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Differential Enrichment Regulation and Genetic Analysis of Tight Sandstone Gas Reservoir

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Abstract: In the deep Paleogene of graben basins in eastern China, not only the tight sandstone oil and gas resources, but also the secondary hydrocarbon generation of source rocks are universal and worth studying. In order to elucidate the laws of oil and gas accumulations in tight sandstone with different phases and explore the diversity of its genetic mechanism, Shahejie Formation in Wendong area was taken as an example in this paper to carry out further research. Firstly, the differential enrichment rules of oil and gas reservoirs are clarified from the aspects of spatial distribution, phase type and fluid properties. Secondly, the reasons for differential accumulation of oil and gas reservoirs were analyzed from multiple perspectives by using a variety of methods, such as source rock thermal evolution simulation, fault activity evaluation and reservoir porosity evolution. A large number of researches have been carried out on hydrocarbon generation and expulsion process of source rocks, paleo-temperature and paleo-pressure changes, the connectivity of skeleton sand bodies, reservoir physical property and densification process, tectonic strength and so on. The results indicate that the deep tight sandstone reservoirs of the Paleogene in the Wendong area have a quasi-continuous distribution characteristic of "planar partition and longitudinal zoning". Secondary kerogen cracking gas, crude oil cracking gas, medium light crude oil, and primary kerogen cracking gas are distributed in a semi-circular manner, from the center of Qianliyuan Sag to Wendong graben and rollover anticline belt at the high structural position. In conclusion, the two periods of hydrocarbon generation and expulsion of source rocks lead to the discontinuity of hydrocarbon accumulation process. Paleo-temperature and paleo-pressure conditions control the phase types of hydrocarbon filling. The lateral connectivity and the difference of physical properties of the skeleton sand bodies limit the distribution range of oil and gas reservoirs. The temporal and spatial availability of faults during the critical accumulation period determines the differential enrichment of oil and gas. The temporal and spatial validity of faults during the critical accumulation period determines the extent of differential enrichment of oil and gas.

Keywords: Enrichment Regulation, Genetic Analysis, Tight Sandstone Oil and Gas Reservoir, Deep Paleogene Layer

1. Introduction

China's tight oil and gas production is growing rapidly, maintaining a good development momentum during the period of profound adjustment in optimizing energy structure, and facing new situations and challenges. Especially since China officially proposed the 2020 "dual carbon" strategic goal, in order to maintain the stable and healthy development of the oil and gas industry, and promote the green and low-carbon energy development, further improving the theoretical system of tight sandstone oil and gas reservoir formation has become an urgent task.

In addition to central and western China (such as the Yanchang Formation in the Ordos Basin, the Xvjiahe Formation in the Sichuan Basin, and the Ahe Formation in the Tarim Basin), the quality and efficiency of tight oil and gas development have also made great breakthroughs in graben basins in eastern China [1-3], among which the east Wenliu area in the Dongpu depression (hereinafter referred to as "Wendong Area") is the most typical. Under the combined action of differential fault activity and rapid stratigraphic burial, the Wendong area has significant potential for tight sandstone oil and gas resources in the Shahejie Formation, with a complete sequence of hydrocarbon phase evolution. It is the most typical and suitable area for conducting research on the formation laws of tight sandstone reservoirs in the eastern faulted basin.

Years of exploration and development experience show that the complex structure, fault development and strong heterogeneity of reservoir sand bodies in Wendong area result in different hydrocarbon distribution characteristics [4]. It greatly increases the difficulty of oil and gas exploration and effective development. In view of the characteristics of complex oil and gas accumulation with multi-stage formation, there are still three major problems that have not been solved, which are manifested in the differences of oil and gas properties, accumulation periods and reservoir formation processes in different structural locations.

In response to the above challenges, this article selects the quasi continuous sandstone oil and gas reservoir of the Shahejie Formation in the Wendong area as the research objective, and carries out the analysis of petroleum geological characteristics and accumulation conditions. By analyzing the difference of hydrocarbon filling time, source rock thermal evolution history, biomarker compound characteristics and tight evolution history of sandstone reservoirs in different structural positions, the distribution laws and controlling factors of quasi-continuous sandstone oil and gas reservoirs are clarified. It is of great practical significance and theoretical value for elucidating the distribution and development characteristics of quasi- continuous sandstone reservoirs and guiding oil and gas exploration.

2. Geological Background

The Dongpu depression is in the southwest region of the Bohai Bay basin in Eastern China and covers about 5300 km^2 (Figure 1a, b). The internal structure of the sag is controlled by a basement rift that forms an "east-west zoning" structural pattern. It is composed of five tectonic units [5]: the western slope zone, western sag zone, central uplifted zone, eastern sag zone and Lanliao fault terrace zone (Figure 1c).

The Cenozoic strata encountered include the Paleogene of the Shahejie Formation (often abbreviated to "Es" or "Sha-") and Dongying Formation, the Neogeno of Guantao Formation and Minghuazhen Formation, and Quaternary of Pingyuan Formation (Figure 1d). The depression has experienced uplifting rift stage (sedimentary period from Sha-4 to Sha-3), contraction and subsidence period of lake basin (sedimentary period from Sha-2 to Sha-1), depression uplift and contraction period (deposition stage of Dongying Formation) and depositional depression disappearance period (deposition stage of Guantao Formation to present) since the Paleogene.

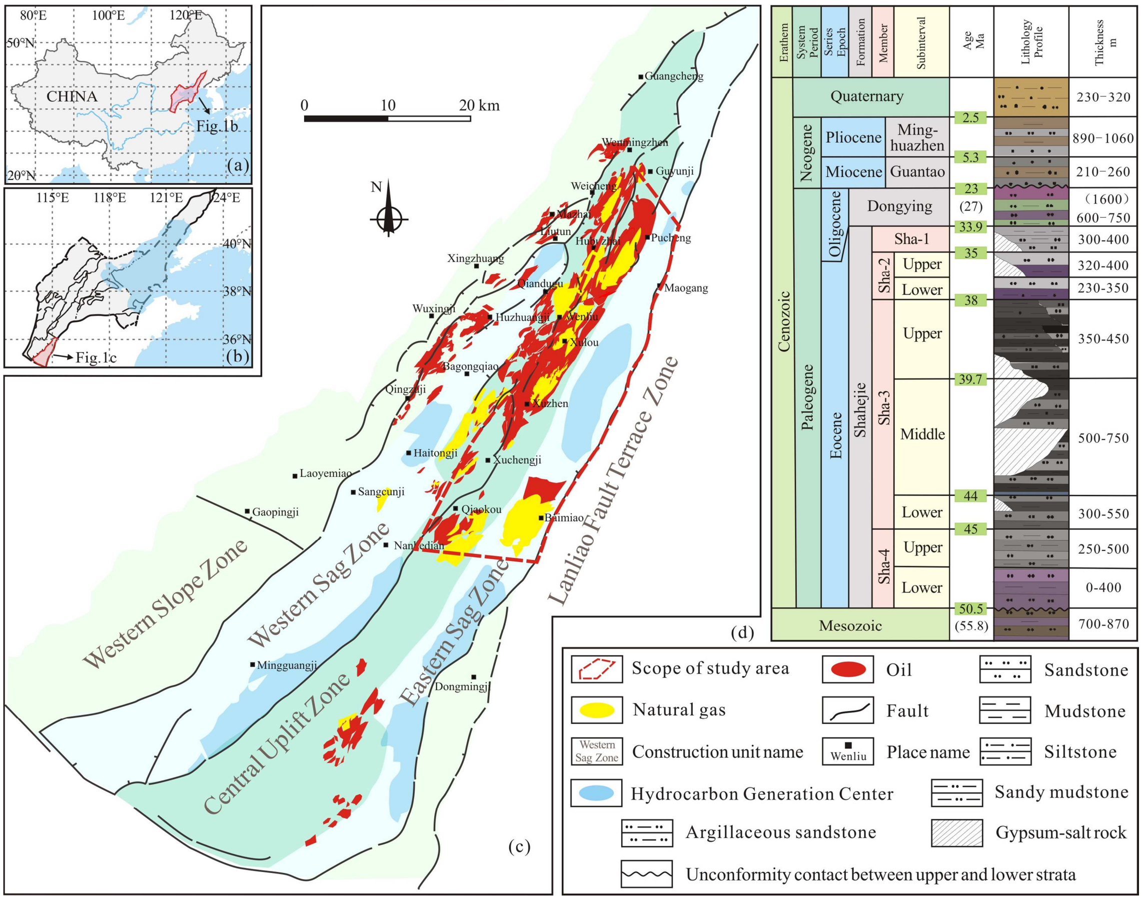


Figure 1. *(a, b) Location of Dongpu depression in Bohai Bay Basin, China; (c) Tectonic units division of Dongpu depression; (d) The stratigraphic distribution table of the Cenozoic in Dongpu depression, and the mid-lower subsection of Sha-3 is the key research object.*

After deposition of the Dongying Formation, the whole depression was uplifted and denudated. Specifically, the erosion thickness in the middle and eastern regions generally ranges between 600–1000 m [6], thus resulting in sharp drops in palaeo-temperature in the mid-lower subintervals of Sha-3 (often abbreviated to "Es3"). From the Guantao period to the current era, the Dongpu depression developed subsidence again, which resulted in the overcompensation of the buried depth in the mid-lower subintervals of Es3. This change further caused the maximum buried depth of the Paleogene to be greater than 5000 meters, and the maximum formation temperature to be greater than 200°C [7].

Based on the disappearance of single oil facies as stratification, some scholars have found that oil and gas resources in the eastern Dongpu Depression are mainly distributed in deep Paleozoic (3000-5200 m) tight sandstone [8]. These tight sandstone reservoirs are derived from the argillaceous rocks, the organic type of which are mainly of II_1, followed by Types I and II_2 [9].

3. Differential Enrichment Characteristics of Oil and Gas

3.1. Planar Distribution Characteristics

The distribution of oil and gas in Wendong area of Dongpu Depression is large and wide. The proven oil and gas resources of the Paleogene Shahejie Formation are mainly distributed around the Qianliyuan Sag. The most abundant oil and gas reservoirs are in the Wendong graben belt and the Wendong rolling anticline belt. The gas reservoirs are mainly concentrated in the Wendong reverse step-fault zone and the near depression belt. There are great differences in the characteristics and properties of these reservoirs.

Further analysis of the above oil and gas reservoirs shows that fault block oil and gas reservoirs are widely distributed in complex fault block areas (such as angular fault block oil and gas reservoirs in Wendong graben belt). Anticlinal oil and gas reservoirs are mainly distributed in the lower plate of the main fault (such as reverse tractive rolling anticlinal oil and gas reservoirs). Lithologic oil and gas reservoirs are mainly distributed in the interior and surrounding areas of Qianliyuan Sag. The structural-lithologic composite oil and gas reservoirs are widely distributed in Shahejie Formation, which are the most important type of oil and gas reservoirs in Wendong area, such as Wen 95 and Wen 210 well blocks in the reverse step-fault zone.

3.2. Vertical Distribution Characteristics

3.2.1. Phase Characteristics of Hydrocarbons

The vertical distribution of oil and gas resources in Shahejie Formation in Wendong area is very uneven due to the comprehensive influence of Paleogene deposition and multiple sets of salt-paste barriers. The distribution sequence of hydrocarbon reservoirs changes regularly from shallow to deep.

1) The first type is low-mature oil and heavy oil reservoirs distributed in the shallowest layer, which is marked by the original gas-oil ratio less than 35 m^3/m^3. Most of these oil and gas reservoirs are distributed in shallow strata with burial depth less than 3400 m, and a small part of them are distributed in salt rock developed areas to form primary low-maturity heavy oil reservoirs, or in local areas with underdeveloped salt rock but large faults and unconformity developed secondary heavy oil reservoirs.
2) Conventional oil reservoirs. The original gas-oil ratio is between 35 and 125 m^3/m^3, and the buried depth ranges from 2400 to 3800 m.
3) Light oil reservoirs. The gas-oil ratio of between 125 and 350 m^3/m^3, it is mainly distributed in areas with good preservation conditions, such as salt rock development at 3100 to 4000 m, which are primary oil reservoirs with high maturity.
4) Critical phase mixed oil and gas reservoirs. These reservoirs are mainly composed of volatile reservoirs and condensate reservoirs with condensate oil. They are distributed in the depth range of 3400 to 4100 m, and most of them occur in areas with good preservation conditions where salt rock and mudstone are intercapped.
5) Condensate gas reservoir. The original gas-oil ratio ranges from 1425 to 12467 m^3/m^3, mainly occur under well preserved gypsum mudstone layers within a depth range of 3900 to 4200 meters, with a very limited vertical distribution interval.
6) Mixed gas reservoir. This kind of gas reservoir is composed of wet gas and dry gas, the original gas-oil ratio of which is greater than 12467 m^3/m^3. It is distributed in the vertical range below 4200 m. The medium and shallow oil-soluble gas is dissolved into dry gas reservoir, and the deep high-over mature source rocks are cracked into wet gas, resulting in the coexistence of wet gas reservoir and dry gas reservoirs in the deep structure.

3.2.2. Hydrocarbon Fluid Properties

The deep Paleogene reservoirs are mainly composed of light and medium crude oil, characterized by low density, viscosity and sulfur content, but high freezing point [10]. The relative density of crude oil is mostly between 0.80 and 0.90 g/cm^3. The viscosity varies greatly from 0.35 to 465.7 mPa·S. The sulfur content of crude oil is mostly less than 0.5%, and the freezing point is mainly between 30 and 40°C (Figure 2).

On the whole, the density, viscosity, and sulfur content of crude oil decreased gradually with the increase of depth, and the decrease range of which increases significantly below 4000 m, indicating that the preservation conditions of crude oil gradually become better with the increase of buried depth.

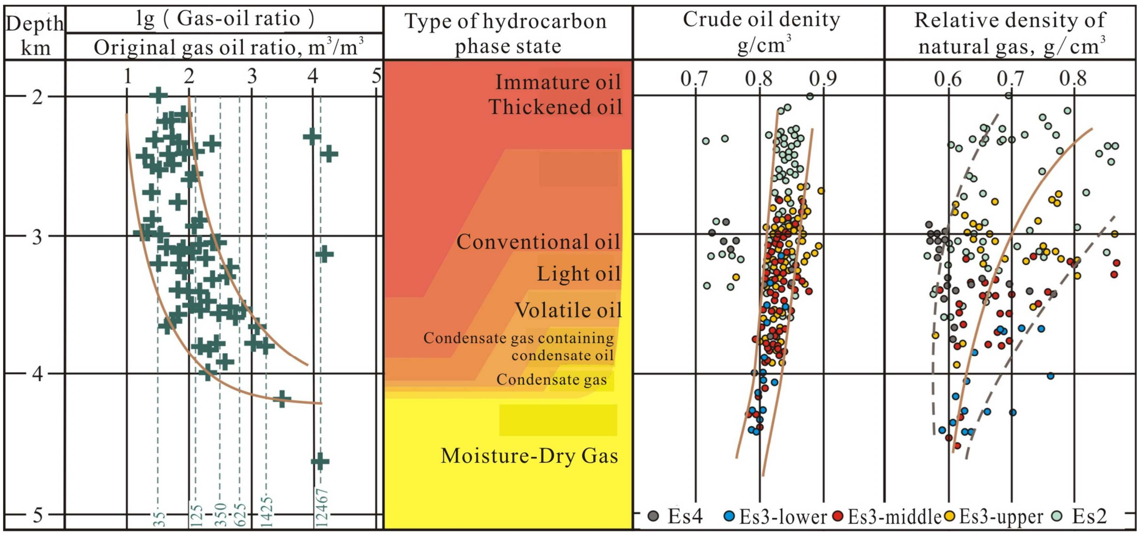


Figure 2. *Vertical distribution sequence of different phase hydrocarbons in Wendong area.*

The tight sandstone gas reservoirs in the Shahejie Formation are dominated by oil-type natural gas in Es2 and Es3. Previously, some scholars subdivided the natural gas in this area into crude oil cracking gas and kerogen cracking gas, according to the parameters, $\ln(C_1/C_2)$ and $\ln(C_2/C_3)$, which were established by model experiments of gold tube closed systems [11]. Among them, the early kerogen cracking gas is distributed in the lower Es2 sub-member of the shallow Wendong graben belt. The late kerogen cracking gas is distributed in the periphery of the depression zone and the Es4 in the Wendong reverse step-fault zone. The oil cracking gas is mainly distributed in the reverse step-fault zone, where the formation burial depth is relatively large, but the source rock cracked gas has not yet reached. In addition, residual bitumen was found in the middle section of Shahejie Formation in Wells Wen 200-6, Wen 74, and Pushen 4 (Figure 3). After purification, the *Easy%* R_o values measured at room temperature of 23°C and humidity of 30% were 2.34%, 2.29%, and 2.57%, respectively, which provided objective evidence for the existence of crude oil cracking gas.

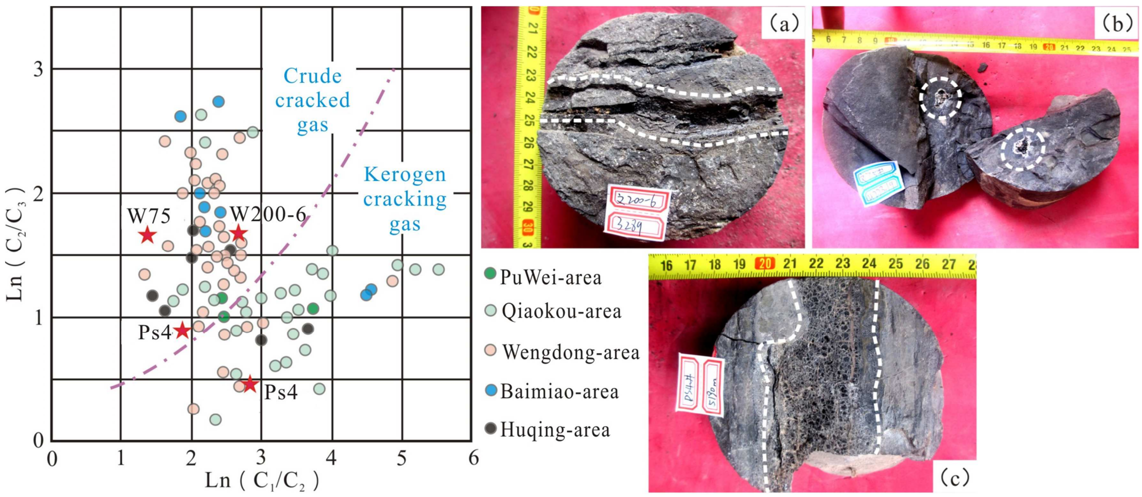


Figure 3. *Genetic analysis of natural gas in the middle sub-section of Es3 in Wendong area (a) Well: Wen200-6, 3289.00m; (b) Well: Wen75, 4223.19m; (c) Well: Pushen4, 5190.00m.*

4. Analysis of the Genesis of Differential Enrichment

4.1. Thermal Evolution of Source Rocks and Spatiotemporal Differences in Hydrocarbon Generation and Expulsion

The Paleogene hydrocarbon source rocks in Wendong area are mainly dominated by dark mudstone in Es3 and Es1 of Qianliyuan Sag [12]. Due to the difference in the abundance, quality, and thermal evolution degree of source rocks, the hydrocarbon generation intensities of source rocks in different periods and layers are also different [13], which lays a foundation for the differential enrichment of oil and gas reservoirs in the later period.

From the perspective of quality differences in hydrocarbon source rocks, the Es4 is mainly composed of dark gray and grayish black mudstone, mixed with oil shale and calcareous shale, with large thickness and wide distribution range. The Es3 is mainly composed of dark gray mudstone and siltstone, interbedded with calcareous shale, oil shale and gypsum rock, with a cumulative thickness of 300 to 600 m. The Es2 is mainly composed of dark gray mudstone with thin layers of siltstone, followed by gray to dark gray oil shale, with a cumulative thickness of 200 to 300 m. The source rocks of the Es1 are mainly gray mudstone with a thickness of 100 to 300 meters, which are distributed continuously and steadily in Qianliyuan Sag.

According to the geochemical parameter indicators of the hydrocarbon source rocks in each layer series (Figure 4), the quality of the source rocks in the lower Es3 sub-member is the best, followed by the middle Es3 sub-members, and the quality of the source rocks in the uppe-Es3 is poor.

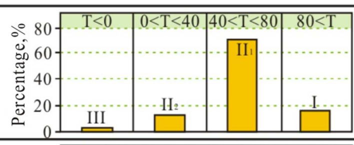
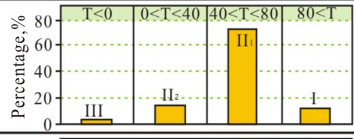
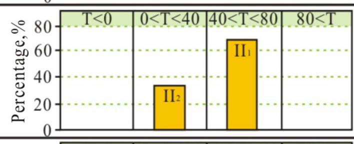
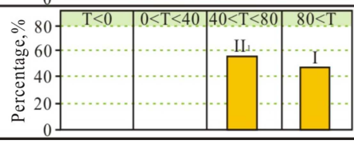
Geological horizon / Type		Organic carbon %	Chloroform bitumen "A" %	Hydrocarbon generation potential mg/g	Total hydrocarbon μg/g	Rating Results	T index of Macerals,%
Es3-lower	Min~Max	0.16~5.69	0. 0014~10. 97	0.05~68.53	12~63582	A	
	Average value	1.85	0. 49	4.52	4520		
Es3-middle	Min~Max	0.17~4.05	0. 0029~1. 39	0.01~12.58	18~11882	B	
	Average value	0.75	0. 16	1.60	1459		
Es3-upper	Min~Max	0.17~3.36	0. 0047~0.32	0.10~13.24	35~2563	B-C	
	Average value	0.55	0.056	2.27	632		
Es1	Min~Max	0.57~5.24	0.067~0.17	0.33~4.18	258~1245	A-B	
	Average value	1.35	0.12	1.87	751		

Figure 4. *Distribution of geochemical parameters of Paleogene source rocks in Wendong area.*

According to the spatial and temporal differences in hydrocarbon generation of effective source rocks, the middle and lower sub-members of Es3 have stronger hydrocarbon generation ability. Both the hydrocarbon generation rate and the hydrocarbon generation conversion rate are significantly higher than that of Es1 and the upper sub-member of Es3.

The simulation results of the Paleogene thermal evolution histories and hydrocarbon generation histories of main source rocks, represented by Wells Pushen 12 and Pushen 4, show the following results.

1) The cumulative hydrocarbon generation of the middle and the lower sub-members of Es3 accounts for 40.3% and 52.9% of the total hydrocarbon generation, respectively. The upper sub-member of Es3 accounts for 6.5%, and the contribution rate of Es1 is only 0.3% (Figure 5).
2) All four sets of source rocks experienced two hydrocarbon generation peaks. In the early stage of hydrocarbon generation and expulsion at the end of the deposition in Paleogene Dongying Formation (about 33~27 Ma ago), the thermal evolution of source rocks in Qianliyuan Sag accelerated, which accounted for about 80% of the total hydrocarbon generation. In this process, condensate gas and dry gas were generated in the lower sub-member of Es3, while a large amount of mature oil and a small amount of condensate gas were generated in the dark mudstone of the middle sub-member of Es3. Medium to mature liquid hydrocarbons were generated in the upper sub-member of Es3, while only a small amount of unripe to low ripe oil was produced in Es1.
3) In the late stage of hydrocarbon generation and expulsion stage, that is, from the end of Minghuazhen deposition in Neogene to the present [14] (about 6-0 Ma ago from now), the strata in the depression zone over- compensated, and the Paleogene source rocks began to generate hydrocarbon twice, but the rate of hydrocarbon generation slowed down and the intensity of hydrocarbon generation weakened. Taking Well Pushen12 as an example, in this stage, the source rocks of the middle and lower sub-members of Es3 were over-mature and produced a large number of gaseous hydrocarbons, and the conversion rate was relatively stable, with an average value of 96.83%. At the same time, mature liquid petroleum was generated from the source rocks of the upper sub-member of Es3, not only the hydrocarbon generation rate increased slightly to 1.32 mg/g, but also the conversion rate grew slowly to 81.67%.

4.2. Differential Evolution of Temperature and Pressure Conditions

From the initial sedimentary stage of Shahejie Formation to the final sedimentary period of Dongying Formation, the paleo-temperature and paleo-pressure continued to rise with increasing burial depth. The source rocks of Es3 in Wendong area have accelerated evolution and produced a large amount of volatile liquid hydrocarbons. However, in the central of the deep sag, the middle and lower sub-members of Es3 began to generate condensate gas.

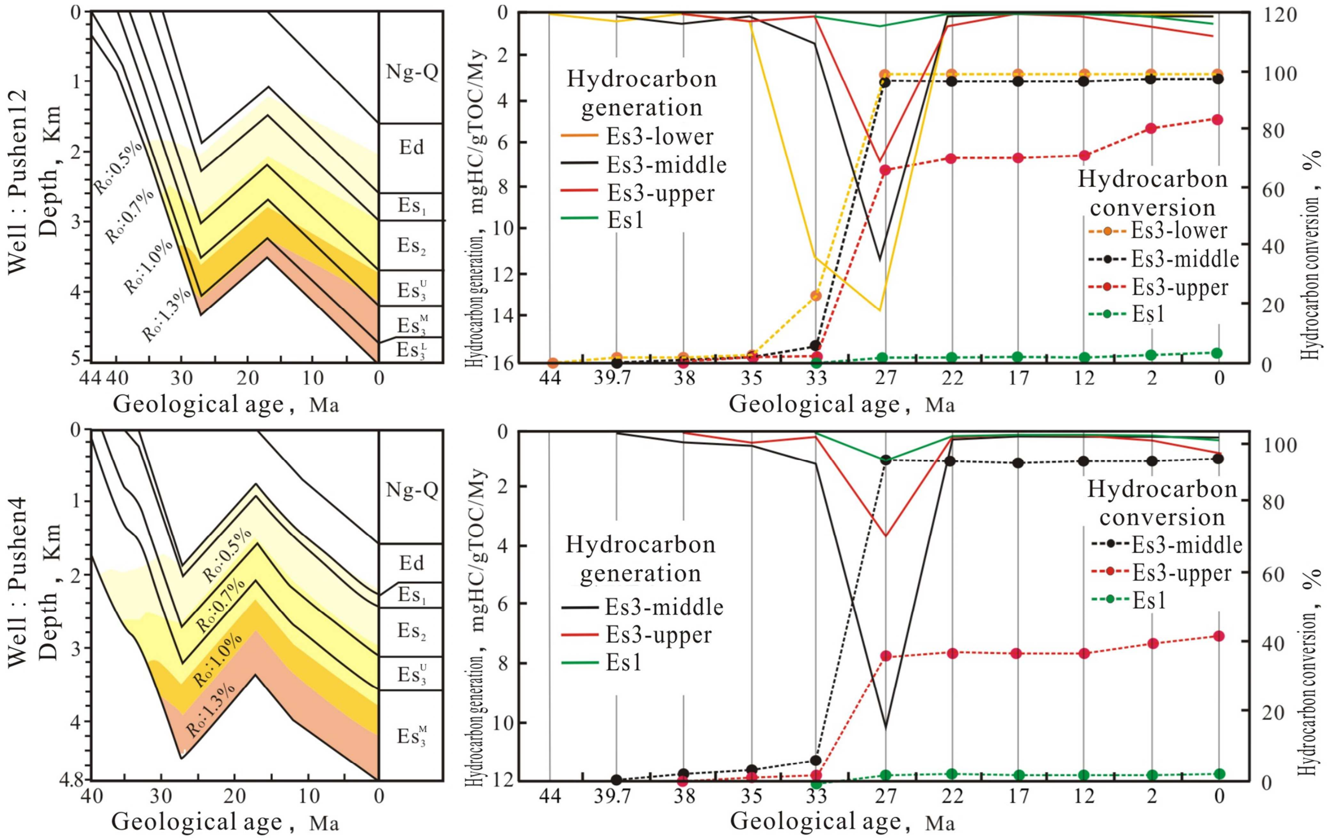


Figure 5. Simulation results of thermal evolution history and hydrocarbon generation history of Paleogene source rocks in the Qianliyuan Sag.

Therefore, in the early stage of hydrocarbon generation, the deep Paleogene in Wendong area showed miscible charging of oil phase and oil gas phase, which were differentiated in the process of transport to the middle and shallow layers. The specific differentiation process is as follows. When the formation temperature dropped to 115~97°C and the pressure was less than 46 MPa, the dry gas escaped due to the dissolution of oil-soluble gas and accumulated in the shallow stratum, where the mudstone and salt rock developed. When paleo-temperature was lower than 80°C, crude oil thickening resulted in differentiation and enrichment of conventional reservoirs. The condensate gas was migrated from the center of hydrocarbon generation to the surrounding slope, which could flush the early oil reservoirs in the tectonic transition area. Combined with all the above reasons, the Paleogene oil and gas reservoirs present the annular distribution characteristics of "gas-oil-gas" around the hydrocarbon generating center.

The deposition of Guantao Formation marks the end of the second phase of Himalayan tectonic movement (about 27 ~ 17 Ma). During this process, the tectonic uplift caused the formation temperature and pressure to drop sharply, and the hydrocarbon generation of source rocks were almost stagnant. At the early stage, the overall burial depth of the reservoirs became shallower, and the differentiation effects of natural gas escaping from the dissolved gas in oil reservoirs and crude oil thickening were more significant, presenting a conventional occurrence state of "lower oil and upper gas".

Since the deposition of Guantao Formation (about 17~0 Ma ago), the strata have been rapidly buried to overcompensation, and the formation temperature has risen to 130~200°C, which met the conditions of oil cracking to form natural gas in the deep Paleogene. The source rocks of the middle and lower sub-members of Es3 had entered the stage of high maturity to over maturity, and the secondary hydrocarbon expulsion process dominated by gas phase occurs, resulting in a three-ring distribution pattern of "gas-oil-gas" in the Wendong area. It is worth distinguishing that this is similar to the distribution characteristics of hydrocarbon reservoirs in the late sedimentary period of the Dongying Formation, but the causes are completely different. At the end of the deposition of Dongying Formation, natural gas in inner ring, crude oil in central ring, and natural gas in outer ring were the result of initial hydrocarbon generation from mature source rocks. But now, natural gas in inner ring near hydrocarbon generation sag is the mixed product of secondary kerogen pyrolysis, crude oil cracking and reverse evaporation and reverse phase dissolution of crude oil. In addition, crude oil in the central ring and natural gas in the outer ring are supplemented by secondary hydrocarbon generation from highly mature to over-mature source rocks, crude oil cracking and reverse evaporation.

4.3. Characteristics and Evolution Differences of Petroleum Migration Pathways

4.3.1. Differences in Physical Properties and Lateral Connectivity of Sand Bodies

There are significant differences in lateral connectivity and physical properties of reservoirs in slope belt and sag zones in Wendong area. In the case of Es3, the sand bodies are finger-like, mostly developed in the form of thin interlayers, and pointed out towards the high part of the structure. Among them, the sand bodies of the 5~10 groups are developed, which accounts for 23%~45% of the total formation thickness, and up to 58% in some well areas, indicating good lateral continuity of sand bodies. On the contrary, the 1~4 sand groups are dominated by mudstone, while sandstone only accounts for 8%-19% of the total thickness of the formation, showing that the smaller interval sand body and poor lateral continuity (Figure 6).

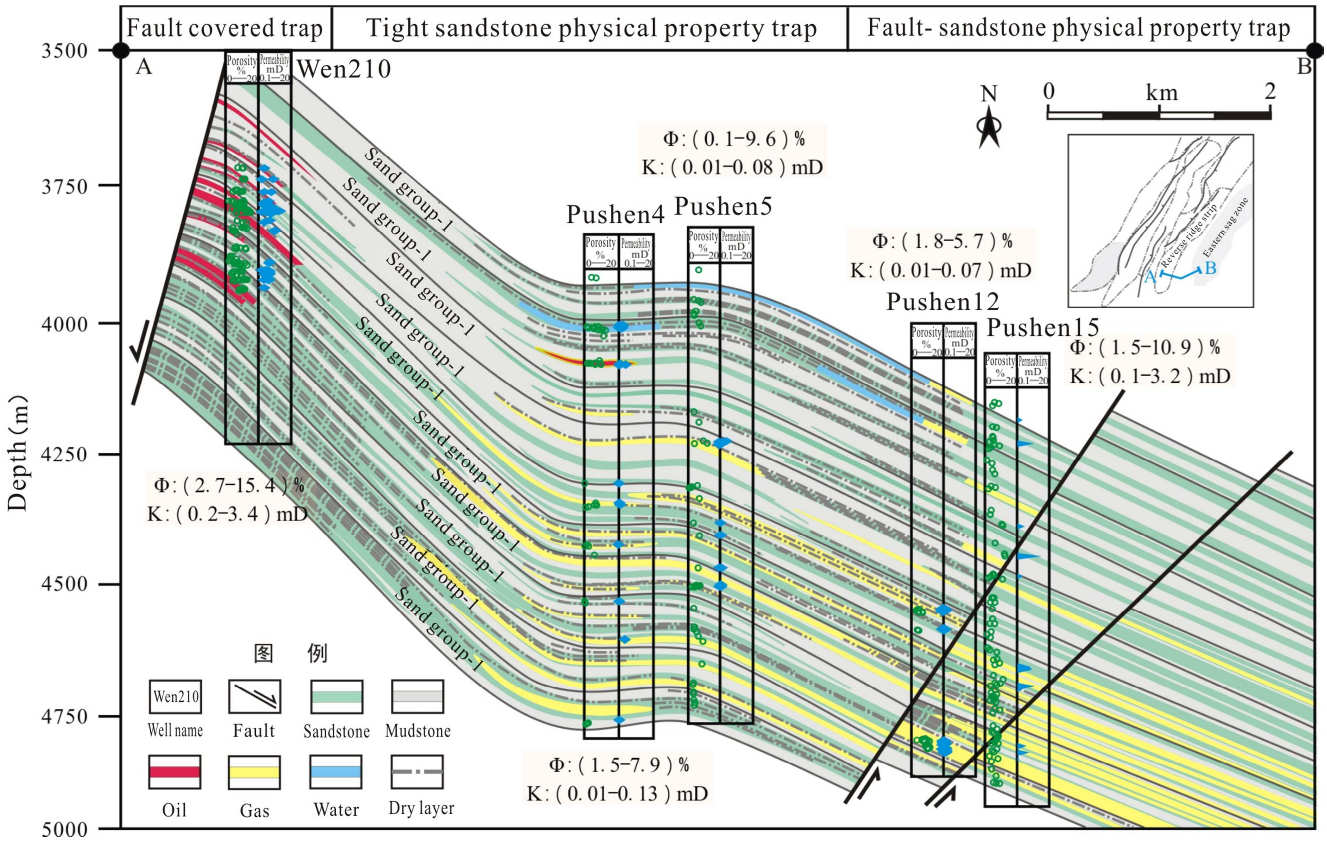


Figure 6. *Section of the oil and gas reservoirs in the middle sub-member of Es3 in Wendong area.*

In terms of the matching relationship between the reservoir physical property and the oil and gas enrichment degree of the middle sub-member of Es3, these two factors have a very obvious influence on each other [15]. The sandstone reservoirs in the sag zone are significantly affected by strong compaction and cementing, and the porosities are mostly distributed in 2%~8%, and the permeabilities are less than 0.1mD, which are tight sandstones with ultra-low porosity and permeability. The porosity of the slope zone is between 7% and 14%, and the permeability distribution is wide. In this tectonic belt, the slope zone is still dominated by sandstone with low porosity and low permeability due to the uneven transformation of dissolution, but there are still local high porosity and high permeability points. The sandstone reservoir of Es3 in the well area of Wen 210 near the faulted area is obviously improved by faults, and the porosity and permeability can reach 15.4% and 3.4mD, respectively. It is shielded by faults to enrich liquid crude oil. In contrast, the late gas charging occurred mainly in Wells Pushen 12 and Pushen 15, which were also blocked by faults and accumulated to form gas reservoirs. Wells Puzhen 4 and Puzhen 5 are far from the faulted zone and experience strong diagenesis, resulting in poor reservoir properties. The hydrocarbons migration had to overcome high resistances along the sand bodies, which leads to a short migration distance of natural gas. Therefore, due to physical trapping, the natural gas accumulates in the direction of sandstone dipping (Figure 6).

4.3.2. Difference in Reservoir Densification Processes

The inversion results of sandstone porosity since the Cenozoic era indicate that the process of tightness development in sandstone reservoirs varies in different structural locations in Wendong area [16]. This is one of the main factors that affect the spatial differentiation of oil and gas resources in the deep Paleogene, Wendong area.

The sandstone reservoir of middle and lower sub-memebers, located in the Wendong faulted belt and the reverse step-faulted belt, exhibits a low degree of compaction. The B period reservoir of the intermediate diagenesis, which occurred approximately 5 million years ago, gradually became compacted, resulting in a remaining porosity of 9.62% in the current sandstone reservoir. Therefore, both early oil and oil-gas mixed-phase injection and late gas-phase charging can form effective filling, enriching and forming tight sandstone oil and gas reservoirs of the "Densification and charging occur simultaneously" type.

In contrast to the aforementioned characteristics, the deep Paleogene sandstone in Qianliyuan sag zone has a high degree of compaction. Early mature liquid crude oil charging occurred in the sandstones of the middle and lower sub-members of Es3 from the late middle diagenesis A_1 to the early middle diagenesis A_2. At this stage, the porosities of sandstones were mostly between 9.68% and 10.03%, slightly higher than the critical porosity value of 7.5%, representing a conventional charging process.

To the B stage of diagenesis, that was, the late high maturity to over-mature natural gas filling period, the carbonate rocks such as iron dolomite and iron calcite were strongly cemented, so that the porosity of the sandstone was maintained at about 6%.

Therefore, early generated crude oil was selectively injected into local high-permeability and high-porosity zones along the sag zone, forming tight sandstone oil reservoirs, which were pre-accumulated and then compacted. Late-stage natural gas, limited by the discontinuity of skeleton sand bodies and the sealing properties of tight sandstones in the near-sag zone, only formed tight sandstone gas reservoirs that were pre-compacted and then accumulated in the periphery of the sag zone.

5. Conclusion

The deep tight sandstone oil and gas reservoirs of the Paleogene in the Wendong area have the spatial distribution characteristics of "plane zoning and vertical zoning".

On the plane, oil and gas reservoirs are centered around the Qianliyuan Sag, and are continuously enriched in the central sag zone, the sag edge belt, the Wendong reverse faulted zone and the Wendong graben belt, forming a concentric semi-annular distribution pattern characterized by "gas-oil -gas". In the vertical direction, the distribution of hydrocarbons is most concentrated in lower sub-member of Es2, and lower and middle sub-members of Es3. Various types of hydrocarbon reservoirs, including mixed natural gas, condensate gas, light oil, conventional oil, low-abundance dry gas, and heavy oil, sequentially appear from deep to shallow layers of the Shahejie Formation.

The influencing factors of differential enrichment of oil and gas in deep Paleogene in Wendong area can be summarized as follows. The formation of the two discontinuous charging stages, namely the early oil and oil-gas mixture charging phase and the later pure gas charging phase, are not only controlled by the evolution difference of the source rock, but also by the change of paleo-temperature and paleo-pressure conditions, which laid the foundation for the inverted distribution. The lateral connectivity of skeleton sand bodies and the difference in reservoir properties, define the range of oil and gas reservoirs, further consolidating the distribution characteristics of "oil above and gas below". The degree of differential enrichment of hydrocarbons is determined by the degree of reservoir compaction and the spatiotemporal effectiveness of fractures during key reservoir forming periods.

In summary, the basic laws of continuous distribution of hydrocarbon reservoirs in tight sandstone are defined, which are in the context of secondary hydrocarbon generation and have different phase states, and the main influencing factors are analyzed. These understandings can serve as references for the study of reservoir formation with similar geological conditions. However, it is worth noting that with the widespread use of high-precision three-dimensional seismic technology, some small-scale fractures have been discovered in the sag zones. These small-scale fractures can also affect the distribution of oil and gas in later stages. Therefore, in the following research, it is necessary for us to continuously carry out investigations and focus on the development characteristics of small-scale fractures and their sealing ability.

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