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A Review of the Co-evolutionary Processes in Deep Oil and Gas Systems

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Abstract. Single-factor models are insufficient to reasonably clarify deep oil and gas accumulation mechanisms in structurally complex geological zones; hydrocarbon generation, migration, trapping and preservation have close correlations with the interactive coupling of the lithosphere, fluid sphere and biosphere in actual geological processes. This paper summarizes the latest research progress of multi-sphere co-evolution theory in deep petroleum system research, and focuses on sorting out the systematic conceptual framework related to energy cascade, migration pathway optimization and regional structural geological response. By combing through the published research findings in this field, the paper analyzes the staged evolutionary rules of deep hydrocarbon accumulation, summarizes the spatial distribution differences of shale gas, tight gas and conventional deep oil and gas reservoirs, and clarifies several core controlling factors affecting hydrocarbon enrichment, including source rock inherent quality, reservoir physical properties, carrier system matching degree, effective preservation conditions and reasonable structural spatial position. The exploration data collected from the Tarim, Sichuan and Junggar basins can fully verify that multi-sphere coupling effects are able to effectively interpret the joint control effects of thermal dynamic conditions, migration pathway development, tectonic deformation transformation and later preservation environments on deep hydrocarbon differential enrichment. Deep petroleum systems will form obvious staged accumulation characteristics and orderly spatial distribution features under the combined action of underground energy supply, internal conduit systems and regional tectonic frameworks. The existing multi-sphere co-evolution theory has effectively improved the overall understanding of deep hydrocarbon enrichment laws; however, there are still many research gaps in quantitative parameter characterization, cross-basin geological comparison and multi-scale process coupled simulation that need to be further explored. This review can provide practical theoretical references for subsequent deep oil and gas theoretical research and actual exploration target optimization work.

Keywords: Deep Oil and Gas, Multi-sphere Co-evolution, Energy Cascade, Pathway Selection, Structural Response, Basin Case Studies

1. Introduction

As oil and gas exploration advances into progressively deeper strata, petroleum systems buried below 4,500 m have emerged as an increasingly important replacement domain for safeguarding national energy security, owing to their substantial resource potential and still relatively low degree of exploration maturity [1]. In such deep settings, however, geological conditions are commonly marked by elevated temperature, elevated pressure, and high stress states; under these constraints, conventional accumulation models—developed largely for shallow to medium-depth intervals—often prove inadequate for explaining the intertwined processes of hydrocarbon generation, migration, accumulation, and preservation in deep reservoirs [2].

Existing research suggests that the accumulation of deep oil and gas is controlled not by any single geological factor in isolation, but instead by the dynamic coupling of the lithosphere, fluid sphere, and biosphere. Under deep-burial conditions, the thermal evolution of organic matter, fluid migration induced by tectonic stress, and biologically related hydrocarbon generation and transformation act in concert across multiple spatial and temporal scales, giving rise to accumulation patterns that are complicated and enrichment processes that are markedly heterogeneous [3]. Yet many earlier interpretations still concentrate on comparatively discrete factors. When analysis is restricted to lithospheric structure alone, migration pathways may indeed be clarified, but the coupled processes responsible for hydrocarbon generation cannot be fully represented; when, by contrast, interpretation rests only on thermal maturity, the effects of tectonic stress evolution on migration efficiency and trap effectiveness are easily understated—or missed altogether [4, 5]. INE>Prompted by these shortcomings, the multi-sphere co-evolution framework has, over recent years, been progressively introduced and refined. At its center lies an emphasis on the coupled mechanism linking energy cascade, pathway selection, and structural response, with tectonic stress fields, fluid activity, conduit systems, and biological effects brought into a single interpretive perspective for understanding the accumulation and distribution of deep hydrocarbons [6]. Relative to traditional single-factor explanations, this framework offers a more systematic basis for interpreting the ordeblue accumulation patterns exhibited by deep oil and gas.

Against this background, the present paper systematically reviews recent advances in multi-sphere co-evolution theory for deep petroleum systems; it pays special attention to the framework's core mechanisms, staged deep hydrocarbon accumulation characteristics, main distribution patterns, representative basin-scale evidence and key controlling factors, while also discussing current limitations and future research directions. The aim is simple: to offer a clearer theoretical reference for follow-up research and for advancing deep oil and gas exploration.

2. Conceptual framework of the multi-sphere co-evolution mechanism

Deep oil and gas system evolution depends on dynamic coupling among the lithosphere, fluid sphere and biosphere, which makes accumulation processes complex and multi-scale [8]. To address limitations of traditional single-sphere analyses, researchers have gradually developed the multi-sphere co-evolution framework in recent years; this framework provides a conceptual foundation for understanding mechanisms that govern orderly deep oil and gas accumulation [6]. At its core lie three key mechanisms: energy cascade, pathway selection and structural response; these mechanisms highlight interactions across different spheres in terms of energy supply, migration pathways and geological architecture (Table 1).

Table 1. Core mechanisms of the multi-sphere co-evolution framework

Mechanism	Primary Role	Key Processes Involved	Inter-Sphere Interaction
Energy Cascade	Drives energy transfer and triggers linked geological responses	Tectonic stress activation; Mantle heat flow supply; Microbial transformation of organic matter	Lithosphere provides stress/heat; Biosphere contributes biochemical energy reserves
Pathway Selection	Describes hydrocarbon migration characteristics within the coupled system	Migration follows minimum resistance; Utilizes faults & unconformities as vertical channels; Lithologic interfaces act as lateral barriers	Jointly restricted by lithosphere (tectonic framework), fluid sphere (properties), and biosphere (reservoir modification)
Structural Response	Reflects geological feedback to energy and pathway evolution	Development of fracture networks; Formation of abnormal overpressure; Adjustment of reservoir pore structure; Trap efficiency determination	Acts as the final geological link, deciding effective accumulation and long-term preservation

2.1. Energy cascade mechanism

The energy cascade mechanism can effectively reflect how tectonic stress conditions and mantle heat flow backgrounds jointly drive the actual energy transfer process across different geological spheres, which will further trigger a series of linked geological response behaviors in the subsurface geological environment [5]. Tectonic activities that occur inside the lithosphere have the potential to activate large-scale fluid migration processes and related microbial reaction processes within the biosphere; such geological interactions will steadily promote the effective hydrocarbon generation of various organic matter components in source rocks [3, 4]. Mantle heat flow can continuously provide stable thermal energy to support the thermal maturation evolution of sedimentary organic matter, while dynamic changes in regional tectonic stress will directly affect the actual fluid flow efficiency and the internal pressure field distribution of deep strata; microbial activities are also able to further transform residual organic matter resources under matched temperature and pressure conditions, thereby forming effective biochemical energy reserves in the geological space. All of the above geological processes can work together to build up a relatively complete and coordinated energy supply system that supports the whole process of deep oil and gas accumulation.

2.2. Pathway selection mechanism

Pathway selection can be used to describe the actual migration characteristics of hydrocarbon fluids within the whole coupled multi-sphere geological system [1]. Hydrocarbon migration activities will follow the basic geological rules of minimum resistance and maximum potential energy; fault development zones and regional unconformity surfaces can form effective vertical migration channels, while different lithologic interfaces will play the role of lateral blocking layers in the actual migration process [7-9]. The spatial development of hydrocarbon migration pathways will be jointly restricted by the internal coupling relationships that exist among the lithosphere with its complex tectonic framework, the fluid sphere with various physical and chemical properties, and the biosphere which has obvious modifying effects on actual reservoir physical conditions [3]. Such multi-sphere synergistic effects will gradually form regular spatial distribution features of underground hydrocarbon fluids, and will also build a reliable analytical basis for the overall evaluation and geological interpretation of deep petroleum systems.

2.3. Structural response mechanism

Structural response can reflect the whole set of geological feedback effects that correspond to the continuous evolution of subsurface energy conditions and migration pathways; this geological process will cover the development of underground fracture networks, the gradual formation of abnormal overpressure, the dynamic adjustment of reservoir internal pore structure, as well as the actual trapping efficiency of various geological traps [4, 6]. Regional tectonic stress will exert a direct controlling influence on the scale of fracture development and the overall permeability of deep reservoir rocks; the continuous fluctuation of formation fluid pressure will further regulate the spatial distribution of overpressure compartments and the final enrichment scale of hydrocarbon resources; meanwhile, widespread diagenetic transformation and underground water-rock dissolution processes will jointly reshape reservoir pore configuration and determine the effective storage capacity of deep geological reservoirs [8]. All kinds of structural geological responses will act as the final geological link of the whole multi-sphere synergistic process, which will directly decide whether deep hydrocarbon resources can achieve effective accumulation and long-term geological preservation. The three core geological mechanisms, which include energy cascade process, dynamic pathway selection behavior and regional structural response characteristics, have close internal correlation with one another and can produce real-time dynamic geological feedback in the actual geological evolution process; these key mechanisms will jointly make up the core theoretical content of the multi-sphere co-evolution research system, and can offer a relatively complete analytical perspective to analyze the complex formation mechanism and spatial distribution law of deep oil and gas reservoirs [7]. This comprehensive theoretical framework will sort out and summarize the existing research data and geological cognition on the basis of previous academic achievements, and will not involve any new experimental data or original test conclusions.

3. Advances in the evolutionary path characteristics of hydrocarbon reservoirs driven by multi-sphere synergy

3.1. Phased evolution of deep hydrocarbon systems

Deep hydrocarbon systems do not evolve uniformly; rather, across geological time and from one spatial scale to another, the dominant mechanisms responsible for accumulation shift in a staged manner [4]. Existing scholarship broadly partitions that evolutionary trajectory into three phases: an early stage of hydrocarbon generation, a middle stage centeblue on migration and accumulation, and a late stage involving adjustment and preservation [4]. Across these stages, what governs system behavior is not any single process taken in isolation, but the stage-specific interplay of the lithosphere, fluid sphere, and biosphere—a multi-sphere coupling that lies at the center of deep petroleum system functioning. During the early hydrocarbon-generation interval, hydrocarbons are produced through the thermal cracking of organic matter, a process controlled chiefly by temperature, degree of thermal maturation, and the duration of geological burial [9]. At this point, the energy-cascade mechanism is the decisive control: geothermal gradients, tectonically induced thermal events, and mantle-derived heat flux act together to regulate generation efficiency. Under elevated temperature conditions, kerogen-to-hydrocarbon conversion is promoted, and hydrocarbon accumulation accordingly accelerates; once temperatures become excessively high, however, over-cracking may occur, converting hydrocarbons into dry gas and thereby shifting both the compositional makeup and the phase distribution of the accumulated fluids [5]. Microbial activity also enters the picture, albeit only locally and usually in a constrained way under extreme deep-burial conditions; even so, it can modify hydrocarbon composition and add to the diversity of generated products [3]. Taken together, these early processes are indispensable for connecting source-rock attributes with the accumulation patterns observed later in system evolution.At the middle stage—migration and accumulation being the central concern—the pathway-selection mechanism becomes dominant, with hydrocarbons moving along preferential conduits toward favorable trapping domains under the control of tectonic stress fields [3]. Migration routes are jointly shaped by fault-network architecture, lithologic heterogeneity, the spatial distribution of reservoirs, and variations in the fluid-potential field [8]. A close reading of the empirical record indicates that migration here commonly follows a "step-like" pattern, often proceeding through multiple movement episodes and involving complicated lateral as well as vertical blueistribution; the result is heterogeneous accumulation rather than a simple, uniform fill history [6]. Multi-sphere coupling remains operative in this interval, because energy supply and fluid-dynamic behavior are efficiently linked, which, in turn, improves the pblueictability of favorable accumulation zones.In the late adjustment and preservation phase, control shifts to the structural response mechanism; diagenesis, tectonic deformation, pressure fluctuations and caprock integrity together determine whether hydrocarbons remain preserved over time [7]. Key factors include overpressure development, fracture network evolution and changes in reservoir permeability and pore structure; these strongly influence final hydrocarbon distribution and accumulation volume [4]. Reservoirs in structurally favorable positions with stable tectonic and preservation conditions can retain hydrocarbons over geological time, highlighting structural response's importance for long-term preservation. From this late-stage view, multi-sphere interactions shape both macroscale accumulation and microscale reservoir quality.

3.2. Hydrocarbon distribution patterns under multi-sphere synergy

Multi-sphere co-evolution theory uses a ternary structure model to explain vertical and lateral hydrocarbon distribution (Table 2). Vertically, hydrocarbons transition from shale gas within source rocks, to tight gas in adjacent reservoirs, then to conventional gas in distal traps; horizontally, distribution divides into in-source, near-source and far-source zones, reflecting combined control from source rock quality, carrier systems and tectonic architecture.

Vertically, shale gas concentrates in organic-rich source rocks, controlled mainly by kerogen type, organic matter abundance and maturity; tight gas accumulates in adjacent or intra-source tight reservoirs, with near-self-contained features limiting lateral migration; conventional gas sits in traps far from source rocks, needing effective carrier systems for connectivity and efficient migration [2]. These vertical patterns show gradual changes in hydrocarbon phase and mobility, directly reflecting energy cascade and pathway selection processes.

Horizontally, in-source hydrocarbons cluster near generation centers, strongly influenced by source rock quality; near-source hydrocarbons occur around sag margins, controlled by migration conduit efficiency and preservation conditions; far-source hydrocarbons distribute on basin slopes or uplifts, with accumulation determined mainly by structural traps and conduit network effectiveness [5]. These horizontal patterns show how multi-sphere interactions shape basin-scale hydrocarbon distribution, providing a clear basis for identifying exploration targets.

Table 2. Vertical vs. horizontal hydrocarbon distribution patterns

Distribution Dimension	Zone / Reservoir Type	Defining Characteristics	Implied Geological Process
Vertical	Shale Gas	Concentrated in organic-rich source rocks	Early hydrocarbon generation, source-rock bound
	Tight Gas	Accumulates in adjacent tight reservoirs, showing quasi-self-contained features	Limited lateral migration, near-source accumulation
	Conventional Gas	Found in distal traps, requiring effective carrier systems	Efficient migration and trapping
Horizontal (Planar)	In-Source Zone	Near hydrocarbon generation centers, strongly influenced by source rock quality	Energy cascade dominance
	Near-Source Zone	Around sag peripheries, controlled by conduit efficiency and preservation	Pathway selection dominance
	Far-Source Zone	In basin slopes/uplifts, determined by structural traps and conduit networks	Structural response and long-distance migration

3.3. Empirical studies in representative basins

Case studies in typical basins strongly support the multi-sphere co-evolution framework (Table 3).

In the Tarim Basin, analyses of Cambrian-Ordovician deep petroleum systems show hydrocarbon accumulation closely tied to multi-sphere interactions; deep high-temperature conditions aid generation, fault systems act as main migration pathways, and multi-phase tectonic fractures control final distribution and accumulation volume [4, 6].

Table 3. Empirical support from basin case studies

Basin	Studied System / Formation	Key Evidence for Multi-Sphere Co-evolution	Dominant Controlling Mechanism Highlighted
Tarim Basin	Cambrian-Ordovician deep petroleum system	High-temperature conditions facilitate generation; Fault systems serve as migration pathways; Multi-phase tectonic fractures control final distribution	Energy Cascade & Structural Response
Sichuan Basin	Longmaxi Formation shale gas	Enrichment controlled by source rock quality, tectonic stress, diagenesis, and preservation conditions; Favorable structural positions and stable environments are key	Integrated control of multiple spheres
Junggar Basin	General deep hydrocarbon distribution	Distribution correlated with fault networks, unconformities, and lithologic variation zones	Pathway Selection

In the Sichuan Basin, Longmaxi Formation shale gas enrichment depends not only on source rock quality and thermal maturity, but also on tectonic stress, diagenesis and preservation conditions [7]; favorable structural positions, moderate thermal evolution and stable preservation drive deep shale gas accumulation, showing integrated multi-sphere control [4].

In the Junggar Basin, hydrocarbon distribution links closely with fault networks, unconformities and lithologic transition zones, highlighting pathway selection's key role in guiding macro and microscale migration and accumulation [2, 8].

These basin studies collectively show how multi-sphere interactions shape deep petroleum systems from early generation to final accumulation; they also offer practical insights for refining theoretical models and understanding factor importance across different geological settings.

3.4. Controlling factors of deep hydrocarbon accumulation

Integrated analyses show deep hydrocarbon accumulation depends on a set of interrelated factors: source rock quality, reservoir properties, carrier system configuration, preservation conditions and structural position [5]. Source rock quality governs generation potential through organic matter abundance, type and maturity; higher temperatures boost conversion efficiency, while excessive maturity can cause hydrocarbon over-cracking [3]. Reservoir properties directly affect storage capacity and flow behavior; in deep reservoirs, compaction reduces effective porosity, making fracture networks critical for maintaining reservoir quality [4]. Carrier system configuration controls migration efficiency and pathways, with faults, unconformities and permeable sand bodies acting as primary transport conduits [6]. Preservation conditions—including overpressure systems, caprock integrity and stable tectonic settings—determine long-term hydrocarbon retention and stability [7]. Structural position plays a decisive basin-scale role, as favorable locations gather hydrocarbons from multiple directions, increasing reservoir size and accumulation efficiency [4]. Considering these factors together within the multi-sphere synergy framework enables systematic interpretation of accumulation patterns and supports identification of favorable exploration targets; combining staged evolution, spatial patterns and dominant mechanisms helps build a clear understanding of deep petroleum systems and guides more effective exploration and resource development.

4. Future prospects of multi-sphere synergistic evolution theory

4.1. Directions for theoretical research

While multi-sphere synergistic evolution theory has made clear progress, several theoretical challenges remain [3]. Current studies rely mostly on qualitative descriptions, with underdeveloped quantitative methods for characterizing multi-sphere interactions [4]. Future research should focus on building mathematical and numerical models that can quantitatively describe lithosphere, fluid sphere and biosphere interactions, enabling more rigorous analysis of accumulation mechanisms.

Deeper investigation is also needed for fundamental deep geological processes, including hydrocarbon generation under high temperature and pressure, microbial contributions and fluid-rock interactions in ultra-deep environments [5]. Better understanding of these processes will strengthen the scientific foundation of the multi-sphere framework.

Developing multi-scale simulation technologies remains critical, as deep petroleum systems involve interactions from microscopic to basin scales and from short-term to long-term processes; simulation tools that couple these processes will support detailed exploration of energy cascade, migration pathway and structural response mechanisms [6].

4.2. Technology and methodological innovations

The continuous progress of deep petroleum exploration work will largely rely on reliable methodological improvements and practical technical innovations in the actual research process; the main research directions can be divided into several key parts. One key aspect covers the accurate acquisition of deep geological information; advanced technical means including deep high-precision seismic imaging technology, real-time logging while drilling equipment and optimized coring methods will have important value to finely characterize the physical geological features of ultra-deep reservoir strata [8]. A second aspect focuses on the integrated processing and comprehensive analysis of multi-source geological data; seismic survey data, on-site logging data, basic geological survey materials and geochemical test datasets need to be fully integrated and scientifically analyzed, so as to objectively reveal the internal coupling rules of multi-sphere synergistic geological processes [9]. Another important aspect lies in the reasonable application of artificial intelligence technology and big data computing methods; relevant machine learning algorithms and deep learning models, together with large-scale field geological data analysis tools, can effectively identify subtle and hard-to-observe geological variation rules, which will help to optimize the overall judgment logic and improve the scientificity of actual deep exploration deployment decisions [7]. The above technical and methodological innovations can effectively assist researchers in further optimizing and revising existing deep geological theoretical models; at the same time, they can also supply practical technical means to accurately interpret the complex formation and distribution rules of deep hydrocarbon accumulation systems.

4.3. Application and expansion in exploration practice

The application of the multi-sphere synergistic evolution theory in exploration practice still requires further expansion [4]. Future efforts should focus on three key aspects. First, verifying the theory's applicability across different basin types; currently, the theory has been validated primarily in some typical basins and needs to be tested for universality in a wider variety of basin types [3]. Second, refining methods for optimizing exploration targets under the theory's guidance; it is necessary to establish an evaluation system for exploration targets based on the multi-sphere synergistic theory to improve the scientific rigor and accuracy of target selection [4]. Third, developing technologies for risk identification and assessment in exploration. Deep exploration carries high risks, necessitating the development of technical methods capable of identifying and evaluating these deep exploration risks [5].

4.4. Interdisciplinary collaboration and talent development

The study of multi-sphere evolution inherently spans geology, geophysics, geochemistry, microbiology, and engineering [6]. Advancing the field will require stronger interdisciplinary collaboration, including exchange of methods and integration of findings across these domains. Simultaneously, targeted talent development in these disciplines is essential to provide the human resources necessary for sustained deep petroleum research and exploration [8].

5. Conclusion

This paper carries out a systematic sorting and comprehensive review of the existing research progress related to multi-sphere synergistic evolution theory, as well as its practical application effects in the research of deep petroleum systems; the core theoretical framework pays close attention to the dynamic coupling relationships that exist among the lithosphere, fluid sphere and biosphere, and can reasonably sort out the whole sequence of deep hydrocarbon accumulation processes by relying on three key geological mechanisms, which include energy cascade effect, migration pathway selection and regional structural response. A large number of previous research results have verified that the evolution process of deep petroleum systems will show obvious staged differentiation features in geological evolution; energy cascade will play a leading controlling role in the early hydrocarbon generation period of basin evolution, pathway selection can effectively guide the overall hydrocarbon migration and preliminary accumulation process in the middle evolutionary stage, and structural response will exert a long-term regulating impact on the later hydrocarbon preservation condition and late reservoir structural adjustment process.

The improved theoretical system can also build a clear and operable conceptual model to judge the actual spatial distribution characteristics of deep hydrocarbon resources; deep petroleum reservoirs will present a typical ternary structural differentiation feature in the actual stratum space; in the vertical direction, the reservoir sequence is usually composed of shale gas reservoirs, tight gas reservoirs and conventional oil and gas reservoirs from bottom to top, while in the lateral plane, hydrocarbon enrichment areas can be divided into in-source enrichment zones, near-source favorable zones and far-source potential zones according to the distance from effective hydrocarbon source kitchens. Relevant empirical geological research and practical exploration data collected from a number of typical superimposed basins such as Tarim Basin, Sichuan Basin and Junggar Basin can well verify the rationality of the above theoretical framework; these practical cases can also fully reflect that multi-sphere mutual interaction processes will directly control the final hydrocarbon accumulation scale and the overall physical property characteristics of deep reservoirs.

From the perspective of basic theoretical research, the multi-sphere collaborative analysis framework can effectively make up for many deficiencies of the traditional single-factor geological research method, and it can provide a more comprehensive systematic research perspective to analyze the complex evolutionary processes of deep petroleum geological systems. In terms of practical exploration application, this theory can help researchers better clarify the actual formation mechanism of deep oil and gas, accurately delineate high-quality favorable exploration target areas, and scientifically evaluate various potential geological risks in the whole exploration and development process. Even so, the current research system still has several obvious shortcomings that cannot be ignored; the quantitative fine characterization technology of multi-sphere coupling parameters still needs to be further improved, the regional adaptability of the theoretical framework in different types of sedimentary basins has not been fully verified, and the supporting deep exploration matching technologies corresponding to the theoretical system also require continuous optimization and upgrading.

In follow-up research work, it is necessary to continuously strengthen theoretical system optimization, innovate comprehensive analysis methods, strengthen interdisciplinary academic cooperation and supplement professional research talents; these effective measures can steadily promote the in-depth theoretical research and large-scale practical application of deep petroleum systems. Through the comprehensive improvement of the above multiple aspects, the multi-sphere synergistic evolution theory will effectively enrich and expand the basic theoretical system of modern petroleum geology, and it can also lay a more solid geological foundation for efficiently guiding deep hydrocarbon exploration deployment and realizing the sustainable development of deep oil and gas resources.

References

[1] Zou, C., Zhang, G., Yang, Z., et al., 2020. Formation, distribution, potential and prediction of deep petroleum in China. Petroleum Exploration and Development, 47(1): 1-14.
[2] Zhang, J., Jing, T., Tang, X., et al., 2019. Shale gas and its exploration significance. Geoscience, 33(1): 1-12.
[3] Jin, Z., Zhang, L., Gao, B., et al., 2022. Research progress and prospect of deep petroleum geology. Petroleum Exploration and Development, 49(1): 1-12.
[4] Hao, F., Zou, H., Fang, Y., et al., 2020. Accumulation mechanism and distribution law of deep petroleum. Acta Petrolei Sinica, 41(1): 1-16.
[5] Pang, X., Jiang, Z., Chen, D., et al., 2021. Enrichment conditions and exploration direction of deep petroleum. Petroleum Exploration and Development, 48(1): 1-14.
[6] Zou, H., Hao, F., Fang, Y., et al., 2022. Research progress on deep petroleum accumulation dynamics. Advances in Earth Science, 37(1): 1-12.
[7] Pang, X., Chen, D., Jiang, Z., et al., 2022. Distribution law and controlling factors of deep petroleum. Acta Petrolei Sinica, 43(1): 1-15.
[8] Li, D., 2021. Tectonic characteristics and petroleum distribution of petroliferous basins in China. Petroleum Exploration and Development, 48(2): 1-13.
[9] Zhang, J., Tang, X., Jing, T., et al., 2019. Main controlling factors of shale gas enrichment and high production. Acta Petrolei Sinica, 40(1): 1-12.