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柴达木盆地北缘典型构造断层封闭性与天然气成藏

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摘要:柴达木盆地北缘冷湖五号二高点构造深部 42 号、浅部 I 号断层和南八仙构造深部仙南、浅部仙北断层对成藏起主要控制作用,通过地质分析和数理评价发现,这两个构造断层的封闭性具有明显的差异:冷湖五号构造深部断层比浅部断层侧向封闭性好,南八仙构造浅部断层比深部断层侧向封闭好;不同构造深浅部对应的断层中,冷湖五号构造比南八仙构造的断层具更强的垂向封闭。南八仙构造仙南断层垂向封闭性较小,开启期发生于油气成熟到生烃高峰期,起通道作用,仙北断层具下开上闭性,有利成藏。

关键词:柴达木盆地;断层;封闭;天然气;涂抹系数

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断层在油气成藏中具有遮挡和通道双重作用。遮挡强调的是断层的侧向封闭,而通道则强调断层的垂向开启程度。在我国西北地区挤压性盆地很多油气田与烃源断层有关,但一些同时具有烃源断层的构造,有的发现了油气田,有的则没有发现,这说明了断层封闭与开启的重要性,因此,对断层的封闭性研究在油气勘探中具有积极意义。我们在柴北缘油气成藏研究时,有意识地选择了两个构造形态相似,一个已为油气田(南八仙),一个钻探还未突破的构造(冷湖五号二高点)中的 4 条关键性断层进行封闭性研究后,发现其封闭性具有明显的差异。

1 构造背景

柴北缘是自中生代以来经历了断陷、拗陷和强烈逆冲褶皱等不同演化阶段发展起来的压扭性前陆型挠曲盆地。三叠纪的印支运动,柴达木地块周缘秦岭海槽和巴颜喀喇海槽的关闭,杨子板块与塔里木一中朝板块碰撞,加之中特提斯洋的南北扩张和阿尔金走滑断裂的转换调节作用,使柴北缘长期处于持续压应力或压扭应力作用背景下,形成一系列对沉积、沉降拗陷起控制作用的北西向冲断裂和部分北东向平移断裂。在这样的区域构造背景下,使柴北缘成为盆地中断层最为发育的地区,局部构造基本上都伴有断层,其中燕山期和喜山期断层对油气成藏起决定性作用。

2 断层封闭性

2.1 断层基本特征

冷湖五号二高点(下称冷湖五号)构造发育 4 条主要逆断层,其中 42 号和 I 号断层对油气成藏起关键作用(图 1),深部 42 号断层,断开侏罗系(J)、第三系路乐河组(E_{1+2})和下干柴沟组(F_3),可作为烃源断层,断层在燕山早期开始活动,持续到晚第三纪末期;浅部断层 I,是晚喜山运动受强烈水平挤压而形成的具有走滑性质的大逆断层,断开第三系下干柴沟组至地表,直接影响到油气的保存。南八仙构造发育多条断层,但对成藏起主要控制作用的是仙南断层和仙北断层(图 2),仙南断层断开侏罗系和下第三系,与侏罗系烃源相通,早燕山期开始活动,持续到晚第三纪末期;仙北断层对油气的运移和保存有重要的影响,断层形成于喜山晚期,断开干柴沟组并延至油砂山组而未达地表。其它特征见表 1。

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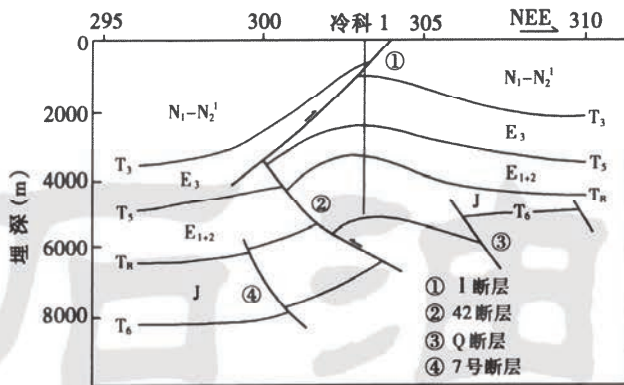


图1 冷湖五号二高点构造剖面图

Fig. 1 The section of culmination-2 in Lenghu-5 structure

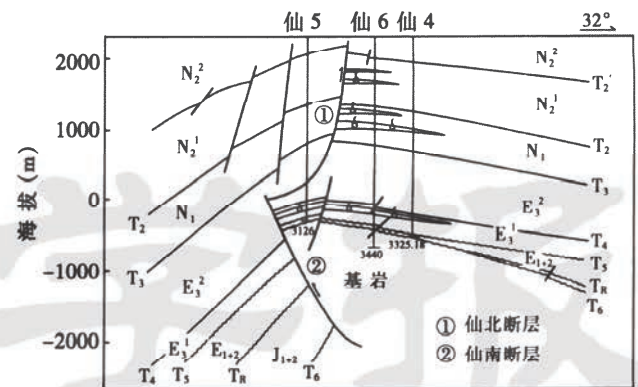


图2 南八仙气田剖面图

Fig. 2 The section of Nanbaxian gas field

表1 冷湖五号、南八仙构造断层基本特征

Table 1 Essential characteristics of the faults in Lenghu-5 and Nanbaxian structure

构造	断层名称	性质	走向(°)	倾向(°)	倾角(°)	断开层位(地震)	断距(m)	延伸长度(km)	形成期	活动特点
冷湖五号	1	逆	NNW	SWW	44	T ₄ 、T' ₂ 、地面	1000左右		喜山期	
	42	逆	NNW	NEE	40	T ₅ 、T _R 、T ₆	750~1650		燕山期	持续性
南八仙	仙北	逆	97	187	70	T' ₂ 、T ₂ 、T ₃	215~265	9.25	喜山期	
	仙南	逆	95	5	66	T ₄ 、T ₅ 、T _R 、T ₆	1190~3250	10.2	燕山期	持续性

2.2 断层封闭性地质认识

2.2.1 冷湖五号42号断层

断层断开侏罗系和第三系路乐河组,从冷科1井剖面分析,侏罗系顶部3473~4300m基本上以泥质岩为主,泥质岩占层厚85.6%,4300~4660m是一套以砂岩为主的储集层段,4660m以下又是一套泥质岩,可见顶部泥岩段厚827m,比中部砂岩段厚,而断层断距为750~1650m,推测上盘砂岩段与下盘泥岩段基本对接,具侧向封堵^[1];路乐河组也是砂泥互层,砂泥岩是否对接不好判断。断面为一下缓上陡的弧形,因断层形成于燕山期,主滑面应为缓面,由于挤压应力作用,上陡面对上盘的运动起较大的阻碍作用,具封闭性^[2]。断层活动时间长,可能具开启性,但该断层主压应力基本与走向垂直,其封闭性又增大^[3]。

2.2.2 冷湖五号I断层

断开的干柴沟组(E₃、N₁),冷科1井剖面上泥质岩占层厚70%以上,砂泥对接的机率较大,同时该断层倾角较缓,断距大,断面易形成断层泥,具侧向封闭的可能性很大;断层断至地表,挫动强烈,增大了形成裂缝的可能性,垂向封闭性减小^[4]。

2.2.3 南八仙仙南断层

断层断开侏罗系和下第三系,下盘J—E₃¹地层与上盘基岩对接,仙6井钻遇的基岩以闪长岩为主,岩石坚硬性脆,电测曲线表明为较致密层,对下盘具有侧向封闭;上盘E_{1,2}和E₃¹与下盘E₃²对接,仙4、仙5、仙6井砂泥岩统计中E₃¹和E₃²泥地比约小于60%,其砂泥岩对接的机率减小,侧向封堵相对较差。从断层两盘地层变化特点可以看出,该断层形成于燕山期,活动持续到早第三纪渐新世,垂向具有开启特点。

2.2.4 南八仙仙北断层

断层断开干柴沟组和油砂山组(N₂),仙4井、5井、6井岩性统计表明,上干柴沟组(N₁)和油砂山组泥地比超过70%,两盘砂泥对接的机会更大,具有侧向封闭。断层没有完全断开上油砂山组盖层,在垂向上是封闭的^[4];断面特征为下缓上陡,根据应力分析,其主滑面应为陡面,因此,断层上段是封闭的,而下部缓面由于应力释放而具开启性。

由此可见,这4条断层都具有不同程度的侧向封闭性,而垂向封闭性则有一定的差异,冷湖五号42号断层

封闭性的可能性大于开启性, I号断层的开启性更大;南八仙构造仙南断层活动期具开启性可能性大,仙北断层具有下开上闭的特点。

2.3 断层封闭性的数理评价

2.3.1 泥岩涂抹系数法

泥岩涂抹是断裂带中普遍存在的地质现象,是在断层活动过程中,由于泥岩塑性大,在挤压应力或重力的作用下,使泥岩粉碎成粘土在其上下盘断壁间削截砂岩层上形成的一个糜棱岩化的泥岩隔层而具封闭性。泥岩涂抹封闭是断层侧向封闭的一种形式,其封闭性的好坏,与断层性质、产状、断移地层的泥地比和断面产状及形态有关,在实际应用中可由断层发生的位移及断开的泥岩厚度等信息来求取泥岩涂抹系数^[5]。

$$f_m = \frac{L}{\sum_{i=1}^n h_i} \quad L \geq H \quad (1)$$

$$f_m = \frac{L}{R_m} \quad L < H \quad (2)$$

式中 f_m 为泥岩涂抹系数; L 为断层断距, m; h_i 为被断层错开的第 i 层泥岩岩层厚度, $i = 1, 2, \dots, n, m$; N 为被断层错开的泥岩层数; H 为被断层错开地层厚度, m; R_m 为被断层断开地层的泥岩厚度与地层厚度的比值。

泥岩涂抹系数越小,泥岩涂抹层在空间上分布的连续性越好,侧向封闭也越好,反之则越差。据付广等^[5]调研结果,只要泥岩涂抹系数小于4,其泥岩涂抹层就能保持空间分布上的连续性,所形成的断层侧向封闭性就好。

根据目前所能收集到的地质信息,按在不同的断距下的泥岩涂抹系数计算公式计算出这4条断裂的涂抹系数,通过分析,这4条断层中,断距(L)超过断开层位厚度(上盘)的是仙南断层,其 E_{1+2} 底断距为1285m,故用式(1),其余断层断距均未超过断开地层厚度,用式(2)计算。计算结果表明,除仙南断层涂抹系数较大外,其余3条断层均小于4,具侧向封闭,总的情况是冷湖五号构造深部断层比浅部断层侧向封闭性好,而南八仙构造则是浅部断层比深部断层侧向封闭好(表2)。

表2 冷湖五号、南八仙构造主控断层涂抹系数

Table 2 The paint factors of master control faults in Lenghu-5 and Nanbaxian structure

构造	断层名称	满足条件	断开层位	层厚(m)	泥地比(%)	涂抹系数 f_m	资料井	
冷湖五号	I	$L < H$	N_1	850~1200	68.5	1.39	冷科1	
			E_3	1500~1700	75.63			
	42	$L < H$	E_{1+2}	1000	59.45	1.37	深83	
			J_1	>1800	86.28			
南八仙	仙北	$L < H$	N_2^2	>800	81.5	1.41	仙4	
			N_2^1	500~700	74.73			
				N_1	400~650	76.7		仙5
				E_3^2	800~1300	49.83		
	仙南	$L > H$		E_3^1	245	60.8	6.66	仙6
				E_{1+2}	96	45.8		

2.3.2 断层压力计算法

影响断层垂向封闭性好坏的关键因素是断面的紧闭程度,若断面紧闭,断层垂向封闭性好,油气不能沿断面作垂向运移,否则,断层开启,断层作为油气运移的通道,断面的紧闭程度可用断面所受正压力大小来衡量,其计算公式为^[6]

$$p = H(\rho_r - \rho_w) \times 0.009876 \cos \theta$$

式中 p 为断面所受的正压力, MPa; H 为断面埋深, m; ρ_r 为上覆地层的平均密度, g/cm^3 ; ρ_w 为地层水密度, g/cm^3 ; θ 为断面倾角, ($^\circ$)。

当断面所受正压力大于泥岩的变形强度时,因泥岩变形而导致断层裂缝愈合,由此造成断层垂向封闭,否则断层垂向开启。根据断移地层泥质岩的变形强度,按断面所受正压力的大小,并考虑断移地层泥岩层含量的影响,将断层垂向封闭性细分为五个级别^[6]:当砂地比小于50%时,断面压力<1.5MPa、1.5~3.5MPa、3.5~5.5MPa、5.5~7.5MPa和>7.5MPa,垂向封闭性依次为差、较差、中、较好和好。

利用断面压力公式对柴北缘冷湖五号和南八仙构造4条断层进行垂向封闭研究,断面埋深取断层中部埋深,由于该区地层以泥质岩含量占大部分,所以,上覆地层的平均密度主要根据实测的泥岩和粉砂质泥岩密度取值,地层水密度尽量利用本构造钻井水样测试的密度值,在无法取得实测值的情况下,借助相邻构造或有成因联系的构造钻井的地层水

测试值来确定,因此,可对这4条断层进行断面压力计算,计算结果反映出,除了仙北断层垂向封闭性为较好-好外,其余3条断层的断面压力都较高,深部断层比浅部断层垂向封闭性好,而不同构造深浅部对应的断层中,冷湖五号构造比南八仙构造的断层具更强的垂向封闭(表3)。

表3 冷湖五号、南八仙构造主控断层断面压力

Table 3 The section presses of master control faults in Lenghu-5 and Nanbaxian structure

构造	断层名称	砂地比 (%)	埋深 (m)	断开层位	上覆层密度 (g/cm ³)	地层水密度 (g/cm ³)	断面压力 (MPa)	资料井	
冷湖五号	I	<50	1300	N ₁	2.5	1.023	14.62	冷科1	
				E ₃	2.51			冷四1	
	42	<50	4100	E ₁₊₂	2.37	1.031	39.86	冷七1	
南八仙	仙北	<50	1630	J ₁	2.49	1.066	7.35	深86、鄂3	
				N ₂ ²					
				N ₂ ¹	2.3			1.082	仙3、仙4
				N ₁	2.51			1.083	仙5、仙6
				E ₃ ²	2.41			1.026	仙7、仙8
仙南	<50	3780	E ₃ ¹	2.61	1.037	23.88	仙9、北1		
			E ₁₊₂						

以上定量评价中所考虑的是目前的状况,是在静态下进行的,实际上,断层性质、构造形态、活动状况等,在不同的地史时期是不同的,因此,在对断层的封闭性进行评价时,要综合进行考虑,把静态和动态相结合,这样才能正确评价断层的封闭效果。根据以上地质分析和定量评价结果,可以认为冷湖五号构造I断层和42号断层具很好的封闭性,并且在地史时期也是偏向于紧闭;南八仙构造仙南和仙北断层,现今均具有较好的封闭,但在地史时期,仙南断层过去有人认为是由正转逆的特点,这一观点是否正确估且不提,但从两盘地层差异来看,仙南断层为高角度逆断层是可能的,垂向具有良好开启性,而仙北断层也具有下开上闭的可能。

3 断层封闭性与天然气成藏

根据冷湖五号构造和南八仙构造4条主控断层封闭性分析研究后发现,这两个构造的断层封闭性具有明显的差异,这或许就是由于断层封闭性不同而造成这两个构造含油气程度不同的原因之一。冷湖五号构造的2条断层,其封闭性比南八仙构造的断层要好,并且从地质历史的角度分析,断层始终受到挤压应力作用,从而使断层始终

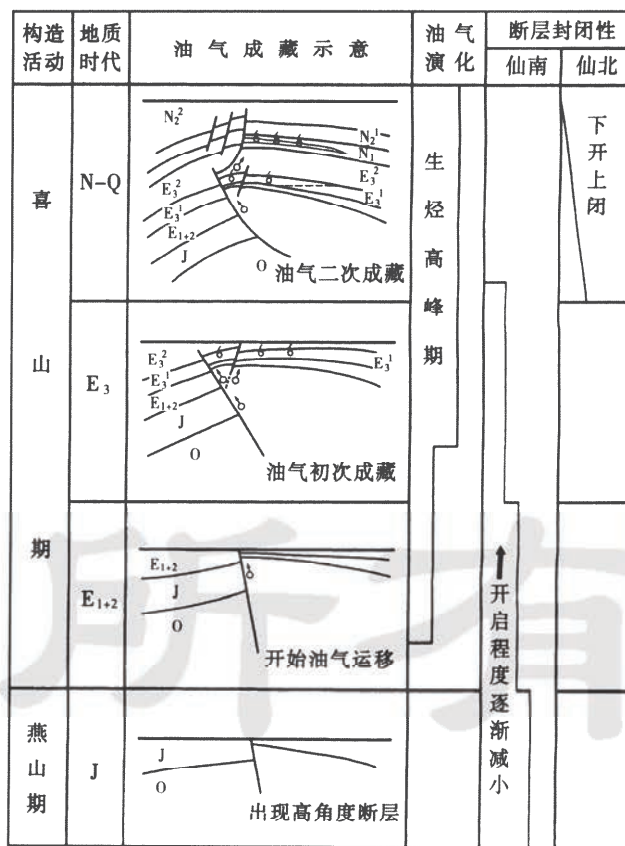


图3 南八仙气田断层封闭性与成藏关系

Fig. 3 The relationship between the faults sealability and gas pool formation of Nanbaxian gas field

处于相对封闭的状态,其结果是使侏罗系气源没能沿断层面运移到上部有利储集层聚集,既使有气源沿断层运移,由于断层 I 断达地表,也不利于天然气的保存,而侏罗系储集层物性较差,从而使冷湖五号构造二高点没有形成气藏而成为可能,冷科 1 井的失利也说明了这一点。南八仙构造仙南断层是在燕山期开始形成高角度断层并处于活动状态,垂向封闭较小,其开启期很有可能发生在 $E_3 - E_{1+2}$ 时期(喜山晚期第二期断层形成之前),也就是油气开始成熟并达到生烃高峰时期,从而起通道作用,使侏罗系部分天然气沿断层和沿不整合面运移来的天然气初次聚集在 E_3^1 层中,到喜山晚期,仙北断层开始形成,由于主滑面在断层上部,并且该断层没有断至地表,下部是开启的,而上部是封闭的(顶封),这样原来 E_3^1 油气藏的天然气或沿深部断层来的天然气又再次向浅部运移,在上干柴沟组和油砂山组聚集成藏(图 3),仙 6 井、仙 4 井试气产量深层位比浅层位普遍大也可作为天然气从下往上运移及断层由下往上逐渐封闭的一个佐证。

4 结 论

(1) 柴达木盆地北缘断层发育,对天然气成藏起决定性作用的主要有两期断层即燕山期和喜山期形成的断层。

(2) 研究的 4 条断层在静态前提下具有不同程度的侧向封闭和垂向封闭,在地史时期由于断层活动特点、断面形态、受力方向不同其封闭程度也不一样,南八仙构造主控断层开启程度比冷湖五号构造断层要好,断层在动态条件下更偏向于气源运移道通作用,从而比冷湖五号构造更易形成次生气藏。

(3) 柴达木盆地北缘次生气藏的关键是气源通道,具有正转逆或高角度燕山期烃源断层和未切地表的喜山期断层的构造钻获气藏的可能性大。

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俄罗斯将投巨资开发新油气田

据俄罗斯新闻局公布,根据俄罗斯“2002~2005 年能源效益经济”计划,在未来 4 年俄罗斯将新增超过 2050 亿卢布(1 美元约合 30 卢布)的投资用于开发新的石油和天然气田。

此外,根据这一计划,俄罗斯期还将投资 1030 多亿卢布的资金用于更新老油田设备;2380 亿卢布将用于石油钻探和生产油井建设;674.5 亿卢布用于封存老油井,393 亿卢布用于增加现有油田的产量,775 亿卢布用于研究开发新的原油生产技术。建造原油初加工新设施的投资将为 82.5 亿卢布。

实施该计划所需的资金将由地方预算和预算外资金组成。

摘自《石油综合信息》

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PETROLEUM EXPLORATION

THE FOUNDATION AND APPLICATION OF THE INTEGRATED MODEL OF ECONOMIC EVALUATION IN EXPLORATION AND DEVELOPMENT

JIN Zhi-jun, et al. (*Petroleum University, Beijing 102200, China*) ACTA 2002,23(2):1~5

Abstract: The economic evaluation of play in the oil and gas basin is significant for the improvement of the return of exploration and development investment in the oil companies. The paper discusses the method and process about the foundation of reserve model, engineering model, production model and economic model in detail, also takes the resource economic evaluation for the nine plays in one of strata of a western basin. By the formation of the valuing map, the paper have optimized four plays of them, which are recommended as the prior targets in the investment decision of exploration & development.

Key words: exploration & development; play; economic evaluation; model; optimize

TIMING AND FILLING HISTORY OF NATURAL GAS RESERVOIRS IN KUQA FORELAND THRUST BELTS, TARIM BASIN

ZHAO Jing-zhou, et al. (*Xi'an Petroleum Institute, Xi'an 710065, China*) ACTA 2002,23(2):6~10

Abstract: Based on the synthetical analyses of the timing of trap formation, gas maturity and hydrocarbon inclusions, 3 periods of the formation and filling history of natural gas reservoirs in Kuqa foreland thrust belts are discerned, i. e. the early-middle Kangcun period (17~10Ma), late Kangcun to early-middle kuqa period (10~3Ma) and late Kuqa to Xiyu period (3~1Ma). Among them the late Kuqa to Xiyu period is the major one for the formation of natural gas pools in the foreland thrust belts, in which the discovered Kela 2, Kela 3, Dabei 1, Yanan 2 and Tuzi 1 gas fields were formed. The Kangcun to early-middle Kuqa period is the critical moment for the formation of original oil and condensate pools. Nevertheless, those early oil and condensate accumulations were generally adjusted and even destroyed by the latter strong tectonic movements and/or the filling of natural gas of high maturity and over-maturity in the late Kuqa to Xiyu period. The remained oil accumulations are mostly secondary reformed in this period.

Key words: natural gas reservoirs; accumulation timing; filling history; Kuqa foreland thrust; Tarim Basin

THE FAULT SEALABILITY OF TYPICAL STRUCTURES AND GAS POOL FORMED IN NORTH EDGE OF QAIDAM BASIN

HONG Feng, et al. (*Research Institute of Petroleum Exploration and Development of China, Beijing 100083, China*) ACTA 2002,23(2):11~15

Abstract: The plutonic fault-42, shallow fault-I in culmination-2 in Lenghu-5 structure, plutonic Xiannan fault and shallow Xianbei fault in Nanbaxian structure play a principal role in gas pool forming in north edge of Qaidam

Basin. According to geological analysis and mathematical estimation, the fault sealability in those two structures shows obvious diversity; the lateral sealability of plutonic fault is better than that of the shallow one in Lenghu-5 structure; the lateral sealability of shallow fault is better than that of the plutonic one in Nanbaxian structure. The vertical sealability in Lenghu-5 structure is stronger sealability than that in Nanbaxian structure in corresponding depth in different structure synthem. The vertical sealability of Xiannan fault in Nanbaxian structure is relative inferior, which stretch as channel-way of oil-gas from maturation period of oil-gas to peak-period of hydrocarbon generation. Xianbei fault is patulous lower and obturation upper which is adventageous to gas pool formation.

Key words: Qaidam Basin; fault; sealability; natural gas; paint factor

EFFECT OF MESOZOIC TECTONIC EVOLUTION ON HYDROCARBON ACCUMULATION IN BURIED HILLS IN HUANGHUA DEPRESSION

WU Yong-ping, et al. (*Dagang Oil Field Company, PetroChina, Tianjin 300280, China*) ACTA 2002, 23(2): 16~21

Abstract: Huanghua Depression is a structurally complicated rift basin formed during Tertiary in Bohai Bay Region. Its pre-rift structural system, mainly generated during Mesozoic era, dramatically affected the rifting tectonics and the structural styles of buried-hills in Huanghua Depression. According to seismic interpretations and tectonic analysis, Mesozoic tectonic deformation can be clarified into Indosinian and Yanshanian episodes. A complexes N-S trending strike-slipping fault and fold system in Huanghua Basin which developed during Jurassic-Cretaceous overprinted Indosinian anticlinorium and synclinorium. It formed the basic structural sketch of "relics" and "hybrid" buried-hill and made a great influence on the evolution of Tertiary faulted-block hills. Thus, Mesozoic tectonic events in Huanghua Depression can be treated as an most important factor for evaluating hydrocarbon bearing potential in buried-hills, due to their domination in buried-hill traps, reservoirs, oil types, and the scale of oil pools in Huanghua Depression.

Key words: Huanghua Depression; buried-hill; Mesozoic; tectonic; hydrocarbon accumulation

OIL-ACCUMULATING STAGES OF THE TRIASSIC TPAP WITHIN THE SHANSHEN STRUCTURE IN TUHA BASIN

YANG Yong-tai, et al. (*Research Institute of Petroleum Exploration and Development, PetroChina, Beijing 100083, China*) ACTA 2002, 23(2): 22~25

Abstract: The Shanke-1, a scientific research well, is the first well which penetrated the Triassic and encountered light oil in the Taibei Depression, Tuha Basin. Based on the analysis of Triassic oil-accumulating conditions, a study of organic inclusions and advanced thermometry, three oil-accumulating stages are identified for the Triassic pool in well Shanke-1. The first stage is in late Xishanyao of Middle Jurassic, forming a small oil accumulation with a low organic maturity. The second stage, or the main one, occurs in late Sanjianfang of Middle Jurassic, but the oil trapped in this stage has been oxidized into asphalt. The third stage, lasting from Late Jurassic to Early Cretaceous, has resulted in accumulation of light oil, forming a productivity in Shanke-1. In Taibei Depression of Tuha Basin, therefore, we should continue searching for non-oxidized oil trapped during the second stage, which will have a much higher productivity than that in Shanke-1. It is also emphasized that petroleum preservation conditions, together with source and reservoir rocks, have to be deeply studied.

Key words: Tuha Basin; Shanshen structure; Triassic; oil accumulation; accumulating stages