AVO 属性在致密砂岩储层流体检测中的应用

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摘 要 四川盆地 WD 区块低平构造上的 WD7 井在上三叠统须家河组二段获工业性气流并稳产了 20 多年, 证实了该区具有巨大的勘探潜力。然而, 依据该井地震响应模式相继钻探的 WD8 井、WD11 井等测试产水, 给后续钻探井位的部署带来了不确定性因素。因此, 对该区砂岩储层的气水预测显得尤为重要。为此, 利用流体替换、AVO 正演模拟方法, 提取了多种 AVO 属性, 通过 3 种 AVO 属性分析, 认识到截距* 梯度属性可以区分须二段上部薄砂岩储层的含水和含气特征。进而采用三维叠前时间偏移获得的高质量 CRP 道集, 提取截距* 梯度属性数据体, 预测了须二段上部致密砂岩储层的含气区分布, 并提交了 2 口建议井位, 经钻井检验, 预测结果与实钻吻合。该方法对类似地区致密砂岩储层的气水识别具有一定的指导意义。

关键词 地震勘探 AVO 流体替换技术 气水识别 致密砂岩 储集层 四川盆地
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1 地质背景

四川盆地蜀南 WD 区块上三叠统须家河组二段岩性为砂岩、泥岩互层, 主要目的层为须二段上部的砂岩, 埋深介于 2 000~ 2 100 m, 砂岩储层单层厚度为 1~ 5 m, 累计厚度介于 10~ 20 m。储层孔隙度主要分布于 8% ~ 10% 之间; 渗透率一般介于 0.1~ 0.5 mD, 属于典型的低孔隙、低渗透、致密砂岩储层[1-4]。须二段上部砂岩顶界与须三段泥岩接触, 底界与须二段内部的一套 8~ 10 m 厚的页岩直接接触(图 1)。

本项目工作开展前该区共钻遇目的层 4 口井, 4 口探井基本上均能钻遇储层(孔隙度大于 8%), 但砂岩储层的含流体性质差异较大, 1 口井获工业气流, 2 口井测试产水, 1 口井测试干层。2 口产水井构造海拔位置均高于气井。构造的高低关系无法解释该区块气、水井分布的原因。振幅、频率、吸收系数等叠后地震动力学信息, 均无法表征 4 口井的含气性差异。

由于 WD 区块部署了高覆盖次数的宽方位三维地震, 最大偏移距 2 922 m, 目的层最大入射角接近 30° 左右, 为在该区块开展 AVO 属性来对该区气水分布情况进行预测奠定了基础。

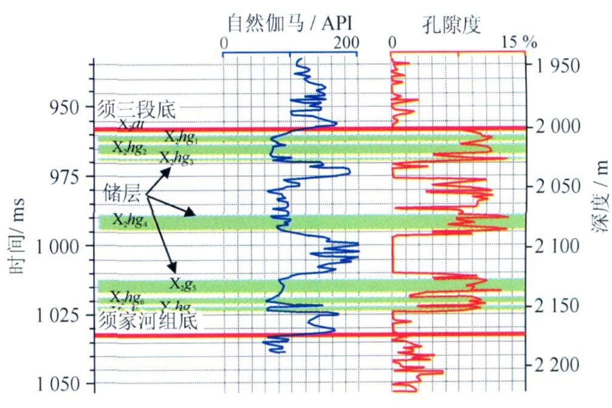

图 1 研究区储层电性变化特征图

2 流体替换及 AVO 正演模拟

通过一种含流体饱和岩石的弹性参数, 利用 Biot-Gassmann 方程, 计算另外一种含流体饱和岩石的弹性参数, 从而分析不同流体性质对弹性参数的影响, 这就是流体替换技术。

研究区仅 WD8 井有阵列声波测井, 纵波、横波、密度资料齐全, 为了了解该区不同流体性质对弹性参

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数、地震响应特征的影响,采用流体替换方法对 WD8 井深度 2 000~ 2 020 m 段上部储层进行流体替换,分别将目的层段替换成含水饱和度为 100%、85%、65%、45%、25%、5% 的流体。

利用上述流体替换结果,采用 Zoeprlitizz 方程,进行 AVO 动校道集的正演模拟(图 2)。储层对应图中所示的黄色段。从定性分析来看,无论是储层顶界还是储层底界振幅(绝对值)均随着偏移距增大而增大。

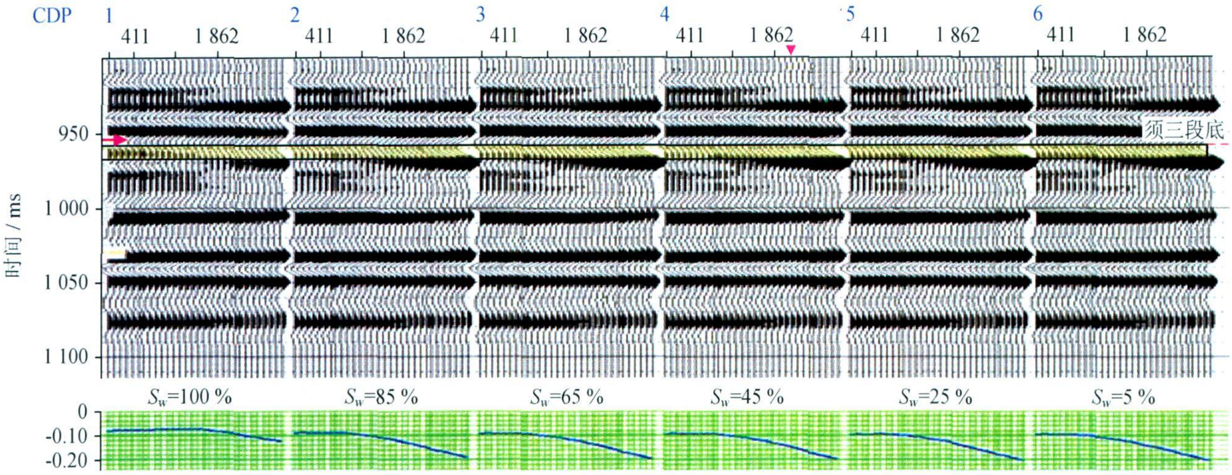

图 2　WD8 井 AVO 正演道集图

3　AVO 属性分析

3.1　梯度分析

对储层顶界的振幅进行拾取,其结果见图 2。可以看出:上部储层含流体后,振幅(绝对值)均随偏移距增加而增大,但振幅变化的幅度有所不同,含气比含水振幅增加的幅度更大。

对 AVO 正演道集提取梯度属性,其梯度属性值变化见表 1。储层含气后梯度(振幅变化率)比储层含水后高 55%~97%,显然梯度属性可以区分气水层。从表 1 中还可以看出:梯度变化虽然对气层、水层敏感,但对含气饱和度的大小不敏感。

表 1　AVO 属性变化表

含水饱和度	100%	85%	65%	45%	25%	5%
梯度值	－0.142	－0.220	－0.240	－0.260	－0.275	－0.280
$P*G$	0.006	0.015	0.016	0.016	0.017	0.018

3.2　P-G 属性交会分析(截距—梯度交会分析)

图 3 是 WD8 井正演模拟道集的 P-G 交会分析结果,其中右边小图中橙色和红色区就是建立的气层顶、底识别模版。图 3 中 WD8 井储层段在 CDP1—CDP5 含水饱和度为 100%、CDP6—CDP10 含水饱和度为 85%,以此类推每 5 个 CDP 点含水饱和度减小 20%,至 CDP26—CDP30 储层段含水饱和度降至 5%。P-G

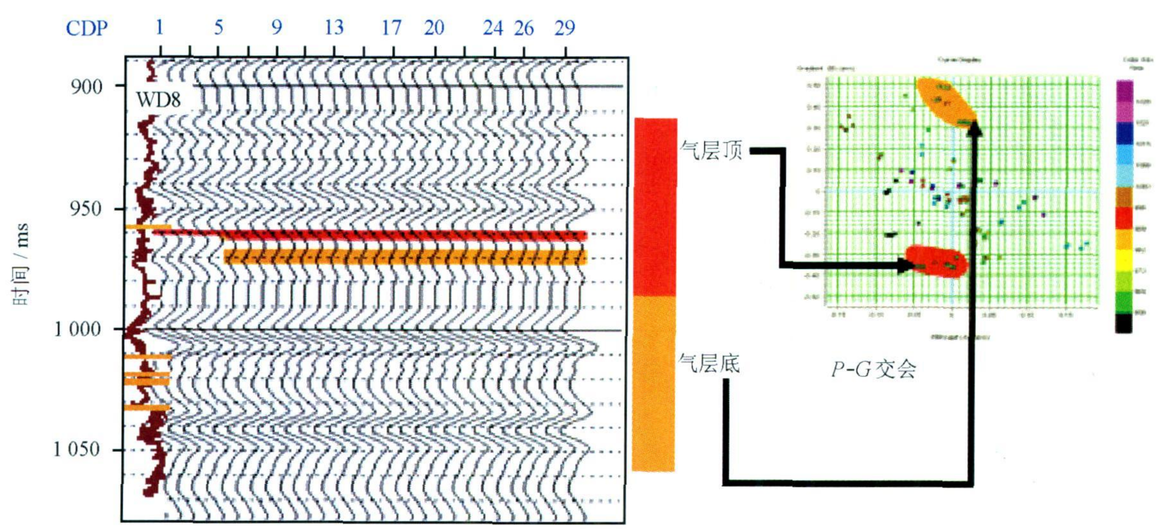

图 3　WD8 井不同含水饱和度模型图

交会分析结果表明: 含气层与水层可以通过 *P*-*G* 交会分析加以识别, 但 5% ~ 45% 含气饱和度的储层与含气 65% ~ 85% 的储层之间的 *P*-*G* 差异很小。

3.3　*P** *G* 分析(截距* 梯度属性分析)

图4 是 WD8 井正演模拟道集的 *P** *G* 属性剖面, 剖面下方为储层顶界的 *P** *G* 值, 随着含水饱和度的降低, *P** *G* 值逐渐升高, 具体 *P** *G* 的变化见表 1, 气层 *P** *G* 绝对值大于水层, 储层含气后 *P** *G* 比储层含水后高 150% ~ 200%, 显然 *P** *G* 属性相对于梯度属性对气水层更为敏感。与梯度属性一样, 5% ~ 45% 含气饱和度的储层与含气饱和度 65% ~ 85% 的储层之间 *P** *G* 的差异很小。

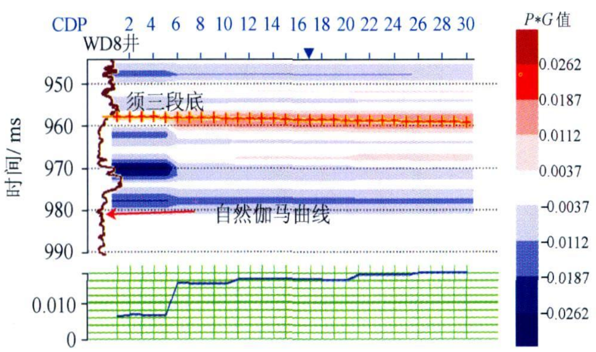

图 4　**WD8 井 AVO 正演模拟获得的 *P** *G* 剖面图**

4　流体检测

模型正演结果表明: 梯度属性、*P*-*G* 属性交会分析、*P** *G* 属性可以区分气层、水层, 但 *P** *G* 属性是区分 WD 区块气层、水层的最佳属性。

对 WD 区块宽方位三维地震资料进行了保真叠前处理, 获得了高质量的 CRP 道集, 在此基础上进行 AVO 处理, 提取了 *P** *G* 属性, 利用该属性可以判别储层的含气性, *P** *G* 属性值大区(红色) 是含气概率高值区。图 5 是分别截取了井附近的须二段储层 *P** *G* 平面分布图, 图中暖色调代表 *P** *G* 值大, 指示可能的有利含气区分布, WD7 井(气井) 位于 *P** *G* 相对高值的红色区域内, WD8 井、WD11 井(水井)、WD2 井(干井) 位于 *P** *G* 相对中低值区域内, 该属性很好地解释了 4 口井的含气性差异。下一步钻探目标可以根据预测结果在红色区域进行布井, 建议井 J1 井和 J2 井均位于 *P** *G* 相对高值的红色区域, 经钻井检验, 2 口井分别获得 8.2×10^4 m^3/d、92×10^4 m^3/d 的工业气流。

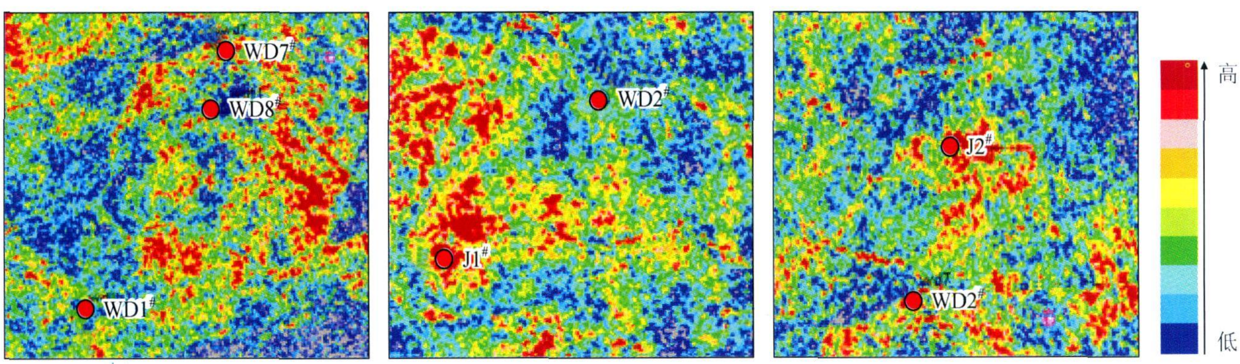

图 5　***P** *G* 属性平面分布图**

5　结束语

充分利用叠前 AVO 属性信息, 可以解决叠后方法所不能解决的气水识别问题, 预测含气有利分布区, 降低致密砂岩储层的勘探风险。但是笔者认为 AVO 属性的应用好坏与地震资料的保真处理密切相关。另外, 笔者仅对气层、水层的检测工作进行了研究, 但该方法对含气饱和度的大小不敏感, 下一步还需要研究分析对含气饱和度大小敏感的属性。

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regional seismic tracing, it is believed that the distribution area of source rocks in the Queerqueke Formation is up to 50000 km^2. Hydrocarbon-source correlation reveals that some of the oil/gas in the Tadong area is derived from the source rocks in the Queerqueke Formation. Caohu in the northwest, Yingdong in the northeast, and Gucheng in the Southwest have well-developed source rocks with moderate thermal maturity are favorable areas for hydrocarbon accumulation. In the Caohu and Gucheng areas, the Cambrian-Ordovician play with an area of 8000 km^2 has large traps of reef-shoal type and are laterally in direct contact with the source rocks, thus having great possibilities of discovering large lithologic carbonate reservoirs. It is thought to be possible to discover moderate-small secondary hydrocarbon reservoirs in the Yingdong area, where several reservoir-seal combinations occur in the Jurassic and Silurian clastic rocks and faulted anticline traps and source faults are both well developed.

Key words: Tarim Basin, Middle-Late Ordovician, Queerqueke Formation, source rock, distribution characteristics, seismic stratigraphic interpretation, oil-source correlation, exploration potential

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Process of hydrocarbon pooling in the Cretaceous and Paleogene of Yakela faulted uplift, Tarim Basin

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Abstract: Previous researchers have studied the process of hydrocarbon pooling in Yakela faulted uplift of the Tarim Basin and proposed various hydrocarbon pooling models. However, the timing of hydrocarbon pooling is generally based on qualitative analysis of pooling conditions. Moreover, the differences of hydrocarbon migration from different sources have not been accounted in the establishment of carrier patterns. For this reason, 177 fluid inclusion samples from 26 wells were systematically analyzed and the hydrocarbon pooling process was discussed in combination with hydrocarbon generation and expulsion history, thermal evolution history and carrier systems. The following conclusions are obtained. 1) Carrier systems of "fault-connecting" type are common in the study area due to the superimposition of multiple tectonic movements, providing not only pathways for vertical migration of hydrocarbons, but also favorable conditions for the formation of secondary hydrocarbon reservoirs. 2) Hydrocarbon charging mainly occurred in 3 stages, including 14-5 Ma (million years ago), 5-2 Ma (million years ago), and 2-0 Ma (million years ago), of which the second stage is the major one. 3) Hydrocarbon pooling mainly occurred in the middle-late Himalayan, a relatively late time for hydrocarbon accumulation, and are featured by continuous and rapid charging. A comprehensive study of pooling history reveals that the hydrocarbon charging and the factors controlling hydrocarbon pooling (such as hydrocarbon generation and expulsion history, traps and their sealing conditions as well as the "fault-connected" carrier systems) matched well both temporally and spatially in this study area.

Key words: Tarim Basin, Yakela faulted uplift, "fault-connecting" carrier system, hydrocarbon pooling, carrier system, pooling pattern, inclusion, fault

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Application of AVO attribute to the detection of tight sandstone reservoirs

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Abstract: Since achieving an industrial gas flow from the second member of the Upper Triassic Xujiahe Formation 20 years ago, the well WD7 drilled in the Block WD of the Sichuan Basin has been under steady production, verifying that great exploration potential exists in the study area. However, the following wells of WD8 and WD11 drilled according to the seismic responses from the WD7 well started to produce water, making it uncertain to emplace successive wells. Therefore, the accurate prediction of oil and gas distribution in the sandstone reservoirs in the study area is especially important. Fluid replacement and AVO forward modeling methods are used to extract several AVO attributes. Among three methods of AVO attribute analysis, the P + G attributes are proved to be effective in detecting the water-bearing and gas-bearing properties in the thin sandstone reservoirs in the upper part of the second member of the Xujiahe Formation. The high-quality CRP gathers obtained through 3D prestack time migration are used to obtain the P + G attributes, which is then applied to the prediction of gas-bearing zones. Two wells are proposed based on the prediction results, which are verified by the drilling data. This method can be popularized for the detection of water and gas zones in tight sandstone reservoirs in similar areas.

Key words: seismic exploration, AVO, fluid replacement technique, gas/water detection, tight sandstone, reservoir, Sichuan Basin

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An optimal design of horizontal wells applied in the productivity construction of the Puguang Gas Field

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Abstract: The Puguang Gas Field is characterized by complex topography, deep burial depth, fast sedimentary facies transition, and abundant edge water. To ensure the high-efficiency development of this gas field, the optimal design methods have been discussed for horizontal wells after the feasibility of horizontal well development is verified. First of all, according to the technical and economic indexes such as the minimum thickness of the encountered pay zone, which is calculated by use of the contribution margin analysis, the locations for disposing horizontal wells are determined. After that, according to the geological model of a single well, the production relationship between horizontal and vertical wells is established and the length of horizontal section is optimized. Finally, with the reservoir distribution, structural trend, pattern well spacing, and gas/water relations taken into consideration, the wellbore trajectory is optimized. This study shows that the development of this gas field can be improved by adopting horizontal well development at the districts with relatively thin layers or around the gas water boundary. The optimal length of horizontal section is designed as 400 - 600 m and the targets Ⅰ and Ⅱ are about 10 m away from the top and bottom of the gas pay zone respectively. This technique has shown such a better performance in practice during the design of development wells at the Puguang Gas Filed as to be used as a reference when developing similar gas reservoirs in the future.

Key words: Puguang Gas Field, development, horizontal well, technical and economic limits, optimal design, production capacity, wellbore trajectory optimization

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