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# 杭锦旗东部盒1段储层宏观非均质性与气藏类型关系研究

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**摘要:**针对鄂尔多斯盆地杭锦旗东部盒1段南部和北部砂岩储层宏观非均质性的差异性大及其与气藏类型的关系不明确的问题,以盒1段砂岩储层为研究对象,通过砂岩分类明确储层和隔层的识别标准,建立砂体组合样式。根据研究区储层发育特征,优选砂地比值、储地比值、隔层个数、隔层分布频数及分布密度表征盒1段储层宏观非均质性特征,对盒1段储层宏观非均质性与气藏类型的关系进行了研究。①将盒1段砂岩划分为3类,Ⅰ类储层箱型心滩微比Ⅱ类储层齿化箱型河道充填微相物性好;②建立了盒1段3种砂体组合模式,南部以Ⅰ类和Ⅱ类砂岩组合模式为主,北部以Ⅲ类砂体组合模式为主;③盒1段储层宏观非均质性呈现出南强北弱的特征;④南部储地比小于0.3,发育岩性气藏;北东部储地比大于0.3,储层连通性好,主要作为天然气运移通道,有利于形成构造气藏、构造—岩性复合气藏。整体上南部Ⅰ类储层含气性较北部好。研究结果表明:盒1段储层宏观非均质性南部强,北东部弱;储层宏观非均质性影响了气藏的类型,南部为岩性气藏区,北东部为构造—岩性复合气藏区,南部储地比小于0.3的Ⅰ类储层为井位部署有利目标区,为该区盒1段气藏勘探选区指明了方向。

**关键词:**储层宏观非均质性;储地比;隔层;特低—低渗透砂岩储层;杭锦旗东部

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## Relation between macro-heterogeneity of reservoir and gas reservoir types of He-1 Member in eastern Hangjinqi

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**Abstract:** In order to solve the problems of the difference in macro-heterogeneity between the southern and northern sandstone reservoirs in the southern and northern He-1 Member of Hangjinqi, Ordos Basin, and the unclear relationship with gas reservoir types, the He-1 sandstone reservoir is taken as the research object and its identification criteria for reservoirs and compartments are defined by sandstone classification. Then, the sand body combination style is established. And according to the development characteristics of the reservoir in the study area, the ratio of reservoir thickness to formation thickness, the ratio of reservoir thickness to formation thickness, the number of barriers, and the frequency and density of barriers are selected to characterize the characteristics of macro-heterogeneity of He-1 Member. The relation between the macro-heterogeneity and gas reservoir types is discussed. The researches are conducted as follows. ① The sandstone of the He-1 Member is divided into three types. The properties of the microfacies of box-shaped core beach in the type I reservoir is better than that of the filling facies of the toothed box channel in the type II reservoir. ② Three sand body assemblage modes of the He-1 Member are established. The southern part is dominated by the assemblage modes of type I and type II sandbody, and the northern part is dominated by the assemblage

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modes of type III sandbody. ③The macro-heterogeneity of the reservoir in He-1 Member is strong in the south part and weak in the north part. ④Lithological gas reservoirs are developed in the south part with the ratio of reservoir thickness to formation thickness of less than 0.3. While the ratio of reservoir thickness to formation thickness of the north-east part is greater than 0.3 with good reservoir connectivity, which is mainly used as a natural gas migration channel and conducive to the formation of structural gas reservoirs and structural-lithological composite gas reservoirs. The gas-bearing capacity of type I reservoirs in the south is better than that in the north. The conclusion is that the macro-heterogeneity of the reservoir of He-1 Member is strong in the south part and weak in the north-east part; the macro-heterogeneity of the reservoir affects the type of gas reservoirs, making the south part to be a lithologic gas reservoir area, and the north-east part to be a structure-lithological complex gas reservoir area. Type I reservoirs with a ratio of reservoir thickness to formation thickness of less than 0.3 in the south part are the favorable target areas for well location deployment. It points out the direction for the selection of exploration area in He-1 gas reservoir.

**Keywords:** reservoir macro-heterogeneity; ratio of reservoir thickness to formation thickness; barrier layer; sandstone reservoir with ultra-low to low permeability; eastern Hangjinqi zone

鄂尔多斯盆地上古生界天然气勘探主要集中在盆地中北部,天然气资源量为 $13.32 \times 10^8 \text{ m}^3$ ,先后发现有苏里格、大牛地、柳杨堡、东胜等多个大型气田<sup>[1-2]</sup>。中国石化在伊陕斜坡北部构造转换带东胜气田已累计提交探明地质储量超千亿立方米,提升了盆缘天然气资源价值,拓展了勘探领域<sup>[3]</sup>。

杭锦旗地区东部位于鄂尔多斯盆地伊陕斜坡北部(图1),泊尔江海子断裂以南,区内构造平缓,宏观上呈北东高、南西低的西倾单斜,坡降为7.8 m/km,发育少数鼻状构造<sup>[4]</sup>。目前已在二叠系山西组山1段和山2段,下石盒子组盒1段和盒3段发现4套特低-低渗透砂岩岩性气藏<sup>[5]</sup>。其中,盒1段属于冲积平原辫状河沉积环境,河道方向近南北向,水体纵横向变化

快,多期分流河道相互叠置,心滩和河道充填砂体发育,地层厚度在60~70 m左右,砂体厚度在20~50 m左右<sup>[6]</sup>,该区盒1段储层物性较西部的新召和独贵加汗好,但是钻井钻遇气层的概率低于西部邻区,该区累计提交控制和预测地质储量达 $4400 \times 10^8 \text{ m}^3$ 。盒1段试气结果东西差异大,从西向东,产气量降低,产液量升高,井口平均产气量小于 $1.0 \times 10^4 \text{ m}^3/\text{d}$ ,出水井出水量为2~20  $\text{m}^3/\text{d}$ ,液气比为 $13 \text{ m}^3/10^4 \text{ m}^3$ 。

盒1段气藏呈现出不同程度的含水,东部气水关系复杂,低产、低效井多,储量动用难度大是近期勘探开发面临的关键问题,主要原因是对气藏类型及其富集主控因素认识不够清楚。随着特低-低渗透砂岩储层精细地质研究的深入,认为碎屑岩储层普

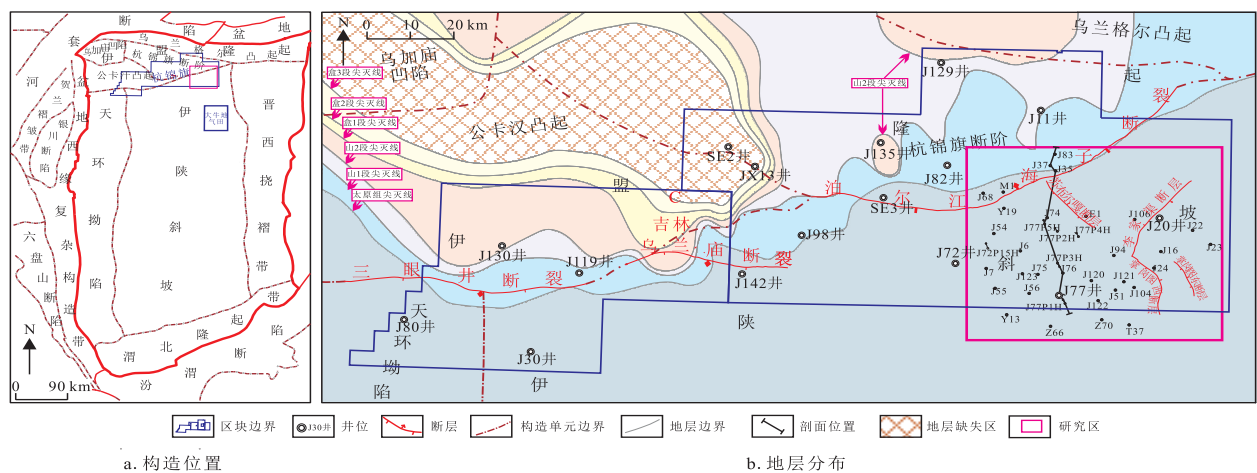


图1 杭锦旗地区构造位置及地层分布  
Fig. 1 Construction location and stratum distribution of Hangjinqi

遍具有非均质性,然而,在勘探尺度的油气运聚和成藏研究中,储层非均质性被忽略,致使储层非均质性特征及其对油气运聚和地层流体分布的作用没有被重视<sup>[7]</sup>。近年来的勘探实践表明,地下油气的赋存状态十分复杂。一般认为,油气藏中普遍存在的油水界面倾斜<sup>[7-11]</sup>及储层中存在的复杂油水关系<sup>[12-13]</sup>是水动力作用的结果,或由圈闭不同位置的储层物性差异所造成<sup>[7]</sup>,但许多研究<sup>[14-16]</sup>证实并非如此。在目前的重要油气发现中,有相当一部分都不属于油气地质学认识的有利区,许多盆地的凹陷部位和斜坡部位均发现有油气聚集<sup>[17-19]</sup>。一些学者认为,这些现象可能与地层在沉积方面的非均质性密切相关<sup>[7,20-21]</sup>,所以,深入研究该区盒1段储层宏观非均质性特征,对认识气藏类型、分布特征、提高钻井成功率及储量动用率有很大的意义。

## 1 储层宏观非均质性特征

裘亦楠等<sup>[22]</sup>将碎屑岩储集层非均质性由小到大分为储层微观孔隙非均质性和宏观非均质性,储层宏观非均质性又可以分为层内非均质性、层间非均质性和平面非均质性<sup>[23]</sup>。对于常规砂岩,常用的储层宏观非均质性表征参数有砂地比、分层系数、渗透率突进系数、隔层相关参数等。刘金华等<sup>[24]</sup>提出一种在超强非均质性储层定量表征中的渗透率滑度指数法,该方法需要基于各个深度段大量岩心测试渗透率实验数据分析,运用熵权数学算法计算非均质

综合指数,实现储层非均质性定量描述储层层间、层内、平面非均质性。但该方法成本高,已经不能满足气田勘探开发需求,而从钻井参数获取储层及隔层参数,开展储层宏观非均质性研究的方法,操作简便,适用性更强。

### 1.1 砂地比

在常规砂岩发育区,由于砂体物性好,砂岩厚度与储层基本相当,砂地比可以表征储层连通性。裘亦楠等<sup>[22]</sup>与罗晓容等<sup>[23]</sup>认为存在一个砂地比门限值,低于该门限值时砂体之间基本不连通,砂地比越高砂体连通性越好,当全部砂地比达到该门限值时,砂体全部连通,为油气运移输导层。通过对实际砂地比统计研究认为:当砂地比小于0.3时,多属于孤立的砂体;当砂地比介于0.3~0.5时,可能会有局部连通;当砂地比大于0.5时,砂体大面积连通。

研究区盒1段储层属于特低—低渗透砂岩气藏,中北部盒1段地层砂地比介于0.31~0.72,平均为0.51,说明盒1段砂体大面积连通;南部盒1段地层砂地比介于0.22~0.45,平均为0.45,说明盒1段砂体可能会有局部连通。研究表明:盒1段砂体纵向多期叠置,横向叠合连片分布,中北部砂体连通性比南部砂体连通性好(图2、图3)。

### 1.2 储地比

钻井数据揭示控制杭锦旗地区盒1段储层连通性的是有效砂体发育规模而非砂体发育规模。砂地

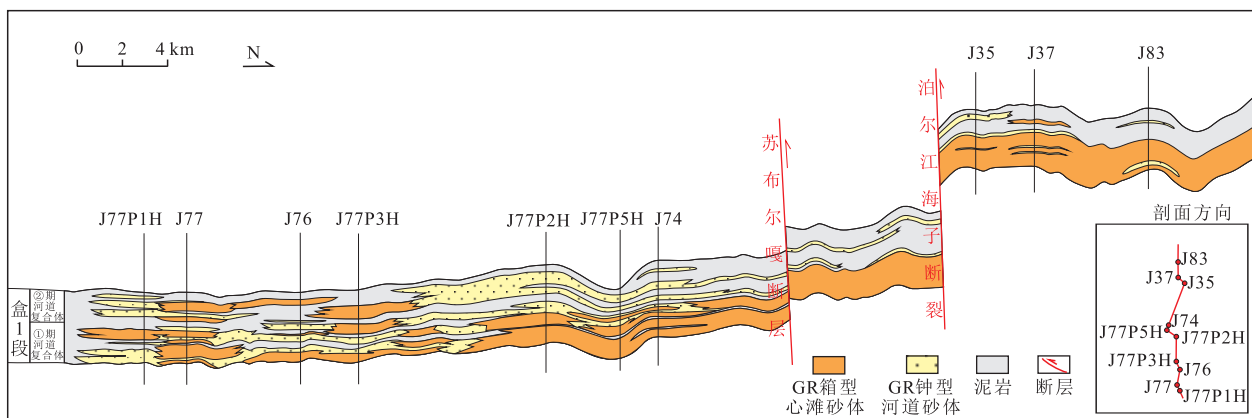


图2 杭锦旗东部盒1段顺河道方向砂体连井剖面

Fig. 2 Sectional view of connected wells along channel direction sand body of He-1 Member in eastern Hangjinqi

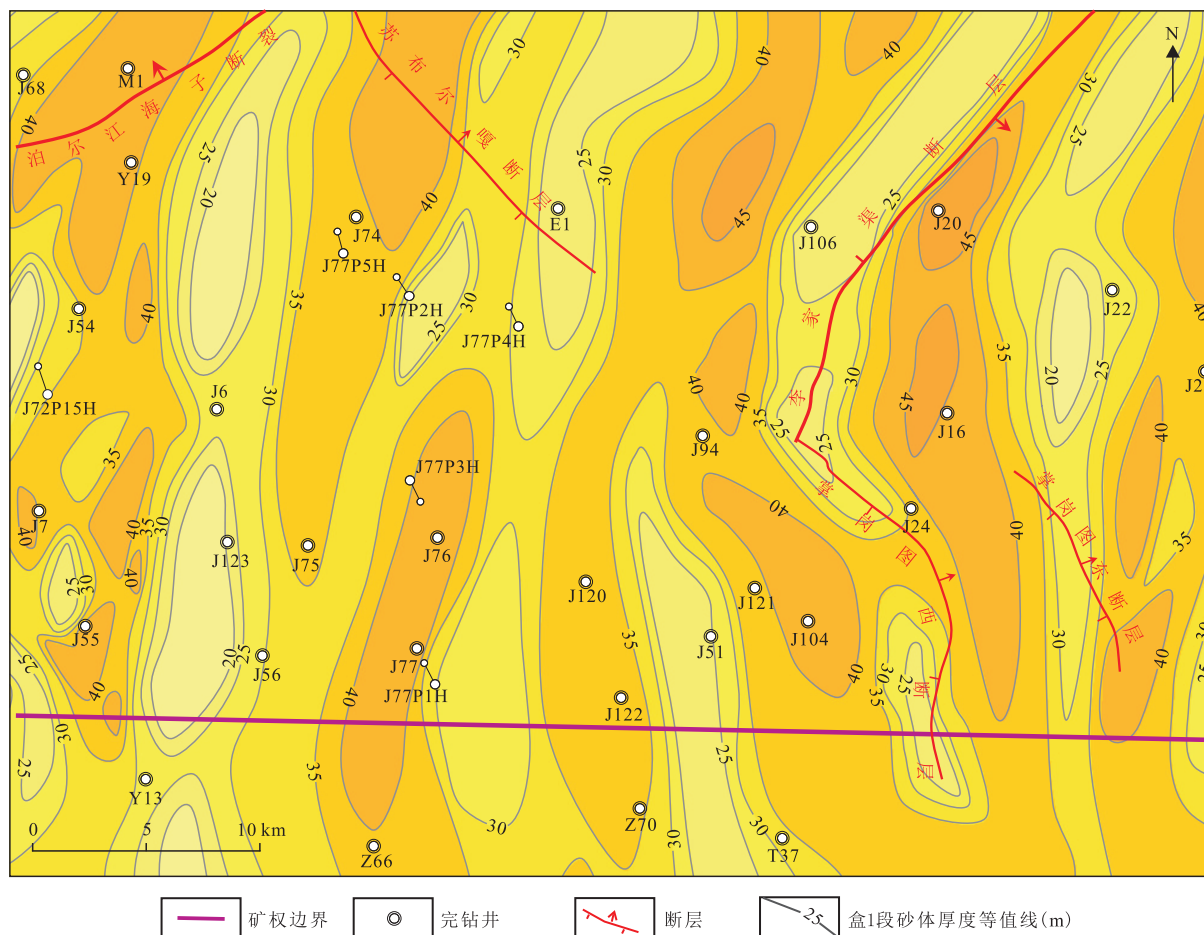


图3 杭锦旗东部盒1段砂体厚度等值线平面图

Fig. 3 Plane map of sand body thickness contours of He-1 Member in eastern Hangjinqi

比参数在研究区特低—低渗透砂岩领域具有一定的局限性,不能精确表征特低—低渗透砂岩储层连通性,同时,由于隔夹层差异发育致使储层纵向层内非均质性复杂化。因此,提出采用有效砂体厚度,即储层厚度与地层厚度的比值(简称储地比)来表征储层连通性。

受辫状河沉积环境影响,研究区内盒1段砂体纵向上发育有薄层孤立砂体、多期叠置砂体,同时不同砂体叠置样式下砂体厚度、物性、连通性以及含气性也具有一定的差异性。而储层是油气储集的主要空间和载体,储层的厚度、分布以及物性对油气的聚集成藏有重要的作用。因此,开展盒1段特低—低渗透砂岩储层下限标准以及砂体组合关系分析是储层非均质性研究的基础。

### 1.2.1 砂岩分类标准

研究区盒1段岩石类型为(含砾)粗—中粒石英砂岩和岩屑石英砂岩。南部孔隙类型以粒间溶孔和原生粒间孔为主,其次为粒内溶孔和晶间微孔;北部孔隙类型以原生粒间孔为主,其次为粒间溶孔。统计南部盒1段108个砂岩样品,其孔隙度介于1.71%~19.26%,以5%~15%为主,平均为9.54%;渗透率分布在 $(0.05 \sim 3.53) \times 10^{-3} \mu\text{m}^2$ ,以 $(0.15 \sim 2.50) \times 10^{-3} \mu\text{m}^2$ 为主,平均为 $0.80 \times 10^{-3} \mu\text{m}^2$ ,属于特低孔—特低渗透砂岩储层,统计北部盒1段统计56个砂岩样品,其孔隙度分布在2.3%~19.9%,以5.0%~18.0%为主,平均为12.8%;渗透率介于 $(0.09 \sim 6.71) \times 10^{-3} \mu\text{m}^2$ ,以 $(0.15 \sim 3.00) \times 10^{-3} \mu\text{m}^2$ 为主,平均为 $1.08 \times 10^{-3} \mu\text{m}^2$ ,

属于低孔—低渗透砂岩储层,北部盒1段砂岩物性较南部物性好。

通过四性关系分析,将盒1段砂岩分为三类,分别对应着3种不同的电性特征,建立了盒1段砂岩分类标准。I类砂岩和II类砂岩的物性和含气性较III类砂岩好,因此,I类和II类砂岩为盒1段主要的储

层,III类砂岩物性和含气性差,一般测井解释为致密层,也称之为非储层。储层孔隙度下限值为5%;渗透率下限值为 $0.15 \times 10^{-3} \mu\text{m}^2$ ;电性特征为自然伽马曲线呈箱型或钟型(图4、图5),自然伽马上限值为75 API,声波时差下限值为 $220 \mu\text{s/m}$ ,电阻率下限值为 $15 \Omega \cdot \text{m}$ ,补偿密度上限值为 $2.55 \text{ g/cm}^3$ ;含气性特

表1 杭锦旗盒1段砂体分类标准  
Table 1 Reservoir lower limit standard of He-1 Member in Hangjinqi

砂体分类	岩性		物性		电性				含气性	
	岩石类型	泥质含量 (%)	孔隙度 (%)	渗透率 ( $10^{-3} \mu\text{m}^2$ )	自然伽马 (API)	声波时差 ( $\mu\text{s/m}$ )	深侧向电阻率 ( $\Omega \cdot \text{m}$ )	补偿密度 ( $\text{g/cm}^3$ )	气测全烃 (%)	含气饱和度 (%)
I类	含砾粗砂岩	2~8	$\geq 10$	$\geq 0.5$	25~55	235~260	30~60	2.10~2.40	$\geq 2$	50~70
II类	粗—中砂岩	8~15	5~10	0.15~0.50	55~75	220~235	15~30	2.40~2.55	1~2	40~55
III类(非储层)	中—细砂岩	15~25	$< 5$	$< 0.15$	75~80	210~220	8~15	2.55~2.60	无显示	$< 35$

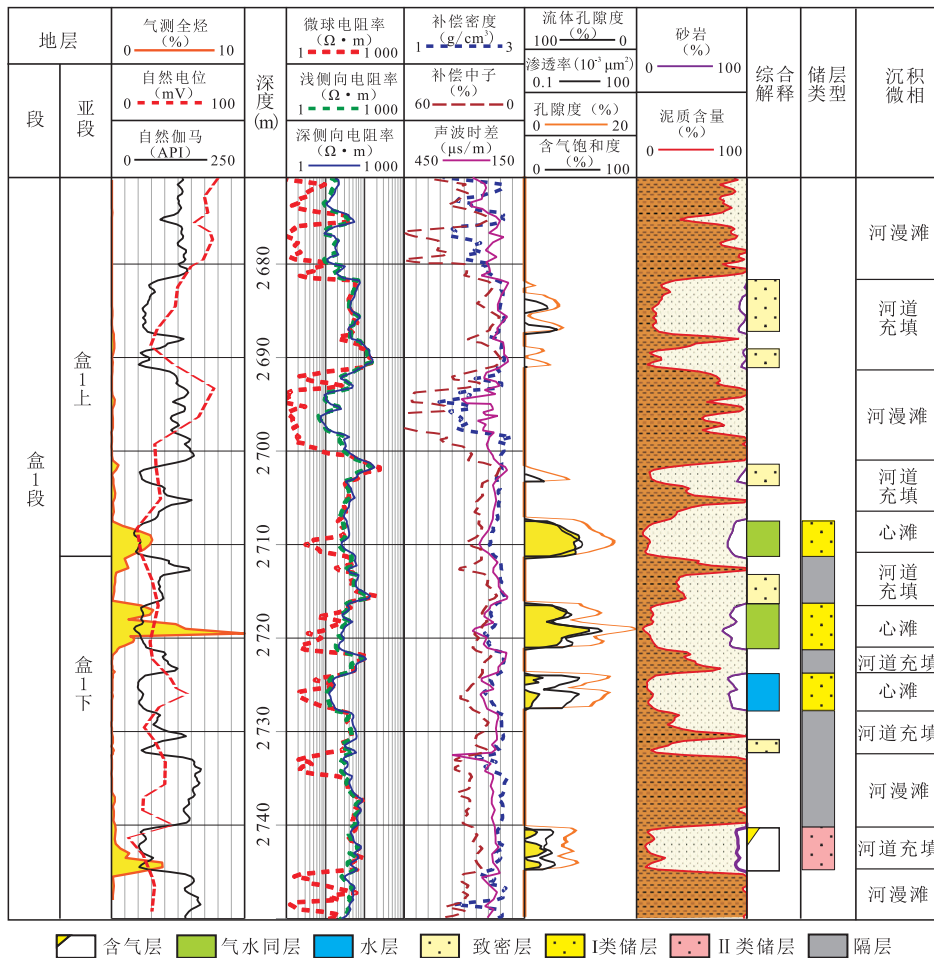


图4 J51井盒1段储层及隔层划分

Fig. 4 Reservoir and barrier layer division of He-1 Member of Well-J51

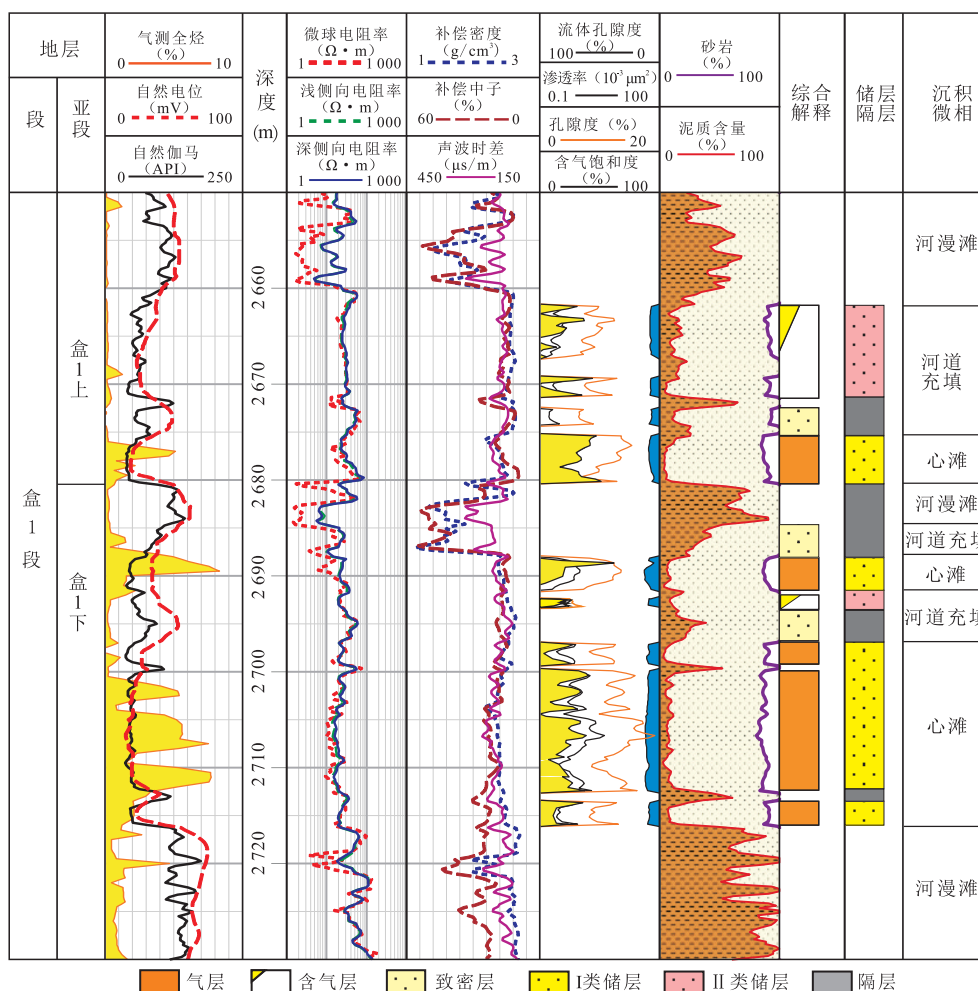


图5 J77井盒1段储层及隔层划分

Fig. 5 Reservoir and barrier layer division of He-1 Member of Well-J77

征采用气测全烃来表征,其下限值为1%(表1)。钟型的河道充填砂体物性及含气性较差,由于沉积微相的变化造成盒1段砂岩纵向上储层段的致密层砂岩与泥岩作用类似,在气田开发过程中对流体运动具有隔挡作用,即为隔层<sup>[22]</sup>(图2、图4、图5),致密层段和泥岩段相互叠合,而研究发现:盒1段I类储层主要以光滑箱型心滩微相砂体为主;II类储层占比较少,以齿化箱型河道充填微相砂体为主。因此,统计得出砂体厚度不等于储层厚度。

### 1.2.2 砂体组合模式

根据盒1段砂岩物性、电性及其含气性特征,单井纵向上可识别出储层段、隔层段,其中,隔层段进

一步划分为致密层与泥岩层。

储层段与致密层或泥岩相互叠置(图4、图5),因此,根据盒1段砂岩纵向上的沉积特征、厚度及叠置关系(图2),将研究区盒1段划分为3种砂岩组合模式(图6): I类砂岩组合模式为迁移弱叠置型,纵向上发育多个储层段,自然伽马曲线呈箱型特征,隔层较发育,常被致密层和泥岩封隔,如J51井、J77P3H井; II类砂岩组合模式为弱迁移强叠置型,纵向上多期心滩叠置,储层厚度大,隔层主要是泥岩和致密层,隔层厚度相对较薄,夹层发育,在盒1段底部储层较发育,如J77井; III类砂岩组合模式为强叠置型,储层厚度大、连通性好,隔夹层欠发育,如J77P2H井。

研究结果显示:在平面上,研究区内南部砂体组





## 2 储层宏观非均质性对气藏类型的影响

泊尔江海子断裂南部的研究区内,石炭系太原组和二叠系山西组的煤层及暗色泥岩是盒1段气藏的主要烃源岩,煤层累计厚度为15~25 m,  $R_0$ 值介于1.1%~1.3%,生烃强度为 $(15\sim40)\times 10^8\text{ m}^3/\text{km}^2$ ,呈现“广覆式”生烃的特征。北部什股壕区带烃源岩发育差,下石盒子组气藏却能大规模聚集。孙晓<sup>[20]</sup>对什股壕区带大量天然气的组分特征、同位素特征及成藏条件的研究,认为该区带具有运移距离远、成藏晚、甲烷含量高、干燥系数较大、相对密度小、异构烷烃与正构烷烃比值大、甲烷与乙烷碳同位素较重等异地运聚特征,且存在与断裂南部相似的特征。综合什股壕区带烃源岩发育特征分析认为,长距离侧向运移天然气是断裂北部什股壕区带主要气源,盒1段厚层砂体以及断裂和不整合面是天然气向北部侧向运移的主要通道<sup>[3]</sup>。因此,从储地比和隔层2个参数来分析盒1段储层宏观非均质性对气藏类型的影响。

### 2.1 气水分布特征

杭锦旗地区东部盒1段单井产气量总体较西部邻区低、水层较多,如:J77井日产气量为 $33\ 480\text{ m}^3$ ,日产水量为 $5.08\text{ m}^3$ ,综合评价为工业气层;J6井、J74井、J76井均不产气,日产水量分别为11、22.7、17.2  $\text{m}^3$ ,

为纯水层。横向上,该区高产气井主要集中在南部地区,且平面差异性明显,北部井产水量大;纵向上,该区气层、含气层、气水同层、水层、干层相互叠置,天然气在砂体上倾方向富集,并且以盒1段下部为主要的富集层段,呈现出上气下水的分布特征(图9)。

### 2.2 储层宏观非均质性对气藏类型的影响分析

从砂岩储层条件看,下石盒子组盒1段由南向北储层物性变好,储层非均质性变弱,即向上倾方向砂体物性和连通性变好(图2),分析认为这是控制气藏类型变化的主要因素。由图7、图8可知:研究区北东部盒1段产水量整体比南部高,该区砂体连片发育,储层厚度大、物性好、储地比值大于0.3,河道心滩以垂向加积叠置为主,河道充填不发育、隔层个数少、隔层分布密度小,说明储层宏观非均质性弱,储层厚度大且纵横向连通性强,上倾方向遮挡条件差,由连片心滩叠合构成的河道形成天然气向北运移的通道,不具备形成岩性气藏的条件,当河道砂体与局部构造相匹配时,天然气才能聚集成藏,可形成构造气藏、构造—岩性复合气藏。已钻井及其试气成果揭示,该区纵向上多为含气水层,局部优质储层与局部构造的复合部位含气性好,试气井产水量多,产气量少,为构造气藏、构造—岩性复合气藏区(图9)。

中部地区盒1砂体受沉积相差异控制,砂体连通性由南部缓坡区向北部隆起区逐渐变强,天然气运聚模式由南部岩性封堵向圈闭聚集过渡。在纵向

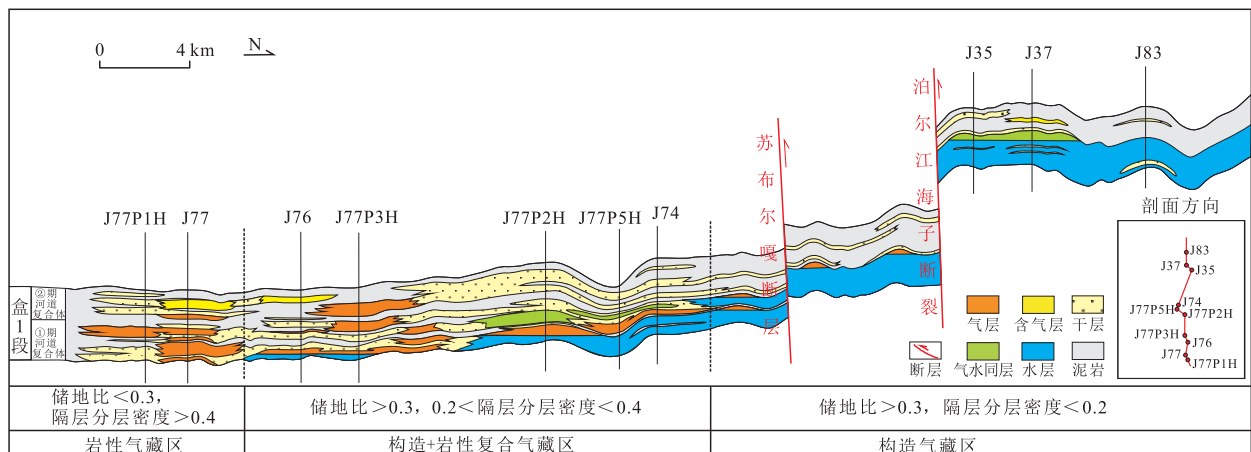


图9 过J77—J83井顺河道方向气藏剖面图

Fig. 9 Cross-sectional view of gas reservoirs along channel direction of Well-J77 to Well-J83

上,南部盒1段多为多套隔层分隔的砂体组合而成,由于侧向上泥岩或致密层发育,起遮挡作用,天然气易聚集成藏,物性好的Ⅰ类储层易形成气层、气水同层,物性差或者砂体孤立层段的Ⅱ类储层易形成含气层、孤立束缚水层。储层厚度小、储地比值低、隔层个数大、隔层分布密度大、局部储地比值大于0.3,说明储层宏观非均质性强,储层纵横向连通性差。已钻井及其试气成果揭示,该区纵向上气层—含气层—气水同层—干层—水层叠置互层分布格局,为岩性气藏区。

研究区内从南向北盒1段顺主河道方向,以Ⅰ类储层为主,局部为Ⅱ类储层。Ⅰ类储层厚度逐渐增大,隔层欠发育,储地比大于0.3,储层宏观非均质性强,但连通性好、含气性整体较差,成为天然气向北侧向运移的主要通道,在局部构造发育区见明显的气水分异现象,高部位含气性较低,而低部含气性好,局部低部位以水层为主,局部构造高部位以气层和气水同层为主,发育范围小。Ⅱ类储层以含气层为主,整体含气饱和度较低。

研究区南部盒1段储层宏观非均质性强,含气性优于中部和北部,高储地比值的厚储层地区是岩性气藏发育区的井位部署有利目标区(图7、图8)。目前,依据储层宏观非均质性强关键参数的描述及气藏类型分区方法已推广至杭锦旗探区,并依据气藏类型划分方法进行了不同层位的气藏类型平面分区,为井位部署工作提供了理论依据,同时也指明了勘探方向,使探井成功率从43%提高到59%。

### 3 结论

1) 盒1段砂体纵向多期叠置,横向叠合连片分布,中北部砂体连通性比南部砂体连通性好。Ⅰ类储层为箱型心滩微相,Ⅱ类储层为齿化箱型河道充填微相,Ⅰ类储层物性较Ⅱ类储层物性好。通过储层纵向发育特征精细解剖,明确了3种砂体组合模式及其分布特征,南部以Ⅰ类和Ⅱ类为主,北部以Ⅲ类为主。

2) 盒1段储层宏观非均质性强呈现出南强北弱的特征:南部储地比小于0.3,隔层发育,隔层分布密度大于0.4;北东部储地比大于0.3,隔层欠发育,隔层分布密度小于0.4。

3) 储层宏观非均质性强是影响盒1段储层气藏类型的主要因素。南部储地比小于0.3的地区,储层宏观非均质性强,发育岩性气藏;北东部储地比大于0.3的地区,储层宏观非均质性强,在局部微幅构造发育区有利于形成构造气藏、构造—岩性复合气藏。因此,南部岩性气藏区为井位部署有利目标区。

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