Analysis of Reservoir Characteristics and the Same Main Controlling Factors in Gulong Area of Songliao Basin

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Abstract. Due to a breakthrough in the exploration on shale oil in Qingshankou group, the oil layer series in Gulong sag, one of the most significant depressions in Songliao Basin, are once more implemented to be extended in vertical dimension. Its oil-bearing layers in majority are included in sandstone formations such as Heidimiao, Saertu and Putaohua, and shale oil layer in Qingshankou. This paper systematically draws a conclusion on reservoir characteristics of each layer. Under a further study by comparisons, discrepancies have been found out between newly oil layers and the previous ones, achieving a new perception of previous layers, and sequentially providing some basis for new theories visually through a three-dimensional reveal. With a substantial number of data of different layers being applied in the test, a detailed research has been put into practice on mineral constituents, physical characteristics and pore structures, which indicates the mineral constituents of sandstone layers, in formations of Heidimiao, Saertu, and Putaohua, consist mostly of arkose, in the meantime, the reservoir space is formed out of primary intergranular pores in majority and dissolution pores take the second place. Its porosity and permeability tend to descend with the increase in depth, therefore, Heidimiao, which is buried the shallowest, appears to be superior to those formations underneath it in physical properties, of which the permeability changes prominently. However, the shale reservoirs are other than conventional reservoirs, out of which the mineral constituents are mostly clay, intergranular pores, intercrystalline pores and shale bedding fractures can be seen develop and the porosities are inferior to that of sandstones but with a high areal permeability. Overall speaking, the main identical controlling factors that affect the reservoir properties lie in 4 aspects which are environment of sedimentation, grain size, burial depth and diagenetic evolution.

Keywords: Gulong area · Sandstone reservoir · Reservoir characteristics · Main controlling factors

Sandstone reservoir has always been one of the core issues of continental petroleum geology research in Songliao Basin. The theory of "oil generation in mudstone and oil storage in sandstone" has been deeply rooted in the minds of petroleum geologists. In the

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early years, even the research on mudstone reservoirs was limited to mudstone fractured reservoirs, and the mudstone matrix itself was not used as a storage space for research and analysis. Inspired by the success of the shale oil revolution in North America, many countries, including China, have intensified their research efforts in this field in recent years and achieved certain results. The resource evaluation results show that our country is rich in shale oil resources, which are mainly distributed in Songliao Basin, Ordos Basin, Junggar Basin and Sichuan Basin etc. However, the shale oil in Songliao Basin is different from the shale oil in other countries and other domestic oil fields. It not only achieved success in interbedded and sandwich-type shale oil, but also made major breakthroughs in pure mud shale oil exploration [1].

Oil and gas exploration in Gulong area of Songliao Basin has been started since 1960s. Many important discoveries and good exploration achievements have been obtained in decades of exploration. Sandstone reservoirs such as Heidimiao, Saertu and Putaohua are the main oil reservoirs explored in the past. Nowadays, the achievements of pure mud shale oil exploration have broken through the traditional petroleum geological theory on the understanding of reservoirs, and also expanded the vertical oil-bearing series in Gulong area. This article will compare and analyze the reservoir characteristics of each oil layer, which can not only deepen the understanding of the reservoir in the study area, but also re-understand the new and old oil layers. Finally, the common influencing factors of different reservoirs are analyzed and summarized, which can effectively guide the next exploration and provide a basis for new theoretical.

1 Geological Survey

Gulong area is located in the southern part of Qijia-Gulong sag in the central sag of Songliao Basin (Fig. 1). The study area includes Gulong sag and several nose structures, and they are Puxi nose structure, Xinzhao nose structure and Da'an nose structure etc. Many oil fields were developed around the study area, which make great contribution to the oil production in Songliao Basin [2]. There are not only several sets of source rocks developed in Gulong area, which is favorable oil generation sag in the basin, but also several sets of good reservoirs (Fig. 1). In previous oil and gas exploration, industrial oil flows have been found in HeidiMiao, Saertu, Putaohua, Gaotaizi and Fuyu reservoirs. Due to the influence of traditional petroleum geology theory and technological development level, previous studies on reservoirs in this area have mainly focused on the sandstone reservoirs and mudstone fractured reservoirs as mentioned above. However, a major breakthrough has been made in the exploration of shale oil in Qingshankou group with theoretical breakthroughs and technological innovations in recent years, and oil-bearing layers have been expanded vertically. The achievement of Gulong Shale Oil has broken through the traditional petroleum geology theory on the understanding of reservoirs. The exploration results show that there are not only sandstone reservoirs but also shale reservoirs in different oil layers in Gulong area.

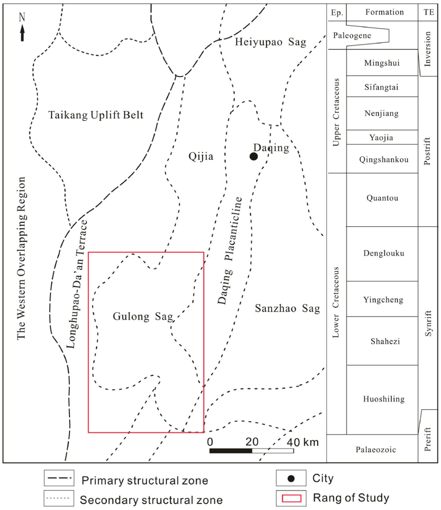


Fig. 1. Stetch map of structural units and stratigraphic column in the part of northern Songliao Basin

2 Reservoir Characteristics

2.1 Reservoir Sedimentary Characteristics

Lacustrine and deltaic sedimentary systems are the main types of sedimentary systems in the target strata of Gulong area, Songliao Basin. Qingshankou sedimentary period is the lake flooding period, and the bottom-up is the regressive sedimentation process. A wide range of semi-deep-deep lacustrine facies have formed. The semi-deep-deep lacustrine facies developed in the first section of Qingshakou has the largest scale, and that has laid a good sedimentary environment foundation for the formation of shale oil. The lithology of Qingshankou group is mainly shale, mudstone, siltstone, limestone and dolomitic rock. During Putaohua oil layer deposition period, Songliao Basin regressed to its maximum. As the western and northern delta sedimentary systems both advanced far into Gulong sag, the source supply of Gulong sag was sufficient, and extensive delta front subfacies have developed. The sand bodies are mainly deposited in underwater distributary channels, estuary dam, and sheet sand micro-lithofacies. The lithology is mainly siltstone, argillaceous siltstone, and silty mudstone. During the deposition of the Saertu oil layer, the gradual expansion of the lake basin and the formation of the delta front deposit of the water-ingress type due to the deepening of the water body. From west to east, the delta front subfacies underwater distributary channel, estuary dam and sheet sand micro-lithofacies develop in sequence, and the facies to Gulong sag become semi-deep-deep lacustrine mudstone. The overall lithology is mainly siltstone, argillaceous siltstone and mudstone. The deposition period of the Heidimiao oil layer is controlled by the northern sedimentary system. The reservoir is dominated by the subfacies of the delta front subfacies underwater distributary channel, estuary dam, and sheet sand deposition, and the sandstone is thinned or pinched to the west and southwest. The lithology is mainly fine sandstone, siltstone, argillaceous siltstone and mudstone.

2.2 Petrological and Mineralogical Characteristics of Reservoir

The reservoirs of Heidimiao, Saertu and Putaohua oil layers are mainly sandstone reservoirs, and the clastic components mainly include quartz, feldspar and lithiclast. The sandstone reservoir of each reservoir has the general characteristics of relatively low quartz content medium feldspar content and high lithiclast content. The rock types of sandstone reservoirs in the study area are mainly feldspathic lithic sandstone and lithic feldspathic sandstone. The shale oil reservoir of Qingshankou is mainly shale reservoir, and its rock and mineral composition mainly includes quartz, feldspar and clay. The contents of quartz and clay minerals in the shale reservoirs of the first member of Qinshankou are both higher, generally higher than the content of feldspar, while the contents of quartz and feldspar in the shale reservoirs of the second member of Qingshankou are higher, generally higher than the content of clay minerals. As a whole, felsic shale is the main rock type, followed by mixed shale and carbonate shale, and almost no clay shale (Fig. 2) [3].

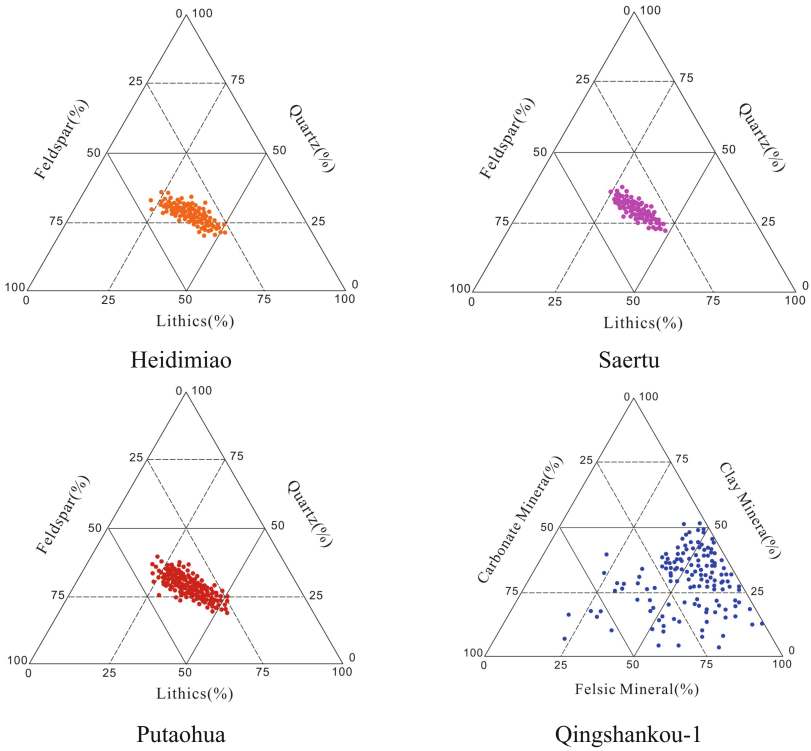


Fig. 2. Triangle map of sandstone composition of different oil layers in Gulong area

2.3 Reservoir Types and Characteristics

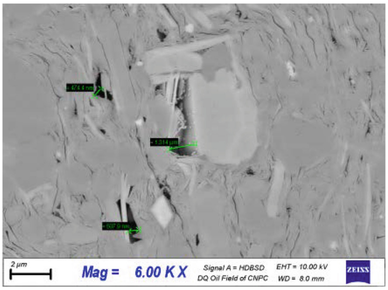
Comprehensive application of core observations, microscopic observation of cast thin sections, field emission scanning electron microscopy, and NMR techniques to analyze the types of reservoirs in multiple oil layers in Gulong area. There are mainly three types of pores in the shale reservoir space of Qingshankou group, and they are micro-nano-scale intergranular pores, intercrystalline pores, and shale bedding fractures [4]. The sandstone reservoirs of Putaohua, Saertu and Heidimiao oil layers are dominated by residual primary intergranular pores, followed by silicate granular dissolved pores (especially feldspar dissolved pores), including intragranular and marginal dissolved pores and mold hole (Fig. 3).

According to the distribution interval, the data distribution law of porosity and permeability measured after drilling in the study area is calculated. The results show that different samples and different layers have different distribution frequencies in different intervals. The shale reservoir of Qingshankou group has a total porosity of 2–12%, with an average of 7.9%, and its effective porosity is 2–8%, with an average of 3.7%. Affected by lithology, there are mainly mesopores (2–50 nm) and a small number of macropores (pore size > 50 nm), and alao micro-fractures appear locally [5]. The reservoir porosity of Putaohua oil layer is 5–20%, which belongs to medium to ultra-low porosity. The permeability of Putaohua is 0.04–190 $\times$ 10−3 μm^2, which belongs to the medium to non-permeable layer. The reservoir porosity of the reservoir in Saertu oil layer is 7–21%, which belongs to medium to ultra-low porosity, and the permeability is 0.1–282 $\times$ 10−3 μm^2, which belongs to medium to ultra-low permeability layer. The reservoir porosity of Heidimiao oil layer is 9–25%, which is from mesoporous to ultra-low porosity, and the permeability is 0.1–700 $\times$ 10−3 μm^2, which belongs to the high-permeability to ultra-low permeability layer. The physical properties of the Heidimiao reservoir is better than those of Putaohua and Saertu reservoirs, and the permeability is particularly obvious. This phenomenon shows that the physical properties of the reservoir gradually get better from deep to shallow.

3 Main Controlling Factors of Multi-reservoir

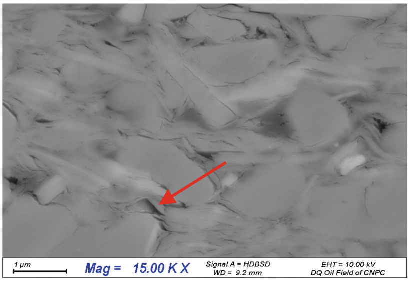
3.1 Sedimentary Environment and Facies

Sedimentary environment and sedimentary facies control the lithology distribution in the study area, and then affect the reservoir properties. According to the previous study, Qingshankou group is mainly developed by semi-deep-deep lacustrine facies. The large distribution of lacustrine facies controls the distribution of shale oil reservoirs in the study area. The lithology is dominated by large sections of mudstone and shale. Putaohua, Saertu and Heidimiao oil layers are controlled by delta sedimentary system, which mainly develop underwater distributary channle, estuary bar, sheet sand and other sedimentary micro-lithofacies. These sedimentary facies control the distribution of sandstone reservoirs. Studies show that the sedimentary facies not only control the lithology distribution of the reservoir, but also control the grain size, the content of interstitials and the type of clay minerals, thus controlling the reservoir properties. In the delta sedimentary system, the reservoirs of estuary bar and distributary channel sand body have the best



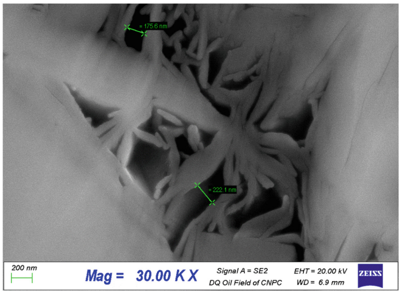
Intergranular Pore

Qingshankou-1



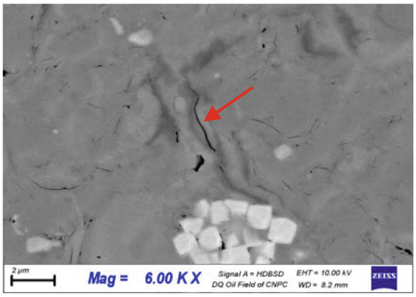
Intercrystalline Pore Of Clay Minerals

Qingshankou-1



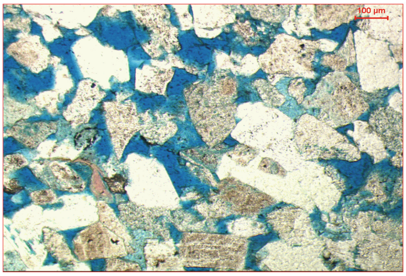
Intercrystalline Pore Of Clay Minerals

Qingshankou-1



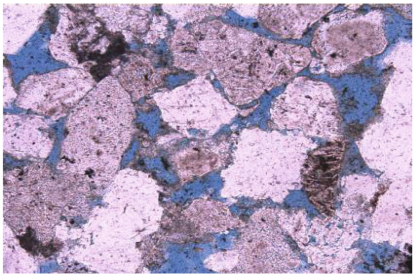
Shale Bedding Fractures

Qingshankou-1



Primary Intergranular Pore

Putaohua



Granular Dissolved Pores

Putaohua

Fig. 3. Types of sandstone and shale reservoirs in Gulong area

properties, followed by distant sand bar-sheet sand [6], and those are generally better than the siltstone reservoirs and shale reservoirs of semi-deep-deep lacustrine facies.

3.2 Grain Size

Grain Size is an important factor affecting the properties of sandstone and shale reservoirs. The physical property data of different horizons and different particle sizes in the study area were collected and the histogram of the relationship between different particle sizes and average porosity and permeability was compiled. Siltstone reservoirs are developed in different oil layers, but the distribution of silts-fine stone and fine sandstone is quite different. Therefore, siltstone is the representative of different oil layers for analysis and characterization. It can be seen from the figure that as the grain size gets coarser, porosity and permeability also get better correspondingly. The change of porosity with different grain size drops from more than 20% to less than 10%. In the sandstone reservoir, the porosity of fine sandstone is the largest, while that of siltstone is the smallest, and shale reservoirs are also less porous. The impact of particle size on permeability is greater than the impact on porosity. There is an order of magnitude difference between the permeability of different grain size [7]. It should be noted that the lateral permeability is significantly greater than the longitudinal permeability due to the development of shale shale, so the permeability of shale does not participate in the comparative analysis. The above shows that the grain size has a decisive control effect on the reservoir properties. In addition, the physical properties of the shallow Heidimiao oil layer with the same grain size are significantly better than those of the deep Saertu and Putaohua oil layers (Fig. 4–Fig. 5).

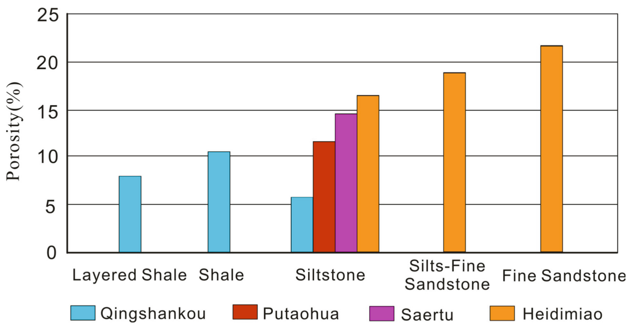


Fig. 4. Histogram of the relationship between grain size and average porosity

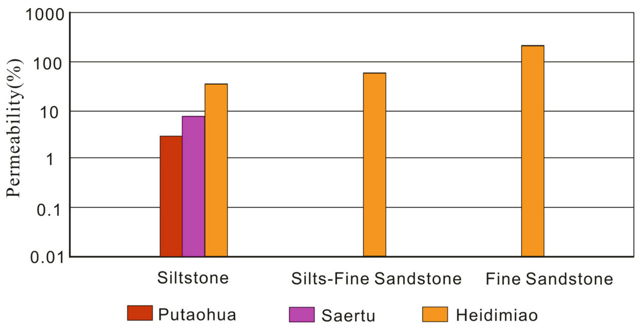


Fig. 5. Histogram of the relationship between permeability and average porosity

3.3 Burial Depth

In general, the physical properties of the reservoir will become worse as the burial increases. The buried depth of the top interface varies greatly in different areas of the study area, for example the buried depth of the top interface of Heidimiao is 650–1600 m, the buried depth of the top interface of Saertu is 1150–2050 m, the buried depth of the top interfac of Putaohua is 1250–2100 m, and the depth of the top interface of the first section of Qingshakou is mainly 1700–2560 m. The change of burial depth leads to the different diagenetic compaction intensity of reservoir, which affects the physical properties of reservoir. The relationship between burial depth and porosity or permeability can be seen that the physical properties of reservoirs of the same grain size become worse with the increase of burial depth, and the burial depth controls porosity better than the permeability. For controlling effect, burial depth is negatively correlated with porosity, and negatively correlated with permeability (Fig. 6, Fig. 7). The physical properties of shallow-buried reservoirs are significantly better than those of deep-buried reservoirs. For example, the physical properties of Heidimiao oil layer are significantly better than those of Putaohua oil layer. Shale reservoir of Qingshankou group in buried depth is less than 2000 m also have the same change trend, but when the buried depth of more than 2000 is different, the porosity increases with burial depth. There are two peaks around 2100 and 2380 m (Figs. 3, 4, 5, 6, 7 and 8). It is concluded that the contribution of these two peaks mainly comes from the dissolution pores produced by organic acid action and the organic pores produced by hydrocarbon generation [4]. In general, whether it is a sandstone reservoir or a shale reservoir, the buried depth also has an important effect on the properties of the reservoir.

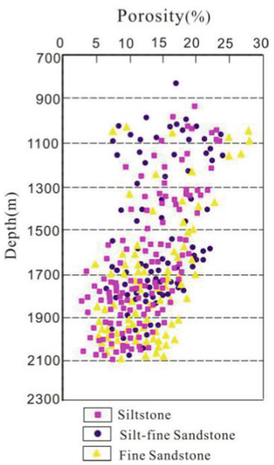


Fig. 6. Graph of buried depth and porosity in Putaohua, Saertu, and Heidimiao reservoirs

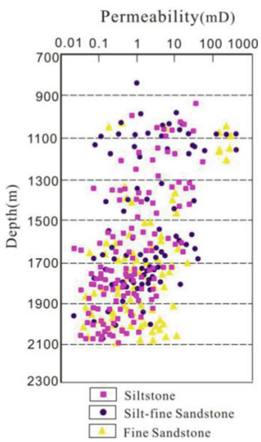


Fig. 7. Graph of buried depth and permeability in Putaohua, Saertu, and Heidimiao reservoirs

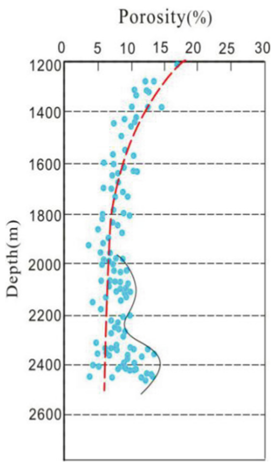


Fig. 8. Graph of buried depth and porosity in Qingshankou reservoir

3.4 Diagenetic Evolution

Diagenesis evolution has varying degrees of influence on sandstone reservoirs and shale reservoirs. The division of diagenetic stages is closely related to Ro, and usually the buried depth can establish a certain functional relationship with Ro. The Heidimiao oil layer is the shallowest buried, and its top surface is between 650 and 1600 m deep. It is in the early stage B to the middle stage A of diagenesis. The top burial depth of other oil layers is generally below 1150 m, and they are in the A phase of the middle diagenetic stage. The top surface of Qingshankou group can be buried at a maximum depth of about 2600 m, most areas are in the middle diagenetic stage A, and some are in the middle diagenetic stage B. When the shale reservoir of the Qingshankou group entered the early stage B of early diagenesis, due to the rapid conversion of the illite/smectite layer to illite, the lamellar clay minerals contracted along the shale, resulting in the formation of a large number of shale bedding fractures. In the mid-diagenetic rock A2 period, it enters the peak of hydrocarbon generation, and a large number of organic slab fractures may also be formed. The existence of shale fractures effectively improves the storage capacity of shale. The pore type of sandstone reservoirs in Gulong area is dominated by residual intergranular pores. As the depth of burial deepens, diagenesis gradually strengthens, resulting in the modification of residual intergranular pores by diagenesis, which complicates the pores of sandstone. Heidimiao oil layer is mainly in the early diagenetic stage, and there are a lot of primary intergranular pores in the reservoir. However, as the burial depth increases, the pressure of the overlying formation increases gradually, causing the loss of primary pores and fewer secondary pores. As the overburden pressure increases with the increase of burial depth, primary pores are gradually lost, but there are fewer secondary pores at this stage. Saertu and Putaohua oil layers are mainly in the middle diagenetic stage A. Secondary pores such as dissolution pores have greatly improved the pore condition of the reservoir. Due to the increase of secondary pores, a secondary pore development zone is formed. However, as the burial depth further increased, to the late stage A of the middle diagenesis, the pores continued to decrease due to more precipitation of authigenic minerals at this stage, and only a small amount of secondary pores existed at this stage. Comprehensive research shows that different diagenetic evolution stages have different degrees of influence on sandstone reservoirs and shale reservoirs.

4 Conclusion

(1) There are sandstone and shale reservoirs longitudinally in Gulong area of Songliao Basin. The oil layers of Heidimiao, Saertu and Putaohua mainly develop sandstone reservoirs controlled by delta facies, and Qingshankou group mainly develops shale reservoirs controlled by semi-deep -deep lacustrine facies;
(2) Sandstone reservoirs are dominated by residual primary intergranular pores, followed by secondary dissolution pores. Shale reservoirs are dominated by intergranular pores, intercrystalline pores and shale bedding fractures;
(3) There are four aspects of the same controlling factors for the properties of sandstone reservoirs and shale reservoirs of different layers in Gulong area., they are sedimentary environment and sedimentary facies, grain size, burial depth, and diagenetic evolution.

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