苏里格气田强非均质致密砂岩储层的地质建模*

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摘 要：苏里格气田属辫状河沉积，具有特低渗、强非均质性特征，有效砂体呈孤立状分布在致密砂岩中，规模小且连续性、连通性差。气田密井网解剖区的实际建模表明，采用小网格建立井组(或局部)地质模型，有利于有效地表征储层强非均质性的特点；通过辫状河沉积储层的专家研究经验、露头观测和沉积物理模拟实验所形成的地质知识库来确定关键的建模参数，并从多个实现中优选模型储量出现概率最大的作为地质模型的建模思路和方法，可以较好地描述储层的复杂地质特点和强非均质性特征。

关键词：苏里格气田；低渗透；强非均质性；沉积露头；地质建模

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苏里格气田属沼泽背景下的辫状河沉积，储层具有特低渗、强非均质性特征，有效砂体多呈孤立状分布在致密砂岩中，约占整个辫状河砂岩总厚度的35%～40%。有效砂体规模小，连续性和连通性差[1]。国内外对在辫状河沉积储层建模方面已有比较成熟的技术和方法，功能强大的商业化软件也较多，但建立这类储层可靠程度较高的三维地质模型仍具有较大的难度，主要表现在：①气田有效砂体规模小，空间叠置模式和分布规律十分复杂；②在800m井距条件下仍不能定量统计有效砂体的地质特征参数；③现有的地震储层预测技术还不能准确预测有效砂体的规模和分布。

1 气藏地质特征

(1) 构造。苏里格气田为一宽缓的西倾单斜构造，在单斜背景上发育多排北东—南西走向的低缓鼻隆，幅度在10～20m左右，构造对天然气聚集不起控制作用。

(2) 地层划分。气田目的层划分为盒$_8^上$、盒$_8^下$、山$_1$3段9个小层，其中盒$_8^上$两个小层、盒$_8^下$4个小层、山$_1$3个小层。

(3)河道砂体分布。苏里格气田为沼泽背景下的辫状河沉积，整体呈南北向展布，砂体钻遇率高(多数大于70%)，连续性好，呈大面积连片分布[2]。

(4)有效砂体分布。有效砂体为心滩主体和河道下部充填中的粗砂岩和含砾粗砂岩，多呈孤立状分布在致密砂岩中，钻遇率多数小于50%，东西向延伸范围较小，南北向具有一定的连续性，总体来说规模小，连续性和连通性差[2]。

(5) 储层物性。储层经受了强烈的成岩改造，有效储层以次生孔隙为主，具有低孔、特低渗特点，孔隙度主要在3%～15%，峰值为7%；渗透率主要分布在(0.025～15.6)×10^{-3} μm^2，峰值为0.63×10^{-3} μm^2。

2 建模井组优选

为了解剖有效砂体的叠置模式和分布规律，在苏6井区部署12口加密井(图1)，至今生产约3年，同时区内有6口老井，生产约4年，加密井组为解剖苏里格气田有效砂体的分布规律起到了十分重要的作用，提高了对有效砂体的叠置模式和分布规模的认识。相对来

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说，该井组动、静态资料较丰富、地质认识程度较高，是理想的建模区。因此，选取图1中虚线标出的部分作为井组建模区，区内有生产井18口，东西长10.94km，南北宽5.0 km，面积为54.7km²。

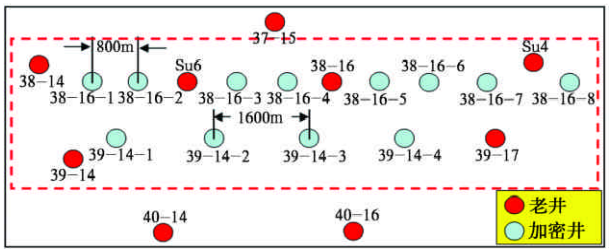


图1 苏6井区12口加密井部署图

Fig.1 Well locations of 12 dense wells deployment in Su-6 well block

3 主要建模参数确定

3.1 建模网格系统

苏里格气田有效砂体尺度很小，主要呈长条形，近南北向展布，长度大于600m，宽50～200m(多数小于100m)，网格尺寸过大(超过100m)，有可能一个网格中包含多个有效砂体，很难描述有效砂体的分布形态。因此，该气田不宜大面积整体建模，适合选取井组、采用小网格系统建立局部模型。密井网解剖区网格系统为：Δ x(东西向)20m，Δ y(南北向)50m，Δ z(纵向)1m，网格总数548×100×132=7233600。

3.2 微相在沉积体系中的比例

根据沉积微相与有效储层的对应关系，将微相归为4种类型：河道充填、心滩+河道底部充填、溢岸+决口+堤岸、泛滥平原。各微相在沉积体系中所占的比例是辫状河沉积模拟的关键参数，其取值对建模结果影响很大，为了确保该数据具有代表性，将统计范围扩大到整个苏6井区，共包含39口井的信息(表1)。

3.2.1河道充填微相规模

辫状河道的几何规模参数控制着河道的空间分布，从苏里格气田的地质认识程度来看，统计出具有代表性的河道宽厚比参数仍有一定困难，因此，这里参考了国内外专家对砂质辫状河的研究成果，同时借鉴了与该气田类似的山西大同砂质辫状河露头观测数据。

国内外专家的研究成果表明，辫状河砂体的宽厚比大致在40～100之间[3,4]。山西大同砂质辫状河沉积

表1 各微相在沉积体系中所占的比例

Table 1 Proportion of each microfacies in depositional system

小层	河道充填(%)	心滩+河道底部充填(%)	溢岸+决口+堤岸(%)	泛滥平原(%)
1	50.2	1.6	5.7	42.5
2	52.9	6.5	9.2	31.4
3	50.2	17.7	1.1	31.0
4	51.0	27.4	6.8	14.8
5	39.4	18.6	14.5	27.5
6	47.4	23.3	10.6	18.7
7	45.8	17.8	13.1	23.3
8	51.6	15.4	5.0	28.0
9	29.4	8.7	3.8	58.1

露头观测资料显示，该地区辫状河砂体的宽厚比在30～70之间(表2)。

表2 大同砂质辫状河露头河道规模统计表

Table 2 Statistics of channel size for Datong braided-river outcrop

成因单元编号	最大厚度(m)	追踪目测宽度(m)	宽厚比
Ⅰ-1	3.80	180	47.36
Ⅰ-2	3.40	235	69.12
Ⅰ-3	5.07	160	31.45
Ⅰ-4	1.30	68	52.31
Ⅰ-5	1.90	120	63.16
Ⅰ-6	4.80	260	54.17
Ⅰ-7	1.45	—	—

综合分析认为，建模中苏里格气田河道微相的宽厚比取30～70比较合适。

3.2.2心滩+河道底部充填微相规模

心滩微相是苏里格气田有效储层的发育场所，其几何规模参数直接决定了模型中有效砂体的发育程度和分布形态，由于苏里格气田有效砂体叠置模式和分布规律的复杂性，通过地质研究还不能对该参数进行统计，因此，该参数的确定综合了以下研究成果：

(1)修正等时试井解释。气田有效砂体呈条带状分布，单个砂体平均长1800m，宽140m；采用多层模型解释，单井控制有效砂体仍为条带状，部分封闭，部分开放，宽30～200m，长度在600m以上。

(2)密井网解剖的认识。有效砂体以孤立状分布为

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主，部分砂体切割相连，在800m井距条件下，3/4以上的有效砂体为单井钻遇。

(3)露头及沉积物理模拟。山西大同露头观测资料也提供了砂质辫状河露头砂坝的数据，心滩微相的宽厚比在20～50之间变化，多数在30以下(表3)。同时以观测数据为基础，进行了室内沉积物理模拟，测得在不同时期心滩的长宽比在2～5之间变化(表4)。综合认为，心滩的宽厚比取20～30，长宽比取2～5。

表3 大同辫状河露头砂坝规模统计表

Table 3 Statistics of channel bar size for Datong braided-river outcrop

成因单元编号	最大厚度(m)	追踪目测宽度(m)	宽厚比	成因单元体系
Ⅱ-1	1.85	160	53	
Ⅱ-2	3.4	68	20	纵向砂坝
Ⅱ-3	2.26	55	24	
Ⅲ-1	4.2	105	25	斜向砂坝

表4 辫状河沉积模拟砂体几何形态特征

Table 4 Geometric parameters of sandbodies in braided-river sediment simulation

微 相	平均长宽比		
	洪水期	平水期	枯水期
心 滩	2.62～5.65	2.6～4.78	2.16～5.21
主水道	2.4～4.6	2.1～3.67	2.57～5.99
水道侧缘	2.6～5.23	2.33～4.9	1.88～3.94
溢岸沉积	3.4～4.9		
水道间	1.9～3.6	1.8～4.1	1.3～2.6

3.3 其他参数

储层物性模拟主要受各微相储层物性分布的控制，建模中由实际钻井资料统计确定。

有效砂体的模拟是在相模型、属性模型的基础上，通过两个限定条件来模拟：①沉积相研究认为，只有心滩和河道底部沉积才能形成有效储层，建模中，有效储层必须是心滩微相。②根据测井气层识别标准，有效砂体孔隙度ϕ大于5%，泥质含量小于40%，在模型中，满足这两个条件才能划分为有效层。

4 三维地质模型

4.1 建模过程

建模采用挪威Roxar公司开发的RMS软件进行辫状河沉积储层模拟，过程分为以下几步：

(1)地层构造。苏里格气田构造相对简单，平面上起伏不大，建模中仅采用气井分层数据内插形成各小层顶面构造[5]。

(2)沉积体系。在构造模型和完钻井点的约束下，根据各微相的统计参数模拟生成各沉积微相的空间分布状态。

(3)储层物性。采用井点数据和相模拟结果为约束条件，根据储层物性参数概率分布统计结果和变差函数，建立孔隙度、渗透率、泥质含量的三维模型。

(4)有效储层。沉积相、属性模型完成后，根据气层识别标准，将满足条件的所有网格单元设定为有效砂体。

(5)模型粗化。地质模型过于精细，不适合于数模研究，必须进行粗化，在保证储量、储层连续性、储层物性分布基本不变的条件下，减少网格数量。

4.2 模型可靠性保障措施

针对苏里格气田的复杂地质条件，采用以下3项措施以提高模型与实际地质体的符合程度：

(1)构造与沉积相的建模中，均采用井点约束，通过条件模拟来保证取样点的模型误差为零[6]，与地质认识保持很好的一致性；

(2)沉积相、储层物性参数的模拟中，采用样品点数据的统计特征进行约束，保证了模拟参数具有与样品数据一致的概率分布；

(3)从多个实现中选择模型储量出现概率最大的实现作为地质模型。

4.3 三维地质模型

输入建模数据体，按建模过程逐步实施，共完成了50个实现，模型储量分布在(81.60～87.25)×10^8m^3，概率最大的区间为(84.43～84.99)×10^8m^3，中值为84.71×10^8m^3(图1)，对应的最佳实现号为44，该实现被确定为目标地质模型。

沉积相模拟结果显示，平面上，由于辫状河道的多期摆动和相互叠置，河道微相呈大面积连片分布，连续性较好；而心滩微相则多呈长条形，孤立分布于河道中，南北向具有一定的连续性，而东西向连续性差，心滩与心滩之间连通程度非常低，并且宽度有限(图3)。连井剖面上更清楚地反映了这一点(图4)，这些与地质认识和气井动态所反映的特征是一致的，说明沉积相建

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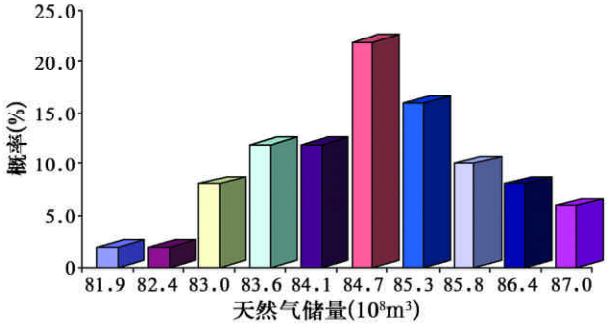


图2 50个实现模型储量概率分布图

Fig.2 The probability distribution of reserves in 50 realizations

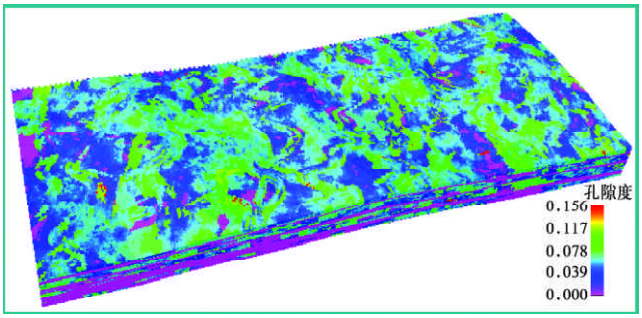


图5 第6小层孔隙度分布图

Fig.5 Porosity distribution in No. 6 layer of the geological model

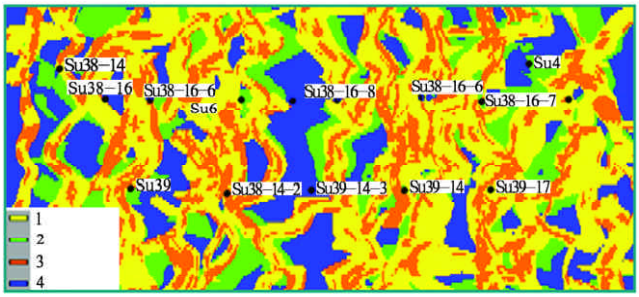


图3 第6小层沉积相分布图

Fig.3 Distribution of microfacies sandbodies in No.6 layer

1—河道充填；2—溢岸+决口+堤岸；3—心滩+河道底部充填；4—泛滥平原

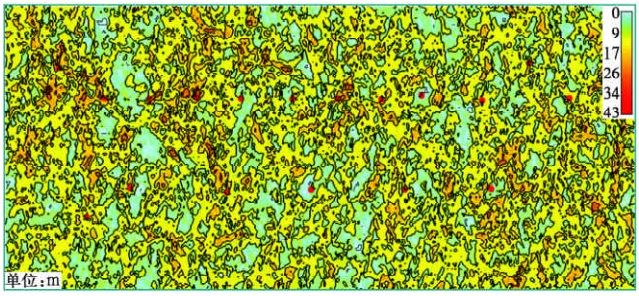


图6 密井网解剖区有效厚度叠合图

Fig.6 Superposition of effective pay thickness in dense wells network block

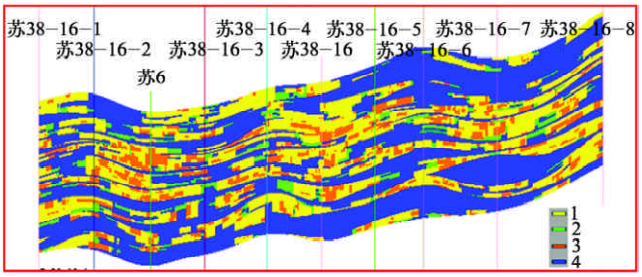


图4 沉积相分布连井剖面图

Fig.4 Microfacies sandbodies distribution in drilled well cross sections

1—河道充填；2—溢岸+决口+堤岸；3—心滩+河道底部充填；4—泛滥平原

模结果可靠程度较高。

属性模拟结果显示，储层物性参数非均质性很强，而且受相控十分明显，心滩微相物性较好，河道微相次之(图5)，这一点也与地质认识是一致的。

有效砂体模拟结果显示，有效砂体的分布规律性不明显，基本是比较孤立的成因单元单独分布（图6），这从一个侧面反映出了苏里格气田地震预测有效砂体分布难度大、钻井成功率相对较低的真正原因。

沉积相、属性、有效砂体等几个方面的建模结果分析表明，建模过程中所选取的参数是正确的，采取的保障措施是有效的，地质模型与实际地质体符合程度较高，反映了气田的复杂地质特点和强非均质储层特征。

4.4 模型的粗化与拟合

地质模型不适合直接用于数值模拟研究，有必要通过粗化来减少网格数量。分析认为，密井网解剖区的模型粗化应该满足：储量基本不变，储层的连通性和连续性基本不变、模型节点数量满足数模的要求。要保证这3个条件，模型粗化比较困难。通过多种粗化方案的对比，认为在平面上保持原网格系统不变，垂向上以自然地质分层为网格单位比较好，按此方案，粗化后模型的有效节点数为926273。

粗化模型储层物性参数分布显示，粗化模型基本上保留了原地质模型物性参数的分布趋势，反映了储

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层的强非均质性特征(图7);同时,粗化后的模型地质储量基本不变，为 83.53 × 10^8m³，绝对误差为 -1.2 × 10^8m³，相对误差为 -1.42%。

但粗化过程在一定程度上改变了有效砂体的连通性和连续性，如图8所示，有效砂体1和有效砂体2经过纵向粗化压缩后,将连成一体,连续性和连通性发生变化。为此，采用了密井网解剖区18口井的生产数据进行历史拟合,对模型做进一步的修正,提高粗化模型的可靠程度。

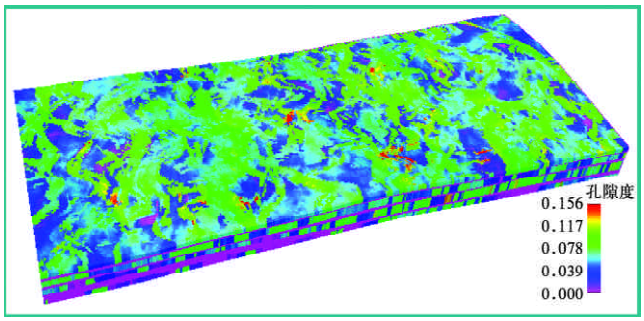


图7 粗化模型第6小层孔隙度分布图
Fig.7 Porosity distribution in No.6 layer of the geological model after upscaling

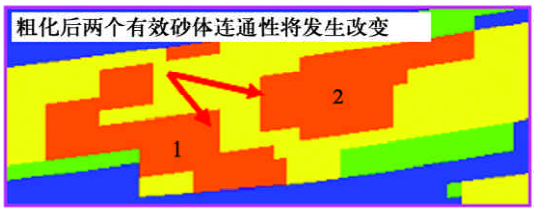


图8 模型粗化改变有效砂体连续性示意图
Fig.8 Sketch map of upscaling changing connectivity between effective sandbodies

5 结 语

苏里格气田有效砂体的规模小、叠置模式复杂,采用小网格建立井组(或局部)地质模型,有利于有效地表征储层强非均质性的特点。

对强非均质性辫状河沉积储层而言，开发早期的地质研究很难确定各微相的几何形态参数,该类储层的建模难度较大。通过辫状河沉积储层的专家研究经验、露头观测和沉积物理模拟实验所形成的地质知识库来确定关键的建模参数,并从多个实现中优选模型储量出现概率最大的作为地质模型的建模思路和方法,比较适合于该类储层的建模。苏里格气田密井网解剖区的建模结果显示,模型可以较好地描述储层的复杂地质特点和强非均质特征,与实际地质体基本相符。

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ABSTRACT

Rift Basin still Be Important Target for Oil and Gas Exploration in the Future /Xie Zhan//*China National Oil and Gas Exploration and Development Corporation (CNODC), Beijing 100034*

Abstract: Chinese oil and gas exploration in the past five decades revealed that new breakthrough will be achieved as long as new progress is made in the idea and methods of exploration.While the degree of oil-gas exploration of sedimentary basins is high, there is still great potential of exploration in rift basins. The rift basin will be the target of exploration for oil and gas for its abundant resources and perfect petroleum system. It is generated from large-scale tension fault and breaks into the mantle variously.Then the volcanic activity occurred. Rift basin generally features in different sedimentary characteristics before rifting epoch, rifting epoch and after rifting epoch. It can be classified into six categories including single rift basin, opposite rift basin, support or opposite rift basin, minor rift basin, rift-depression basin and large continental depression basins developed from rift basin.Moreover, on the basis of analysis for different cases, it discusses the petroleum geological features of these six rift basins and their potential of next exploration.

Key words: plow fault; flower fault; axial flow; deposition of rift basin; types of rift basin

Geological Modeling for Sandstone Reservoirs with Low Permeability and Strong Heterogeneity in Sulige Gasfield/Jia Ailin[1], Tang Junwei[1], He Dongbo[1], Ji Yecheng[2] and Cheng Lihua[1]//*1 PetroChina Research Institute of Petroleum Exploration and Development,Beijing 100083; 2CNPC Changqing Petroleum Adminstration Bureau, Xi'an City, Shaanxi Province 710021*

Abstract: Sulige gasfield is formed in a sandy braided river system environment, and its reservoir features in low permeability and significant heterogeneity. Most of its net effective sandbodies, characterized by small size and poor continuousness and connectivity, are dispersively distributed in the tight sandstones and mudstones. Geological model based on trial block with dense well spacing shows that fine grids used in the model is favorable for characterizing the feature of significant heterogeneity. The model parameters are defined by geologic knowledge database of expertise for braided river sedimentary formation, outcrop observation and sedimentary physical simulation. It improves the description of the complicated reservoir characteristic and strong heterogeneity with the method and schedule for geomodeling by selecting the maximum frequency probability from multi-realizations.

Key words: Sulige gasfield; low permeability; significant heterogeneity; outcrop; geomodeling

Identification of Strike-slip Fault and Its Petroleum Geology Significance/Xia Yiping, Liu Wanhui, Xu Ligui, Zheng Lianghe// *CNPC BGP, Zhuozhou City, Hebei Province, 072751*

Abstract: The strike-slip fault can be graded into five scales, i.e. plate-scale, basin-scale, trend-scale, trap-scale, and microscope-scale based on its difference in size and petroleum geological significance. It is up to the steep fault surface, flower structure, abundant distribution configuration, dolphin effect, and rapid change of strata thickness in two sides of a fault to identify the strike-slip fault. The strike-slip fault can be accurately interpreted and evaluated with the combination of data of surface geology, air-magnetic, gravity, land-sat image, 3-D seismic, etc. It is of great significance to petroleum exploration. It can dominate the structure framework and depositional system of the basin by which to affect the formation of petroleum system and available trap for oil and gas accumulation. It can affect reservoir on the basis of improving the property of reservoir and acting as the path for oil migration, however, it may destruct the preservation conditions of traps and connect the bottom water of oilfield so as to affect the development effect.

Key words: strike-slip fault; classification; identification signs; integrated interpretation; petroleum geological process

Study on Oil and Gas Accumulation of Kumtak Uplift in Turpan-Hami Basin/Zhang Jinxue[1,2], Deng Yong[2] , Suo Xiaodong[3] and Zhang Xufeng[2]//*1 China University of Petroleum(East China), Dongying City, Shangdong Province 257061; Research Institute, CNPC BGP, Zhuozhou City, Hebei Province 072751; 3 Integrated Geophysical & Geochemical Exploration Department, CNPC BGP, Zhuozhou City, Hebei Province 072751*

Abstract: The unknown oil and gas reservoir formation conditions, oil and gas accumulation patterns, and exploration direction greatly restrict the exploration progress of Kumtak uplift. Based on the study in recent years, it is considered that the distribution of hydrocarbon source rocks and favorable facies belts, and the direction of oil and gas migration are determined by the ancient uplift that continuously develops. The research shows that the Pre-Jurassic reservoir is lower-generation and upper-storage structure and/or stratigraphic reservoir developed under the lateral migration of sandstones and the denudational stratigraphic traps. The Jurassic reservoir is lower-generation and upper-storage structure and/or lithologic reservoir developed over the lateral migration of unconformity surfaces and the overlapped stratigraphic traps. It is pointed out that Lukeqin and Yingyeer structural belts are the targets of exploration for oil and gas.

Key words: Turpan Depression; Kumtak uplift; oil and gas reservoir-forming law; oil-gas formation model

Analysis of Fracture Generation Mechanism and Controlling Factor: An Example from Sangonghe Formation of Baobei Structure in Yanqi Basin/Liu Ming[1], Ma Lixiang[1], Zeng Zuoxun[2], Zhao Qing[2,3] and Huang Zheng[2,3]//*1 Faculty of Resources, China University of Geosciences, Wuhan City, Hubei Province 430074; 2 Faculty of Earth Sciences, China University of Geosciences, Wuhan City, Hubei Province 430074; 3 Research Institute of Sinopec Henan Oil Company, Nanyang City, Henan Province 473132*

Abstract: On the basis of the core fracture observation of Sangonghe Formation and the analysis of partial structural features of Baobei structure in Yanqi Basin, investigates the partial stress field and the fracture growing feature from the aspects of anticline and fault. The combinational fracture model is shown as follows: bedding detaching fractures, longitudinal tensile fractures, high angle conjugate shear fractures, middle/low angle conjugate shear fractures and left-lateral tensile fractures. The two former types are related to the formation and development of the anticlines, the three latter types are controlled by the fault induction. Through the fitting calculation based on choosing the fracture line density and different parameters, it is hold that the thickness of coal bed and the distance from anticlines axis dominate the developing degree of bedding detaching fractures and the fault inducting fractures are controlled by the distance from great faults. According to the interpolation and extrapolation under the conciliation of controlling factor, the synthetical fracture density of Baobei structure is predicted.

Key words: Baobei structure; structural fracture; controlling factor; fracture prediction; generation mechanism

Comparative Analysis of Petroleum Geological Features Between Yingen-Ejinaqi Basin and Erlian Basin/Wei Pingsheng[1], Zhang Huquan[1,2], Chen Qilin[1] and Zhang Jinglian[1]//*1 PetroChina Exploration & Development Research Institute (Northwest), Lanzhou City, Gansu Province 730020; 2 Southwest Petroleum Institute, Chengdu City, Sichuan Province 610500*

Abstract: Based on the comparative study of Yingen-Ejinaqi Basin and Erlian Basin from the aspects of Mesozoic strata, regional structures, magmatic activity, source rocks, reservoir, oil and gas reservoir formation characteristics, oil and gas distribution, and deep crustal structure, it shows that these two basins are similar to each other in regional geology and petroleum geological features. However, the reservoir porosity and permeability of lower

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