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新场气田致密砂岩储层储渗体差异识别技术

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摘要: 在运用地震、测井多种处理解释手段基础上, 以动态信息为线索, 以测试与实验分析相结合为手段, 以表征储层储渗差异现象的地质模型为突破口, 以建立等效地球物理模型为纽带, 筛选并形成了识别储渗体差异性的方法技术。

关键词: 致密气藏; 储渗体; 识别
中图分类号: **TE112. 23**　　文献标识码: **A**

1　地质背景及地质特征

四川盆地川西坳陷具多期次、低强度、继承性的特征, 在坳陷的构造中, 以燕山中、晚期为低幅隆起, 喜马拉雅期形成现今构造格局的鸭子河—孝泉—丰谷北东东向隆起带为天然气长期运移的指向带, 对气藏形成极为有利。新场气田便是该隆起带上的孝泉背斜向北东东方向倾没的一个鼻状构造, 该气藏受构造、岩性双重控制, 属超高压构造—岩性复合型气藏类型(图 1)。沙溪庙组气藏由 4 套稳定的含气砂体组成, 这些属于三角洲平原河道叠置砂体每层约 6~ 30 m, 埋深 2 150~ 2 500 m, 平面叠合含气面积 100 km^2[1]。

沙溪庙组气藏储集岩岩石类型为浅绿灰色块

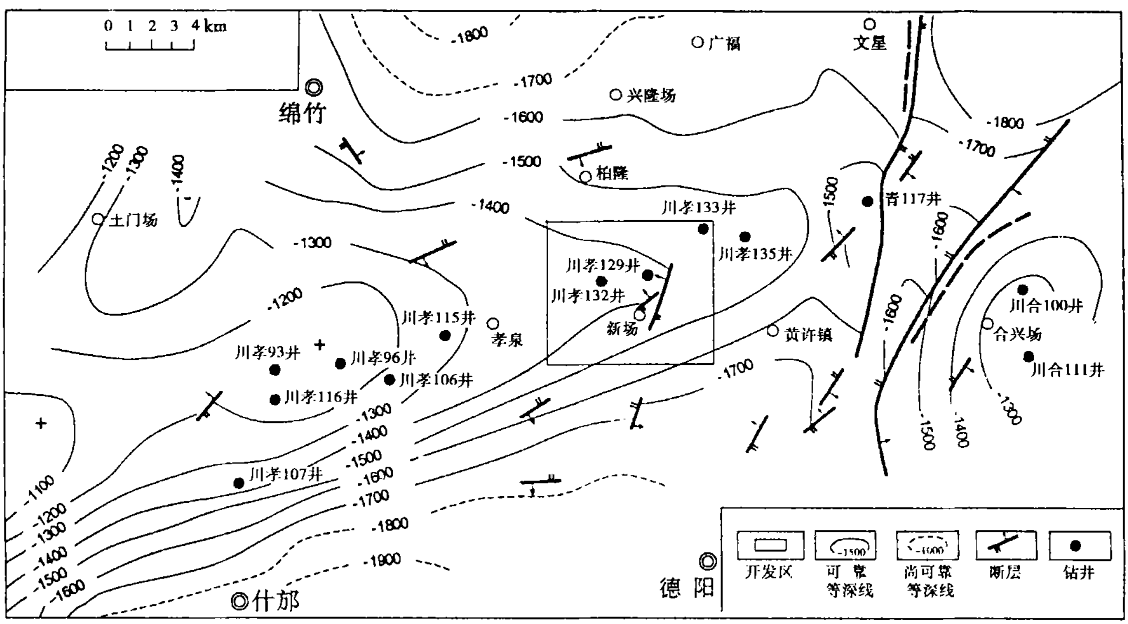

图 1　新场地区沙溪庙组顶构造(T2)

状中—细粒岩屑长石砂岩, 局部夹有少量薄层棕红色混岩, 粉砂质泥岩及泥质粉砂岩。碎屑矿物成份和含量十分相近, 碎屑以石英为主, 含量 40% ~ 50%, 长石次之, 占 20%~ 40%, 岩屑 20% ~ 35%, 胶结物以方解石为主, 少量泥质、硅质。据28 口井 1 973 个样品统计平均岩心分析孔隙

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度为 9.03%, 平均岩心分析渗透率为 0.157 × 10^{-3} μm², 试井分析有效连通渗透率低于岩心分析渗透率 1～2 个数量级, 一般小于 0.100 × 10^{-3} μm², 部分小于 0.010 × 10^{-3} μm², 排驱压力 1.93～7.89 MPa, 中值半径 0.014～0.050 μm, 储集层非均质性严重, 孔喉比差, 具有大孔小喉的配置特点。储层物性及孔隙结构条件均属典型致密储层范畴。

沙溪庙组气藏储层产能的大小受裂缝和基质物性条件的控制, 自然产能悬殊, 工业气井成功率低(30%左右); 产层具强水敏、碱敏和中等速敏效应; 地层压力梯度为 0.018～0.020 MPa/m。

从以上特征可以看出, 新场气田沙溪庙组气藏是典型的致密砂岩气藏, 在储层致密化背景下寻找气藏中相对中、高产富集区块, 沿用常规方法对储层储渗体识别显然难以奏效。通过试井、测井、地震三相技术对储渗体储渗条件差异性进行探讨, 从中总结出规律, 可以指导气田的开发。

2 储渗体储渗条件差异机理

沙溪庙组气藏储渗体储渗条件差异机理: 长石含量是形成相对高孔隙度和中、中高产能的基本条件; 孔隙结构的差异对产能的大小具有决定性的控制作用; 成岩晚期溶蚀强弱是大孔喉发育的主要因素; 微裂缝的发育状况是决定不同成岩环境的主要因素; 微裂缝网络系统分布控制着储渗体产状[2]。

沙溪庙组气藏各井在气层厚度及孔隙度近似的情况下, 产能相差悬殊; 岩性和物性条件近似的储层, 其含气性能却并不相同, 反映储渗体储渗条件的差异性(表 1)。

表 1 单井产能、厚度、孔渗性综合数据

井号(层)	储层有效厚度/m	测试自然产能/$10^4m^3 \cdot d^{-1}$	试井分析渗透率/$10^{-3}\mu m^2$	测井解释孔隙度, %
CX-134-2(A)	21.0	4.015	0.337	9.10～10.40
CX136(C)	19.1	1.151	0.045	13.00
CX154(A)	3.0	少量	0.003	11.00
CX158(A)	11.2	4.955	0.300	10.60～12.20
CX160(A)	18.0	1.305	0.400	12.50
X803(A)	17.0	0.731	0.145	9.08～10.34

3 储渗体差异识别技术

3.1 储渗体差异识别的试井分析技术

通过新场气田沙溪庙组气藏气井测试及试井分析, 可以清楚地划分出由三种数量级别的渗透性能所控制的具有不同产能的储层类型(表 2), 储渗体动态特征可由平面向复合渗流模型表征, 并且可以通过试井分析确定储渗体范围和产状以及储渗体渗流特征参数、储量等。

3.2 储渗体差异识别的测井分析技术

鉴于常规测井解释方法对致密储层评价的局限性, 开发应用测井相技术, 选择对含气性及储集性显示灵敏的 Ac 曲线、反映岩性的相对纯净度的 GR 曲线、反映储层渗透性及流体性质的 ρ_D、RS 曲线作为指相曲线构造测井相分析的最小集合, 参考动态特征与静态物性参数分类成果, 建立测井相模型[3]。

表 2 沙溪庙组气藏储渗体动态特征分类

类型	试井分析渗透率/$10^{-3}\mu m^2$	显示	测试产能/$10^4m^3 \cdot d^{-1}$	生产稳定性	边界反应	代表井(层)
Ⅰ	0.10～1.00	好	自然产能 > 1.0 自然解堵 > 2.0	中产稳产	未见低渗边界	160, 129, 132
Ⅱ	0.01～0.10	一般	自然产能 0.2～1.0 压裂改造 2.0～10.0	低产稳产	未见低渗边界	133, 136
Ⅲ	> 0.10	强烈	难以求稳, 最高达 10	高产快速递减	小	158, 113, 803
Ⅳ	< 0.01	无	干层			151

3.3 储渗体差异识别的地震分析技术

储层物性和流体性质的空间变化, 造成了地震反射波速度、振幅、相位、频率等相应的变化, 当储渗体的这些特征参数的变化达到了相应的限度时就要在地震剖面上表现出来。

在对钻遇沙溪庙组的所有井准确标定的基础上, 对其各砂体的测井响应特征及产能状况, 结合地震资料进行了仔细的分析比较, 发现利用地震保幅剖面上各砂层的波形特征、振幅、频率及波阻抗这几种参数可以把各已知井的地质模型在地震剖面上表现出来, 我们把这种方法称之为储渗体

差异的波形识别法。通过典型井的分析, 沙溪庙组气藏储渗体差异现象在地震剖面上其波形特征与其它参数结合可以较为清晰的分辨。

通过对沙溪庙组气藏所有钻井特别是对典型井的仔细分析研究, 确定了地震响应模式为“低频强振幅、低波阻抗”。

3.4 储渗体差异识别综合模型

运用上述技术方法及多学科全方位的研究成果, 对沙溪庙组气藏找到了渗流网络差异为核心的控制因素, 总结了储渗体类型划分与识别的四种综合模型: 连通相对高渗透体; 低渗透体; 局限渗透体; 致密体(表3)。

表 3 储渗体差异识别综合模型

类别	评价	物性		孔隙结构	电性			地震响应	动态特征	长石含量, %	含气饱和度, %	微裂缝网络
		Φ, %	$k/10^{-3}\mu m^2$		$\rho_D/g\cdot cm^{-3}$	$Ac/\mu s\cdot m^{-1}$	SP/mV					
Ⅰ	连通相对高渗透体。储集规模大, 自然产能高, 具有较好经济开采价值	> 9	> 0.20	粒间溶孔发育, 喉道粗, 孔喉连通呈网络状	≤2.45	≥255	负异常幅度大	低频, 低波阻抗, 强振幅, 其振幅绝对值大于25 000, 且延伸范围大	$K_{有效}=0.2\times10^{-3}\sim1.0\times10^{-3}\mu m^2$, 测试自然产能大于 $1\times10^4 m^3/d$, 生产较稳定	> 35	> 50	发育
Ⅱ	低渗透体。储集规模大, 低产稳定, 加砂压裂改造效果显著, 可达中高产	> 7	> 0.10	粒间孔、溶蚀孔发育, 喉道细小或部分堵塞	≤2.50	≥239	负异常	相对低频, 低波阻抗, 较强振幅, 振幅值绝对值一般 19 000 ~ 25 000, 延伸范围大	$K_{有效}=0.1\times10^{-3}\sim0.2\times10^{-3}\mu m^2$, 测试自然产能 $0.2\times10^4\sim1.0\times10^4 m^3/d$, 低产量长期稳产	25~35	> 50	欠发育
Ⅲ	局限渗透体。储集规模小, 初期产量高, 迅速递减, 无工业开采价值	6~9	0.10~0.17	粒间孔、粒间溶孔发育, 孔喉连通好, 局部呈网络状	2.40~2.50	≥246	具负异常	在地震剖面上不易识别, 频率较低, 延伸范围小	$K_{有效}>0.1\times10^{-3}\mu m^2$, 测试产能初期大于 $1\times10^4 m^3/d$, 投产后递减快	25~35	40~50	局部发育
Ⅳ	致密体。加砂压裂增产效果差, 现阶段不具开采价值	< 6	< 0.10	孔隙喉道极少, 基本无连通孔喉, 方解石呈孔隙式胶结。	> 2.50	≤246	负异常不明显	弱振幅, 高频, 高波阻抗	$K_{有效}<0.1\times10^{-3}\mu m^2$, 自然产能很低, 小于 $0.1\times10^4 m^3/d$	< 25	< 40	不发育

4 成果应用

各砂体Ⅰ、Ⅱ类储渗体在实践中发挥作用, 不仅是相对中、高产富集区块预测与评价的依据, 也是压裂开发评层选井的依据(表4)。

表 4 新场气田沙溪庙组气藏典型井压裂效果表

井号	储集类型	无阻流量/$10^4m^3\cdot d^{-1}$		增产倍比
		压前	压后	
L102-2	Ⅱ	0.100	31.774	318
L104	Ⅱ	0.929	29.151	31
CX168-1	Ⅱ	0.898	23.018	25
X816	Ⅱ	1.141	25.867	22
CX170-1	Ⅰ	3.404	20.271	6
CX170-2	Ⅰ	3.924	24.380	6
CX373	Ⅰ	2.513	24.914	10

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ABSTRACTS

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01 Palaeogeomorphology Features of Early Hercynian Weathering Crust in Tazhong Area

TIAN Na - xin et al (China University of Geosciences, Beijing, 100083)

Palaeohight in Tazhong area (central part of Tarim basin), which appeared at Early Ordovician and finalized at Early Hercynian, is the major upwarped area for prospecting karst reservoirs of Paleozoic marine carbonate in Tarim basin. Palaeogeomorphology restoration by using thickness method reveals that weathering crust of Early Hercynian in Tazhong area was high in the central part (palaeohigh), low in both the south and the north (depressions), while high in the east and low in the west. Weathering crust of Lower Ordovician carbonate outcrops mainly on the highly uplifted part of faulted fold structure and show small block (buried hill) or zonal (buried hill zone) distributions. Area of single block is small and interconnection is poor.

Key words: Tazhong area, Early Hercynian, Palaeohigh, Palaeogeomorphology

04 Restudy on Source of Sediments and Sedimentary System of Lower Sha— Ⅰ in Banqiao—Qibei Area

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Lower Sha - Ⅰ (the lower part of the first interval in Shahejie Formation) is one of the main intervals for exploration in Banqiao - Qibei area. Based on comprehensive study on heavy mineral combinations, ZTR factor, compositional maturity factor and lithic fragment components, this paper analyzes the sediment sources of Lower Sha - Ⅰ and reveals that there exist three sources including Yanshan fold belt, Cangxian uplift and Gangxi rise. The following new knowledge, different from the previous ones, are presented: the northern source from Yanshan fold belt was the only sourcing area for Lower Sha - Ⅰ in Qibei area; sources from western Cangxian uplift could not cross Gangxi rise to Qibei area; and the influencing area of source in central Gangxi rise was limited. These sources controlled distribution of sedimentary system in this period: underwater fan sandbody developed in Xiaozhan area; fan delta frontal sandbody developed in Lujuhe area; and gravitational channel sandbody developed from slumping of fan delta front in Qibei area. Combined with the thick mudstone in Middle Sha - Ⅰ, these favorable sandbodies might form some favorable lithologic traps in the slope and pitching areas in Gangxi rise, Dazhangtuo area and Qibei area.

Key words: Huanghua depression, Yanshan fold belt, sediment source, sedimentary system, lithologic trap

07 Application of ^{13}C NMR Wave Spectrum in Description of Kerogen Properties

HU Hai - yan et al (China University of Geosciences, Wuhan, 430074)

As one of the most effective methods to study mass structure, 13 C NMR achieves structure information of molecular from atom levels. In order to study its specific effects in petroleum geology and based on the previous achievements, this paper presents in detail the application of ^{13}C NMR in study of kerogen properties and evolution and its relationship with hydrocarbon generation, and introduces the ways to achieve structural parameters and to reveal hydrocarbon generating process and evolution of kerogen from ^{13}C NMR wave spectrum.

Key words: ^{13}C NMR, kerogen evolution, hydrocarbon generation evolution

09 Combinatory Relationship of Sandbody and Structure in Biyang Depression

TAI Huai - zhong et al (China University of Geosciences, Wuhan, 430074)

There exist six types of combinations between sandbody and structures in Biyang depression including downward dipping - upward dipping type, downward dipping - downward dipping type, downward dipping - upward oblique type, downward dipping - downward oblique type, vertical major axis type and parallel major axis type. The types of sandbody and structure combination directly influence hydrocarbon accumulation. The better the combination is, the more proved reserves exist.

Key words: Biyang depression, sandbody, structure, combination, control on hydrocarbon accumulation

11 Identification of Permeability Contrast of Tight Sandstone Reservoirs in Xinchang Gas Field

DENG Li - jian (Xinan Company, SINOPEC, Sichuan, 618000)

Based on utilization of several processing and interpretation methods of seismic and logging, geologic models for characterizing permeability contrast of reservoirs are

established by using dynamic data and through combination of test and experimental analysis. Equivalent geophysical models are built. This paper presents ways to identify permeability contrast of reservoirs.

Key words: tight gas reservoir, reservoir body, identification

14 A Study on Fine Cutting Logging

ZHANG She-min (Geological Logging Company of Henan Petroleum Exploration Bureau, Henan, 473132)

Formation of fine cuttings depends on bit type, engineering parameters and rock properties. Fine cuttings present complexities to conventional geological logging such as discrimination of lithology being difficult, positioning of cuttings uneasy, and easy omitting of hydrocarbon shows. Cutting Gamma ray is used to positioning cuttings, dual shaking screen and "double-cross" coring method are used to solve the problem of cuttings sampling, and cutting description methods are improved. It is proposed that chloroform spraying and drenching bag-by-bag methods should be applied to look for hydrocarbon shows and fine cutting logging should change from focusing on cutting itself to focusing on drilling fluids. These measures improve discovery rate of hydrocarbon shows and basically solve the relevant problems of fine cutting logging.

Key words: fine cutting, logging, PDC drill bit, method

17 Application of Interlayer Velocity Contrast Analysis in Prospecting Hydrocarbons in Deep of Anpeng Area

LUO Tao et al (Henan Petroleum Exploration and Production Research Institute, Henan, 473132)

Deep reservoirs in Anpeng area in Biyang depression have large buried depth, complex distribution, and poor physical properties. Lateral variation of velocity is large, multiple waves are rich, and seismic resolution of deep layers is low. Therefore conventional hydrocarbon prospecting methods are not effective. Interlayer velocity contrast analysis is used to predict hydrocarbons based on available geological data. Comparison with real drilling results shows that prediction results are accurate, indicating that this method is reliable and practical in directly detecting hydrocarbons in deep of Anpeng area.

Key words: Anpeng area, interlayer velocity contrast, deep layer exploration

19 Comprehensive Logging Evaluation of Watered-out Zones at High Water-cut Stage in Machang Block

ZHAO Jun-feng et al (Beijing University of Petroleum, Beijing, 102249)

In order to accurately evaluate residual oil distribution at late stage of waterflooding oilfields, producing layer parameters with residual oil saturation as the core are quantitatively studied through comprehensively analyzing core and logging data and taking waterflooding in Machang block in Zhongyuan oilfield as an example. It is proposed to determine residual oil saturation, Sos, with the improved Archie equation and to evaluate watered-out level with sweep efficiency. Interpretation software for watered-out zone is programmed, which makes watered-out zone evaluation more accurate, systematic and normalized and improves reliability of remaining oil appraisal.

Key words: watered—out zone, cross plot, layer parameter, sweep efficiency, watered—out level

22 A Study on Fracture Features and Application in Development of Super Low Permeability Reservoirs in Anpeng Oilfield

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Deep layers in Anpeng oilfield belong to super low porosity and super low permeability reservoirs with very low or even no natural productivity. Occurrence of natural fractures in deep layers is defined through directional coring and acoustic and electric imaging logging. The major fractures trend nearly EW with a dip angle of 70°～90°. Most of the fractures have a width under 1mm and a length within 30cm and fracture porosity is below 0.3%. A program for development of deep layers in Anpeng oilfield is made based on fracture study results. It includes: (a) five-spot pattern with injection-production well array paralleling fracture trend; (b) well points of oil wells array and water well array are staggered, and the included angle between connection line of two oil well arrays and the maximum main stress is 45°; and (c) intervals with well developed primary fractures and relatively low earth stress in producers are selected for performing fracturing operation. The initial average daily oil production of a single well is 16～87 t after the first group of new wells is put into production.

Key words: Anpeng, low permeability, oil reservoir, fracture, development application

25 Watered—out Features and Residual Oil Distribution in Interval Dong—Ⅱ in H26 Fault Block

XIE Jun et al (Shandong Science and Technology University, Shandong, 271019)

This paper evaluates watered-out features and re-