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Perspective

Basic properties and exploitation strategies of source rock strata

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Abstract:
Source rock strata are filled and aggregated with large-scale continuous hydrocarbon resources, including significant volumes of in-place retained, short-distance migrated and potentially generated hydrocarbons. Source rock strata simultaneously possess the properties of reservoirs and hydrocarbon source rocks, known as source-reservoir coexisting systems. Reservoir properties refer to the physical properties concerning the storage and transmission of oil and gas, while hydrocarbon source rock properties refer to the physicochemical properties related to governing the generation, retention and expulsion of oil and gas in the source rock strata. These properties fundamentally determine the technical path for the successful exploitation of petroleum and natural gas in the source rock strata. With regard to reservoir properties, in-depth research and development of the advanced energy-storing fracturing technology can aid the construction of complex fracture networks to overcome the limitations in the connectivity properties of source rock strata. Focusing on the hydrocarbon source rock properties, an underground in-situ conversion technology should be created and developed to alleviate the shortcomings of organic matter quantity and maturity properties of the source rock strata. Furthermore, selecting the appropriate exploitation path based on the property characteristics can promote the achievement of commercial and sustainable development of oil and gas in the source rock strata.

1. Introduction

Coexisting source-reservoir systems of source rock strata are usually distributed continuously in large areas and multiple layers, and are rich in oil and gas resources. (Baillie et al., 2019; Muther et al., 2022; Zou et al., 2022). This includes both in-place retained or short-distance migrated hydrocarbons as well as residual organic matter with transformation potential (Cardott et al., 2015; Wood et al., 2015; Milliken et al., 2021). Currently, hydrocarbons developed by artificial fracturing technology only account for part of these resources (Jarvie, 2014). To maximize the utilization of oil and gas resources in source rock strata, a deeper understanding of their corresponding reservoir properties and hydrocarbon source rock properties is required, which will enable the more targeted development of artificial intervention technologies and ultimately achieve a more thorough exploration of the potential of existing resources.

In this study, the geological connotation and characteristics of source rock strata are discussed. Then, the reservoir and hydrocarbon source rock properties of source rock strata are compared and analyzed. Finally, the crucial influences of the property parameters weight on the development paths of oil and gas in source rock strata are considered and explored. This work aims to provide references for petroleum explorationists to more clearly and accurately evaluate and develop oil and gas in source rock strata.

2. Geological connotation and characteristics

2.1 Geological connotation

Oil and gas in source rock strata are large-scale continuously distributed hydrocarbon resources generated by the source rock layers and then retained in the source rocks or gathered in the tight reservoirs immediately adjacent to the source rocks, which can be industrially exploited using special

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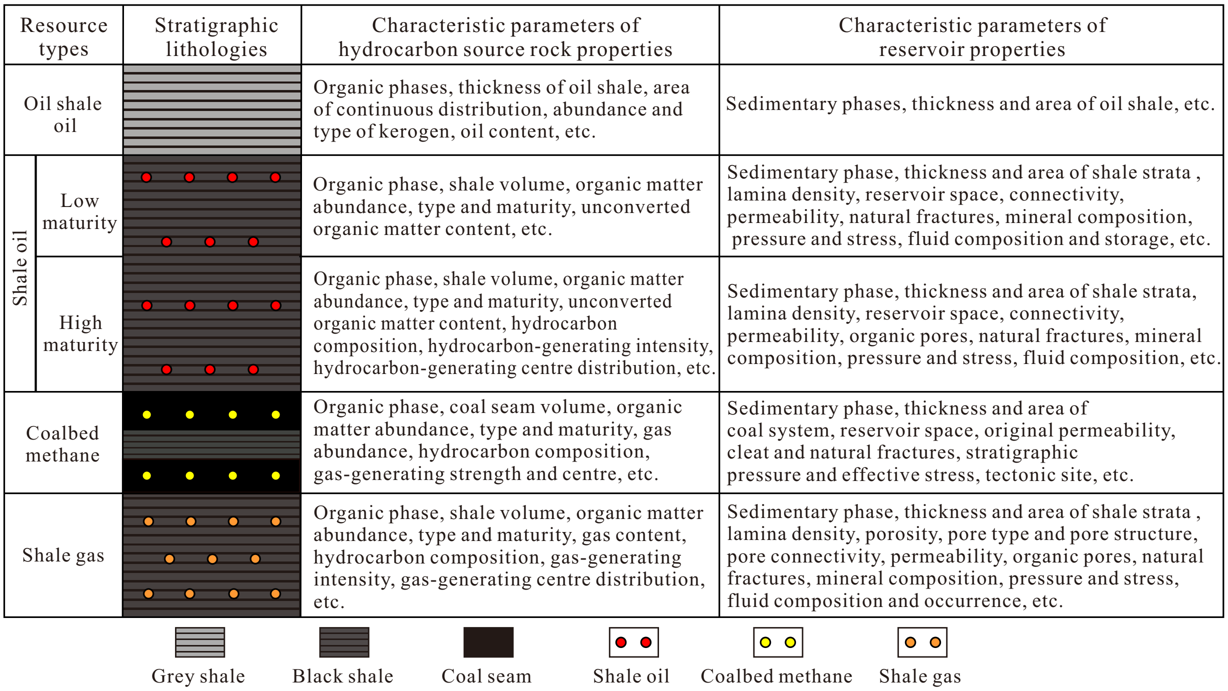

Resource types		Stratigraphic lithologies	Characteristic parameters of hydrocarbon source rock properties	Characteristic parameters of reservoir properties
Oil shale oil			Organic phases, thickness of oil shale, area of continuous distribution, abundance and type of kerogen, oil content, etc.	Sedimentary phases, thickness and area of oil shale, etc.
Shale oil	Low maturity		Organic phase, shale volume, organic matter abundance, type and maturity, unconverted organic matter content, etc.	Sedimentary phase, thickness and area of shale strata , lamina density, reservoir space, connectivity, permeability, natural fractures, mineral composition, pressure and stress, fluid composition and storage, etc.
Shale oil	High maturity		Organic phase, shale volume, organic matter abundance, type and maturity, unconverted organic matter content, hydrocarbon composition, hydrocarbon-generating intensity, hydrocarbon-generating centre distribution, etc.	Sedimentary phase, thickness and area of shale strata, lamina density, reservoir space, connectivity, permeability, organic pores, natural fractures, mineral composition, pressure and stress, fluid composition, etc.
Coalbed methane			Organic phase, coal seam volume, organic matter abundance, type and maturity, gas abundance, hydrocarbon composition, gas-generating strength and centre, etc.	Sedimentary phase, thickness and area of coal system, reservoir space, original permeability, cleat and natural fractures, stratigraphic pressure and effective stress, tectonic site, etc.
Shale gas			Organic phase, shale volume, organic matter abundance, type and maturity, gas content, hydrocarbon composition, gas-generating intensity, gas-generating centre distribution, etc.	Sedimentary phase, thickness and area of shale strata , lamina density, porosity, pore type and pore structure, pore connectivity, permeability, organic pores, natural fractures, mineral composition, pressure and stress, fluid composition and occurrence, etc.

Fig. 1. Resource types and main source-reservoir characteristic parameters of source rock strata (Yang et al., 2022a).

technology (Jiao et al., 2020; Jia et al., 2021; Yang et al., 2021; Jin, 2023; Zou et al., 2023). These resources consist of two types: oil and gas distributed in the strata of the source-reservoir integrated type (such as shale oil, shale gas, coal bed methane, coal rock oil, oil shale oil), and oil and gas existing in the strata of the source-reservoir adjacent type (Song et al., 2015; Vedachalam et al., 2015; Zou et al., 2022).

Through research methods from the "source-control theory" to the "source-reservoir coexisting system", it has been deeply recognized that a huge amount of industrial oil and gas resources can be extensively gathered in the source rock layers and their closely contacted tight reservoir layers. In general, the "source-reservoir coexisting system" has the dual properties of hydrocarbon source rocks and reservoirs. The prominence of hydrocarbon source rock properties and reservoir properties of source-reservoir coexisting systems varies between distinct thermal evolution stages (Fig. 1). Tight oil and gas usually highlight the reservoir properties of the source rock strata (Yang et al., 2022a; Yang et al., 2022b).

The main strategy for oil and gas exploration in source rock strata is to search for "sweet spots" within the "source-reservoir coexisting system", which are continuously distributed over a large area. In the context of the overall regional distribution of oil and gas in the source rock strata, "sweet spots" are generally referred to as the favorable reservoir distribution zones (regions or sections) that are typically richer in hydrocarbons, have better physical properties, are more amenable to modification, and hold commercial development value under existing economic and technological conditions. The above exploration principle based on the "source-reservoir coexisting system" has guided the large-scale development of tight sandstone gas, the breakthrough discovery and large-scale industrial development of shale gas, and the rapid development of tight oil and shale oil (Hein et al., 2019; Feng et al., 2020).

2.2 Geological characteristics

Oil and gas in the source rock strata exhibit the characteristics of extensive and continuous aggregation, distributed in contiguous patterns within tight reservoirs around the main large-scale hydrocarbon source rock strata. A widely developed micro-nanoscale pore throat network system plays a crucial role in connectivity, controlling the continuous distribution of oil and gas. This kind of distribution is not constrained by traps, resulting in a substantial resource scale (Baillie et al., 2019; Ben-Ammar et al., 2020).

The core of hydrocarbon occurrence in the source-reservoir coexisting system is the hydrocarbon source rock, and the core of resource enrichment is the favorable reservoir (Fig. 1). The distribution ranges of hydrocarbon source rock layers are controlled by the distribution ranges of organic-rich facies. With increasing burial depth and thermal evolution, hydrocarbon generation and rock diagenesis proceed synchronously in the source rock strata (Curtis et al., 2012). The simultaneous evolution of hydrocarbon source rock layers and tight reservoirs will form multiple types of pores, which can present favorable storage space for hydrocarbon enrichment (Loucks et al., 2021). Hydrocarbon source rock layers generate, retain and expel hydrocarbons to varying degrees, while adjacent tight reservoirs capture, aggregate and disperse hydrocarbons (Kinley et al., 2008).

The hydrocarbon enrichment characteristics of source rock strata include hydrocarbon source rock control, near-source aggregation, overall regional distribution, and high productivity under overpressure. The hydrocarbon enrichment of source

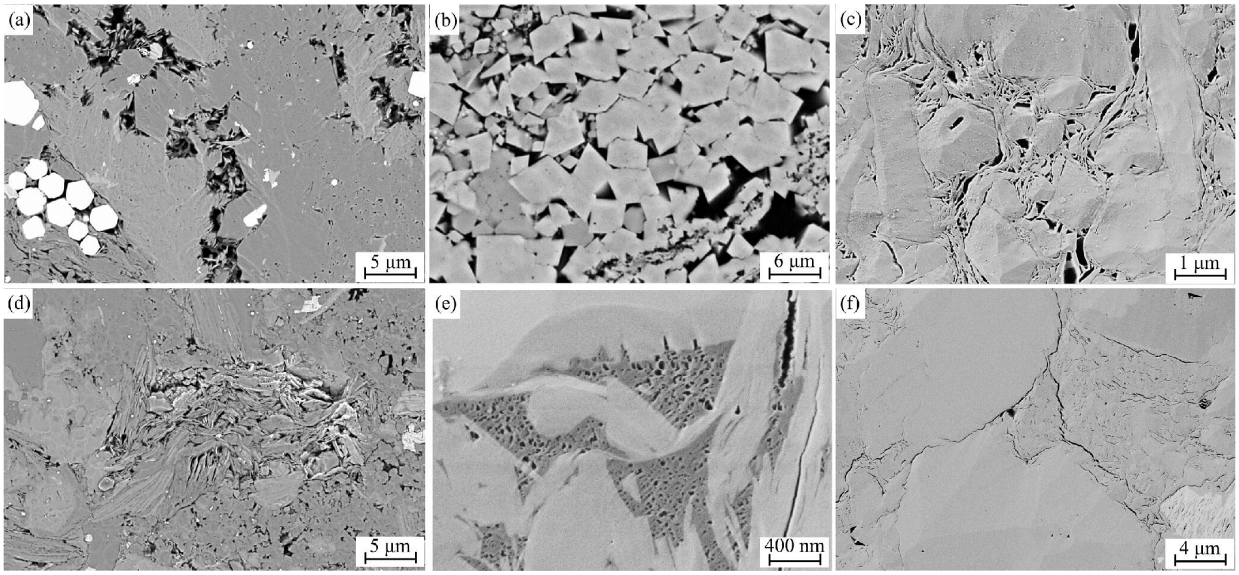

Fig. 2. Microscopic scanning electron micrographs of reservoirs in source rock strata in key basins. (a) Quartz feldspar intergranular pores, Qingshankou Formation, GY-1 well, Qijia-Gulong Depression, Songliao Basin; (b) dolomite intergranular pores, Lucaogou Formation, J305 well, Jimushar Depression, Junggar Basin; (c) clay mineral intergranular pores, N228 well, Yanchang Formation, Ordos Basin; (d) clay mineral intragranular pores, Ganchaigou Formation, CP-2 well, Yingxiongling area, Qaidam Basin; (e) organic matter pores, Daanzhai section, YB-2 well, Yuanba area, Sichuan Basin and (f) microfractures, Kongdian Formation, GD14 well, Cangdong Depression, Bohai Bay Basin.

rock strata is affected by multiple factors. Maturity is the primary influencing factor that governs the accumulation and distribution zones of oil and gas in the source rock strata. In addition, the type of source-reservoir combinations, the scale of high-quality hydrocarbon source rocks, the size of favorable reservoirs, and conducive overpressure conditions are crucial influencing factors controlling the occurrence and enrichment of oil and gas in the source rock strata (Yang et al., 2021; Cai et al., 2022).

3. Basic properties of source rock strata

3.1 Reservoir properties

Source rock reservoirs are generally tight reservoirs, with micro- and nanoscale pores as the main storage space (Fig. 2), and throat channels, microfractures and laminar fractures as important seepage channels (Loucks et al., 2020; Fan et al., 2022a). Compared with conventional reservoirs, reservoirs in source rock strata generally have more complex lithological assemblages, finer mineral grains, smaller pore throat sizes, poorer pore connectivity, and stronger organic-inorganic interactions (Fan et al., 2022b).

The key parameters of reservoir properties in source rock strata include the area and thickness of favorable reservoir facies, porosity, pore types, main radius of throats, oil saturation, free hydrocarbon content, formation pressure, gas-oil ratio, matrix permeability, development degree of fractures between shale laminas, brittle mineral content, horizontal stress difference, etc. Although the key parameters of reservoir properties may vary for different types of source rock strata, the overall focus is on the parameters related to hydrocarbon storage and flow.

The size, structure and relationships of pores, throats, lamina fractures, and microfractures in the micro- and nanoscale pore throat connectivity systems profoundly affect the permeability and fluid flow in tight reservoirs of source rock strata (Larson et al., 2023; Silva et al., 2023). The natural connectivity and seepage capacity of the reservoirs in source rock strata are usually poor, and it is generally impossible to obtain natural industrial production through conventional techniques. Therefore, large-scale artificial modification of the reservoir properties is required to achieve the industrial development of oil and gas from source rock strata. The focus of technological breakthroughs lies in two aspects: the connectivity properties and the permeability properties of tight reservoirs. Connectivity is primarily improved through techniques such as artificial fracturing to modify fracture networks, whether artificial or natural. The seepage properties are predominantly enhanced through methods including artificial supplementation of the stratum energy, utilization of the natural reservoir energy, and improvement of the inherent fluid flow capabilities of oil and gas.

3.2 Properties of hydrocarbon source rock

Hydrocarbon source rocks in source rock strata generally include clayey, sandy or carbonate dark mudstones and shales, as well as coal-measure fine-grained sediments (Soto-Kerans et al., 2021). High-quality hydrocarbon source rocks are usually formed in geological environments characterized by calm water, warm climate, abundant organisms, and stable sedimentation (Hanson et al., 2007). They typically contain abundant kerogen, microfossils, protogenetic dispersed pyrites, and free bitumen. Hydrocarbon resources in source rocks

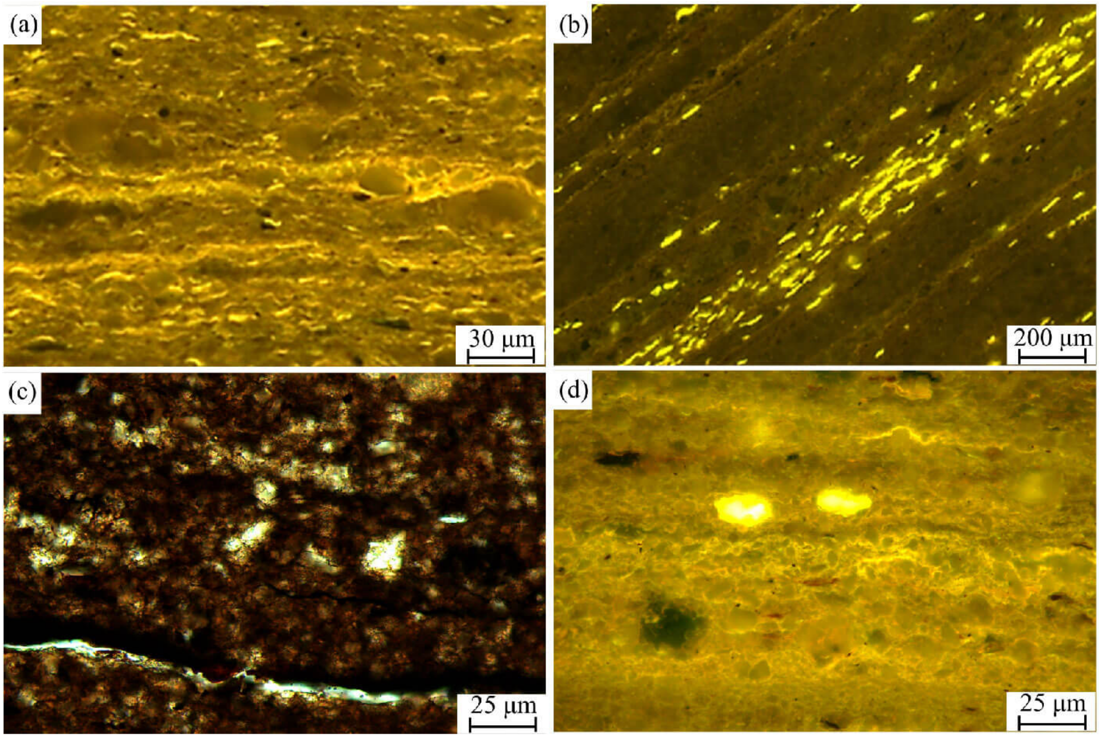

Fig. 3. Fluorescence photographs of geological thin sections of source rock strata in key basins. (a) GY-1 well, Qingshankou Formation, Qijia-Gulong Depression, Songliao Basin; (b) C2-4 wells, Ganchaigou Formation, Yingxiongling Area, Qaidam Basin; (c) NY-1 well, Shahajie Formation, Dongying Depression, Bohai Bay Basin and (d) G108-8 wells, Kongdian Formation, Cangdong Depression, Bohai Bay Basin.

encompass both transformed in-place retained oil and gas and untransformed residual organic matter (Chalmers et al., 2022). These resources exhibit extensive and continuous distribution, indicating the presence of substantial actual or potential oil and gas resources (Fig. 3).

The key parameters of hydrocarbon source rock properties include the following: area and thickness of high-quality organic facies, organic matter content, hydrocarbon potential, organic matter type, vitrinite reflectance, hydrocarbon composition, amount of in-place retained hydrocarbons, residual organic matter, hydrocarbon-generating intensity and hydrocarbon-generating center, and so on.

Exploration and development practices have shown that despite variations in the key parameters of hydrocarbon source rock properties among distinct types of source rock strata, the overall focus should be on the quantity of organic matter and the degree of thermal maturation. The focus of technological breakthroughs is to improve the degree of thermal evolution and enhance the potential for hydrocarbon conversion through solutions such as artificial heating.

4. Property analysis and exploitation strategies of source rock strata

4.1 Property analysis

The property parameters of source rock strata can be comprehensively analyzed from three main aspects (Fig. 4). Firstly, the reservoir properties mainly determine the ability of source rock strata to store, connect and transmit hydrocarbons. Secondly, the hydrocarbon source rock properties primarily control the ability of source rock strata to generate or potentially transform hydrocarbons. Thirdly, the public property parameters mainly determine the non-geological and non-technical factors to achieve large-scale commercial development of oil and gas in the source rock strata. The reservoir properties and hydrocarbon source rock properties are the intrinsic potential foundation for achieving scale development of oil and gas, while the public property parameters are the external environmental basis. The prerequisites and foundations for the sustainable commercial development of oil and gas from source rock strata need the accurate assessment and selection of intrinsic property parameters as key technological breakthroughs, and the systematic integration and optimization of all extrinsic property parameters to form the appropriate production support conditions.

4.2 Exploitation strategies

A comprehensive understanding of the intrinsic properties of source rock strata, coupled with the in-depth exploration of key technologies to overcome the limitations of these properties, is of utmost importance in determining evaluation methods and development pathways for oil and gas exploration and development in source rock strata. Considering the future technological strategies and development positioning of oil and gas in source rock strata, two main suggestions are proposed (Fig. 5):

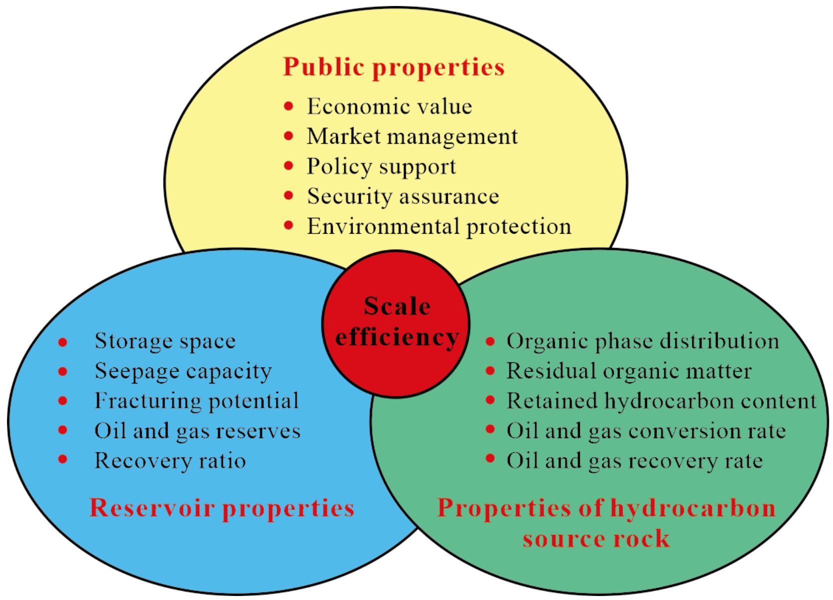

Fig. 4. Three types of essential property parameters for achieving large-scale economic development of oil and gas in the source rock strata (Yang et al., 2022a).

(1) From the perspective of the reservoir properties of source rock strata, an advanced energy-storing artificial fracturing technology should be developed, which can construct complex fracture network channels to break up the tight reservoir. In addition, suitable stratum energy should be supplemented to establish a stratum system with fluid compatibility, energy accumulation, and hydrocarbon lightening. The ultimate objective is to maximize the contact area between the matrix pores of the reservoirs and the fracture systems, minimize the flow distance, and optimize the driving pressure. This strategy primarily addresses the limitations of the connectivity property of source rock strata, enabling the transformative advancement and extensive development of the in-place retained hydrocarbon resources within a significant portion of the source rock strata.

(2) By considering the hydrocarbon source rock properties of the source rock strata, an underground in-situ conversion technology should be created and developed. This technology should be designed to address the exploitation challenges posed by organic-rich shales or coal rocks in the middle-deep strata. Through methods such as artificial heating, residual organic matter can be converted or modified to increase the generation of light hydrocarbons and formation pressures. In this process, pore-fracture network channels may be also formed. The focus of this approach lies in the lightweight transformation and utilization of organic-rich shales and coal beds, overcoming the limitations of hydrocarbon viscosity in the source rock strata. Theoretically, this will enable the large-scale development of highly viscous hydrocarbons within a significant portion of the source rock strata.

Whether the reservoir energy-storing fracturing technology or the in-suit heating conversion technology should be selected as the exploitation strategy. In this context, the comprehensive consideration and judgement of the source-reservoir properties of different types of source rock strata will provide the theoretical and technical direction for the targeted, scientific and sustainable development of oil and gas in source rock strata.

5. Conclusions

Source-reservoir coexisting systems within the source rock strata exhibit a large-scale and continuous distribution of oil and gas resources. The reservoir properties and the hydrocarbon source rock properties fundamentally determine the technical path for the successful development of oil and gas in the source rock strata. To achieve oil and gas flow in tight reservoir formations, two main approaches exist. The first is to break up the tight reservoirs through energy-storing artificial fracturing technology, mainly to overcome the shortcoming of the connectivity property. The development of gas from organic-rich shales with high/over-maturity and oil from medium-high mature shales rich in gaseous hydrocarbons are considered as priority areas. The second approach involves the transformation, reforming or release of potential hydrocarbons through artificial heating conversion technology or other methods, with the primary objective to overcome the viscosity limitations of oil and gas in the source rock strata. Targeted strategic development areas include oil from medium- and low-maturity organic-rich shales, oil from oil shales, oil from low-metamorphic-degree coal rocks rich in volatile components, and deep-layer coals with gasification potential. A deeper understanding and exploration of the reservoir properties and hydrocarbon source rock properties and their advantages are essential in this regard. By respecting the scientific principles and utilizing advanced technologies and high-quality managements, the development potential and utilization efficiency of hydrocarbons from source rock strata can be continuously enhanced. Furthermore, this will make petroleum and natural gas resources better serve the national

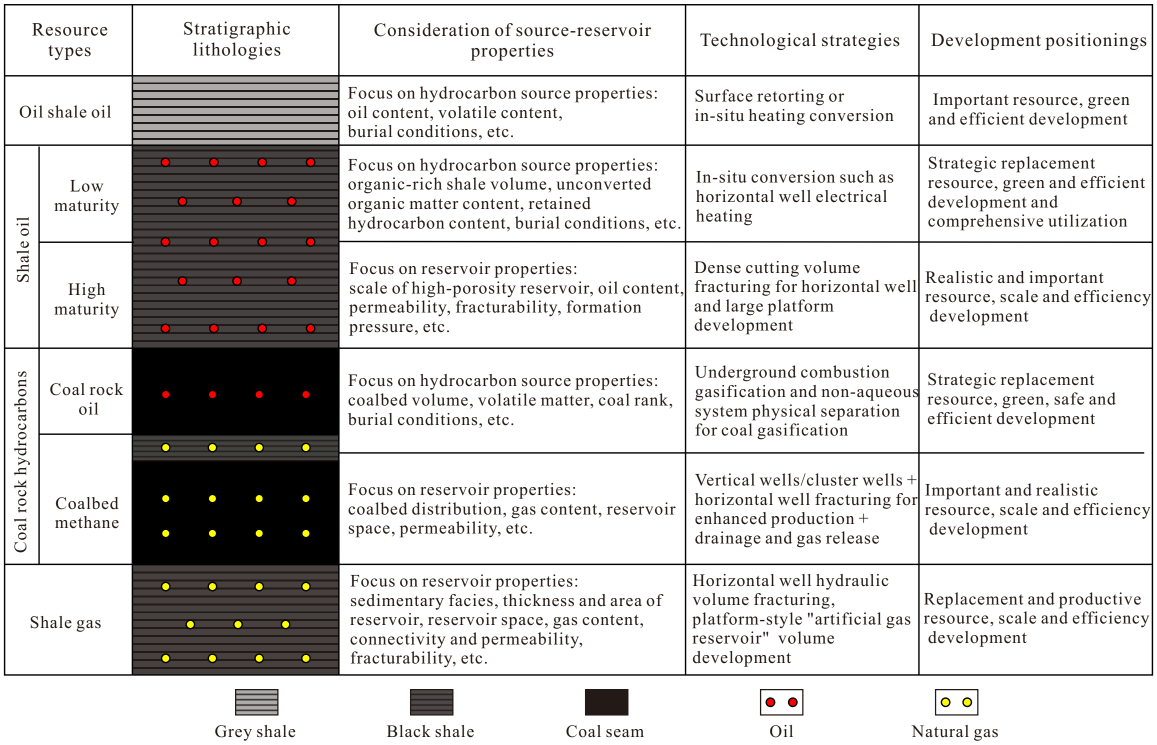

Fig. 5. Technological strategies and developmental positioning of oil and gas in the source rock strata (Yang et al., 2022a).

energy transition and energy security.

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Conflict of interest

The authors declare no competing interest.

References

Baillie, J., Risk, D., MacKay, K. Methane emissions from conventional and unconventional oil and gas production sites in southeastern Saskatchewan, Canada. Environmental Research Communications, 2019, 1(1): 011003.

Ben-Ammar, S., Riahi, S., Layeb, M. Source rock characterization of the upper Barremian, Albian and Cenomanian-Turonian organic-rich strata outcropping in Oued Bazina area, NE of Thibar diapir: Northern Tunisia. Arabian Journal of Geosciences, 2020, 13(24): 1282.

Cai, J., David, A. W., Hadi, H., et al. Multiscale and multiphysics influences on fluids in unconventional reservoirs: Modeling and simulation. Advances in Geo-Energy Research, 2022, 6(2): 91-94.

Cardott, B. J., Landis, C. R., Curtis, M. E. Post-oil solid bitumen network in the Woodford Shale, USA-A potential primary migration pathway. International Journal of Coal Geology, 2015, 139: 106-113.

Chalmers, G. R. L., Silva, P. L., Bustin, A. A., et al. Geology and geochemistry of the hydrocarbon compositional changes in the Triassic Montney Formation, Western Canada. Energies, 2022, 15(22): 8677.

Curtis, M. E., Cardott, B. J., Sondergeld, C. H., et al. Development of organic porosity in the Woodford Shale with increasing thermal maturity. International Journal of Coal Geology, 2012, 103: 26-31.

Fan, Y., Liu, K., Pu, X., et al. Morphological classification and three-dimensional pore structure reconstruction of shale oil reservoirs: A case from the second member of Paleogene Kongdian Formation in the Cangdong Sag, Bohai Bay Basin, East China. Petroleum Exploration and Development, 2022a, 49(5): 1085-1097.

Fan, Y., Liu, K., Yu, L., et al. Assessment of multi-scale pore structures and pore connectivity domains of marine shales by fractal dimensions and correlation lengths. Fuel, 2022b, 330(1): 125463.

Feng, Q., Xu, S., Xing, X., et al. Advances and challenges in shale oil development: A critical review. Advances in Geo-Energy Research, 2020, 4(4): 406-418.

Hanson, A. D., Ritts, B. D., Moldowan, J. M. Organic geochemistry of oil and source rock strata of the Ordos Basin, north-central China. AAPG Bulletin, 2007, 91(9): 1273-1293.

Hein, F. J., Ambrose, W. A., Hackley, P., et al. Unconventional Energy Resources: 2017 Review. Natural Resources Research, 2019, 28(4): 1661-1751.

Jarvie, D. M. Components and processes affecting producibility and commerciality of shale resource systems. Geological Acta, 2014, 12(4): 307-325.

Jia, C., Pang, X., Song, Y. The mechanism of unconventional hydrocarbon formation: Hydrocarbon self-containment and intermolecular forces. Petroleum Exploration and Development, 2021, 48(3): 437-452.

Jiao, F., Zou, C., Yang, Z. Geological theory and exploration & development practice of hydrocarbon accumulation inside continental source kitchens. Petroleum Exploration and Development, 2020, 47(6): 1147-1159.

Jin, Z. Hydrocarbon accumulation and resources evaluation: Recent advances and current challenges. Advances in Geo-Energy Research, 2023, 8(1): 1-4.

Kinley, T. J., Cook, L. W., Breyer, J. A., et al. Hydrocarbon potential of the Barnett Shale (Mississippian), Delaware Basin, west Texas and southeastern New Mexico. AAPG Bulletin, 2008, 92(8): 967-991.

Larson, T. E., Loucks, R. G., Sivil, J. E., et al. Machine learning classification of Austin Chalk chemofacies from high-resolution x-ray fluorescence core characterization. AAPG Bulletin, 2023, 107(6): 907-927.

Loucks, R. G., Larson, T. E., Zheng, C., et al. Geologic characterization of the type cored section for the Upper Cretaceous Austin Chalk Group in southern Texas: A combination fractured and unconventional reservoir. AAPG Bulletin, 2020, 104(10): 2209-2245.

Loucks, R. G., Peng, S. Matrix reservoir quality of the Upper Cretaceous Austin Chalk Group and evaluation of reservoir-quality analysis methods; northern onshore Gulf of Mexico, USA. Marine and Petroleum Geology, 2021, 134: 105323.

Milliken, K. L., Zhang, T., Chen, J., et al. Mineral diagenetic control of expulsion efficiency in organic-rich mudrocks, Bakken Formation (Devonian-Mississippian), Williston Basin, North Dakota, USA. Marine and Petroleum Geology, 2021, 127: 104869.

Muther, T., Qureshi, H. A., Syed, F. I., et al. Unconventional hydrocarbon resources: geological statistics, petrophysical characterization, and field development strategies. Journal of Petroleum Exploration and Production Technology, 2022, 12(6): 1463-1488.

Silva, P. L., Bustin, R. M. Basin-wide unconventional potential of the Doig Formation, Triassic of the Western Canada Sedimentary Basin. Marine and Petroleum Geology, 2023, 155: 106394.

Song, Y., Li, Z., Hong, F. The concept and the accumulation characteristics of unconventional hydrocarbon resources. Petroleum Science, 2015, 12(4): 563-572.

Soto-Kerans, P., Loucks, R. G., Kerans, C. Deeper-water deposition in intrashelf basins: Example from the Lower Cretaceous (Albian) upper Glen Rose Formation in the Houston trough, eastern Texas. AAPG Bulletin, 2021, 105(7): 1405-1434.

Vedachalam, N., Srinivasalu, S., Atmanand, M. A. Review of unconventional hydrocarbon resources in major energy consuming countries and efforts in realizing natural gas hydrates as a future source of energy. Journal of Natural Gas Science and Engineering, 2015, 26: 163-175.

Wood, J. M., Sanei, H., Curtis, M. E., et al. Solid bitumen as a determinant of reservoir quality in an unconventional tight gas siltstone play. International Journal of Coal Geology, 2015, 150: 287-295.

Yang, Z., Zou, C., Wu, S., et al. From source control theory to source-reservoir coexisting system: On the theoretical understanding and practice of source rock strata oil and gas geology in China. Acta Geological Sinica, 2021, 95(3): 618-631. (in Chinese)

Yang, Z., Zou, C., Wu, S., et al. Reservoir fracturing or hydrocarbon generating?–on the reservoir and source rock properties of source rock strata oil and gas. Acta Geological Sinica, 2022a, 96(1): 183-194. (in Chinese)

Yang, Z., Zou, C., Wu, S., et al. Characteristics, Types, and Prospects of Geological Sweet Sections in Giant Continental Shale Oil Provinces in China. Journal of Earth Science, 2022b, 33(5): 1260-1277.

Zou, C., Yang, Z., Dong, D., et al. Formation, Distribution and Prospect of Unconventional Hydrocarbons in Source Rock Strata in China. Earth Science, 2022, 47(5): 1517-1533. (in Chinese)

Zou, C., Yang, Z., Zhang, G., et al. Theory, Technology and Practice of Unconventional Petroleum Geology. Journal of Earth Science, 2023, 34(4): 951-965.