Advances in Geo-Energy Research

Vol. 6, No. 3, p. 264-266, 2022

Perspective

Geological characteristics and main challenges of onshore deep oil and gas development in China

Zhi Yang*, Caineng Zou, Zhidong Gu, Fan Yang, Jiarui Li, Xiaoni Wang

Research Institute of Petroleum Exploration & Development, PetroChina, Beijing 100083, P. R. China

Keywords:
Deep oil and gas
myriameter deep well
paleo stratum
ultra deep burial

Cited as:
Yang, Z., Zou, C., Gu, Z., Yang, F., Li, J., Wang, X. Geological characteristics and main challenges of onshore deep oil and gas development in China. Advances in Geo-Energy Research, 2022, 6(3): 264-266.
https://doi.org/10.46690/ager.2022.03.09

Abstract:
More than 30 years of continuous development has made onshore deep and ultra-deep conventional and unconventional oil and gas become an integral part of increasing the energy reserves and output by China's petroleum industry. Based on the deep oil and gas geological conditions in the country, the present study finds that paleo stratum and deep burial are the two basic geological characteristics of deep oil and gas. Furthermore, we put forward the notion that it is necessary to strengthen the fundamental research of theories in four aspects and the core technology in five aspects of deep oil and gas. It is suggested that it is of special importance to promote the scientific and technological research of deep oil and gas through the scientific exploration of "myriameter deep" wells as the starting point, so as to boost the development of deep oil and gas field in China.

1. Introduction

Compared to the global trend, deep and ultra-deep oil and gas development have not yet achieved full scale in China. Nonetheless, the country's onshore deep and ultra-deep oil and gas have been rapidly developed in recent years. For instance, the deepest well of Niudong 1 in the eastern region and Luntan 1 in the western region reaches 6,027 m and 8,828 m, respectively. Breakthroughs have been made in the deep and ultra-deep strata of Tarim, Sichuan, Junggar, Ordos, Qaidam, Bohai Bay and other basins (Guo et al., 2020; He et al., 2021; Li et al., 2020). Ultra-deep fields with 6,000-8,000 m of burial depth in the central and western regions have been subject to overall scale development, and the improvement of 3,500 m deep shale gas has also begun (Zhao et al., 2014; Jin et al., 2021). Deep oil and gas are expected to become strategic sources in China's oil and gas upstream operations (Ma et al., 2011; Sun et al., 2013; Jia and Pang, 2015). Therefore, based on the fundamental geological characteristics of China's onshore deep oil and gas, this paper discusses the main scientific challenges faced in the aspects of geological theory and core technology, and realize the prediction of future prospects in onshore deep oil and gas development.

2. Basic geological characteristics

Onshore deep oil and gas are mainly distributed in the central and western basins of China. These two resources, which have a dual connotation of depth and stratum, constitute conventional and unconventional oil and gas accumulations that have been subject to deep-buried high-temperature and high-pressure hydrocarbon generation, diagenesis and reservoir formation under cross-tectonic or multi-stage tectonic movements. At present, the buried depth of the target strata is great, the geological engineering conditions are complex, and special technical means are needed for industrial exploitation. In principle, buried depths greater than 4,500 m and 6,000 m are respectively regarded as deep and ultra-deep depth boundaries of conventional oil and gas resources. Meanwhile, for unconventional oil and gas resources, these depth boundaries correspond to buried depths greater than 3,500 m and 4,500

Yandy Scientific Press

*Corresponding author.
E-mail address: yangzhi2009@petrochina.com.cn (Z. Yang); zcn@petrochina.com.cn (C. Zou); guzhidong@petrochina.com.cn (Z. Gu); yf2010@petrochina.com.cn (F. Yang); LJR347092254@163.com (J. Li); wxnriped@163.com (X. Wang).

Received May 3, 2022; revised May 18, 2022; accepted May 21, 2022; available online May 22, 2022.

m, respectively (Yang and Zou, 2019a; Li et al., 2021).

Paleo stratum and deep burial are the two basic characteristics of deep oil and gas. Paleo stratum generally experience complex structural changes, mixed hydrocarbon sources, poor reservoir physical properties, less oil and more hydrocarbon gas, and the difficulty to seal traps. Typically, it is challenging to restore the lithofacies paleogeography and hydrocarbon diagenesis as well as the reservoir forming process of the prototype basin. Deep burial generally means "four highs", "four complexities" and "two mutual existences". "Four highs" stands for high temperature, pressure, stress and steepness. The "four complexities" includes complex lithology, fluid, surface and well conditions. The "two mutual existences" comprises the mutual existence of loose layer, salt gypsum rock and fracture cave layer, and that of multiple sets of pressure systems, and also the great difficulty in geophysical signal acquisition and drilling reconstruction engineering. In general, compared with conventional oil and gas in the middle and shallow strata, that in the deep stratum in the mainland of China has the characteristics of more complex structural sedimentation, more variable reservoir fluid, weaker response signal, and higher temperature and pressure stress. At the same time, compared with shallow shale gas, deep shale gas in southern Sichuan has the characteristics of more difficult identification of sweet section, higher temperature and pressure stress, and higher production target (Yang et al., 2019; Cai et al., 2020; Zhao et al., 2022). Therefore, in the face of new objectives and associated challenges, it is necessary to strengthen the research on the fundamental theory and core technology of deep oil and gas.

3. Main scientific challenges

Expanding the fundamental geological research in the following four aspects is highly important for theory formations regarding deep oil and gas (Ma et al., 2020; Ren et al., 2020; Yang et al., 2021):

1) The deep stratum has experienced complex structural evolution and deformation transformation, therefore it is difficult to restore the structural sedimentary lithofacies paleogeography of the prototype basin.
2) Under the conditions of high temperature and pressure resulting from deep underground, it is difficult to study the hydrocarbon generation mechanism and accumulation contribution of multiple-source stoves, judge the effectiveness of source stoves, and evaluate the favorable resource areas.
3) In a deep-buried complex diagenetic environment, it is complicated to predict the reservoir pore development mechanism, the favorable reservoir control factors, and the large-scale reservoir distribution.
4) Under the condition of deep-buried multi-reservoir, it is difficult to study and judge the source reservoir allocation relationship, the plugging and preservation mechanism, and the main controlling factors of enrichment.

Increasing the efforts to tackle key technical problems in the five following aspects is constructive to build a core technology series of deep oil and gas (Liu et al., 2020; Yang et al., 2021).

1) The lower signal-to-noise ratio and resolution, seismic data acquisition and processing, and reservoir fluid detection make it difficult to meet the requirements of ultra-deep formation structure and achieve a satisfactory imaging accuracy of exploration targets.
2) As a result of higher temperature and pressure as well as increased complexity of well conditions, logging tool operation, data acquisition accuracy and reservoir evaluation, the requirements of fine identification of ultra-deep oil and gas reservoirs are difficult to meet.
3) The longer drilling cycles and the higher temperature and pressure conditions lead to deep drilling according to higher requirements for borehole structure optimization, pressure control safe drilling, high-efficiency bit speed-up, long horizontal section drilling, special drilling fluid, and so on.
4) Operative objects will be more complex under higher temperature and compressive stress, hence deep fracturing has more requirements for preliminary evaluation, high-temperature resistant materials and equipment, carbonate reservoir reconstruction, complex fracture network reconstruction of the shale reservoir, etc.
5) With stronger heterogeneity and lower seepage capacity, deep oil and gas development sets higher demands for development mode, oil and gas production rate, high sour gas field development, oil and gas field development under critical conditions, development engineering technology, and others.

Myriameter-depth scientific exploration accelerates the promotion of scientific and technological research on deep oil and gas. To this end, the main research directions may be covered by five core strategies, including the potential and selection evaluation of ultra-deep oil and gas resources, the petrophysical and geophysical interpretation and prediction of complex reservoirs, the drilling and completion of complex formations under high temperature and pressure, the transformation of reservoirs under complex conditions, and the effective development of complex oil and gas reservoirs.

4. Future prospects

China is abundant in onshore deep oil and gas resources, which are generally in the early stages of exploration but provide great potential to increase national reserves and production. It is a key priority to vigorously enhance domestic oil and gas exploration and development. According to the preliminary results of the 13th Five-Year Plan resource evaluation, the amount of deep oil resources is about 1.2×10^{10} t, and the proven rate is about 17%; meanwhile, the amount of deep natural gas resources is about 2.7×10^{13} m^3, with a proven rate of about 15%. Deep oil and gas resources are mainly distributed in the central and western basins. Among them, deep oil resources are mainly found in the Tarim and Junggar basins, accounting for 89%, and deep natural gas resources are predominantly located in the Tarim, Sichuan, Junggar, Ordos and Qaidam basins, accounting for 97%. The resource of deep shale gas in the marine facies of southern Sichuan totals about

1.1×10^{13} m^3, its proven rate is about 16%; meanwhile, the oil resources of continental deep shale stratum make up about 3×10^{10} t, and have shown extremely low discovery rates.

It is predicted that scientific and technological innovation will lead China's oil and gas industry into the "myriameter deep era". At around 2030, new deep oil reserves and natural gas reserves are estimated to account for 20% and 50%, respectively. The deep onshore conventional and unconventional oil and gas resources shall be discovered on a large scale and effectively utilized.

5. Conclusions

China's onshore deep oil and gas resources include conventional oil and gas with a buried depth of more than 4,500 m and unconventional oil and gas with a buried depth of more than 3,500 m. The abundant deep oil and gas resources exhibit two basic geological characteristics, "paleo stratum" and "deep burial". It is envisaged that myriameter deep scientific exploration will be taken as the starting point, the four fundamental theories and five core technologies of deep oil and gas will be strengthened, and China will lead the global development of deep oil and gas.

Acknowledgement

The authors sincerely thank the National High-Level Special Talent Support Plan (fourth batch), and PetroChina's Shale Oil Major Science and Technology Project (No. 2021dj18), for their financial support.

Conflict of interest

The authors declare no competing interest.

References

Cai, J., Hajibeygi, H., Yao, J., et al. Advances in porous media science and engineering from InterPore2020 perspective. Advances in Geo-Energy Research, 2020, 4(4): 352-355.

Guo, X., Hu, D., Huang, R., et al. Deep and ultra-deep natural gas exploration in the Sichuan Basin: Progress and prospect. Natural Gas Industry B, 2020, 40(5): 1-14.

He, H., Fan, T., Guo, X., et al. Major achievements in oil and gas exploration of PetroChina during the 13th Five-Year Plan period and its development strategy for the 14th Five-Year Plan. China Petroleum Exploration, 2021, 26(1): 17-30. (in Chinese)

Jia, C., Pang, X. Research processes and main development directions of deep hydrocarbon geological theories. Acta Petrolei Sinica, 2015, 36(12): 1457-1469. (in Chinese)

Jin, Z., Zhu, R., Liang, X., et al. Several issues worthy of attention in current lacustrine shale oil exploration and development. Petroleum Exploration and Development, 2021, 48(6): 1471-1484.

Li, Y., Xue, Z., Cheng, Z., et al. Progress and development directions of deep oil and gas exploration and development in China. China Petroleum Exploration, 2020, 25(1): 45-57. (in Chinese)

Li, J., Yang, Z., Wu, S., et al. Key issues and development direction of petroleum geology research of source rock strata in China. Advances in Geo-Energy Research, 2021, 5(2): 121-126.

Liu, H., Zheng, L., Yang Q., et al. Development and prospect of separated zone oil production technology. Petroleum Exploration and Development, 2020, 47(5): 1103-1116.

Ma, Y., Cai, X., Zhao, P. The research status and advances in porosity evolution and diagenesis of deep carbonate reservoir. Earth Science Frontiers, 2011, 18(4): 181-192. (in Chinese)

Ma, X., Xie, J., Yong, R., et al. Geological characteristics and high production control factors of shale gas reservoirs in Silurian Longmaxi Formation, southern Sichuan Basin, SW China. Petroleum Exploration and Development, 2020, 47(5): 901-915.

Ren, Z., Cui, J., Qi, K., et al. Control effects of temperature and thermal evolution history of deep and ultra-deep layers on hydrocarbon phase state and hydrocarbon generation history. Natural Gas Industry B, 2020, 40(2): 22-30.

Sun, L., Zou, C., Zhu, R., et al. Formation, distribution and potential of deep hydrocarbon resources in China. Petroleum Exploration and Development, 2013, 40(6): 687-695.

Yang, Z., Zou, C. "Exploring petroleum inside source kitchen": Connotation and prospects of source rock oil and gas. Petroleum Exploration and Development, 2019, 46(1): 181-193.

Yang, Z., Zou, C., Chen, J., et al. "Exploring petroleum inside or near the source kitchen": Innovations in petroleum, geology theory and reflections on hydrocarbon exploration in key fields. Acta Petrolei Sinica, 2021, 42(10): 1310-1324. (in Chinese)

Yang, Z., Zou, C., Wu, S., et al. Formation, distribution and resource potential of the "Sweet Areas (Sections)" of continental shale oil in China. Marine and Petroleum Geology, 2019, 102: 48-60.

Zhao, W., Hu, S., Liu, W., et al. Petroleum geological features and exploration prospect in deep marine carbonate strata onshore China: A further discussion. Natural Gas Industry, 2014, 34(4): 1-9. (in Chinese)

Zhao, J., Sun, M., Pan, Z., et al. Effects of pore connectivity and water saturation on matrix permeability of deep gas shale. Advances in Geo-Energy Research, 2022, 6(1): 54-68.