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Geologic Characteristics of Reservoir Accumulation in Suganhu Depression in north margin of Qaidam basin

Cheng Zhang[1, a], Guang Yang[1], Yongshu Zhang[2, b]

[1] College of Earth Science, Jilin University, Changchun Jilin, 130061, China

[2] Qinghai Oil Field Company, Petro China, Dunhuang Gansu, 736202, China

[a]bong1986@126.com; [b]zysqh@petrochina.com.cn

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Abstract. Based on the analysis and testing data of rocks, the basic geologic characteristics of Suganhu depression is discussed. It is concluded that the 200m thickness dark mudstone of inshore shallow lake face in the middle–lower Jurassic stratum is the only source rock of this region. It has the characteristics of high abundance of organic matter and in high mature stage. And the type of organic matter is II_2.The reservoir properties is controlled by the influences of both the sedimentation and the diagenesis and belong to the low porosity and low permeability ones. The mudstone of Upper Jurassic is the local cap, the ones of braided river face and braided river delta face which existed in the up-middle of the middle Jurassic can be qualified as sealing bed between the sand bodies. Paleocene–eocene mudstone is the regional cap rock. The ability of upper Jurassic sealing bed is good because of the low porosity and permeability and high break pressure. The regional cap rock has the characteristics of big thickness and large area. Both the local and regional cap rock had been able to seal the petroleum and gas before the time of hydrocarbon accumulation of middle Jurassic. In general, Mesozoic formed reservoir–cap combination with the features of lower–generation and upper–reservoir, upper–cap.

Introduction

The Suganhu Depression is a sub-first order tectonic unit of the north margin of Qaidam Basin, which are located in the northwest of the north margin of Qaidam Basin. In the north of it, it is the junction of Altun Mountain and the Danghenan Mountain, and in the south, it is the Dasaishiteng and the Xiaosaishiteng Mountain, in the southeast it is the north of Tuergendaban Moutain. The area of depression is 7000km^2 of which mesozoic area is 638km^2.The east part of the mesozoic is 183 km^2, and the west part is 453 km^2(Fig 1). The depression has complete formation which is Middle Jurassic series Dameigou Formation (J_2);Upper Jurassic series Hongshuigou Formation(J_3); Paleocene-Miocene series Lulehe Formation; Oligocene series Xiaganchaigou Formation(E_3); Miocene series Shangganchaigou Formation (N_1); Pliocene series Xiayoushashan Formatione (N_2^1); Pleistocene series Qigequan Formation (Q_{1+2}). The deepth of Middle Jurassic series in Sutan1 is 2500-2878m, and it is 2135-2622m in Sucan1 which exist oil core 9.38m in 2552.93-2716.75m.

Because the lack of exploration data of the west part of mesozoic area, the geologic characteristics of reservoir accumulation in Suganhu Depression is discussed on base of the research on the east part.

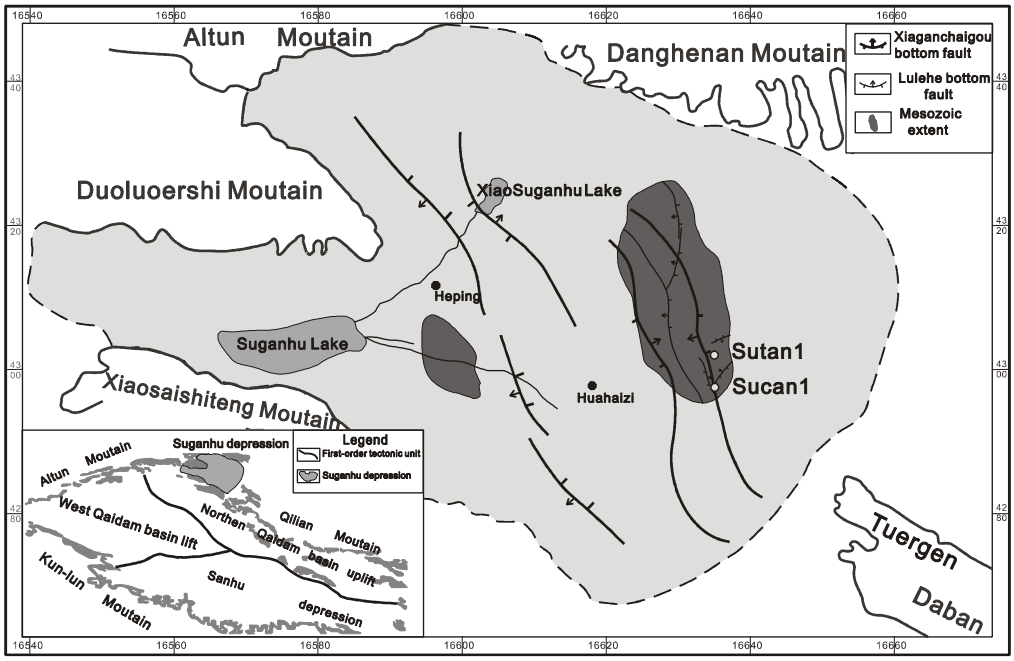

Fig.1 Geographic location of Suganhu Sag

Tectonic and sedimentary evolution

The regional tectonic evolution shows that tectonic evolution of North Margin of Qaidam Basin depends primarily on India-Eurasia plate collision, Altun strike-slip fault and Qilianshan uplift [1].

In the early Jurassic, Tarim block moved eastwards relative to the Qaidam block, so tectonic environment of North Margin of Qaidam Basin converted from extensional environment to compressional environment [2]. At the same time, the Altun fault dextral strike-slipped, and it got bended at the paleo-uplift and the pressure released results in pull effect, and formed Suganhu rift. The drilling data of Sucan 1 illustrates that gray-black mudstones mingled with gravel sandstone at the lower Middle Jurassic directly covered above the weathering crust. With the range expansion of deposition and crustal subsidence, it deposited a set of lacustrine dark mudstone in the rift, which becomes the most significant source rocks in Mesozoic. The drilling data of Sucan1 illustrates that gray-black mudstones mingled with gravel sandstone at the lower Middle Jurassic directly covered above the weathering crust. Coal seam appears at upper part with miscellaneous colors, which shows the sedimentary characteristics of a sudden subsidence followed by rapid filling. With the range expansion of deposition and crustal subsidence, it deposited a set of lacustrine dark mudstone in the rift, which becomes the most significant source rocks in Mesozoic. In the late Jurassic, the Mesozoic sedimentary area converted from rift to depression affected by the early Yanshan Movement. A formation which is mainly composed of inshore shallow lake face clastic rocks was formed under dry and hot climate environment at this period. In early Cretaceous, the movement of Yanshan Movement Ⅳ leads to continued uplift in bruchfaltung mountain of the southern Qilian Mountain and the evolution of thrust and nappe tectonic belt, the corresponding local fault-fold structures are damaged and transformed, some Mesozoic N-NW towards bruchfaltung is formed at the same time [3]. At this period, the depression formation uplift and suffered extensive erosion, which results in the complete erosion of 380m Cretaceous formation formed before.

At Paleocene – Oligocene, the depression is less affected by Altyn Tagh fault, under the condition of NE-SW trending compressive stress, in which compressional deformation is dominant. At Ancient Pliocene, Altyn Tagh fault begins to turn to sinistral strike-slip [4], in which deposition of magnitude is large at this stage, and Alluvial fan –river-flood plain facies is the key sedimentary facies. At Oligocene, stratigraphic thickness changes gently with a low tectonic intensity. At Early Miocene, with the increasing regional compressive stress, the western and southern of depression becomes more active. The maximum thickness in Xiayoushashan Formation appears in the middle

of the depression. The Qinghai-Tibetan Plateau gets into the period of accelerated uplift in Late Miocene – Pliocene. Accompanied by the rise of mountains around, deposition is lost due to the erosion of strata.

Source rocks Characteristics

Source rocks have been only found in Middle Jurassic formation. Middle Jurassic Dameigou deposition can be roughly divided into three sections from below：In Sutan 1, for example, depth range of Middle Jurassic is 2500-2878m (not bottomed), in which the upper segment (2500-2647m, J_2^3) is fluvial sandstone and reddish brown mudstone, sandy mudstone and siltstone; The middle segment(2647-2705m，J_2^2) is delta front -plain facies of gray siltstone, sandstone, brown red gray mudstone; The lower segment is lacustrine mudstone, carbonaceous mudstone, siltstone and sandy mudstone. 46.66% of drilled stratigraphic thickness of Middle Jurassic is occupied by well-developed dark mudstone in lower segment, in which dark gray lacustrine mudstone occupies 119m, gray and black carbonaceous mudstone occupies 54m. Burial depth of Sucan1 formation of J_2 at present is 300m shallower than that of Sutan1.However,the thickness of the Jurassic lacustrine facies mudstone is 2 times deeper. It represents that the segment of Sucan1 is deeper than that of Sutan1 in geological time.

By the study of seismic profiles and tectonic evolution history, it is demonstrated that the situation now is due to the large-scale extrusion uplift which is significantly affected by the later tectonic movement.

The data of resource rock of 2300.5m-2308.5m in Sucan1 the average value of Ro, H/C, IH and degradation is 29.86%, 1.14, 291.64mg/g, 25.73% respectively. Based on the divition and evaluation criteria of types of organic matter in the North margin of Qaidam Basin [5],the type of organic matter is Ⅱ_2.

Based on China's evaluation criteria of source-rock richness of continental facies. It is believed that Middle Jurassic lacustrine mudstone is good source rocks, however, carbonaceous mudstone are all non-hydrocarbon source rocks.

Table1 Middle Juaasic source-rock richness of Suganhu depression

Well location	Lithology	TOC[%]	S_1+S_2[mg/g]	"A" [%]	HC[ppm]
Sutan1	carbon mudstone	2.05/5	5.69/3	0.083/5	—
Sucan1	Lacustine mudstone	1.86/3	—	0.104/3	756.33/3
	carbon mudstone	2.28/16	9.36/9	0.08/7	446.85/7

Take into account of maturity of organic matter, Ro value of measured lacustrine mudstone distribute in the range of 0.61-0.79%; T_{max} distributes in the range of 435-449 ° C, which indicates that source rocks is just in the high evolution degree[6].

Steroid parameters C29ααα-20S / (20S +20 R) value is another reliable basis for judging the maturity of organic matter. Immature organic matter C29ααα-20S / (20S +20 R) value is generally less than 0.25, the value between 0.25-0.4 means low mature organic matter, the value between 0.4-0.55 is called mature organic matter [7]. Middle Jurassic source rocks sterane C29ααα-20S / (20S +20 R) ratio mainly concentrated in the range of 0.45-0.59, according to other maturity parameters, it can be concluded that the source rocks are in the generation peak period.

In summary, organic matter is very abundant in Middle Jurassic lacustrine source rocks of Suganhu depression, the type of organic matter is Ⅱ_2, and is in the generation peak period which is good source rocks.

Reservoir characteristics

3.1 Reservoir physical characteristics. At Mesozoic， Suganhu depression experienced a large-scale process of water regression. The region of sutan1 and sucan1 is gradually transit from shallow lake facies at Middle Jurassic period to Braided River faceis at Late Jurassic period. The lithology of Middle Jurassic reservoir is mainly gray, gray-green siltstone and sandstone of delta and river facies.

The reservoir rock porosity distributes between 2.0% -11.6%, the penetration rate distributes between $0.05 \times 10^{-3}\mu m^2$-$10.3 \times 10^{-3}\mu m^2$ between (Table 2), in which 50% of the samples belongs to the reservoirs of low to ultr-alow pore permeability, and the rest belongs to the low porosity and low permeability reservoirs. The type of reservoirs porosity is mainly belongs to capillary interstice, and the kind of surplus primary intergranular pore and secondary dissolution pore. The pore structure is mainly the one with small pore and thin throat. The overall reservoir capacity and permeability is poor. It should be noted that development of fractures reaches medium permeability at sample 2578.56m, and the development visible cracks significantly improves percolation capacity.

Table 2 Value of Reservoir Physical Property of Middle Juassic of Suganhu depression

Deepth [m]	Porosity [%]	Permeability [$10^{-3}\mu m^2$]	Deepth [m]	Porosity [%]	Permeability [$10^{-3}\mu m^2$]
2553.92	11.6	1.82	2581.00	6.0	0.16
2554.28	12.8	1.20	2581.24	5.0	＜0.05
2556.83	6.6	0.15	2582.25	7.3	＜0.05
2557.03	6.7	0.12	2582.40	2.1	0.96
2558.33	3.5	＜0.05	2582.59	2.3	＜0.05
2558.45	5.6	0.05	2582.90	2.5	＜0.05
2578.35	2.0	＜0.05	2583.23	3.9	＜0.05
2578.56	2.9	10.3(crevice)	2621.49	8.4	0.078

3.2 Main controlling factors of reservoir property. Judging from the distribution characteristics of sedimentary facies, sand body develops as underwater distributary channel and river floodplain facies. Mesozoic depression develops a set of low porosity and low permeability reservoirs, there are two reasons as follows:

(1)Tectonic activity of Jurassic depression is not intense, so it is deposited under the hydrostatic environment, and rich in aquatic and terrestrial plants. In the deposition process or the early stage of diagenesis, the plants quickly decompose and generated humic acid, which forms acidic environment. The acidic environment leads to the difficulty to form precipitation of cements under the conditions of carbonate, sulfate, silicate and alkaline, so cemented filling of minerals, calcite, gypsum, silicate is insufficient at early diagenetic deformation. At the same time, because of the lack of support of cement particles, sediment compaction degree is developed, which contributes to the formation of low porosity and low permeability reservoirs [8].

(2)Diagenesis is the key factor to determine the reservoir properties. Division of diagenetic stages are mainly based on maturity of organic matter, combination of clay minerals, type of rock pore, etc. The study shows that the value of Ro at Mesozoic reservoirs formation distributes in the range of 0.61-0.84, average value of maximum pyrolysis peak temperature is 447℃,which indicates that organic matter has reached a mature stage; Sandstone clay minerals are mainly contained of illite, smectite percentage(C/S) and chlorite; diagenesis environment is in the freshwater - brackish water environment. Types of sandstone porosity are mainly surplus primary intergranular pore and secondary dissolution pore.

According to criterion of clastic diagenetic stage (SY/T5477-2003), diagenetic stage of Middle Mesozoic reservoir is in late stage of A-substage of middle diagenesis [9].However, due to the intensive reservoir compaction activity. The contact relationship is mainly lined intergranular

contacts, and part is concave-convex contact, which leads to the continuous shrinkage of primary porosity in reserviors. Most of the primary porosity tends to disappear, permeability deteriorates.

Characteristics of cap rocks

Based on hydrocarbon exploration in this depression, hydrocarbon show just appears at Middle Jurassic stratum. The mudstone of Jurassic and Paleocene-Miocene forms the cap of hydrocarbon reservoir.

According to classification statistics of rocks, upper Jurassic lithology is mainly reddish brown, brown mudstone and sandy mudstone, which are all without the ability of hydrocarbon generation. Overall, not only total thickness but also continuous single-layer thicknesses of mudstone are all large (Table 3), which is local cap of Middle Jurassic. The thickness of sandy mudstone in Sutan1 is 125m with the similar thickness of mudstone, both mudstone deposits is interbeds frequently. But in Sucan 1，The sandy mudstone content is extremely low with large segment of continuous mudstone deposition. This phenomenon is related to dereliction in depression at Mesozoic, Sucan1 stratum is closer to the deeper side at this period, so particle size of sediment is much finer. It can be inferred that the sealing ability of cap rock at upper Jurassic possibly has a trend of gradual deterioration from south to north.

Table 3 Data of mudstone thickness of Suganhu Depression

Well location	Formation	Thickness(m)	Thickness ratio of mudstone and formation (%)	Maximum continuous thickness(m)
Sucan1	E_{1+2}	371	78	43
	J_3	223	80	53
	J_2^{2+3}	108	40	19
Sutan1	E_{1+2}	116	27	30
	J_3	194	23	10
	J_2^{2+3}	76	40	23

Gray-green, gray mudstone and sandstone of delta-front facies and alluvial flat facies in middle and upper Middle Jurassic, which can form sealing bed between sand reservoirs.

Lulehe Formation (Paleocene-Miocene) is regional cap rock of The North Margin of Qaidam Basin. From a macro perspective, both Lulehe Formation of Sucan1 and Sutan1 develop into thick formation of reddish brown tan, mudstone and silty mudstone, in which mudstone in Lulehe Formation of Sutan1 is mainly sandy mudstone, 144m of 290m mudstone is sandy mudstone, and mudstone is concentrated in middle and upper section of this formation with thickness of 146m. In Sucan1, it is mainly mudstone with thickness of 371m (Maximum continuous thickness is 43m). based on the estimation of seismic profiles of Mesozoic in east region of the depression , the distribution area in eastern depression of Lulehe Formation is larger than 900km^2, which can play a role in sealing due to the wide range of distribution.

Mudstone in Middle Jurassic is relatively compact, in which the cracks does not developed. Due to the measured data of mudstone, mudstone porosity and permeability of sealing bed at Middle Jurassic are relatively low (Table 4). According to Zuyou Deng's evaluation criteria of sealing ability of natural gas cap, the porosity and permeability conditions of cap rocks get at good standard.

Table 4 Property of Sealing bed in J2 of Sutan1

Deep [m]	Permeability [$10^{-3}\mu m^2$]	Permeability [%]	Breakthrough pressure [Mpa]	Diffusion Coefficient [cm^2/s]
2557.2	0.0028	1.9	10.22	9.30E-6
2559.0	0.0055	2.2	17.03	3.22E-5
2716.0	0.0326	1.0	11.46	3.72E-5

Breakthrough pressure is the most intuitive and effective parameters for reflecting the sealing ability of cap rocks, the test data in laboratory is breakthrough pressure under the condition of kerosene saturation in room temperature, which does not match with the actual subsurface conditions. Therefore, the author calibrates the experimental data [11], and translates into breakthrough pressure which under the condition of water displacement underground. The results show that the cap rock has the characteristics of high breakthrough pressure which can reach 10Mpa. The sealing property is well, but with large diffusion coefficient and weak sealing ability for natural gas. Effectiveness of physical property sealing means that before the underlying source rock reaches peak period of hydrocarbon generation and expulsion, whether cap rocks has sealing ability. Based on the burial history of source rock in Dameigou Formation. The source rock begins to enter the mature stage at mid-late of Eocene, most of source rocks in pale-synclines begins to generate a large number of oil at Oligocene [12]. Combined with research of neighboring regions [13-14], it is believed preliminarily that the accumulation time of Middle Jurassic oil and gas reservoirs is Oligocene and Pliocene. By comprehensive statistical analysis of oil and gas fields' cap rock at home and abroad. The shallowest depth to seal oil and gas is 500m[15]. Study of burial history to Sucan1 shows that at these two periods - Upper Jurassic and Paleogene, cap rock all reach the shallowest depth to seal the oil and gas.

Source reservoir cap assemblage

According to geological characteristics of Mesozoic hydrocarbon accumulation. It is considered that Mesozoic develops a source reservoir cap assemblage of bottom generation and upper storage, in other words, coastal shallow-lake facies mudstone is the main source rock at lower of the middle Jurassic on which, deltaic and fluvial sandstone, siltstone constitutes the reservoir. Argillaceous rocks between sand developed are considered as directly sealing bed. Red brown and brown mudstone of fluvial and alluvial fan facies which developed at Upper Jurassic formed the local cap rock of Middle Jurassic reservoir. Paleogene Lulehe Formation mainly contains reddish brown, light brown, brown mudstone and sandy mudstone. As a regional cap rock, average thickness of argillaceous rocks is 400m .

Conclusions

(1) Hydrocarbon source rocks are lacustrine mudstone. At Middle Jurassic coal-bearing strata. Abundance of organic matter in source rock is high; the type of organic matter is Ⅱ2 within the high mature stage. Comprehensive evaluation of this source rock is good.

(2) Type of reservoir space in reservoir layer is mainly residual primary pore and secondary pore, which belongs to low porosity and low permeability reservoirs. The reason to this condition is the lack of cementation and filling in coal measure strata which lead to the trend of sediment compacting. In the late diagenesis, because of the narrow pore, dissolution did not play much role in the improvement of reservoir properties.

(3) The mudstone of Jurassic and Paleocene-Miocene forms the cap of hydrocarbon reservoir in which Upper Jurassic mudstone is local cap rock, Paleocene-Eocene mudstone is regional cap rock. The upper Jurassic is consisted of thick mudstone. The top of middle Jurassic interbed mudstone and sandstone can be considered as sealing bed between reservoir layers. Cap rock of mudstone of Lulehe Formation distributes widely with large thickness. In time, Upper Jurassic and Lulehe Formation have reached reach the shallowest depth to seal the oil and gas before hydrocarbon accumulation of oil and gas in Jurassic, which is effective for sealing of oil and gas reservoirs

(4) Types of source reservoir cap assemblage are mainly bottom generation and upper storage, upper seal.

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