平均孔隙度 (%)	渗透率 ($10^{-3}\mu m^2$)	平均渗透率 ($10^{-3}\mu m^2$)
石盒子组	3~ 16	9.6	0.05~ 6.79	1.09
山西组	4~ 10	6.1	0.01~ 5.63	0.69

该类储层一般必须经压裂改造才有产能, 是否产气的影响因素多, 即使采用成像测井, 也存在多解性, 测井解释难度大。

二、电性特征

在鄂尔多斯盆地上古生界气田, 测井特征受岩性物性作用比较明显, 随岩石中岩屑含量增加, 或粒度变细, 孔隙度减小, 渗透率降低, 密度增大, 电阻率增大, 双测向曲线趋于重合。相反, 随岩石中岩屑含量减小, 或粒度变粗, 孔隙度增大, 渗透率升高, 密度变小, 双测向曲线幅度差异变大。一般纯石英砂岩的自然伽马值小于 35 API, Pe 值小于 2 b/e, 骨架密度值为 2.65 g/cm^3, 井径正常或缩径; 岩屑砂岩自然伽马值大于 40 API, Pe 介于 2.2~ 3.2 b/e, 骨架密度值为 2.7 g/cm^3, 常扩径。高低阻气层并存, 山$_2$段储层电阻率在 100 Ω·m 可能出水, 而盒 8 段电阻率 20 Ω·m 可出纯气。

三、气层测井识别新方法

常规测井识别气层主要是通过气层与水层的电阻率差异来识别, 对于低孔、低渗、低阻气层识别难度较大。测井新技术的应用, 为气层识别提供了新的依据。利用核磁共振测井、交叉偶极声波测井等成象测井资料提取气层识别方法, 提高气层识别精度。

作者简介: 杨双定, 1966 年生, 高级工程师; 1991 年毕业于西南石油学院测井专业, 1999 年获西南石油学院地球探测与信息专业硕士学位; 现从事测井资料综合解释及方法研究工作。地址: (710201) 陕西省西安市长庆路方元大厦。电话: (029) 86029722。E-mail: cjc_ysd@mail.cnpccq.com

1. 差谱法识别气层

由于水与烃的纵向驰豫时间相差很大,意味着它们的纵向恢复速率很不相同,水的纵向恢复远比烃快。据此可以识别和定量解释油、气、水层。对 58 块饱和盐水状态下的砂岩储层岩心进行变等待时间参数测试。变等待时间测试参数分别为 T_w = 1 s、3 s、6 s 和 8 s,而 T_e = 0.2 ms。由于岩心的状态为饱和盐水,T_2 谱位置普遍比较靠前,许多岩心的纵向恢复在 1 s 后就已经比较完全,因此 1 s、3 s、6 s 和 8 s 的等待时间下的测试结果比较接近,没有明显的差谱效应。可见,如果在地层条件下,岩心含有气,则差谱效应会得到加强,选择 1 s 的短等待时间和 8 s 的长等待时间,即可通过差谱测试识别气和水。

以 A 井为例,该井是位于陕西横山地区的一口气探井,测井目的评价该井的上古生界砂体含气情况,本井山西组砂体在 2751.0～2761.7 m,从曲线上总体看砂体厚度大,自然电位幅度较大,岩性纯,电阻率值平均值高达 2000 Ω·m 以上,最高达 3577 Ω·m,鄂尔多斯盆地上古生界砂岩气层的电阻率一般小于 100 Ω·m,低孔高阻砂岩储层在常规曲线上显示特征与干层相似,难以识别,声波时差为 215 μs/m,孔隙度为 7.1%～7.9%,表现为典型的低孔高阻特性,从常规曲线看应解释为干层(见彩色图版 5)。核磁共振 T_2 谱和差谱显示表明含有一定数量的烃,综合解释为气层,试气结果产气 $4.4031\times10^4 m^3/d$。

2. 移谱法识别气层

利用不同流体的扩散系数不同,选择不同的回波间隔来定性的判断流体的性质。设置足够长的等待时间,使 $T_R > (3\sim5)T_{1h}$(T_{1h} 轻烃的纵向驰豫时间),每次测量时使纵向驰豫达到完全恢复,利用两个不同的回波间隔 T_{EL} 和 T_{ES},测量两个回波串。由于水与气的扩散系数不一样,使得各自在 T_2 分布上的位置发生变化,对含气地层,T_E 增大,气的 T_2 峰前移甚至消失而水峰相对移动不大。

B 井是苏里格地区的一口探井,目的层石盒子组的 3442.1～3448.5 m 储层,电性显示差,电阻率最低仅 16 Ω·m,从常规曲线很难判断流体性质。图 1 为该层移谱流体识别解释成果图,核磁共振测井显示,该层 T_2 谱存在双峰,微孔隙比较发育。具有低阻气层的特征,长回波间隔(T_e)的 T_2 谱明显前移,差谱也显示含气明显,计算的孔隙度 13%,束缚水体积 3%,烃体积含量较大 9%,解释为气层,试气结果,产气 $23\times10^4 m^3/d$,证明了方法的有效性。

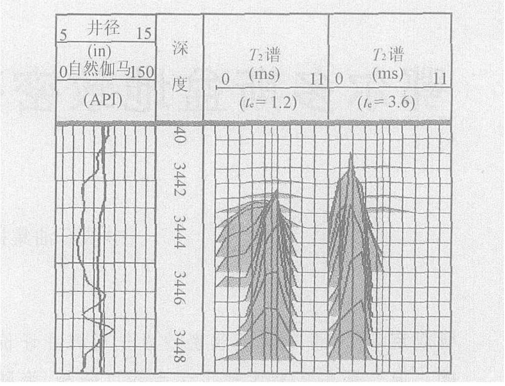

图 1　B 井移谱成象图

3. 纵波差值法识别低阻气层

在纯含水砂岩地层条件下,纵波和横波速度有如下关系:

$$v_P = 1.16v_S + 1.36 \quad (km/s)$$

因而利用偶极横波测井横波时差可计算出含水砂岩纵波时差,实测纵波时差与该值的差值可直观指示气层。

图 2 为 C 井纵波差值法识别气层成果图,图中

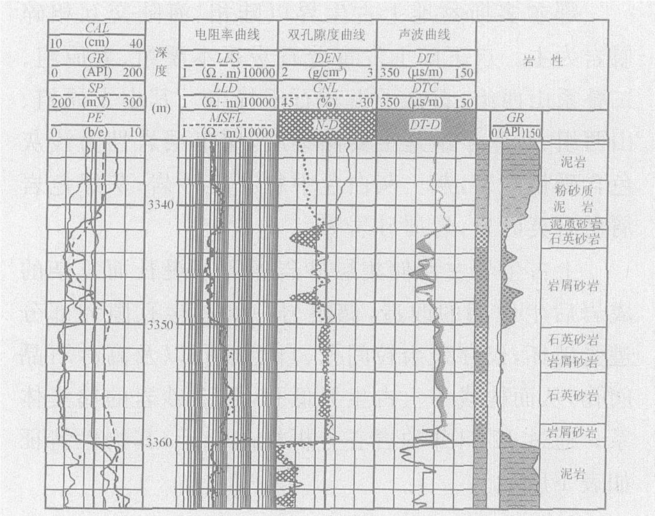

图 2　C 井纵波差值法识别气层成果图

第 5 道的红色充填为纵波时差差值含气指示,其中 3342.0～3344.0 m,3344.5～3347.0 m 两段电阻率 18～20 Ω·m,声波时差 248～252 μs/m,自然伽马 48～50 API;底部气层 3350.2～3358.0 m,电阻率 50～160 Ω·m,声波时差 215～230 μs/m,自然伽马 28～37 API;上下两段气层电阻率、自然伽马呈现一明显台阶,上部为低阻气层,下部为常规气层。上部岩性为含泥中粗粒石英砂岩,正韵律沉积;下部岩性为含硅质粗粒石英砂岩,反韵律沉积;两段气层之间存在沉积间断。分析认为上部低电阻率气层形成的

原因是水云母粘土矿物对孔隙充填改造引起。岩心分析上部平均孔隙度 12.9%, 渗透率 0.7759×10^{-3} μm^2, 含水饱和度 62.69%; 底部平均孔隙度 8.50%, 渗透率 $0.3828 \times 10^{-3} \mu m^2$, 含水饱和度 46.84%。对上下两段气层压裂试气获无阻产量 $15.7598 \times 10^4 m^3/d$。

由于测井新方法的应用, 认识了致密气层和低阻气层的响应特征, 指导了气井的测井解释, 解释符合率达 85% 以上。

四、结　论

(1) 气层识别新方法较好的解决了低孔、低渗致密气层和低阻砂岩储层的气层识别问题, 提高了气层识别水平。

(2) 核磁共振测井可提供束缚水孔隙和可动流体孔隙等信息, 在低阻气层的识别方面有明显的优势。

测井识别气层一直是测井评价的难点, 笔者利用核磁共振, 交叉偶极阵列声波资料建立了适合于鄂尔多斯盆地上古生界的气识别新方法, 解释符合率提高, 为天然气勘探提供了技术支持。

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(上接第 35 页) 它点的视电阻率和相位曲线的反演结果与理论数据拟合得很好, 但总体上视电阻率曲线比相位曲线拟合得要好。

四、结　论

我们用 REBOCC 法和广义逆一维反演法处理了 COPROD-2S1 数据, 结果显示了该模型背景场呈层状分布, 包含 6 个低阻体, 覆存于电阻率为 1000 Ω·m的高阻层中。尽管 TP 与 TE、TP 与 TM 模式的联合反演结果与单独的 TE、TM 反演结果相比没有得到改善, 但是 TE+TM+TP 的联合反演结果表明, 结合 TP 的资料进行三种数据的联合反演能够提高分辨率, 这在实际应用中具有一定的价值。反演的结果还表明, COPROD-2S1 数据是一种检验二维反演算法的很好合成数据, REBOCC 是当前一种较好的 MT 二维反演方法。

感谢 Dr. Varentsov 提供 COPROD-2S1 数据, Dr. Siripunvaraporn 允许使用 REBOCC 软件。

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CALCULATION METHODS OF THE OIL AND GAS SATURATION IN COMPLEX CARBONATE RESERVOIR

Zhao Liangxiao[1], Zhang Shudong[2] and Hu Ling[3] (1. Research Institute of Geological Exploration and Development, SPA; 2. Log Company, SPA; and 3. Chongqing Gas Field, Southwest Oil and Gas Field Branck, PCL). *NATUR. GAS IND.* v. 25, no. 9, pp. 42 – 44, 9/25/2005. (ISSN 1000–0976; **In Chinese**)

ABSTRACT: According to the occurrence conditions of oil, gas and water in the heterogeneous reservoir with pores, cavities and fractures and to the response characteristics of different logging methods, the original reservoir fluid model, drilling fluid invasion model and log response mathematical model were set up, thus developing the calculation methods of relevant fluid saturations and the identification methods of reservoir fluid nature. By applying these models and identification methods mentioned above, the irreducible water saturation, free water saturation, pent-up water saturation, free hydrocarbon saturation and immovable hydrocarbon saturation of the fracture-cavity reservoir with very complicated pore space structure were calculated respectively, then not only can the reservoir fluid nature be accurately identified but also the producing characteristics of the oil, gas and water may be interpreted and predicted on the drilling profile with very complicated oil-gas-water distribution relationship.

SUBJECT HEADINGS: Carbonate rock, Reservoir, saturation, Irreducible water, Drilling fluid, Log interpretation

Zhao Liangxiao (*professorial senior engineer*), born in 1940, graduated in well logging at the former Beijing Petroleum Institute in 1963. Now he is engaged in log interpretation work. Add: No. 1, Section 1, Fuqing Road, Chengdu, Sichuan (610051), China Tel: (028) 86015420 E-mail: zhangsd-007@163.com

NEW METHODS OF LOG EVALUATION OF THE TIGHT SANDSTONE GAS RESERVOIRS IN E'ERDUOSI BASIN

Yang Shuangding (Changqing Utility Department, Logging Co. Ltd., CNPC). *NATUR. GAS IND.* v. 25, no. 9, pp. 45 – 47, 9/25/2005. (ISSN 1000–0976; **In Chinese**)

ABSTRACT: The Upper Paleozoic in E'erduosi Basin is mainly composed of the clastic rocks of continental and transitional facies, and its reservoir belongs in low-porosity and-permeability tight sandstone. Therefore it was difficult to identify correctly the gas reservoir by applying conventional log data because of its low porosity, low permeability and strong heterogeneity. Through analyzing, it was considered that the influence of lithology and petrophysical property on log response was relatively evident; and the log features of quartzose sandstones and lithic sandstones were nonidentical with the gas potential, the gas reservoir showing both high and low resistivities. By use of the new method, multiple information and high-accuracy parameter supplied by imaging logging technique and on the basis of analyzing reservoir characteristics, the log parameter of the variable-waiting time of nuclear magnetic resonance was determined in combination with experimental data; and the effective identification methods of tight gas reservoir was proposed, they including the difference spectrum and migrating spectrum methods based on nuclear magnetic resonance log and the compression wave differential value method based on cross-dipole acoustic logging. Through analyzing an example, it was proved that these methods are effective. Therefore the problem of identifying the low-porosity and-permeability tight gas reservoir and the low resistivity sandstone gas reservoir was well solved and the accuracy of log identification was greatly raised with an interpretation coincidence rate of more than 80%.

SUBJECT HEADINGS: E'erduosi Basin, Nuclear magnetic logging, Sonic logging, Tight sandstone, Reservoir, Fluid

Yang Shuangding (*Master and senior engineer*), born in 1966, graduated in well logging at the Southwest Petroleum Institute in 1991 and received his Master's degree in earth detection and information in 1999. Now he is engaged in the research on comprehensive log interpretation and its methods. Add: Fangyuan Mansions, Changqing Road, Xi'an, Shaanxi (710201), China Tel: (029) 86029722 E-mail: cjc-ysd@mail.cnpccq.com

RESEARCH ON GAS DRILLING TECHNOLOGY AND IT APPLICATION IN WELL QIBEI-101

Wei Wu, Xu Qicong, Deng Hu and Xu Zhongxiang (Research Institute of Drilling and Production Technology, SPA). *NATUR. GAS IND.* v. 25, no. 9, pp. 48 – 50, 9/25/2005. (ISSN 1000–0976; **In Chinese**)

ABSTRACT: Because of a large hole size and complex geological conditions, the penetration rate of deep exploration well was very low, thus causing a long drilling cycle and complicated downhole accidents as drilling pipe breaking and