Characteristics of tight sandstones of the Lianggaoshan Formation in Gongshanmiao Oilfield, Sichuan Basin, China

Mao Cui[1,2], Wang You-zhi[3,4], Osman Salad Hersi[2], Wu Jingfeng[4], Zhang Yongfeng[4]*
[1]School of Geosciences, Northeast Petroleum University, Daqing 163318, China, [2]Department of Geology, University of Regina, [3]College of Energy Resources, Chengdu University of Technology, [4]Exploration and Development Research Institute of Daqing Oilfield Company Ltd.

Summary

Pore structure is a key factor to control the property and permeability of tight reservoirs, and it is of great significance to clarify the characteristics of pore structure for the exploration and development of tight oil. Using high-pressure mercury injection (HPMI), nuclear magnetic resonance (NMR), scan electron microscope (SEM), and rock petrography, we carried-out systematic research on tight reservoirs of Lianggaoshan Formation, Gongshanmiao area, Sichuan Basin. The results show that the tight reservoirs of Lianggaoshan Formation include residual intergranular, dissolution, and intercrystalline pores, as well as micro-cracks. The morphology of HPMI curve shows that there are two types (I and II) of pore structure combinations. The pore-throat distribution of the Type-I curve is dominated by single peaks, mainly large pores. The pore-throat distribution of the type-II curve is dominated by double peaks, and the content of small and mesopores increases. The overall physical properties of the Type-I curve is higher than that of Type-II curve. The T_2 spectrum of the NMR has bimodal characteristics, indicating that small pores have a greater contribution to the reservoir space. The pore throats, reservoir quality and hydrocarbon shows level can be quantitatively characterized by HPMI and NMR.

Introduction

With the continuous breakthrough of exploration and development technology, unconventional oil and gas resources have become an important energy replacement field in the world[1-4].Tight sandstone reservoirs are rich in resources and have been exploited on a large scale. Tight sandstone reservoir is characterized by complex pore structure and strong heterogeneity, and the charging, migration and accumulation mechanisms of oil and gas are different from those of conventional oil and gas reservoirs[5-8]. Therefore, the study of pore structure and inter-connectivity of tight oil reservoirs is of great significance for understanding the distribution and accumulation of tight oil[9]. Observation and quantitative characterization of pore structure have become the core problem of tight reservoir research[10-13]. Scanning Electron Microscopy (SEM), Field Emission Scanning Electron Microscopy (FE-SEM) and Argon Ion Polishing Scanning Electron Microscopy (AIO-SEM) methods can obtain high resolution image of microscopic pore and pore-structure for qualitative observation and description, but can't reflect the microscopic pore-structure of tight reservoir[14]. Mercury injection or cryogenic nitrogen adsorption methods are widely used in the study of pore and fracture characteristics, but the characterization of pore size distribution by these two methods is not comprehensive[15-17]. NMR core technology has the advantages of speed, accuracy and repeatability. T_2 spectrum of the NMR can characterize pore distribution, but cannot characterize reservoir seepage capacity[18]. Due to the uniqueness and complexity of pore structure characteristics of tight reservoirs, multiple research methods can objectively characterize their pore structures. Therefore, we adopt the pore structure parameters of HPMI and NMR technology, combined with rigorous test methods (e.g., SEM and thin section petrography) to quantitatively characterize the pore structure of tight reservoirs of Middle Jurassic Lianggaoshan Formation, Gongshanmiao Oilfield, Sichuan Basin, and then discuss the heterogeneity of the pore-structure controlling factors. Our evaluation is deemed to provide scientific basis for establishing more meticulous geological model for tight oil exploration and development.

Geological overview

Gongshanmiao region is located in the southern margin of the low structural belt occurring north of Sichuan (Fig.1A), which is a low nose structure protruding westward. On the west side, it is connected with the Huluxi syncline and Bajiaochang structure in an oblique saddle; on the east, it is adjacent to the Yingshan structure; on the south, it is opposite the Nanchong structure; and on the north, it is the Xingshanchang syncline[19]. Under the regional east-west trending tectonic background, the Gongshanmiao area is mainly developed near east-west trending faults under the transformation of Yanshan and Himalayan tectonic movements (Fig.1B). The Jurassic System in Gongshanmiao area is a set of lacustrine clastic sedimentary rocks, which successively developed Ziliujing, Lianggaoshan, Shaximiao, Suining and Penglaizhen formations. The Lianggaoshan Fm., which is the focus of this study, ranges between 80 and110 m thick. The upper Lianggaoshan Formation is interbedded with black shale, gray siltstone and gray fine sandstone, while the lower Lianggaoshan Fm. is dominated by purplish red mudstone and argillaceous siltstone (Fig.1C). Source and reservoir superposition in the upper Lianggaoshan Fm. is favorable for tight oil enrichment, which is the main target of this study.

Lithologic properties and pore types of Lianggaoshan Fm.

Lithologic properties: The lithologic properties of the Lianggaoshan Formation consist of alternating lithofacies of siltstone, fine sandstone and shale. Core, cuttings and thin section studies indicate that the sandstone lithofacies is dominated by fine grained lithic arenite and followed by quartzarenite.The texture of the sandstone framework grains are moderately to well-sorted and subangular to subrounded. The grains of the sandstone lithofacies preserve linear to concave-convex contact suggesting fair to high compaction effects.

Pore types: Petrographic and SEM analysis of over 114 samples shed light on the the main reservoir pore spaces of tight sandstone lithofacies of the Lianggaoshan Formation in the study area. There are different pore types which include residual intergranular pores, dissolution pores, intergranular pores and microfractures. Under the influence of compaction and cementation, most of the primary intergranular pores are filled with matrix and cement; only a few residual (unfilled) intergranular pores are preserved (Fig.2A). Dissolution pores mainly include intra-granularand intergranular dissolution pores. The dissolution pores within the grains mainly occur in unstable components, such as, feldspars (Fig.2B). The intergranular dissolution pores are mainly distributed at the grain margins, which are formed by the dissolution of matrix and cement (Fig.2C). The intercrystalline pores are mainly the pores between the crystals of authigenic kaolinite, illite and other clay minerals (Fig.2D). The microfractures are mainly of structural origin and are usually associated with brittle minerals. They occur as subtle fractures around brittle minerals (Fig.2E), or cut through grains (e.g., feldspar and quartz) and cements (Fig.2F). The microfractures of Lianggaoshan Formation not only provide a path for dissolution fluid and expand the dissolution influence range, but also connect the isolated pores, which can improve the overall physical properties (particularly the permeability) of the reservoir.

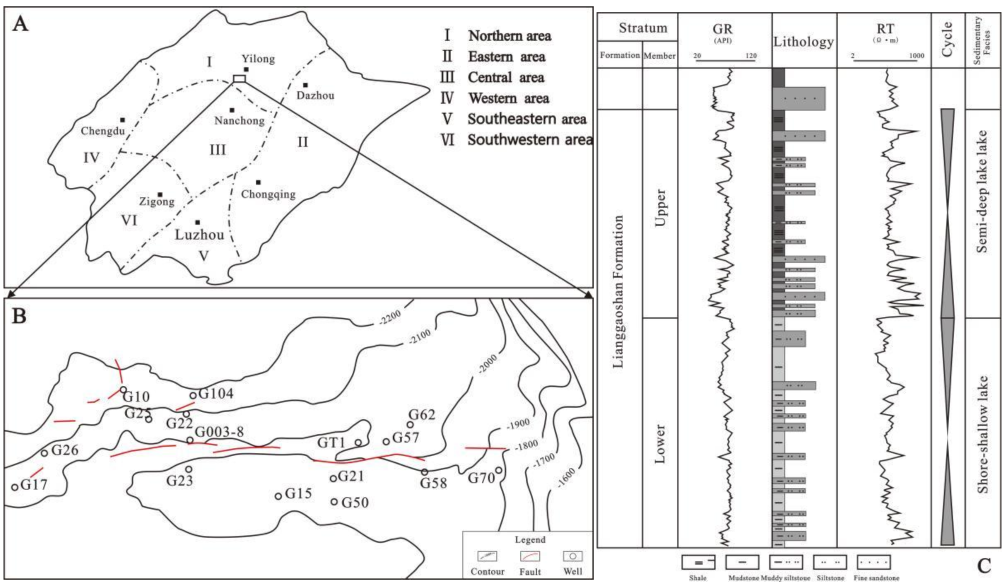

Fig.1 A) The location of the Gongshanmiao oil field; B) Distribution of wells within the oil field, structural map of the Lianggaoshan Fm., and some faults features; C) Stratigraphic log showing the gamma ray, lithologic and resistivity properties of the Lianggaoshan Fm., sedimentary facies of the formation and simplified cyclic properties are also shown.

Discussion

HPMI pore structure analysis: The HPMI analysis is commonly used for deciphering the shape and peak characteristics of pore-throat radius. The HPMI curves of the samples collected from the tight sandstone of the upper member of Lianggaoshan Fm. allow recognition of two classes (I and II) of capillary pressure curves. The capillary pressure curve of Class I has double gentle sections (Fig.3A, sample①, ②, ③), and the distribution of pore throat is dominated by single peak, with peak value being concentrated in 0.6-0.8μm (Fig.3B-sample①, ②, ③). This indicates that the pore size of the reservoir is relatively uniform and large pores are developed. The connectivity and sorting between pores are moderate, and the reservoir physical properties are relatively good, which is conducive to oil and gas charging. Class II capillary pressure curve is dominated by single gentle section (Fig.3A- sample④, ⑤, ⑥), and the pore-throat distribution is

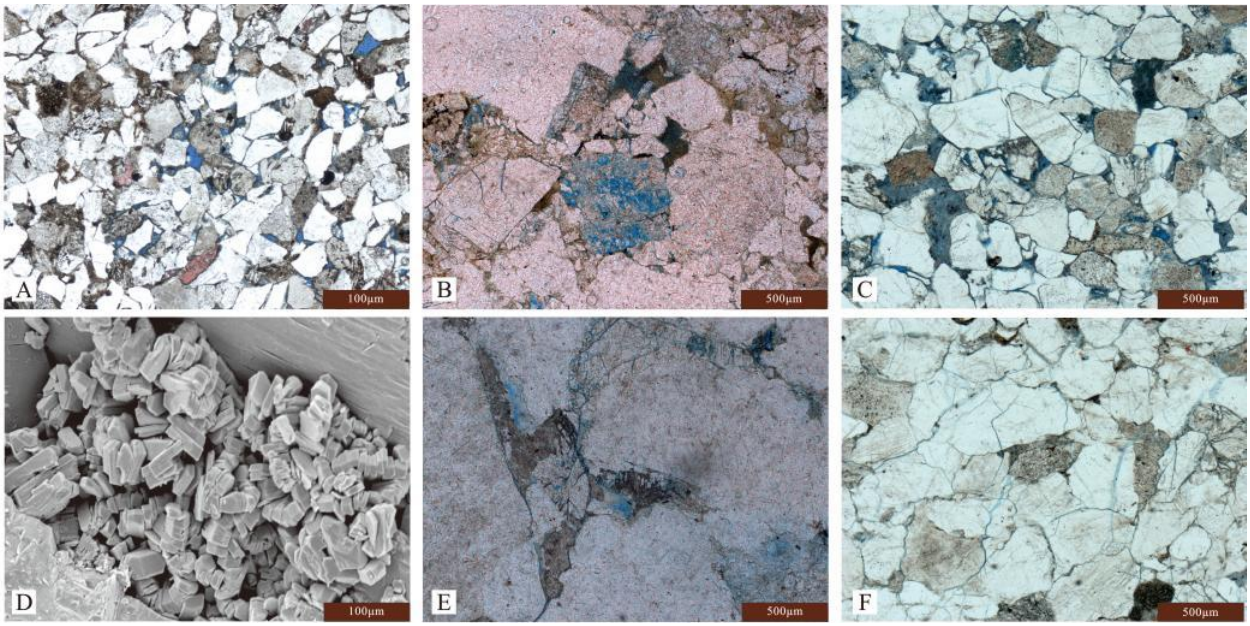

Fig.2 Storage space characteristics of tight reservoirs in Lianggaoshan formation. A) Residual intergranular pores, G17, 2471.2m; B) Dissolution pores in feldspar, G22, 2475.6m; C) Intergranular dissolution pore in fine sandstone, G21,2237.7m; D) Intercrystalline pores in kaolinite, G17, 2466.7m; E) Microfracture around granular edge,G21, 2238.5m; F) Microfracture, G22, 2477.2m.

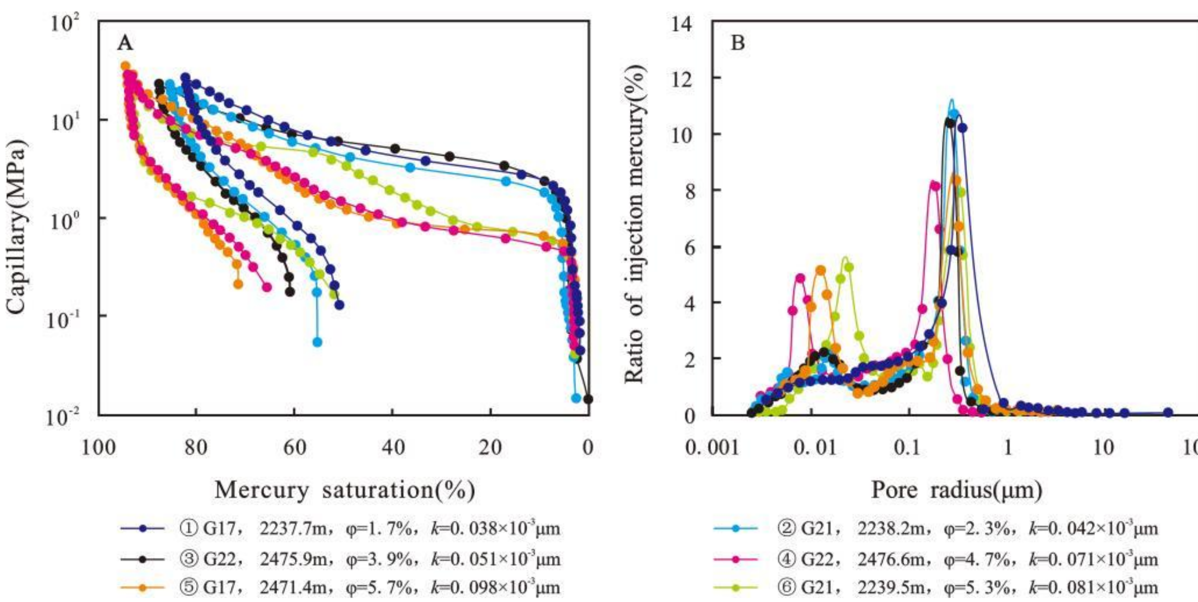

Fig.3 Characteristic of pore throat radius distribution of Lianggaoshan Fm.A)The mercury injection and exit curve of six samples; B) Relationship between pore radius and mercury injection ratio of six samples.

bimodal (Fig.3B- sample④⑤⑥). The pore-throat distribution range is wide, with the left peak range of 0.009-0.03μm and the right peak range of 0.2-0.7μm. With the increase of permeability, the peak value shifts to the right as a whole. This type of sample has a wide distribution range of pore throat radius, poor sorting and complex pore structure. The low mercury intake saturation and mercury removal efficiency indicate that the content of pores increases and the interconnectivity among them is poor.

NMR pore structure analysis: NMR tests indicate that T_2 spectrums of tight sandstone are mainly distributed between 0.01-1000ms and present a bimodal distribution (Fig.4A), in which the left peak was higher, indicating that small pores were developed. There is little difference between the two T_2 spectrums before and after centrifugation, indicating poor pore connectivity. The right peak is relatively low, representing the seepage pore. After centrifugation, part of the spectral peak disappears, indicating that there are partially connected pores in the seepage pore. The pore types can be divided into micropores, small pores, mesopores and macropores. The characteristics of pores indicate that small pores are mainly developed in the upper part of the Lianggaoshan Formation , and there are relatively few mesopores(Fig.4B). These pore characteristics are different from the pore-throat structure characteristics reflected by mercury porosimetry. This is because the pore scale characterized by NMR is broader.

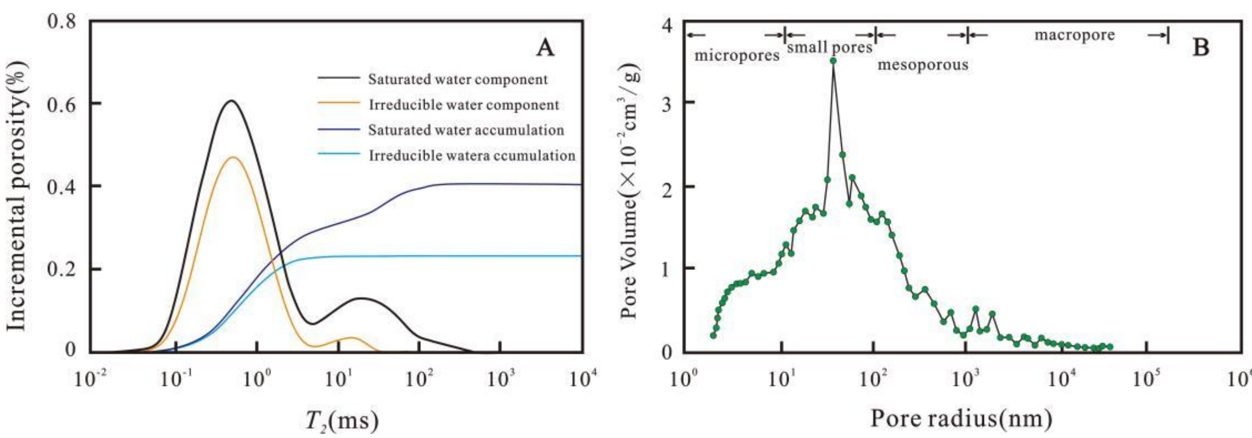

Fig.4 Characteristic of NMR T_2 distribution of Lianggaoshan Fm..A)Incremental porosity before (saturated water) and after(irreducible water) centrifugation; B) The main pore radius range.

Conclusions

The tight reservoir of Lianggaoshan Formation in Gongshanmiao area is mainly composed of siltstone to fine sandstone lithofacies, with various reservoir space types, including residual intergranular pores, dissolution pores, intergranular pores and microfractures. The pore structure of tight reservoir is complex. According to the morphology of high-pressure mercury injection curve, the studied samples of the formation can be divided into two types of pore structure combinations. The pore-throat distribution of Class I curve is dominated by single peak and large pore spaces. The pore-throat distribution of Class II curve is mainly bimodal, and the content of small pores and mespores increases. Between them, Class I pores have good connectivity and relatively high overall physical properties, which is conducive to oil and gas charging. The NMR T_2 spectrum has bimodal characteristics, indicating that small pores contribute more to the reservoir space.

Acknowledgements

This research was funded by the China Scholarship Council. The manuscript was prepared and submitted during the senior author’s scholarly visit at the University of Regina, Regina, Canada.

References

[1] Zou, C., Zhu, R., Liu, K., Su, L., Bai, B., Zhang, X., et al. Tight gas sandstone reservoirs in China: characteristics and recognition criteria[J]. Journal of Petroleum Science & Engineering, 2012, 88,82-91.
[2] Zou, C., Zhang, G., Yang, Z. , et al. Geological concepts, characteristics, resource potential and key techniques of unconventional hydrocarbon:On unconventional petroleum geology[J]. Petroleum Exploration and Development, 2013, 40(4), 385-399.
[3] Zou Caineng, Yang Zhi, Tao Shizhen, et al. Nano-hydrocarbon and the accumulation in coexisting source and reservoir[J]. Petroleum Exploration and Development, 2012, 33(2):173-187
[4] Zou Caineng. Zhu Rukai. Wu Songtao. et al. Types. characteris-tics. genesis and prospects of conventional and unconventional hydrocarbon accumulations taking Itght oil and tight gas in China as an instance[J]. Acta Petrolei Sinica, 2012, 33(2): 173-187.
[5] Du Jinhu, Liu He, Ma Desheng, et al. Discussion on effective development techniques for continental tight oil in China[J]. Petroleum Exploration and Development, 2014. 41(2):198-205
[6] Jia Chengzao. Zheng Min Zhang Yongfeng. Unconventional hydrocarbon resourees in China and the prospect of exploration and development[J]. Petroleum Exploration and Development, 2012, 39(2):129-136.
[7] JIA Chengzao, ZOU Caineng, LI Jianzhong, et al. Assessment criteria, main types, basic features and resource prospects of the tight oil in China[J], Acta Petrolei Sinica, 2012, 33(3): 343-350.
[8] DAI Jinxing, NI Yunyan, WU Xiaoqi. Tight gas in China and its significance in exploration and exploitation[J]. Petroleum Exploration and Development, 2012, 39(3): 257-264.
[9] Zou Caineng. Tao Shizhen, Hou Lianhua, et al. Unconventionaletroleum geology [M]. Beijing Geological Publishing House, 2014:1-310
[10] Xu SQ, Zhou Z J, Yu G S, et al. Effects of pyrolysis on the pore structure of fourChinese coals[J]. Energy Fuel, 2010(24): 1114-1123.
[11] Zhang Yan, Liu Jincheng, Xu Hao et al. Comparison between pore structure and fractal characteristics of continental and transitional coal measures shale: a case study of Yan’an and Taiyuan formations at the northeastern margin of Ordos Basin[J]. Acta Pctrolci Sinica, 2017, 38(9):1036-1046.
[12] Cao Taotao, Song Zhiguang, Wang Sibo, et al. Characterization of pore structure and fractal dimension of Paleozoic shales from the northeastern Sichuan Basin,China[J]. Journal of Natural Gas Science and Engineering, 2016, 35: 882-895.
[13] Tian H, Pan L,Xiao X M,et al． A preliminary study on the pore characterization of lower Silurian black shales in the ChuandongThrust Fold Belt, Southwestern China using low pressure N_2 adsorption and FE-SEM methods[J]. Marine and Petroleum Geology, 2013(48):8-19.
[14] Li P P, Zhang X D, ZhangS.Structures and fractal characteristics of pores in low volatile bituminous deformed coals by low-temperature N_2 adsorption after different solventstreatments[J]. Fuel, 2018, (224):661-675.
[15] Yao Yanbin, Liu Dameng, Tang Dazhen, et al. Fractal characterization of adsorption-pores of coals from North China: an in- vestigation on C;Hadsorption capacity of coals[J]. International Journal of Coal Geology, 2008, 73(1): 27-42.
[16] Li Fengli, Jiang Bo, Song Yu, et aL. Nano scale pore structure and fractal characteristics of low-medium metamorphic tectonically deformed coal[J]. Natural Gas Geoscience, 2017, 28(1):173-182.
[17] Yao, Y.B., Liu, D.M., Yao, C., et al..Petrophysical characterization of coals by low-field nuclear magnetic resonance (NMR)[J]. Fuel, 2010(89):1371-1380.
[18] Yao Y, Liu D. Comparison of low-field NMR and mercury intrusion porosimetry in characterizing pore size distributions of coal[J]. Fuel, 2012(95):152-158.
[19] Chen Shijia, Gao Xingjun, Wang Li, Factors controlling oiliness of Jurassic Lianggaoshan tight sands in central Sichuan Basin, SW China[J]． Petroleum Exploration and Development, 2014, 41(4)：421-427.