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Reaserch on Geological Structure Characteristics and Distribution of Favorable Areas for Shale Gas Accumulation in LX Area

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Abstract

China is rich in shale gas geological reserves, mostly distributed in basins with shale source rocks. In response to the national exploration and development plan, CNOOC has analyzed the geological reserves and production potential of shale gas reservoir in LX District, Ordos Basin. In view of the problem that the single layer of organic rich shale in this block is thin, and the shale gas content in pure shale is small, which is difficult to form industrial exploitation, this paper investigates the structural and sedimentary facies characteristics of LX gas field, analyzes the positive significance of magmatic intrusion from the aspects of maturation, hydrocarbon generation, improvement of physical properties and shale gas migration, and demonstrates the main reasons for the formation of gas bearing traps, The main distribution horizons of shale gas in lithologic traps are predicted and put forward, which has important guiding significance for the accurate exploration and development of shale gas reservoir in LX District in the later stage.

Keywords

LX Gas Field; Shale Gas; Exploration and Development; Magmatic Intrusion; Geological Structure.

1. Introduction

Shale gas is a natural gas resource that can be exploited in shale layer. China has large recoverable reserves of shale gas. The formation and enrichment of shale gas has its own unique characteristics. It often occurs in the thick and widely distributed organic shale and its interlayer in the basin. It is a continuously generated biochemical gas, thermogenic gas or a mixture of the two unconventional natural gas. Shale gas mainly exists in adsorption and free state. Free shale gas mainly exists in natural fractures and pores of shale source rock stratum, adsorbed shale gas exists on the surface of kerogen and clay particles, and a very small amount is stored in kerogen and asphaltene in dissolved state. Compared with conventional natural gas, shale gas development has the advantages of long production life and long production cycle. Most of the produced shale gas has a wide distribution range, large thickness and generally contains gas, which enables shale gas wells to produce gas at a stable rate for a long time [1][2].

By investigating the structural and sedimentary facies characteristics of LX gas field, this paper analyzes the positive significance of ZiJin Mountain rock body on the maturation and hydrocarbon generation of shale source rock strata, improving physical properties and shale gas migration in this block, studies the geological structure and trap characteristics under the influence of volcanic rock intrusion, and puts forward the main distribution horizons of lithologic trap shale gas, It can guide shale gas exploration and development in LX district.

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2. Difficulties of Shale Gas Development in LX Area

Continuous exploration and development of shale gas is one of the key plans of the 13th five year plan. At present, CNOOC carries out shale oil and gas exploration and development in many blocks of the East China Sea basin, Qinshui Basin and Ordos Basin. LX area on the eastern edge of Ordos Basin is a key exploration block of CNOOC shale gas. At present, LX district mainly exploits coalbed methane and tight gas, and there is relatively little research on the distribution law of shale gas reservoir. The understanding of the overall geological reserves of the block is not deep enough and is only in the initial stage. During drilling, good natural gas display was seen in the shale section, and the combustible natural gas was desorbed at the shale site of Shanxi formation of well LX2-48, indicating that the area has certain shale gas exploration potential.

Previous research results show that LX block is mainly deposited in sea land transitional facies, the thickness of single layer of shale rich in organic matter is small, and the shale gas content in pure shale is small. It is difficult to develop shale gas in this area by traditional methods. It is necessary to clarify the target section of the study area and find the thin sand layer of shale interlayer Silty sand and mud coated sand layer to expand shale gas exploration results [3][4]. Therefore, it is imperative to systematically carry out the research on the geological characteristics of shale and the analysis of shale gas exploration and development potential in LX District, so as to achieve the replacement of reserves and production capacity, and better solve the problems that the current situation of tight gas exploration and development in the study area is not optimistic, the production decline is fast, the water breakthrough is fast, and the reservoir is difficult to develop.

3. Geological Structure Characteristics

3.1 LX Gas Field and Zijin Mountain Rock Mass

ZiJin Mountain rock body is located in the southeast of LX gas field on the plane, with an area of about 23km2, in the shape of rock barrel and rock bed. The surface surrounding rock of ZiJin Mountain rock mass is grayish green arkose intercalated with red mudstone of Middle Triassic ermaying formation, which is mostly covered by quaternary system. It is distributed radially outward with the high point of Zijin Mountain as the center. Each rock belt is distributed in a "semi ring" and belongs to alkaline complex. The alkaline complex is located at the compound of the nearly East-West 38° line concealed fault and the two groups of NNE faults, so the magma upinvasion position is high, and under the action of melting erosion, it broke through the caprock to produce volcanic eruption and multi-stage activity, as shown in Figure 1.

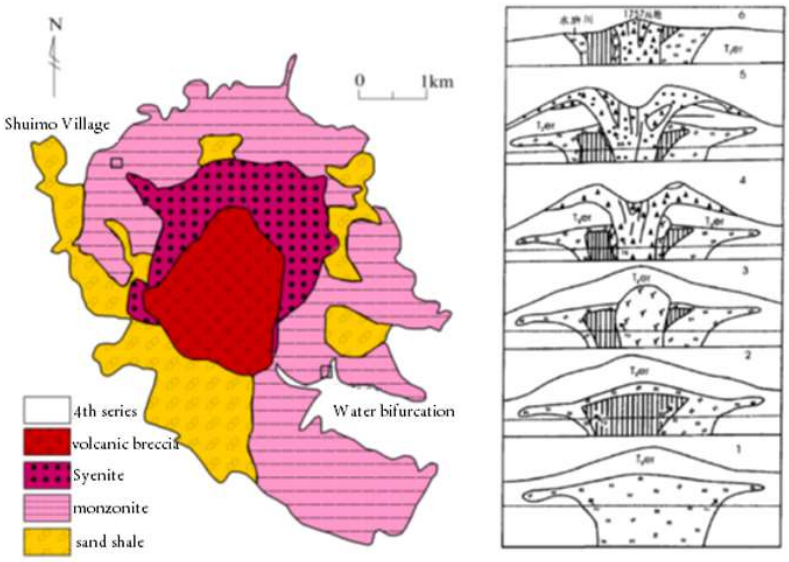

Figure 1. Formation diagram and facies distribution of Zijin mountain rock mass in LX gas field

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The ZiJin Mountain alkaline complex outcropped in the eastern Ordos Basin is the representative of the thermal effect of Yanshan magmatic intrusion in the eastern Ordos Basin. Through field investigation, petrology, petrochemistry, geochemistry and shrimp dating of Single Zircon, it is considered that the middle and deep part of the basin is a meso plutonic intrusive dome type thermal structure, which is the product of point type deep-source magmatic thermal action. The main characteristics are that the magma intrusion has obvious directionality and multi-stage, the horizon is relatively fixed, and the alkaline deep-source magma can invade the Ordovician limestone at low level, and the Triassic strata at medium or high level.

The early Cretaceous magmatic thermal action event belongs to a typical point type middle and deep intrusive extrusive magmatic thermal structure, which represents the deep asthenosphere upwelling event in Luliang mountain area, which is consistent with the early Cretaceous tectonothermal events such as lithospheric thinning and mantle derived magma underplating in North China [5].

Through research, it is considered that the formation of ZiJin Mountain rock mass has the following three effects on LX gas field:

(1) Promoting hydrocarbon generation of source rock

The research shows that the heat dissipation of magmatic intrusion can accelerate the maturation of organic matter in surrounding rock. Affected by the heat dissipation of magmatic intrusion, the reflectance of organic vitrinite in surrounding rock increases sharply, which is much higher than the maturity of normal thermal evolution of sedimentary basin [6].

On the plane, under the same burial depth, the maturity of LX gas field closer to ZiJin Mountain is greater than that of Shenfu gas field in the north, and some LX samples (LX-1, LX-6, LX-23 and LX-27) closer to volcanic dikes have higher maturity, belong to over mature samples, and their ro is higher than 2.0%, indicating that the maturity of coal source rocks increases and hydrocarbon generation is promoted due to the baking of volcanic rocks, As shown in Figure 2. Vertically, the RO of coal seam samples of Shanxi formation is about 1.00%. With the increase of buried depth, the maturity increases slightly. The maturity of coal seam samples of Taiyuan formation is between 1.00~1.20%, and that of coal seam samples of Benxi Formation is between 1.00 ~2.13%. However, the sample of LX-23 well nearest to ZiJin Mountain volcanic vein has the highest RO, indicating that ZiJin Mountain volcanic activity has obvious baking effect on coal seams, Promote the increase of maturity, which is conducive to natural gas accumulation [7].

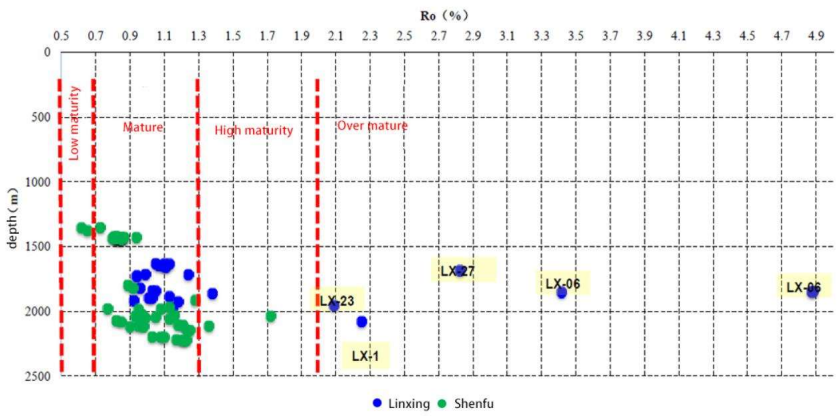

Figure 2. Cross plot of Ro and burial depth of source rocks in LX gas field and Shenfu gas field

(2) Transformation of reservoir

The effect of ZiJin Mountain activity on reservoir reconstruction is mainly manifested in the generation of a large number of fractures. Affected by ZiJin Mountain uplift, the fault system near

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the uplift area is more developed, and the reservoir permeability has been greatly improved. According to the statistical results of reservoir physical properties and distance from ZiJin Mountain rock body of Lower Shihezi Formation in LX gas field, it is found that the average permeability of sandstone reservoir is low near igneous rock, but with the increase of distance from volcano, the average permeability of reservoir begins to increase rapidly, and after a certain distance, the average permeability of reservoir begins to decrease. In general, sandstone reservoir has good permeability (average permeability ≥0.5×10-3μm2) in the range of 3~15km away from igneous rock.

(3) Transport effect on natural gas migration

Sand bodies, faults and fractures are the main channels of natural gas migration in LX gas field, and ZiJin Mountain volcanic activity is the main reason for the development of faults and fractures [8][9]. Faults on the plane of the gas field are mainly developed around ZiJin Mountain, with good inheritance from bottom to top and high degree of superposition. Faults in ZiJin Mountain structural area are distributed in arc and radial shape, with high development density, about 3/ km2; The plane extends about 1 ~7km; The fault pattern on the section is simple, the vertical fault distance is small, and most of them are inclined at an angle of nearly 90°. The development density of faults in gentle structural area is low, about 0.18~0.20 pieces/km2; The extension length is short, about 0.5~5km; The strike is mainly north-south; The property is mainly reverse fault, and some are accompanied by compressive torsional strike slip, as shown in Figure 3.

Many sets of gas bearing sandstones are vertically developed in LX gas field, and three types of reservoir forming combinations of in source, near source and far source are developed. Far source gas reservoirs are mainly distributed in the gently tectonic area far away from ZiJin Mountain, and have obvious correlation with the distribution of local faults. The fault communication caused by ZiJin Mountain activity leads to the migration and accumulation of natural gas in a certain range of endogenous and near source reservoirs in vertical and far source reservoirs. Abnormally high carbon isotope values of methane and ethane appear in the remote reservoir, indicating that rapid reservoir formation has occurred by direct migration from the source to the remote source [10].

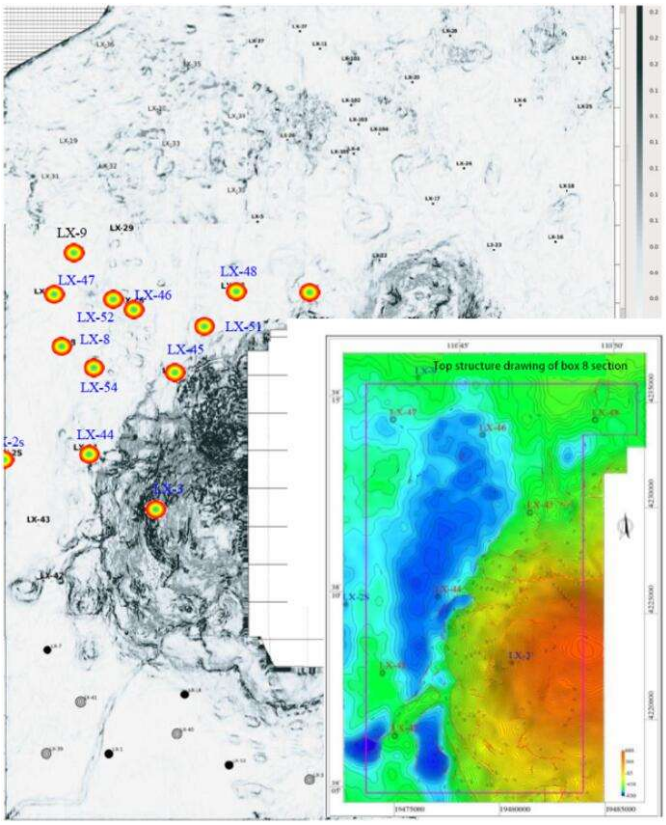

Figure 3. Fracture development characteristics of LX gas field

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LX gas field reservoir was generally dense in the Middle Jurassic, and hydrocarbon expulsion began in the late Jurassic. A large number of natural gas generated by coal measures gradually diffused from the source to the near source, and accumulated in the sandstone reservoir under the cap rock in the middle of SHZ Formation. The intrusion of ZiJin Mountain in the early Cretaceous (138~132Ma) resulted in the development of upper and surrounding faults, the regional caprock was damaged locally, and the source and near source natural gas migrated to the shallow layer along the fault and formed reservoirs at the far source; With the suspension of volcanic intrusion, some faults are closed, and the shallow migration of gas in and near the source is weakened; Since then, the eruption of ZiJin Mountain volcano (127~125Ma) reactivated the pre-existing faults and led to the generation of a large number of new faults, formed the second peak of intra source and near source migration to shallow layer, and led to the destruction of a large number of gas reservoirs at the top and around the volcano. The regional uplift from the early Cretaceous (120Ma) caused the denudation of part of the lower Triassic and a large set of strata above it, which may lead to the reactivation of some early faults, the upward migration of intra source and near source gas reservoirs, and the accumulation and escape in the far source and shallow layers. The tectonic movement in this period mainly affected the fault development area and the far source shallow gas reservoir above the regional caprock.

3.2 Structure and Trap Characteristics

The regional structure of LX gas field belongs to the transition position between Yishan slope and Western Shanxi fold belt in Ordos Basin, and is located in the west of Lishi fault zone, with structural conditions similar to Yishan slope. The regional tectonic background is a wide and gentle regional West dipping large monocline with a slope of 6~10m/km and an inclination of less than 1°.

The structural form of LX gas field has obvious inheritance. Affected by the intrusion of ZiJin Mountain volcanic rocks, the overall structural pattern can be divided into three structural zones: ZiJin Mountain uplift area, ZiJin Mountain gully area and flat gentle slope area, which is generally characterized by high in the East and low in the West. Under the influence of ZiJin Mountain intrusive rock, a local dome anticline is formed. Its faults are relatively developed. The faults are distributed in multiple groups of circular radiation directions. The faults in the block from bottom to top have the characteristics of inherited development. Affected by different in-situ stresses, the fault structural zones in this area are mainly divided into three types: ①the ring ZiJin Mountain fault zone caused by ZiJin Mountain activity; ②Near north-south fault development; ③Small interlayer faults. The overall shape of the northern structure of LX gas field is affected by the NW-SE compressive stress, and the faults are distributed in a nearly north-south direction. The southern part of the study area is affected by the intrusion of ZiJin Mountain igneous rocks to develop dome anticline. The formation fold deformation of the southern dome anticline structural belt is large. The bedding intrusion of igneous rocks increases the local thickness of Ordovician strata, and the fold deformation of overlying strata forms dome anticline.

The north of LX gas field can be divided into four anticline zones from east to west, including LX-6 well zone anticline, LX-102 well zone anticline, LX-30 well zone anticline and LX-19 well zone anticline. Some local traps are developed on each zone, and the traps are mainly low amplitude anticlines. Exploration practice shows that these low and gentle anticline structures do not play a major role in controlling natural gas accumulation, and there is no correlation between gas bearing property and structural height. However, some horizon gas reservoirs in ZiJin Mountain uplift area are destroyed and dissipated by faults, and the productivity is low. Among them, faults are the main channel for vertical migration of oil and gas.

T2 gas reservoir of Taiyuan Formation in LX gas field is mainly controlled by barrier sand bar and tidal channel sand body. The trap genesis is related to lateral pinch out of sandstone and tight lithologic shielding. The comprehensive study shows that the main sand belt of T2 member distributed in the near east-west direction generally contains gas because it is close to the coal measure

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gas source rock. The vertical direction of the main sand belt is controlled by sedimentary microfacies. It changes into lagoon to the north and shallow sea shelf to the south, forming lateral shielding; Vertically, the top of T2 member of Taiyuan formation is composed of thick mudstone and carbonaceous mudstone with three sets of thin coal seams, and the lower part is composed of regional stable coal seams 8#, 9# coal seams, mudstone and carbonaceous mudstone, which form a "sandwich" favorable reservoir cap combination.

Shan 1 gas reservoir of Shanxi formation, H8, H7 and H6 gas reservoirs of Lower SHZ formation, H4, H3, H2, H1 gas reservoirs of upper SHZ Formation and Q5 gas reservoirs of SQF Formation in LX gas field are mainly continental lake delta sedimentary system, which is mainly controlled by river sand body. Reservoir forming and enrichment is related to lateral pinch out of sandstone and tight lithologic shielding. The comprehensive study shows that the main sand belt distributed in the near north-south direction is affected by the difference between sedimentary microfacies and sediment fabric along the strike. The lithology on both sides of the main sand belt becomes dense or changes into distributary Bay facies argillaceous deposits, forming lateral shielding; Vertically, the coal seams, carbonaceous mudstone and dark mudstone of Shanxi Formation and Taiyuan formation, and the thick sandy mudstone and mudstone in each layer series of Shihezi Formation and Shiqianfeng Formation form a good caprock.

Comprehensive analysis shows that argillaceous rock deposits are widely distributed in the vertical direction of each gas reservoir in LX gas field, with obvious reservoir cap combination characteristics, and tight lithology and shielding development in the horizontal direction, which together constitute the lithologic closed gas reservoirs of T2, S1, H8, H7, H6, H4, H3, H2, H1 and Q5 members of the upper Paleozoic.

4. Conclusion

(1) According to the national energy development plan of the 13th five year plan, CNOOC carries out exploration and development for the shale gas reservoir in LX District, Ordos Basin. However, the deposition of this block is dominated by sea land transitional facies, and the shale reservoir is thin and has little gas content. In order to realize the industrialized exploitation of shale gas, It is necessary to deeply study the geological characteristics of shale in LX area and analyze the exploration and development potential of shale gas.

(2) The geological structure characteristics of LX gas field are greatly affected by high-temperature magmatic intrusion. The baking effect of magmatic intrusion on the reservoir can accelerate the maturation of surrounding rock organic matter, promote source rock hydrocarbon generation and facilitate shale gas accumulation; Rock mass intrusion will improve reservoir physical properties, form a large number of fractures and improve average permeability; The volcanic movement resulted in the development of fault structures in the block, which were distributed in arc and radial shape as a whole, promoting the rapid accumulation of near source and far source areas.

(3) The overall structure of LX area is a wide and gentle regional West dipping large monocline. Only near the magmatic intrusion, the stratum rises greatly, forming four low amplitude anticlines that have no significant effect on shale gas accumulation. It is found that the formation of gas bearing traps in this block is due to the lateral pinch out of sandstone and tight lithologic shielding. Based on this understanding, The main distribution horizons of shale gas traps are predicted.

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