两北地区三叠系深部碎屑岩储层特征及控制因素

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摘要: 运用钻井岩心、铸体薄片和扫描电镜等资料，对两北地区三叠系深部碎屑岩的储层特征及储层发育的控制因素进行了研究。结果表明，三叠系储层主要岩石类型为长石岩屑砂岩和岩屑砂岩，具有成分成熟度低和结构成熟度中等的岩石学特征，储集空间以粒间溶孔为主，其次为裂缝，属于中孔、中—低渗透储层。两北地区三叠系主要发育冲积扇—河流—湖泊—三角洲沉积体系，沉积主体为三角洲平原、三角洲前缘亚相及滨浅湖沉积，储集砂体主要为分流河道和河口坝沉积。成岩作用是深部碎屑岩储层后期改造的关键因素，压实作用使得储层原始孔隙遭受破坏; 同时储层中方解石、长石、石英、岩屑及杂基在大气、水和有机酸的溶蚀作用下，产生大量的溶蚀孔隙，改善了储集性能，溶蚀作用是两北地区三叠系形成优质深部碎屑岩储层的关键因素。

关键词: 储层特征 控制因素 碎屑岩 三叠系 两北地区
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两北地区位于塔北地区的西部，主要包括阿瓦提断陷的北斜坡、顺托果勒低隆西北翼和沙雅隆起的西南部，总面积为 9 008.7 km^2。前人研究[1-7]表明，深部碎屑岩储层在塔北地区三叠系中广泛发育，储层物性好，孔隙度大于 10%，渗透率大于 100×10^{-3} μm^2，具备形成大中型油气藏的条件，是中外少见的深埋优质碎屑岩储层。已发现具有工业价值的油气主要分布于轮南断垒、桑塔木断垒及解放渠—吉拉克地区，而两北地区的油气勘探始终未获得突破。研究区位于沙雅隆起和塔中隆起 2 大油气富集带之间，处于以下古生界为主体的沙雅古隆起斜坡地带，既是有利储集相带的发育区，又是油气运移的指向和汇集地区。钻井资料显示，胜利 1 井和顺 8 井见到少量的沥青质，北缘的沙南 1 井钻遇少量轻质油，表明三叠纪早期有过烃类流体的活动。因此，储层条件是影响研究区油气成藏的关键因素。笔者从储层的微观特征入手，依据铸体薄片、扫描电镜和钻井岩心等各项资料，开展两北地区三叠系碎屑岩储层特征研究，并分析储层发育的主控因素，以便有效指导三叠系碎屑岩油气的勘探。

1 岩石学特征

通过钻井岩心以及铸体薄片分析可知，研究区三叠系储层岩屑粒径主要为 0.10～0.30 mm，岩性主要为细砂岩和中砂岩; 磨圆度以次棱角状、次圆状—次棱角状为主，整体分选中等; 颗粒之间以点、点—线接触为主; 支撑类型主要为颗粒支撑; 胶结类型以孔隙式为主，个别可见基底式和孔隙—接触式。

对研究区及周边 8 口井岩心样品分析可知，三叠系碎屑岩储层主要岩石类型为长石岩屑砂岩，其次为岩屑砂岩和石英砂岩(图1)，平均石英含量为

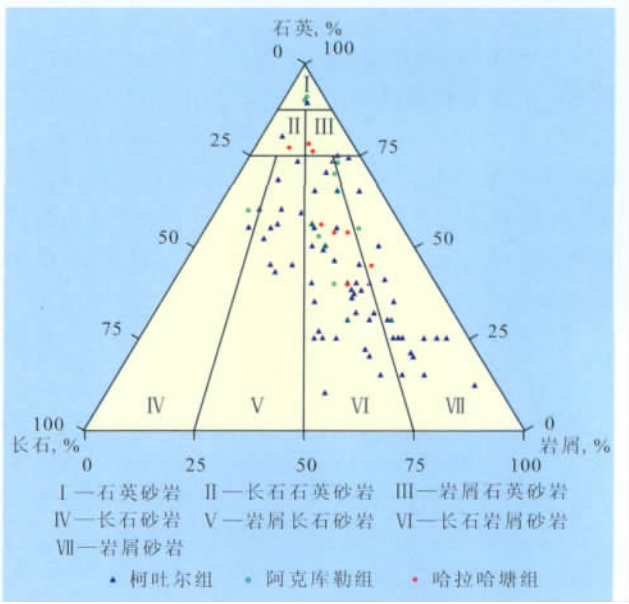

图 1 两北地区三叠系储层砂岩组分

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44.62%，岩屑含量为36.76%，长石含量为18.62%。其中，下三叠统柯吐尔组以长石岩屑砂岩为主，石英含量为 10% ~ 89%，平均为 44.76%，岩屑含量为 5% ~ 83%，平均为 36.85%，长石含量为 5% ~ 40%，平均为 18.39%；中三叠统阿克库勒组以长石岩屑砂岩为主，石英含量为30% ~91%，平均为 58.58%，岩屑含量为 5% ~55%，平均为 27.58%，长石含量为 4% ~25%，平均为 13.83%；上三叠统哈拉哈塘组以岩屑石英砂岩为主，石英含量为40% ~ 78%，平均为 60%，岩屑含量为 8% ~43%，平均为 25.75%，长石含量为 10% ~20%，平均为 14.25%。岩心样品分析表明，研究区三叠系储层成分成熟度低，结构成熟度中等，属于近物源冲积扇—河流—湖泊—三角洲沉积。

2　储层物性特征

储层物性是决定其储集性能的关键[4]。岩心资料分析表明，研究区储层平均孔隙度为 16.5%，平均渗透率为 522.6×10^{-3} μm²。柯吐尔组砂岩孔隙度为 0.5% ~24.8%，平均为 15.13%，孔隙度大于 15% 的样品占 55.1%，平均渗透率为 585.5×10^{-3} μm²，渗透率大于 100×10^{-3} μm² 的样品占 29.4%，属于中孔、中—高渗透储层；阿克库勒组砂岩孔隙度为 3% ~26.2%，平均为 9.08%，多数样品小于 10%，渗透率为 0.4×10^{-3} ~ 25.6×10^{-3} μm²，平均为 10.7×10^{-3} μm²，属于低孔、低渗透储层；哈拉哈塘组砂岩（仅有 3 个样品）孔隙度平均为 22.93%，渗透率为 20.5×10^{-3} μm²，属于中孔、低渗透储层。因此，三叠系碎屑岩储层整体属于中孔、中—低渗透储层，其中柯吐尔组储层物性相对较好。

3　储集空间类型

通过扫描电镜及铸体薄片分析可知，研究区储层储集空间类型以次生孔隙为主，包括粒间溶孔、粒内溶孔和裂缝，原生孔隙大多被破坏。岩屑和长石等颗粒边缘沿粒间孔周围发生不同程度的溶蚀，粒间方解石胶结物和灰泥基质溶蚀较强，普遍见到粒间溶孔，孔隙分布均匀，大部分为收缩状及弯片状喉道（图 2a），少许呈缩颈喉道，局部喉道发育较好，呈连通状，少量颗粒为粒内溶蚀和浸染状，孔隙式胶结，胶结物以粘土矿物为主。

裂缝对沟通孔隙、提高储层的渗透率有明显作用，同时也有利于孔隙水和地下水的活动及溶蚀孔隙的发育，从而进一步改善储集性能[5-6]。镜下鉴定及物性资料表明，研究区裂缝发育，其中大部分被沥青质、白云石半充填或局部充填，也存在未充填裂缝（图 2b），是储集空间类型之一。

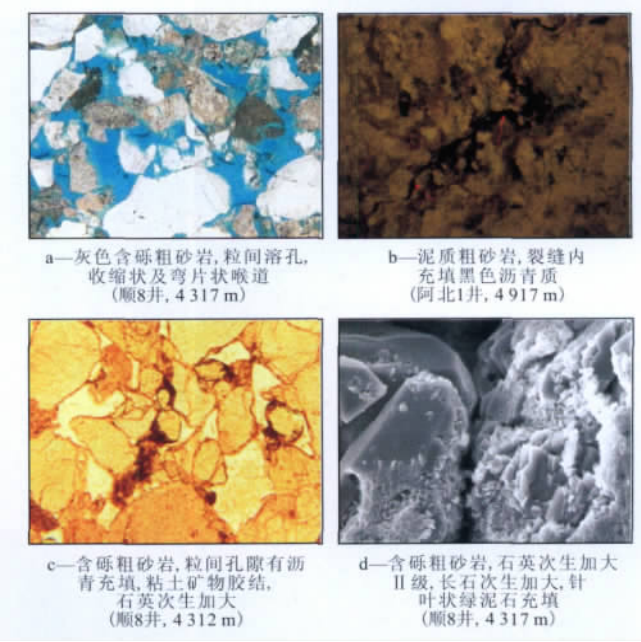

图 2　两北地区三叠系柯吐尔组储层储集空间类型

4　储层控制因素

对于深部碎屑岩储层，大地构造背景和古地温在宏观上控制了储层的演化，沉积条件是形成优质储层的前提和基础，溶蚀作用是形成优质储层的直接原因，异常高压、膏岩、砂泥岩互层状况、烃类注入以及构造裂缝是形成优质储层的辅助因素[8-11]。三叠纪，两北地区地层发育稳定，断层不发育，构造运动影响不明显，沉积相和成岩作用成为储层发育的主要控制因素。

4.1　沉积相

由于岩石成分、粒度、分选、杂基含量和碎屑颗粒组成的差异，砂岩原始孔隙发育程度与渗透性能存在差异，宏观上这些因素又受沉积环境控制，因而深部优质储层多形成于水动力条件较强的高能环境。从沉积相单元上看，三角洲、扇三角洲、滨岸、辫状河三角洲和重力流水道等砂体储层发育较好[12-14]。两北地区总体发育冲积扇—河流—湖泊—三角洲沉积体系。从研究区不同沉积微相储层物性对比（图 3）可以看出，储层物性受沉积相影响较大，辫状河道和河口坝砂体物性相对好，孔隙度总

体大于 15%，河口坝砂体渗透率最高。同一相带渗透率的最大、最小和平均值呈现较为一致的变化趋势；辫状河道和河口坝的孔隙度变化较大，席状砂、重力流和分流河道的孔隙度变化一致，说明后期成岩作用对辫状河道和河口坝砂体孔隙度的影响相对较大。

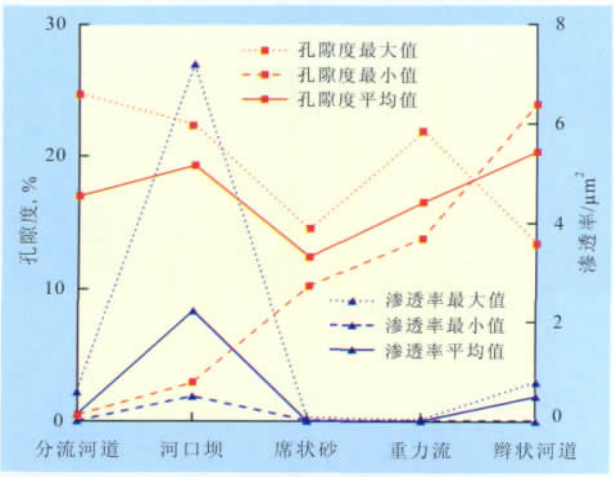

图 3　两北地区不同沉积微相储层物性对比

4.2　成岩作用

深部碎屑岩储层的演化及其非均质性与成岩作用密切相关，沉积物在进入埋藏成岩阶段之后，不同的成岩作用类型及强度对储层的储集性能起决定性作用[15-16]。三叠纪成岩作用类型多，且比较复杂，对储层渗透性能的影响具有双重性，既可充填和破坏孔隙、降低渗透率，又可改善孔隙、提高渗透率。其中，溶蚀作用是改善两北地区深部碎屑岩储层物性的主要成岩作用。

4.2.1　破坏性成岩作用

破坏性成岩作用主要是压实作用和胶结作用。压实作用是一种物理成岩作用，容易造成大量原始孔隙的损失，并且这种损失是不可逆转的。三叠纪两北地区平均埋深为 4 427 m，属于深埋藏范畴，储层的成分成熟度低，岩屑中含有较多的泥质、凝灰岩等塑性、半塑性颗粒，这些颗粒在深度达到 4 000 m 以下时，很容易受压变形[17]。镜下可见石英颗粒局部嵌入千枚岩屑内，黑、白云母片变形且微定向，颗粒呈线接触，泥岩屑变形或被硬颗粒嵌入，或变形呈假杂基状，杂基中的水云母粘土物质在局部范围内呈定向性以及长石双晶变弯曲，说明压实作用相对强烈。

胶结作用存在于整个成岩作用阶段[3]，通过扫描电镜观察发现，主要胶结物有白云石、方解石、石英、硬石膏和粘土矿物，以白云石、方解石胶结和石英的次生加大为主；另见高岭石与绿泥石胶结，伊利石和伊蒙混层在研究区比较少见。胶结作用使许多孔隙遭到破坏，储层物性变差。

4.2.2　建设性成岩作用

溶蚀作用是深层碎屑岩储层一种重要的建设性成岩作用，是形成次生孔隙、改善储层物性的主要成岩方式之一。在一定的成岩环境中碎屑岩中的颗粒、杂基、胶结物和自生矿物等都可以发生一定的溶蚀作用，并且以硅酸岩屑的溶蚀最为强烈[18-22]。根据薄片资料，镜下可见方解石、长石、岩屑、石英及杂基溶蚀，石英的次生加大非常普遍（图 2c，图 2d），溶蚀作用是三叠系深部碎屑岩储层次生孔隙发育的主要原因。

研究区自三叠纪—古近纪末经历了近 200 Ma，古近纪埋深为 1 000～1 500 m；深埋藏发生于新近纪，由于大气、水侵入的深度可达到地下 2 000 m[4,18]，深埋藏之前长时间接受大气、水的淋滤溶解作用导致次生孔隙的广泛发育。

三叠系储层主要为长石岩屑砂岩，岩屑成分含量较高，平均为 36.76%，岩屑中酸性喷出岩、凝灰岩和硅质较多，这些岩屑属于易溶组分，在合适的条件下会发生溶蚀，为次生孔隙的发育提供了条件。这些组分的溶蚀还可以将原来没有连通的孔缝连通，从而改善储层物性。

前人研究表明，塔里木盆地三叠纪古气候温暖潮湿，水介质 pH 值偏低、泥岩以Ⅲ型干酪根为主[1,18,20]，说明三叠系储层在埋藏成岩过程中，基本处于酸性成岩环境，有利于有机酸的生成与保存，为次生溶孔的发育提供了条件。从而使石英、长石及白云石、方解石、碳酸盐质（灰、云质）等胶结成分被有机酸溶蚀，形成粒间溶孔、粒内溶孔及铸模孔等。

由破裂作用形成的裂缝，一方面改善了储层的孔渗性，同时为溶蚀作用提供了有利的通道。通过薄片观察发现在裂缝发育的地方，大量方解石胶结物及部分颗粒被溶解形成大量粒间溶孔，而裂缝不发育的地方，方解石胶结物则保存完好，难以形成好的次生孔隙。三叠系储层破裂作用的表现形式有碎屑颗粒破碎、碎裂条带及裂缝等，这些裂缝很好地改善了储集性能。

研究区三叠系碎屑岩储层的溶蚀作用发育普遍，既有碎屑岩颗粒如长石颗粒、石英颗粒的溶蚀，又有石英次生加大边等胶结物的溶蚀，这些溶蚀作用产生了大量溶蚀孔隙和溶蚀裂缝，提高了储层的储集性能。

5　结论

两北地区三叠系碎屑岩储层成分成熟度低，结构成熟度中等，属于近物源沉积，主要岩石类型为长石岩屑砂岩、岩屑砂岩和石英砂岩，分选中等，磨圆度为次圆状、次棱角状—次圆状，颗粒多呈点、点—线接触，以孔隙式胶结为主。

研究区储集空间类型主要为粒间溶孔，其次为裂缝。储层孔隙结构中等，平均孔隙度为 16.6%，平均渗透率为 522.6×10^{-3} μm^2，属于中孔、中—低渗透储层。

深部碎屑岩储层的发育是多种因素控制的结果，其中沉积相是储层发育的主要控制因素，在分流河道和河口坝有利相带内，岩性粒度粗，水动力作用强，填隙物含量少，为有利的储层分布区。成岩作用的改造是影响深部碎屑岩储层储集性能的主要因素，深埋导致压实作用强烈，对于构造活动影响不明显的地区，溶蚀作用产生了大量的粒间溶孔，改善了研究区储层物性。

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Zhao Lijie, Jiang Youlu, Liu Hua et al. Thermal evolution of Paleogene source rocks and relationship with reservoir distribution in Raoyang sag, Bohai Bay Basin. *PGRE*, 2012, 19(4): 1-4.

Abstract: The Raoyang sag is one of the hydrocarbon-rich sags in Bohai Bay Basin, mainly developed two major source rocks-Es_3 and Es_1x, located in Maxi, Renxi, Hejian-Suning and Raonan sub-sags. Selected 44 exploration wells, combined with the temperature data, the thickness of Ed denudation data in the study area, the evolution of the maturity of planar of Es_1x and Es_3s source rocks in different historical periods are studied from point to plane. The results show that evolutionary history of maturity of source rocks is significantly different in different sub-sags and different structures in Raoyang sag: the degree of thermal evolution in Hejian-Suning sub-sag is the highest, Es_3s source rock entered hydrocarbon generation threshold in the end of E*d*, reached the peak of hydrocarbon generation in the end of Ng and now comes into the associated gas phase; Es_1x source rock entered hydrocarbon generation threshold in the early of Ng and has been always in the stage of mature oil from the interim of Nm to now. Due to serious erosion of E*d*, Es_1x source rock did not enter hydrocarbon generation threshold until now, Es_3s source rock is still in immature stage from the interim of Nm to now in Yangwuzhai-Wuqiang region. Around the hydrocarbon generation center, reservoirs show a zonal distribution in the sag. Enrichment of the reservoirs has a close relationship with the distance between oil source in different structures and exploration strata.

Key words: basin modeling; source rocks; maturity; hydrocarbon generation history; reservoir distribution; Raoyang sag

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Wang Xuejun, Su Hui, Zeng Jianhui et al. Fault sealing and oil-gas migration patterns of Changyuan on western slop, Dongpu depression. *PGRE*, 2012, 19(4): 5-9.

Abstract: Changyuan fault is a secondary contemporaneous fault, and its sealing factors play a significant role in hydrocarbon migration and accumulation on western slop in the Dongpu depression. Analyzing on fault sealing characteristics, including oil and gas transportation based on fault growth index, normal pressure on fault plane, shale gouge ratio (SGR), and lithology contraposition relationship of the fault, shows that, ①Changyuan fault activated earlier and stronger in the south, and it became later and weaker in the north. These variety resulted sealing difference between the north and the south of Changyuan fault, ②variety of the fault factors resulted the difference of normal pressure on fault plane along the fault strike, as well as the difference of sealing characteristics. Abrasion smear of upper Es_2 formation strengthened the lateral sealing, the role of normal pressure on fault plane clay fillings increased the vertical sealing of Changyuan fault. Difference of lithology contraposition relationship between the north and the south of Changyuan fault resulted the difference of oil and gas accumulation in its footwall. Associating fault on footwall of Changyuan fault is a structural fault which activated earlier and is of vertical sealing, oil and gas migrated vertically along Changyuan main fault to Changyuan fractural zone and then migrated laterally. Hydrocarbon accumulation is dominated by lithology contraposition relationship of the fault.

Key words: fault sealing; normal pressure on fault plane; lithology contraposition relationship of faults; Changyuan fault; Dongpu depression

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Zhang Yuxi, Zhou Jiangyu, Li Xiaofeng et al. Reservoir characteristics and control factors of Triassic clastic rocks in Liangbei region. *PGRE*, 2012, 19(4): 10-13.

Abstract: Using the date of drilling cores, cast thin slice, scanning electron microscope and so on, the characteristics and control factors of the Triassic clastic reservoirs in Liangbei region are studied. The rock type is dominantly the feldspar sandstone and debris sandstone, with the petrological characteristics of low compositional maturity and medium textural maturity, and the reservoir spaces are mainly intergranular dissolution pores, secondly cracks, and it is medium porosity to low-medium permeability reservoir. The main sedimentary system in the study area is alluvial fan-rivers-lakes-delta system, the main sedimentary bodies are delta plain, delta front, lakeside and shallow facies. Reservoir sand bodies are distributary channel and estuary dam. The key factor of reforming the deep-buried clastic rock reservoirs is diagenesis, and the primary porosity suffers a great reduction by compaction; Due to the atmospheric water and organic acid, the calcite, feldspar, rock fragment, quartz and miscellaneous matrix experience dissolution, and a lot of dissolution pores increased reservoir property of deep clastic rocks. Dissolution is the key factor favoring the occurrence of high quality reservoir.

Key words: reservoir characteristics; control factors; clastic rock; Triassic; Liangbei area

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Wang Miao, Liao Yuantao, Deng Dafei et al. Reservoir characters and controlling factors of member one of Dongying group in fracture belt 1, Nanpu depression. ***PGRE*****, 2012, 19(4): 14-17.**

Abstract: Reservoir properties of member one of Dongying group in fracture belt 1 in Nanpu depression are studied by analyzing the data of petrophysical characteristics, combined with thin-section petrography and scanning electron microscopic (SEM). And, it is considered that they are controlled by sedimentation and diagenesis. The main reservoir rock type of the study area is feldspar-lithic sandstone, and the main pore type is intergranular porosity. The controlling effect of sedimentation on reservoir is analyzed from two respects: sedimentation controls reservoir lithology characters; and the microfacies types on reservoir lithology characters. The control of sedimentation on reservoir lithology characters is the foundation. Different provenance, different sedimentary environments and sedimentation process determine different lithological characters, which decide directly the petrophysical characteristics of reservoir. The petrophysical properties of submersed channel, mouth bar and turbidite fan channel are the best sedimentary micro-facies which can be good reservoirs. Composite reverse rhythmic are identified in sedimentary micro-facies, and homogeneous rhythmic petrophysical mode is more proper to form favorable reservoirs. Diagenesis influence on reservoir properties is revealed in three aspects: compaction, cementation and dissolution. A large number of interparticle dissolution pores are generated by dissolution which effectively improves the reservoir petrography.

Key words: reservoir characters; controlling factors; sedimentation; diagenesis; member one of Dongying group; Nanpu depression

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Zhang Juan. Study on fault-sealing in Pinghu oil and gas field, Xihu depression. ***PGRE*****, 2012, 19(4): 18-20.**

Abstract: Exploration practice showed that fault-sealing controlled the hydrocarbon distribution in Pinghu oil and gas field of Xihu depression, while the corresponding research had not been carried out. According to the sand-mud docking relationship on both sides of faults and smear gouge ratio calculation, fault-sealing evaluation of the main five faults in research area were studied, and the fault-sealing history in the key hydrocarbon migration period was reconstructed by the technology of layer flatten. The research results showed that fault-sealing in Pinghu Formation was better, and in Huagang Formation was weaker, when smear gouge ratio was more than 68 percent, fault side blocking were formed. Fault-sealing ability was changed by the various tectonic evolutionary stages and had relationship with tectonic stress field: in the faulted stage, the research area was mainly in tensile stress, and the faults was open; in the depression stage, some regions was mainly in compression-torsion stress, and the faults in the area was seal such as number 1 fault and in the north of number zero fault, fault-sealing in the other regions was weak.

Key words: fault mud ratio; mudstone smear potential; tectonic stress field; fault-sealing; Pinghu oil and gas field

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Chang Jianfeng, Xu Yaodong, Tian Tonghui et al. Reservoir fluid type identification for Archaeozoic reservoir in Chengbeigu 7 buried hills. ***PGRE*****, 2012, 19(4): 21-23.**

Abstract: The identification of reservoir fluid types is key to the calculation of oil and gas reserves, optimization of the development way, and decision of the key technology policy. So how to make clear the underground fluid types is of vital significance for reservoir development. Based on the fluid component analysis result and fluid phase behavior experiment of the well flow, and using a variety of statistical methods and fluid phase analysis method, we identify the reservoir fluid type of the Chengbeigu 7 buried hills. The results show that the reservoir fluid type of the Chengbeigu 7 buried hills is represented as the oil gas two-phase state in the original formation conditions. Combined with geologic research results, the reservoir fluid types of Chengbeigu 7 buried hills is condensate gas cap reservoir.

Key words: *reservoir type*; *condensate reservoir*; *gas cap*; *oil ring*; *fluid phase*

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Zhang Jinwei, Yan Aiying, Liu Wenxiu et al. Study on reservoir occurrence rule in Cabiona block of Colombia. ***PGRE*****, 2012, 19(4): 24-26.**

Abstract: Colombia, the fourth largest oil&gas production country in South America, is abundant of petroleum deposits. Cabiona block is located in the forebulge slope of the foreland basin Llanos in Colombia, where is expected to be preferential for hydrocarbon migration and accumulation. By stratigraphic correlation combining with sequcence and tectonic research, the sedimentary facies of the target formation Carbonera have been defined as deltaic facies, including two subfacies of delta-front and prodelta. Four microfacies of submerged distributary channel, inter-distribuary area, mouth bar and sheet sand are identified. On the base of hydrocarbon migration and distribution and trap features, reservoir accumulation mode is built, which is discribed as multiple migration with far source, fault controlled reservoir distribution, structure controlled accumulation, and reservoir properties controlled oil enrichment. Four kinds of oil reservoir are summarized as anticlinal reservoir, lithology-faulted nose-like reservoir, lithology-fault reservoir and fault-lithological reservoir. The results of the research are expected to be used in guiding the E&P work in Cabiona block.