

准噶尔盆地深层油气藏形成条件分析

白桦^{1,2}, 庞雄奇^{1,2}, 匡立春³, 庞宏^{1,2}, 庞莹^{1,2}, 周立明^{1,2}

(1. 中国石油大学(北京)地球科学学院, 北京 102249;

2. 油气资源与探测国家重点实验室, 北京 102249; 3. 中国石油新疆油田分公司, 新疆克拉玛依 834000)

摘要: 全球已开发千余个目的层系埋深超过 4 500 m 的油气田, 深层油气勘探的重要性日益突出, 而准噶尔盆地已开发目的层系埋深均浅于 4 500 m, 尚未在深层取得突破。因此, 有必要开展准噶尔盆地深层油气藏形成条件的研究。在总结前人研究成果的基础上, 总结了深层烃源岩、储集层和盖层的发育情况以及油气的保存条件, 并进行了系统分析。研究认为, 盆地中央坳陷和南缘深层广泛发育多套泥质烃源岩且已处于成熟—高成熟阶段, 生排烃潜力大; 由于溶蚀和超压等地质作用, 盆地深层普遍发育相对优质的储集层段, 出现“差中有优”的现象; 湖盆扩张期形成的多套区域盖层能够起到较好的封盖效果, 有利于深层油气的聚集与保存。根据生储盖在时间和空间上的匹配关系, 以及探井深层油气显示情况, 表明中央坳陷和南缘为深层油气有利勘探区。

关键词: 深层油气; 成藏条件; 烃源岩; 优质储层段; 资源潜力; 准噶尔盆地

中图分类号: TE122.3

文献标识码: A

Formation conditions of deep hydrocarbon in Junggar Basin, NW China

Bai Hua^{1,2}, Pang Xiongqi^{1,2}, Kuang Lichun³, Pang Hong^{1,2}, Pang Ying^{1,2}, Zhou Liming^{1,2}

(1. Basin and Reservoir Research Center, China University of Petroleum, Beijing 102249, China;

2. State Key Laboratory of Petroleum Resources and Prospecting, Beijing 102249, China;

3. Xinjiang Oilfield Company PetroChina, Karamay, Xinjiang 834000, China)

Abstract: With the increasing degree of identified shallow hydrocarbon resources, the possibility of making a breakthrough in shallow strata is decreasing and the direction of oil and gas exploration is turning to deep strata. All around the world, over one thousand hydrocarbon reservoirs have been discovered and developed in deep strata with buried depth greater than 4 500 m. At present, the depth of all the discovered and developed hydrocarbon reservoirs is less than 4 500 m in the Junggar Basin. Considering that a breakthrough has not yet been made in deep strata, a discussion of deep hydrocarbon accumulation conditions has important practical significance in the Junggar Basin. Based on previous studies, source rocks, reservoirs, cap rocks and preservation conditions are taken as research subjects and the accumulation conditions of deep hydrocarbon are analyzed. The southern margin and central depression of the basin developed many sets of argillaceous source rocks in the deep zone and have entered into the mature to high-maturity stage. Due to the geological processes of over-pressure and erosion, etc., relatively high-quality reservoir intervals are widely developed in deep strata. Many regional cap rocks can be effective seals, beneficial to deep oil and gas accumulation and preservation. Timing and spatial relationships among source rocks, reservoirs, cap rocks, and the hydrocarbon shows in deep strata of exploration wells suggest that the central depression and southern margin are favorable zones for deep oil and gas exploration.

Key words: deep oil and gas; hydrocarbon accumulation condition; source rock; favorable reservoir; resource potential; Junggar Basin

目前, 全球已开发 1 000 多个目的层系埋深在 4 500~8 103 m 的油气田^[1-2]。在国内, 2000—2012 年中石油每年新增探明天然气储量中, 深层所占比

例由 1% 增长到 50%^[3], 例如, 在塔里木盆地大北地区埋深超过 5 km 的白垩系砂岩储层中已探明天然气储量 $587 \times 10^8 \text{ m}^3$; 而准噶尔盆地已开发的 30 个

收稿日期: 2016-03-09; 修订日期: 2016-08-19。

作者简介: 白桦 (1985—), 男, 在读博士研究生, 从事含油气盆地分析与油气成藏研究。E-mail: baihua1282@163.com。

通信作者: 庞雄奇 (1961—), 男, 教授, 博士生导师, 从事含油气盆地分析与油气资源评价研究。E-mail: pangxq@cup.edu.cn。

基金项目: 国家重点基础研究发展计划 (973 计划) 项目 (2011CB201100) 和国家重点基金项目 (U1262205) 资助。

油气田的目的层系埋深均浅于 4 500 m,盆地石油探明率为 20.74%,天然气探明率为 3.5%^[4-6];对于埋深较大的二叠系和石炭系,天然气探明率仅为 2.9%和 0.3%^[7]。随着浅部油气勘探工作的逐步深入,在浅部获得大突破将会越来越困难,下一步油气勘探的重点势必转向深层和非常规油气领域。因此,有必要开展深层油气地质研究,助力深层油气勘探。

已有学者分别从构造^[8-10]、储集层^[11-19]和成藏条件^[11, 14-15, 20-21]等不同角度对准噶尔盆地的局部深层油气地质条件进行了一些研究,但对于全盆地的深层油气地质条件尚未形成较全面和系统的认识。本文采用目前使用较多的深层标准:埋深大于 4 500 m^[22],这也与钻井工程通用深层标准一致。

1 地质概况

准噶尔盆地位于新疆北部,面积为 13.5×10⁴ km²,已发现并开发了克拉玛依、百口泉、风城、火烧山和陆梁等 30 个油气田,截至 2013 年底,已累计探明石油地质储量 23.342 8×10⁸ t,天然气 1.972×10¹¹ m³。近 80 年的勘探开发表明,准噶尔盆地为本层系多层组富含油气的大型叠合盆地。

准噶尔盆地具有前寒武系结晶基底与前石炭系褶皱基底构成的双重基底^[23],盆地南部沉积地层普遍比北部厚。盆地经历了海西期、印支期、燕山期、喜马拉雅期等多期构造运动^[17]。盆地可划分为 6 个一级构造单元和 44 个二级构造单元(图 1)^[24]。

盆地主要发育石炭系、二叠系、三叠系和侏罗系等烃源岩层系,其中二叠系与侏罗系的烃源岩最有效,其生排烃量与聚集量占全盆地的 90%以上;发育白碱滩组泥岩和三工河组泥岩等多套区域盖层。

2 深层油气勘探的主要发现

目前,已取得的深层油气勘探发现主要集中在盆地西北缘、中央坳陷和陆梁隆起。在西北缘的夏 72 井区已发现埋深 4 827 m 的风城组构造—岩性油藏,上交探明储量 1 548.51×10⁴ t;在玛湖西斜坡百泉 1 井和风南 4 井等深层风城组获致密油低产油气流,中拐凸起的新光 1 井、拐 3 井、拐 201 井和中佳 1 井等在深层佳木河组获致密气低产油气流。中央坳陷的盆参 2 井和莫 10 井分别在侏罗系八道湾组和三工河组获工业油气流。陆梁隆起的石西 2 井、石 005 井和夏盐 2 井在深层石炭系获工业油气流。

3 深层油气藏形成条件

盆地深层石炭系、二叠系、三叠系和侏罗系等主要分布在中央坳陷和南缘,整体上都具有北薄南厚的特征(图 2)。从二叠系到白垩系,深层地层的分布范围逐步减小,逐渐从玛湖凹陷向盆地南部沙湾—阜康凹陷及南缘收缩,这与新生代以来,北天山向盆地方向强烈挤压,导致盆地整体向南掀斜有关(图 3)。

3.1 多套深层烃源岩

准噶尔盆地深层烃源岩主要为二叠系(风城

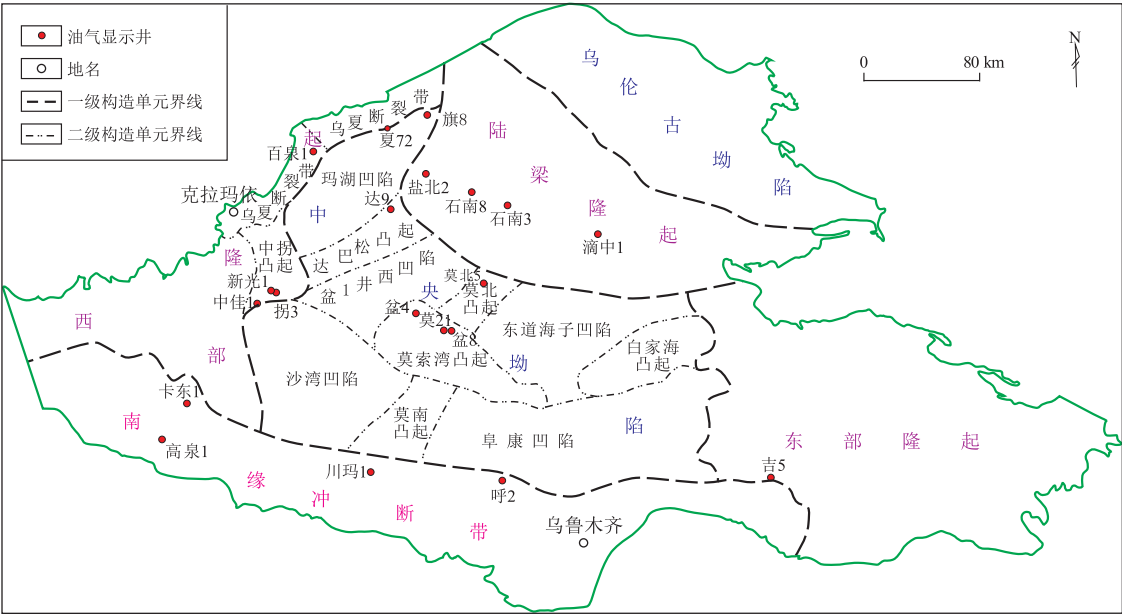


图 1 准噶尔盆地构造单元划分
Fig.1 Structural units of Junggar Basin

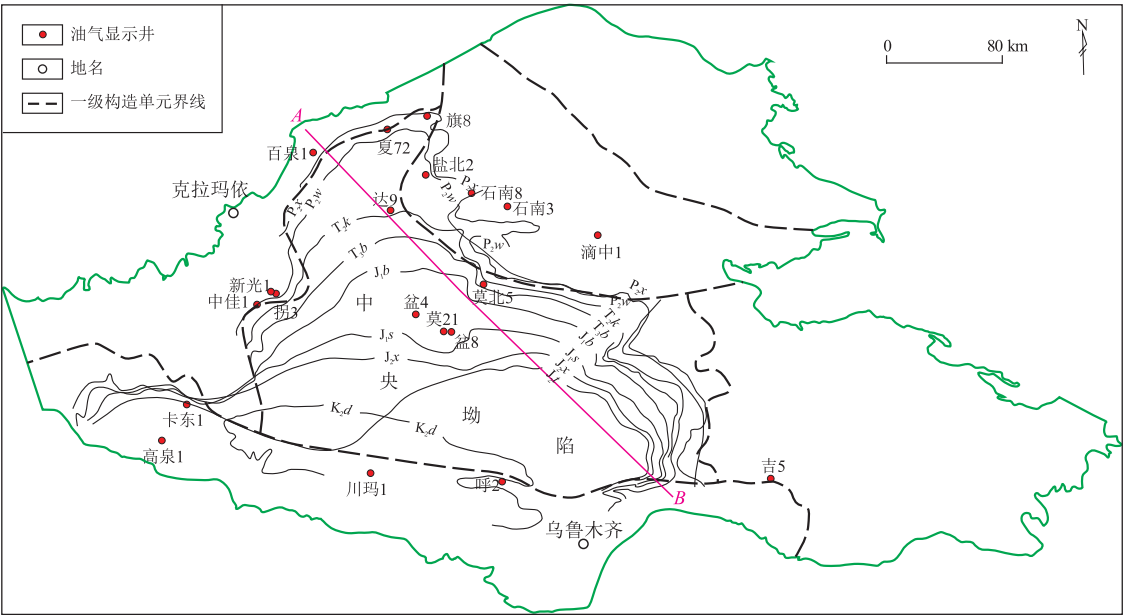


图2 准噶尔盆地深层(>4 500 m)主要地层分布
Fig.2 Distribution of deep-buried strata (>4 500 m) in Junggar Basin

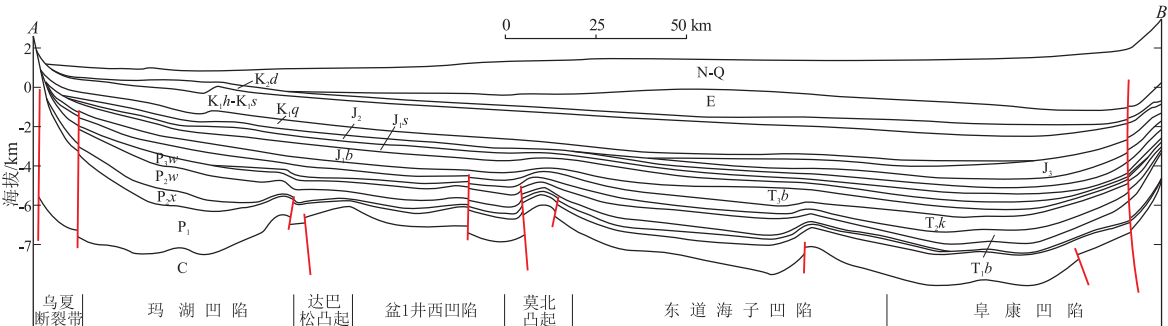


图3 准噶尔盆地 NW-SE 向剖面
剖面位置见图2。

Fig.3 NW-SE direction cross-section of Junggar Basin

组和下乌尔禾组),其次为侏罗系(八道湾组、三工河组、西山窑组)和石炭系等(表1)。

风城组烃源岩为封闭一半封闭湖泊、咸化潟湖环境下形成的泥岩和白云质泥岩,主要分布在中央坳陷,埋深5~12 km,厚度50~350 m,面积 3.2×10^4 km²;w(TOC)=0.5%~3%,平均为1.26%,氯仿沥青“A”含量平均为0.149 3%,总烃含量平均为0.082 0%,S₁+S₂平均为0.73 mg/g,有机质类型多为I-II型,R_o多介于0.85%~1.8%,处于成熟—高成熟阶段,是一套较好—好的烃源岩。风城组烃源岩在晚三叠世末(T₃b)全面生烃,而盆地腹部的深层圈闭在三叠纪末期及之前已基本定型,与生烃史有很好的配置关系^[21]。晚三叠世主要生油中心为阜康凹陷、玛湖凹陷和盆1井西凹陷,生油强度分别为(100~500)×10⁴,(100~200)×10⁴,(50~100)×10⁴ t/km²(图4)。

下乌尔禾组烃源岩分布范围较风城组有所扩大,为扇三角洲和河—湖过渡环境下形成的灰绿色、暗灰绿色砾岩、砂岩与灰黑色泥岩、碳质泥岩互层夹薄煤层。其主要分布在中央坳陷,其中,在玛湖凹陷西斜坡埋深小于4 500 m,其余地区埋深4 500~11 500 m,厚度50~300 m,面积 3.9×10^4 km²;w(TOC)=0.3%~4.2%,氯仿沥青“A”含量为0.001 4%~0.069 6%,平均0.008 8%,有机质类型为II₁-III型,以III型为主,R_o介于0.8%~1.6%,处于成熟—高成熟阶段,是一套差—较好的烃源岩。

侏罗系烃源岩主要为八道湾组、三工河组和西山窑组,以河流、湖泊和三角洲环境下形成的暗色泥岩、碳质泥岩和煤岩为主,暗色泥岩类烃源岩有机质类型以II₂-III型为主,有机质丰度高低相差较大。石炭系烃源岩主要为黑灰色与灰色泥岩、黑灰色粉砂质、砂质泥岩和黑灰色凝灰质泥岩,有机碳

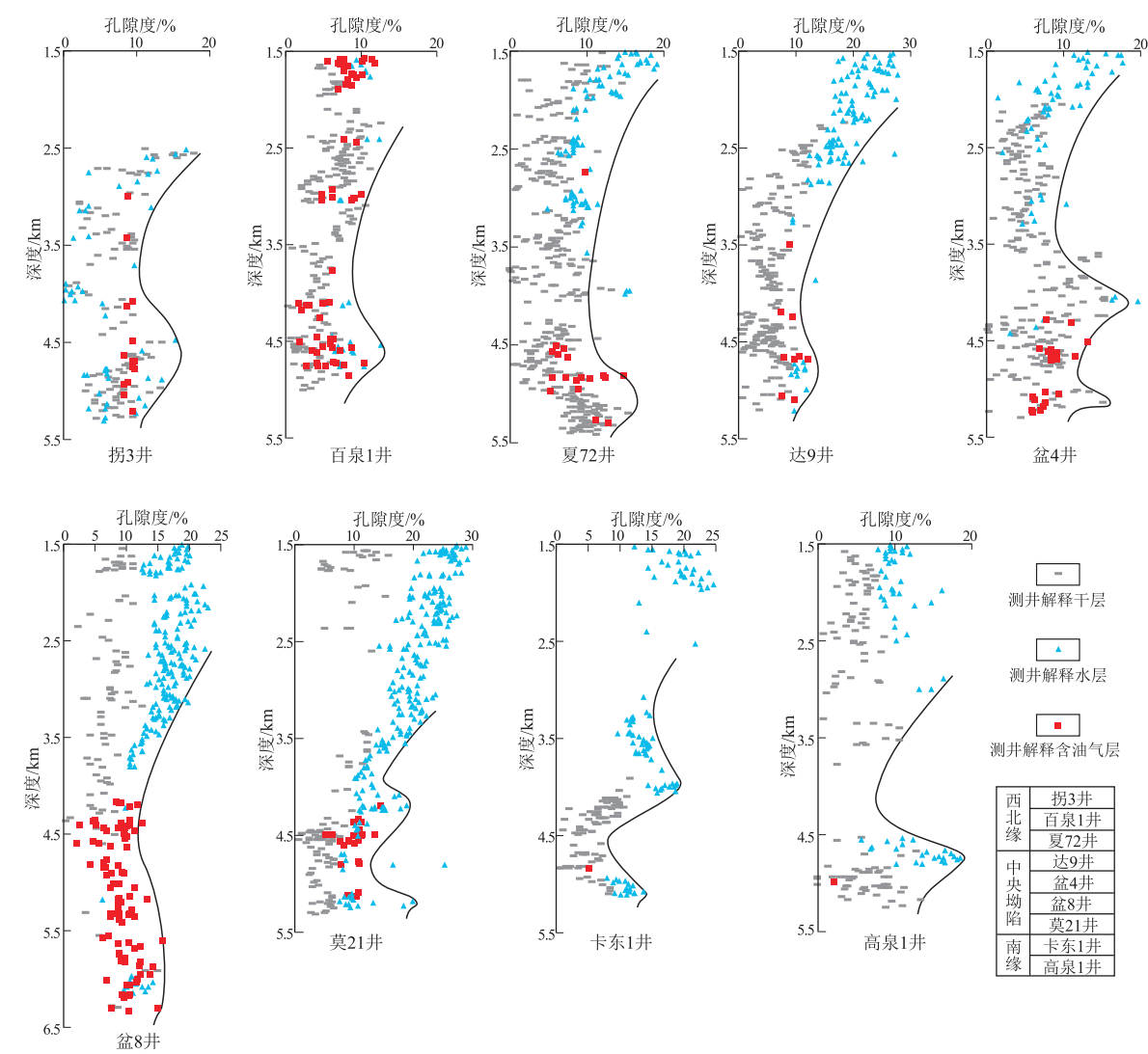


图5 准噶尔盆地深层相对优质储集层段发育特征
井位置见图1。

Fig.5 Characteristics of deeply buried relatively high-quality reservoir in Junggar Basin

盆8井和莫21井等均见良好油气显示(图5)。

盆地南缘深层碎屑岩相对优质储集层段的形成与异常高压、早期长期浅埋—后期快速深埋和溶蚀等因素有关^[14]。在卡东1井和高泉1井等均见油气显示(图5)。

另外,深层百口泉组—克拉玛依组储层在纵向上分布在白碱滩组区域盖层与二叠系烃源岩之间,平面上主要分布在阜康凹陷、沙湾凹陷和玛湖凹陷等构造单元(图6),其在纵向和横向上的展布都有利于油气的赋存。

3.3 多套深层区域盖层

准噶尔盆地在湖盆扩张期(湖侵)形成了下乌尔禾组、白碱滩组和三工河组等区域盖层^[26-28]。白碱滩组分布广泛,在中央坳陷和南缘厚度最大(图7)。白碱滩组泥岩和下乌尔禾组泥岩既是深层最重要的2套盖层,又是深层重要的烃源岩,另

外,中下侏罗统烃源岩也是深层的重要盖层。三叠纪—白垩纪为石炭系和中、下二叠统烃源岩的主要生排烃期^[29-32],上三叠统白碱滩组和中、下侏罗统泥岩区域盖层的形成期与其下伏主要烃源岩生排烃期配置关系良好,能够起到较好的封盖作用。

在深埋过程中,深层盖层整体变得更致密,封堵烃类的能力也更强。盆地腹部广泛发育的异常压力封隔层对深层油气也具有封堵作用^[27,33-36]。

3.4 保存条件

准噶尔盆地二叠纪经历多期构造运动,形成了多个不整合面^[37],并与风城组和下乌尔禾组等多套重要烃源岩紧邻,可以更有效地沟通源岩和圈闭,利于油气运移和聚集。

三叠纪以来,相对于盆地其他构造单元,中央坳陷基本上为构造稳定区,构造变动弱,断裂不发育(图3),有利于油气藏保存,具备形成叠复连续

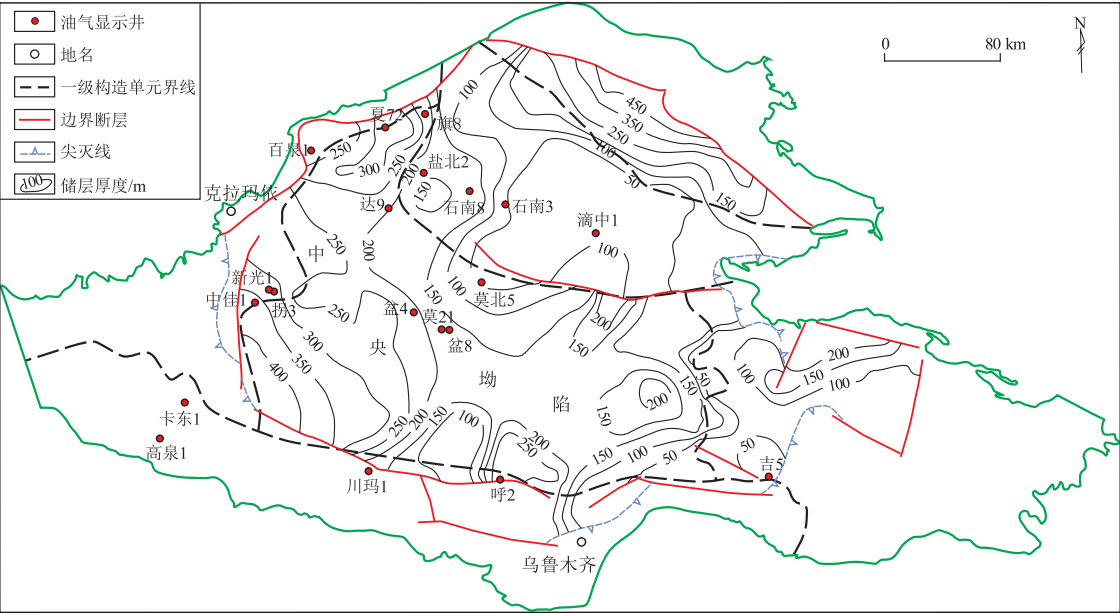


图 6 准噶尔盆地三叠系百口泉组—克拉玛依组储层厚度

Fig.6 Reservoir thickness of Triassic Baikouquan-Kelamayi formations in Junggar Basin

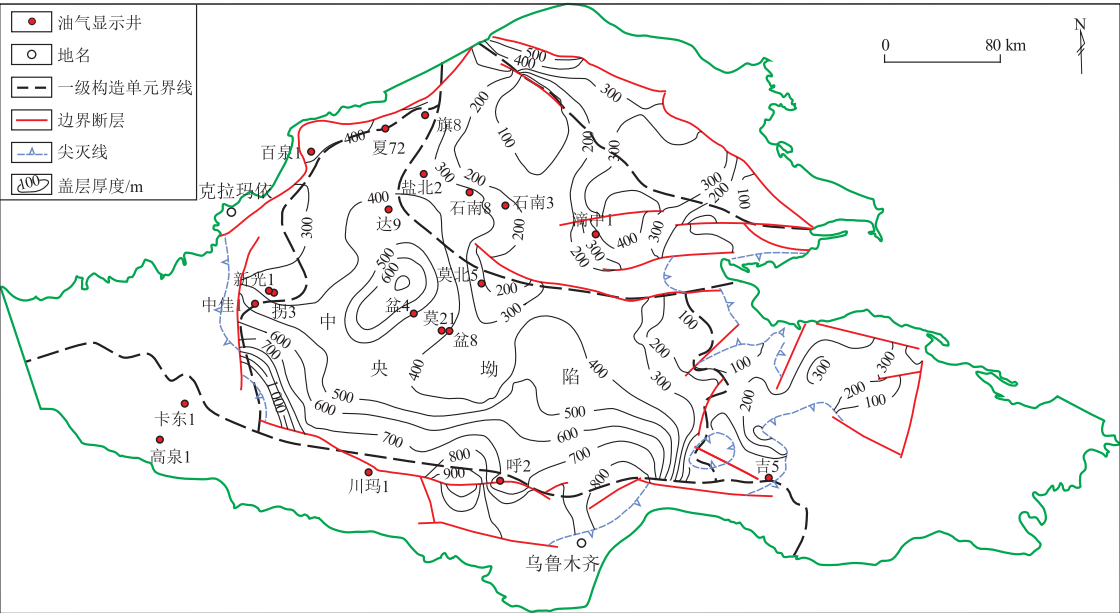


图 7 准噶尔盆地白碱滩组区域盖层分布范围与厚度

Fig.7 Distribution and thickness of Baijiantan Formation in Junggar Basin

致密油气藏的基本条件。叠复连续致密油气藏具有纵向上各目的层段叠加、平面上多目的层段复合成片的分布特征,难以用浮力成藏机制解释,也难以完全用非浮力成藏机制解释^[38]。在近源—优相—低势复合区是叠复连续致密油气藏“甜点”的有利发育和保存区。

4 资源潜力分析

准噶尔盆地 3 km 以下的天然气资源量占总资源量的 93%,5 km 以下的天然气资源量占总资源量

的 30%^[39]。盆地南缘中下侏罗统烃源岩埋深普遍大于 4 500 m,处于成熟—高成熟演化阶段,其排烃量可达 $1\,402.7\times10^8\text{ t}$,远景资源量为 $125.4\times10^8\text{ t}$ ^[40]。

应用成因法计算得到盆地深层风城组烃源岩生油、气量和排油、气量分别为 $603.9\times10^8\text{ t}$ 、 $400.4\times10^{11}\text{ m}^3$ 和 $375.4\times10^8\text{ t}$ 、 $304.9\times10^{11}\text{ m}^3$ 。风城组烃源岩在晚三叠世(T_3b)时期达到生油高峰,早侏罗世(J_1b)时期达到排油高峰,早白垩世(K_1tg)时期达到生气和排气高峰。白碱滩组(T_3b)区域盖层形成之后,风城组排油和排气量分别为 $235.2\times10^8\text{ t}$ 和 $283.4\times10^{11}\text{ m}^3$,

显示了深层巨大的勘探潜力。

根据盆地深层生储盖组合特征分析,结合勘探实践和前人已有认识,认为中央拗陷和南缘具备形成深层油气藏的地质条件,在发育相对优质储集层段的层位可以形成常规油气藏,在致密层则具备形成致密油气等非常规油气藏的条件。

5 结论

(1)准噶尔盆地中央拗陷和南缘深层广泛发育二叠系(风城组和下乌尔禾组等)、侏罗系和石炭系等重要烃源岩,为深层油气的形成提供了充足的烃类来源。

(2)深层地层物性整体较差,孔隙度普遍小于12%,但在后期多种改造作用下,依然可以发育相对优质储集层段,为深层油气聚集提供了充足储集空间。

(3)白碱滩组泥岩、三工河组泥岩和下乌尔禾组泥岩等区域盖层具备良好的封盖性能,在空间展布和形成时间上都利于深层油气的聚集与保存。

(4)相对于盆地的其他构造单元,中央拗陷在三叠纪以来构造变动弱,断裂不发育,有利于深层油气的保存。

(5)准噶尔盆地中央拗陷和南缘是深层油气勘探的有利区,在发育相对优质储集层段的层位可以形成常规油气藏,在物性较差的致密层位则具备形成致密油气等非常规油气藏的条件。应用成因法计算得到盆地深层风城组烃源岩排油、气量分别为 $375.4\times10^8\text{ t}$ 和 $304.9\times10^{11}\text{ m}^3$ 。白碱滩组(T_3b)区域盖层形成之后,风城组排油、气量分别为 $235.2\times10^8\text{ t}$ 和 $283.4\times10^{11}\text{ m}^3$,显示了深层巨大的勘探潜力。

致谢:陈冬霞副教授对本文提出了宝贵的建设性意见,谨致谢忱! 论文研究获得了新疆油田公司勘探院贾希玉、杨海波、陈磊等高级工程师的支持和帮助,在此一并致谢。

参考文献:

[1] 克拉尤什金 B A. 深成油气田[J]. 任俞,译. 新疆石油地质, 2009, 30(1): 136-141.
Krayushkin B A. The plutonic oil-gas fields[J]. Ren Yu, trans. Xinjiang Petroleum Geology, 2009, 30(1): 136-141.

[2] 翟光明, 王世洪, 何文渊. 近十年全球油气勘探热点趋向与启示[J]. 石油学报, 2012, 33(S1): 14-19.
Zhai Guangming, Wang Shihong, He Wenyuan. Hotspot trend and enlightenment of global ten-year hydrocarbon exploration [J]. Acta Petrolei Sinica, 2012, 33(S1): 14-19.

[3] 孙广伯, 张君峰, 赵丽华, 等. 中石油探明天然气储量状况及

变化特点[J]. 新疆石油地质, 2014, 35(6): 636-639.
Sun Guangbo, Zhang Junfeng, Zhao Lihua, et al. Current situation and changing characteristics of natural gas proved reserves in PetroChina[J]. Xinjiang Petroleum Geology, 2014, 35(6): 636-639.

[4] 何登发, 陈新发, 张义杰, 等. 准噶尔盆地油气富集规律[J]. 石油学报, 2004, 25(3): 1-10.
He Dengfa, Chen Xinfu, Zhang Yijie, et al. Enrichment characteristics of oil and gas in Junggar Basin[J]. Acta Petrolei Sinica, 2004, 25(3): 1-10.

[5] 陈萍, 张玲, 王惠民. 准噶尔盆地油气储量增长趋势与潜力分析[J]. 石油实验地质, 2015, 37(1): 124-128.
Chen Ping, Zhang Ling, Wang Huimin. Reserves growth trend and potential analysis of Junggar Basin[J]. Petroleum Geology & Experiment, 2015, 37(1): 124-128.

[6] 刘传虎. 准噶尔盆地隐蔽油气藏类型及有利勘探区带[J]. 石油实验地质, 2014, 36(1): 25-32.
Liu Chuanhu. Subtle reservoir type and favorable exploration belts in Junggar Basin [J]. Petroleum Geology & Experiment, 2014, 36(1): 25-32.

[7] 赵殿栋, 刘传虎. 准噶尔盆地油气勘探潜力及方向[J]. 新疆石油地质, 2005, 26(1): 1-5.
Zhao Diandong, Liu Chuanhu. Prospects and targets for petroleum exploration in Junggar Basin [J]. Xinjiang Petroleum Geology, 2005, 26(1): 1-5.

[8] 况军, 贾希玉, 俞正国, 等. 准噶尔盆地南缘深浅层构造特征分析[J]. 新疆石油地质, 1989, 10(1): 17-27.
Kuang Jun, Jia Xiyu, Yu Zhengguo, et al. The deep-shallow structures analysis on the southern margin of Junggar Basin [J]. Xinjiang Petroleum Geology, 1989, 10(1): 17-27.

[9] 马宗晋, 曲国胜, 陈新发. 准噶尔盆地深浅构造分析及油气展布规律[J]. 新疆石油地质, 2008, 29(4): 411-414.
Ma Zongjin, Qu Guosheng, Chen Xinfu. The deep-shallow structures and oil-gas distribution in Junggar Basin [J]. Xinjiang Petroleum Geology, 2008, 29(4): 411-414.

[10] 薛新克, 王廷栋, 张虎权, 等. 准噶尔盆地深部地壳构造特征与油气勘探方向[J]. 天然气工业, 2006, 26(10): 37-41.
Xue Kinke, Wang Tingdong, Zhang Huquan, et al. The deep crust features of the Junggar Basin and petroleum exploration targets [J]. Na-tural Gas Industry, 2006, 26(10): 37-41.

[11] 陈忠民. 准噶尔盆地侏罗系深部气藏勘探的有利地质条件[J]. 新疆石油地质, 2001, 22(4): 291-293.
Chen Zhongmin. Favorable geological conditions for gas-pool exploration in Jurassic deep-buried basin structure of Junggar Basin [J]. Xinjiang Petroleum Geology, 2001, 22(4): 291-293.

[12] 王芙蓉, 何生, 洪太元. 准噶尔盆地腹部地区深埋储层物性特征及影响因素[J]. 新疆地质, 2006, 24(4): 423-428.
Wang Furong, He Sheng, Hong Taiyuan. Dominant factors affecting the reservoir properties of deeply buried bed in the center of Junggar Basin [J]. Xinjiang Geology, 2006, 24(4): 423-428.

[13] 门相勇, 赵文智, 胡素云, 等. 准噶尔盆地腹部二叠系、三叠系储集层特征及烃类侵位对深部储集层物性的影响[J]. 石油勘探与开发, 2006, 33(2): 208-224.
Men Xiangyong, Zhao Wenzhi, Hu Suyun, et al. Characteristics

- of deep-buried fragmental reservoirs in central Junggar Basin and the effect of hydrocarbon emplacement on reservoirs' diagenetic mineral evolution[J]. *Petroleum Exploration and Development*, 2006, 33(2): 208-224.
- [14] 雷德文,唐勇,常秋生.准噶尔盆地南缘深部优质储集层及有利勘探领域[J]. *新疆石油地质*, 2008, 29(4): 435-438.
Lei Dewen, Tang Yong, Chang Qiusheng. The deep and relatively high-quality clastic reservoir bodies and favorable exploration areas in southern margin of Junggar Basin[J]. *Xinjiang Petroleum Geology*, 2008, 29(4): 435-438.
- [15] 胡海燕,陈元勇,李翻平.准噶尔盆地腹部深盆气成藏条件及识别标志[J]. *油气地质与采收率*, 2009, 16(5): 30-32.
Hu Haiyan, Chen Yuanyong, Li Fanping. Accumulation elements and recognition symbol of deep basin gas in the center of Junggar Basin[J]. *Petroleum Geology and Recovery Efficiency*, 2009, 16(5): 30-32.
- [16] 胡海燕,李平平,王国建.准噶尔永进地区深层次生孔隙带发育机理[J]. *地质科技情报*, 2008, 27(3): 21-25.
Hu Haiyan, Li Pingping, Wang Guojian. Mechanism of secondary porosity development of Xishanyao Formation (J_2x) in Yongjin Block, Junggar Basin[J]. *Geological Science and Technology Information*, 2008, 27(3): 21-25.
- [17] 胡海燕,王国建.准噶尔盆地深层相对优质储层发育机理:淋滤与溶蚀作用[J]. *中国岩溶*, 2009, 28(1): 35-41.
Hu Haiyan, Wang Guojian. Development mechanism of relative high-quality oil reservoir in the deeply buried sandstone in the Junggar Basin: Leaching and corrosion[J]. *Carsologica Sinica*, 2009, 28(1): 35-41.
- [18] 金振奎,苏奎,苏妮娜.准噶尔盆地腹部侏罗系深部优质储层成因[J]. *石油学报*, 2011, 32(1): 25-31.
Jin Zhenkui, Su Kui, Su Nina. Origin of Jurassic deep burial high-quality reservoirs in the central Junggar Basin[J]. *Acta Petrolei Sinica*, 2011, 32(1): 25-31.
- [19] 林潼,李文厚,孙平,等.新疆准噶尔盆地南缘深层有利储层发育的影响因素[J]. *地质通报*, 2013, 32(9): 1461-1470.
Lin Tong, Li Wenhui, Sun Ping, et al. Factors influencing deep favorable reservoirs on the southern margin of Junggar Basin, Xinjiang Province[J]. *Geological Bulletin of China*, 2013, 32(9): 1461-1470.
- [20] 周中毅,范善发,潘长春,等.盆地深部形成油气藏的有利因素[J]. *勘探家*, 1997, 2(1): 7-11.
Zhou Zhongyi, Fan Shanfa, Pan Changchun, et al. Hydrocarbon generation and accumulation in deep part of sedimentary basin[J]. *Explorationist*, 1997, 2(1): 7-11.
- [21] 杨永泰,王社教,培东宏,等.准噶尔盆地腹部深层成藏条件及勘探领域分析[J]. *石油勘探与开发*, 2002, 29(4): 32-34.
Yang Yongtai, Wang Shejiao, Pei Donghong, et al. An analysis of deep hydrocarbon accumulation conditions and exploratory realms in the heartland of Junggar Basin[J]. *Petroleum exploration and development*, 2002, 29(4): 32-34.
- [22] 庞雄奇.中国西部叠合盆地深部油气勘探面临的重大挑战及其研究方法之意义[J]. *石油与天然气地质*, 2010, 31(5): 517-541.
Pang Xiongqi. Key challenges and research methods of petroleum exploration in the deep of superimposed basins in western China[J]. *Oil & Gas Geology*, 2010, 31(5): 517-541.
- [23] 赵白.准噶尔盆地的基底性质[J]. *新疆石油地质*, 1992, 13(2): 95-99.
Zhao Bai. Nature of basement of Junggar Basin[J]. *Xinjiang Petroleum Geology*, 1992, 13(2): 95-99.
- [24] 赵文智,王兆云,张水昌,等.有机质“接力成气”模式的提出及其在勘探中的意义[J]. *石油勘探与开发*, 2005, 32(2): 1-7.
Zhao Wenzhi, Wang Zhaoyun, Zhang Shuichang, et al. Successive generation of natural gas from organic materials and its significance in future exploration[J]. *Petroleum Exploration and Development*, 2005, 32(2): 1-7.
- [25] 庞雄奇,李倩文,陈践发,等.含油气盆地深部高过成熟烃源岩古 TOC 恢复方法及其应用[J]. *古地理学报*, 2014, 16(6): 769-789.
Pang Xiongqi, Li Qianwen, Chen Jianfa, et al. Recovery method of original TOC and its application in source rocks at high mature-over mature stage in deep petroliferous basins[J]. *Journal of Palaeogeography*, 2014, 16(6): 769-789.
- [26] 刘文国,吴元燕,况军.准噶尔盆地区域盖层排替压力研究[J]. *江汉石油学院学报*, 2001, 23(1): 17-19.
Liu Wenguo, Wu Yuanyan, Kuang Jun. Calculation of displacement pressure of regional caprocks in Junggar Basin[J]. *Journal of Jiangnan Petroleum Institute*, 2001, 23(1): 17-19.
- [27] 吴孔友,查明,钟建华.准噶尔盆地超压系统分布及其演化[J]. *地质科学*, 2006, 41(4): 636-647.
Wu Kongyou, Zha Ming, Zhong Jianhua. Distribution and evolution of overpressure systems in the Junggar Basin[J]. *Chinese Journal of Geology*, 2006, 41(4): 636-647.
- [28] 刘文彬.准噶尔盆地上三叠统天然气盖层研究[J]. *天然气地球科学*, 1992, 3(1): 48-51.
Liu Wenbin. Research of Upper Triassic gas cap in Junggar Basin[J]. *Natural Gas Geoscience*, 1992, 3(1): 48-51.
- [29] 何登发,陈新发,况军,等.准噶尔盆地石炭系烃源岩分布与含油气系统[J]. *石油勘探与开发*, 2010, 37(4): 397-408.
He Dengfa, Chen Xinfu, Kuang Jun, et al. Distribution of Carboniferous source rocks and petroleum systems in the Junggar Basin[J]. *Petroleum Exploration and Development*, 2010, 37(4): 397-408.
- [30] Graham S A, Brassell S. Characteristics of selected petroleum source rocks, Xinjiang Uygur autonomous region, Northwest China[J]. *AAPG Bulletin*, 1990, 74(4): 493-512.
- [31] 张义杰,柳广弟.准噶尔盆地复合油气系统特征、演化与油气勘探方向[J]. *石油勘探与开发*, 2002, 29(1): 36-39.
Zhang Yijie, Liu Guangdi. Characteristics and evolution of composite petroleum systems and the exploration strategy in Junggar Basin, northwest China[J]. *Petroleum Exploration and Development*, 2002, 29(1): 36-39.
- [32] 赵孟军,宋岩,柳少波,等.准噶尔盆地天然气成藏体系和成藏过程分析[J]. *地质论评*, 2009, 55(2): 215-224.
Zhao Mengjun, Song Yan, Liu Shaobo, et al. Accumulation systems and filling process of natural gas in Junggar Basin[J]. *Geological Review*, 2009, 55(2): 215-224.

- [29] 宋岩,方世虎,赵孟军,等.前陆盆地冲断带构造分段特征及其对油气成藏的控制作用[J].地质前缘,2005,12(3):31-38.
Song Yan, Fang Shihu, Zhao Mengjun, et al. The structural segmentation of foreland thrust belts and its implications for hydrocarbon accumulation in foreland basins in central and western China[J]. Earth Science Frontiers, 2005, 12(3): 31-38.
- [30] 孟家峰,郭召杰,方世虎.准噶尔盆地西北缘冲断构造新解[J].地质前缘,2009,16(3):171-180.
Meng Jiafeng, Guo Zhaojie, Fang Shihu. A new insight into the thrust structures at the northwestern margin of Junggar Basin[J]. Earth Science Frontiers, 2009, 16(3): 171-180.
- [31] 邵雨,汪仁富,张越迁,等.准噶尔盆地西北缘走滑构造与油气勘探[J].石油学报,2011,32(6):976-984.
Shao Yu, Wang Renfu, Zhang Yueqian, et al. Strike-slip structures and oil-gas exploration in the NW margin of the Junggar Basin, China[J]. Acta Petrolei Sinica, 2011, 32(6): 976-984.
- [32] 陈书平,况军,刘继山,等.准噶尔盆地西北缘克百地区不整合面及其动力学条件[J].高校地质学报,2008,14(2):199-205.
Chen Shuping, Kuang Jun, Liu Jishan, et al. Major unconformities and their dynamic conditions in Ke-Bai area, northwestern margin of Junggar Basin[J]. Geological Journal of China Universities, 2008, 14(2): 199-205.
- [33] 崔泽宏,汤良杰.一种挤压构造背景下正断层的成因模式[J].新疆石油地质,2007,28(2):254-256.
Cui Zehong, Tang Liangjie. A genetic model of normal fault under compressive tectonic setting [J]. Xinjiang Petroleum Geology, 2007, 28(2): 254-256.
- [34] 张纪易.克拉玛依洪积扇粗碎屑储集体[J].新疆石油地质,1980(1):33-53.
Zhang Jiyi. Karamay alluvial coarse clastic reservoir [J]. Xinjiang Petroleum Geology, 1980(1): 33-53.
- [35] 张纪易.粗碎屑洪积扇的某些沉积特征和微相划分[J].沉积学报,1985,3(3):75-85.
Zhang Jiyi. Some depositional characteristics and microfacies subdivision of coarse clastic alluvial fans [J]. Acta Sedimentologica Sinica, 1985, 3(3): 75-85.
- [36] 印森林,吴胜和,冯文杰,等.冲积扇储集层内部隔夹层样式:以克拉玛依油田一中区克下组为例[J].石油勘探与开发,2013,40(6):757-763.
Yin Senlin, Wu Shenghe, Feng Wenjie, et al. Patterns of interlayers in the alluvial fan reservoirs: A case study on Triassic Lower Karamay Formation, Yizhong area, Karamay Oilfield, NW China [J]. Petroleum Exploration and Development, 2013, 40(6): 757-763.
- [37] Bestland E A. Alluvial terraces and paleosols as indicators of Early Oligocene climate change (John Day Formation, Oregon) [J]. Journal of Sedimentary Research, 1997, 67(5): 840-855.
- [38] 吴胜和,纪友亮,岳大力,等.碎屑沉积地质体构型分级方案探讨[J].高校地质学报,2013,19(1):12-22.
Wu Shenghe, Ji Youliang, Yue Dali, et al. Discussion on hierarchical scheme of architectural units in clastic deposits [J]. Geological Journal of China Universities, 2013, 19(1): 12-22.

(编辑 黄娟)

(上接第810页)

- [33] 周勇水,邱楠生,宋鑫颖,等.准噶尔盆地腹部超压地层烃源岩热演化史研究[J].地质科学,2014,49(3):812-822.
Zhou Yongshui, Qiu Nansheng, Song Xinying, et al. Study of source rock thermal evolution in overpressure formations in the hinterland of Junggar Basin [J]. Chinese Journal of Geology, 2014, 49(3): 812-822.
- [34] 杨智,何生,何治亮,等.准噶尔盆地腹部超压层分布与油气成藏[J].石油学报,2008,29(2):199-205.
Yang Zhi, Heng Sheng, He Zhiliang, et al. Distribution of overpressure stratum and its relationship with hydrocarbon accumulation in the central part of Junggar Basin [J]. Acta Petrolei Sinica, 2008, 29(2): 199-205.
- [35] 何惠生,叶加仁,陈景阳.准噶尔盆地腹部超压演化及成因[J].石油天然气学报,2009,31(1):87-91.
He Huisheng, Ye Jiaren, Chen Jingyang. Overpressure evolution and genesis in central Junggar basin [J]. Journal of Oil and Gas Technology, 2009, 31(1): 87-91.
- [36] 谭绍泉,曾治平,宫亚军,等.准噶尔盆地腹部超压控制烃、储演化与油气充注过程[J].断块油气田,2014,21(3):287-291.
Tan Shaoquan, Zeng Zhiping, Gong Yajun, et al. Control of abnormal overpressure on hydrocarbon-reservoir evolution and hydrocarbon filling process in central of Junggar Basin [J]. Fault-Block Oil and Gas Field, 2014, 21(3): 287-291.
- [37] 吴孔友,查明,柳广弟.准噶尔盆地二叠系不整合面及其油气运聚特征[J].石油勘探与开发,2002,29(2):53-57.
Wu Kongyou, Zha Ming, Liu Guangdi. The unconformity surface in the Permian of Junggar Basin and the characters of oil-gas migration and accumulation [J]. Petroleum exploration and development, 2002, 29(2): 53-57.
- [38] 庞雄奇,姜振学,黄捍东,等.叠复连续油气藏成因机制、发育模式及分布预测[J].石油学报,2014,35(5):795-828.
Pang Xiongqi, Jiang Zhenxue, Huang Handong, et al. Formation mechanisms, distribution models, and prediction of superimposed, continuous hydrocarbon reservoirs [J]. Acta Petrolei Sinica, 2014, 35(5): 795-828.
- [39] 王屿涛,况军,丁安娜.准噶尔盆地天然气分布规律及勘探方向[J].天然气地球科学,1996,7(1):1-8.
Wang Yutao, Kuang Jun, Ding Anna. Gas distribution and exploration direction in Junggar basin [J]. Natural Gas Geoscience, 1996, 7(1): 1-8.
- [40] Guo Jigang, Pang Xiongqi, Guo Fengtao, et al. Petroleum generation and expulsion characteristics of Lower and Middle Jurassic source rocks on the southern margin of Junggar Basin, northwest China: Implications for unconventional gas potential [J]. Canadian Journal of Earth Sciences, 2014, 51(6): 537-557.

(编辑 黄娟)