Characteristics of Chang 6 Tight Reservoir in Yuekou Area, Ordos Basin

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Abstract: By using core, slice, Scanning Electron Microscope, high pressure mercury injection and physical property data, this paper analyzes the lithology, pore structure, fracture and physical property characteristics, classifies the reservoir types of Chang 6 oil-bearing formation in Yuekou area. The results shows that fine arkose is the main rock type, about 74% of the reservoir space is residual inter-granular and dissolved pores, high angle inclined or vertical fractures constitute the main core factures, vertical and parallel micro-fractures are discovered under microscope which have the same direction as big fractures, the porosity mainly ranges from 6% to 10%,, the permeability is mostly less than $1\times10^{-3}\mu m^2$, and belongs to tight reservoir. With the integration of multiple factors, Chang 6 reservoir types are divided into good, relatively good, relatively poor and poor.

INTRODUCTION

With the successful exploration and development of North American shale gas, tight reservoir has been an important domain in nonconventional oil-gas exploration at home and abroad [1--3]. As the key tight reservoir prospecting region, the Chinese Ordos Basin has discovered a hundred million tons of proved reserves and has become an important field of enhancing reserves and productivity in Chinese petroleum. In order to enlarge the prospecting region of tight oil, it is necessary to discover new reserves in the adjacent area of Ordos Basin. Therefore, the reservoir development characteristics are studied and reservoir types are divided through the analysis of reservoir lithology, storage space, pore structure as well as physical property of Chang 6 oil-bearing formation in Yuekou area, which point out the direction of tight oil exploration in the next step.

GEOLOGICAL OVERVIEW

Yuekou area lies in Yan'an, Shanxi province geographically and eastern part of Northern Shanxi Slope in Ordos Basin tectonically, the landform is not flat because of ridges and replats, the ground elevation ranges from 880m to 1200m, and the area is about $100km^2$. The strata of Chang 6 oil-bearing formation is relatively stable with the thickness between 90m and 140m, it develops multiple sets of bentonites with the thickness ranges from 2 to 4m, and the log characteristics is obvious and easy to recognize, Chang 6 oil-bearing formation can be divided into 4 layers from top to bottom, they are Chang 6_1, Chang 6_2, Chang 6_3 and Chang 6_4, and structurally it is featured by "high west and low east" and is similar to the structural background of Northern Shanxi slope.

RESERVOIR DEVELOPMENT CHARACTERISTICS

RESERVOIR LITHOLOGY AND SPACE

According to the identification results of cores and slices, the main rock type of Chang 6 reservoir in Yuekou area is fine arkose (Fig.1). Feldspar content of the arkose ranges from 46.1% to 51.5% and the average is 48.5%, among which, potash feldspar content ranges from 17% to 42% and the average is 31.4%, plagioclase content ranges from 5% to 29% and the average is 17.1%. Quartz content ranges from 15% to 33% and the average is 24.1%. Biotite content changes from 2% to 18% and the average is 8.6%, the content of lithic fragment is relatively less, it changes from 2% to 4% and the average is 3.2%, and the lithic fragment type is mainly composed of sedimentary and metamorphic rock debris.

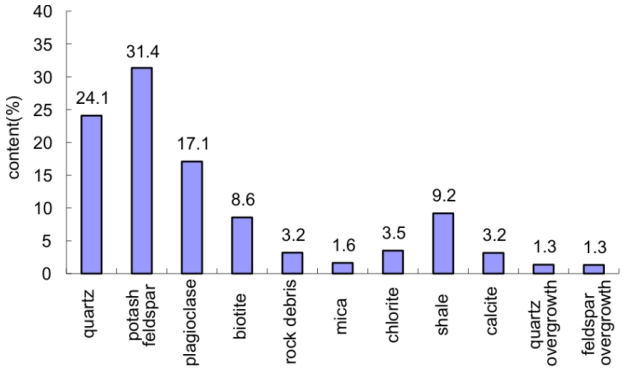

Fig.1 The distribution histogram of sandstone component of Chang 6 oil-bearing formation in Yuekou area

According to the analysis of slice and SEM, the main storage space of Chang 6 reservoir is inter-granular pores, dissolved pores and micro-fractures (Tab.1). The surface porosity content changes from 6.7% to 7.6% and the average is 7.1%. Among which, the residual inter-granular pore is the main pore type, it accounts for 30% to 80% of the total pore and the average content is about 44.1%. The dissolved pore contains inter-granular and intra-granular dissolved pore, its content ranges from 15% to 40% and the average is 29.5%. Micro-fracture is less developed and only accounts for about 3%, other pores also occupy a large proportion in Chang 6 reservoir, the average content is about 23.4% and can reach a maximum of more than 30%, the pore type is mainly intra-crystalline pore of clay mineral and generally occupied by irreducible water.

Tab.1 Statistics of reservoir pore-type of Chang 6 oil-bearing formation in Yuekou area

Well ID	Matrix content (%)				Surface Porosity (%)
	Inter-granular pore	Dissolved pore	Micro-fracture	Other pores	
TJ1	42.1	29.3	2.0	26.6	6.9
TJ2	39.2	29.2		31.7	6.7
TJ3	45.0	29.1	3.0	22.9	7.3
TJ6	40.8	30.0	3.0	26.2	7.2
T73	71.3	19.4	3.0	6.4	7.6
T89	39.4	30.0		30.6	6.9

PORE-THROAT STRUCTURE CHARACTERISTICS

The little change of pore-throat parameters of Chang 6 reservoir indicates a relatively uniform pore-throat distribution. Among which, the displacement pressure mainly ranges from 0.28MPa to 1.8MPa, the corresponding maximum inter-connected pore-throat radius changes from 2.679μm to 0.107μm, saturation medium pressure ranges from 1.761 MPa to 8.399MPa, the medium radius is between 0.426μm and 0.089μm, the average pore-throat radius ranges from 0.152μm to 1.007μm and the mean value distributes in 0.154μm and 0.853μm, the sorting coefficient changes from 0.11 to 4.37, and the relative sorting coefficient changes from 0.69 to 5.17, the pore-throat skewness is larger than 0 and ranges from 0.66% to 11.46%, the mercury withdrawal efficiency is relatively low and is between 12% and 34%. According to high pressure mercury injection data of Chang 6 reservoir, the pore-throat structure is divided into 4 types (Fig.2):

1) Single peak-positive skewness fine pore-throat type: the pore-throat distribution is featured by single peak and deviated to coarse pore-throat, the predominant pore-throat radius ranges from 1.5μm to 2.5μm. This pore-throat type is mainly seen in fine and middle-fine sandstone in which inter-granular pore is relatively developed, the physical property is generally good and mainly develops in the reservoir with permeability larger than $1.0\times10^{-3}\mu m^2$.

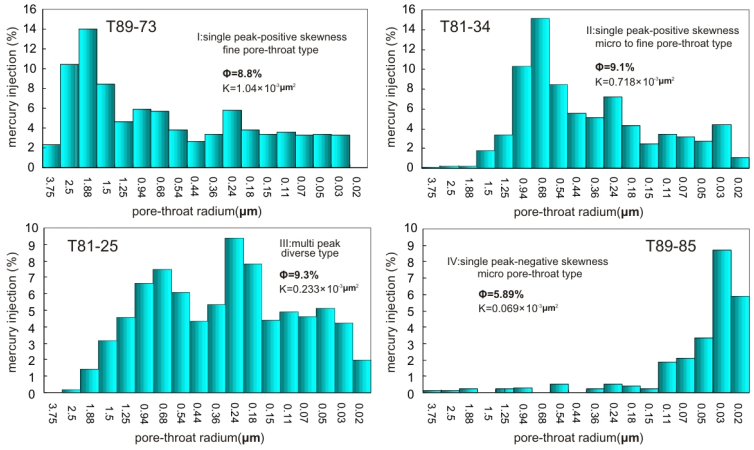

Fig.2 The pore-throat distribution histogram of Chang 6 reservoir in Yuekou area

2) Single peak-positive skewness micro to fine pore-throat type: the pore-throat distribution is featured by single peak and deviated to coarse pore-throat, the predominant pore-throat radius ranges from 0.5μm to 1.0μm. This pore-throat type is the most frequent in Chang 6 reservoir, and mainly seen in fine sandstone in which both residual inter-granular pore and inter-granular dissolved pore are developed, the pore-throat primarily distributes in the reservoir with permeability ranges from $0.5\times10^{-3}\mu m^2$ to $1.0\times10^{-3}\mu m^2$.

3) Multi peak dispersed type: the pore-throat distribution is non-uniform, and there is no obvious predominant pore-throat range. It is mainly seen in fine sandstone in which both residual inter-granular pore and inter-granular dissolved pore are not very developed, the pore-throat primarily distributes in the reservoir with permeability ranges from $0.15\times10^{-3}\mu m^2$ to $0.5\times10^{-3}\mu m^2$.

4) Single peak-negative skewness micro pore-throat type: the pore-throat distribution is featured by single peak and deviated to fine pore-throat, the predominant pore-throat radius ranges from 0.02μm to 0.06μm, this pore-throat type mainly distributes in siltstone and fine sandstone in which permeability is less than $0.15\times10^{-3}\mu m^2$.

FRACTURE DEVELOPMENT CHARACTERISTICS

The core fracture characteristics analysis of Chang 6 oil-bearing formation for 6 coring wells indicates that most fractures occur in a single form and can spread out in a natural state, the fracture surface is straight and there is no secondary mineral filling in it, 12 fractures are developed in the 6 coring wells, the fracture density is 0.079 per meter, most fracture length is less than 0.5m, high angle inclined or vertical fractures constitute the main core factures, and the fracture of inclination larger than 70° accounts for 81.5% of the total. Two types of micro-fracture are discovered under microscope, one type is high angle intersecting or near-vertical with surface, and the development proportion is about 40%, the other type is parallel to surface and accounts for 60%. Micro-fracture occurs in various forms, the fracture surface is straight or curved, most micro-fractures extend a short distance of 0.5mm to 1mm, and the width ranges from 5μm to 40μm and mainly ranges from 5μm to 15μm. Micro-fracture mostly occur in a separating form, the type of micro-fracture with one or two side connecting with pores only accounts for 22.6% of the total. The major direction of micro-fracture is near-parallel to large fracture, namely, the included angle between them is less than 10°.

PHYSICAL PROPERTY CHARACTERISTICS

According to statistics of 1241 pieces of core data analysis for 10 wells in Yuekou area (Fig.3), the reservoir porosity ranges from 0.82% to 13.84%, the average is 7.95%, and it is mainly between 6% and 10% which accounts for 68.3% of the samples. The permeability ranges from $0.02\times10^{-3}\mu m^2$ to $12.07\times10^{-3}\mu m^2$ and the average is $0.71\times10^{-3}\mu m^2$. Samples with the permeability less than $1.0\times10^{-3}\mu m^2$ accounts for 76% and belong to tight reservoir.

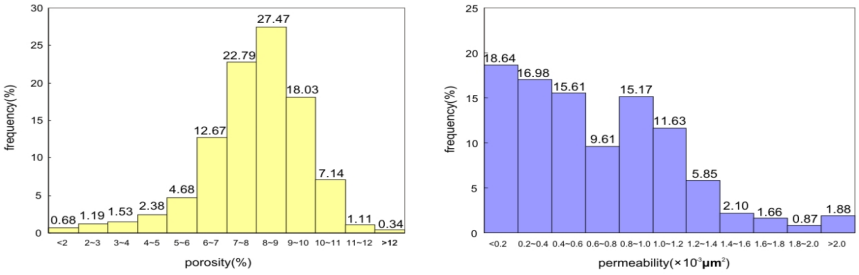

Fig.3 The distribution frequency histogram of porosity and permeability of Chang 6 reservoir in Yuekou area

RESERVOIR EVALUATION AND CLASSIFICATION

According to integrated analysis of reservoir physical property, microscopic pore structure, capillary pressure curve and reservoir anisotropy with lithology and oil-bearing analysis, Chang 6 reservoir types are divided into good (type I), relatively good (type II), relatively poor (type III) and poor (type IV) (Tab.2).

Tab.2 The classification and evaluation indicators of Chang 6 reservoir in Yuekou area

Evaluation Parameter	I	II	III	IV
Permeability ($\times10^{-3}\mu m^2$)	>1.0	1.0~0.5 0.72	0.5~0.15 0.27	<0.15
Porosity (%)	>10.0	10. 0~8.0 8.7	10.0~7.0 8.0	<7.0
Displacement Pressure (MPa)	<0.20	0.20~0.50 0.39	0.17~1.30 0.65	>0.5
Medium Pressure (MPa)	<0.95	1.33~2.27 1.86	1.76~7.25 4.04	>3.5
Maximum Pore-throat Radius (μm)	>3.7	2.50~1.50 1.99	4.41~0.10 1.42	<1.4
Medium Radius (μm)	>0.78	0.56~0.33 0.42	0.43~0.10 0.21	<0.20
Mean Value (μm)	>1.30	0.85~0.57 0.73	0.91~0.18 0.46	<0.35
Sorting Coefficient	>1.20	0.74~0.41 0.59	4.37~0.16 0.64	<0.40
Pore Assemblage Type	Dissolved and inter-granular pore	Inter-granular and dissolved pore	Residual inter-granular based pore	Micro-pore
Evaluation	good	Relatively good	Relatively poor	Poor

Minimum-maximum
Average

Type I: The rock type is fine and medium arkose with good development of dissolved pore, and the main reservoir space is the assemblage of dissolved and inter-granular pore. The porosity is larger than 10% and permeability larger than $1.0\times10^{-3}\mu m^2$. The capillary pressure curve is featured by a narrow platform type, and the displacement pressure is less than 0.2MPa and medium pressure less than 0.95MPa. The maximum pore-throat radius is larger than 3.7μm and medium radius larger than 0.78μm, the mean value of pore-throat radius is larger than 1.3μm, and the sorting coefficient is larger than 1.3, so the pore-throat is featured by relatively poor sorting and coarse skewness. This type of reservoir mainly develops in Chang 6_1 and Chang 6_2 oil-bearing layer.

Type II: The rock type is mainly fine arkose with relatively good development of dissolved pore, and the main reservoir space is residual inter-granular pore. The porosity ranges from 8% to 10% and permeability ranges from $0.5\times10^{-3}\mu m^2$ to $1.0\times10^{-3}\mu m^2$. The capillary pressure curve is featured by a slow slope type, the displacement pressure changes from 0.2MPa to 0.5MPa and the average is 0.39MPa, and the mean pressure ranges from 1.33MPa to 2.27MPa. The maximum pore-throat radius

ranges from 1.5μm to 2.5μm and the average is 1.99μm, the medium radius ranges from 0.33μm to 0.56μm and the average is 0.42μm. The mean value of pore-throat radius ranges from 0.57μm to 0.85μm and the average is 0.73μm. The sorting coefficient changes from 0.41 to 0.74 and the average is 0.59, so the pore-throat is featured by relatively good sorting and coarse skewness. This type of reservoir mainly develops in Chang 6_1, Chang 6_2 and Chang 6_3 oil-bearing layer and is most widely distributed in Yuekou area.

Type III: The rock type is mainly fine arkose with relatively poor development of dissolved pore, and the main reservoir space is the assemblage of residual inter-granular pore, dissolved pore and micro-pore. The porosity ranges from 6% to 8% and permeability ranges from $0.15\times10^{-3}\mu m^2$ to $0.5\times10^{-3}\mu m^2$. The capillary pressure curve is featured by a steep slope type, the displacement pressure changes from 0.17MPa to 1.3MPa and the average is 0.65MPa, and the mean pressure ranges from 1.76MPa to 7.25MPa and the average is 4.04MPa. The maximum pore-throat radius ranges from 0.1μm to 4.41μm and the average is 1.42μm, the medium radius ranges from 0.1μm to 0.43μm and the average is 0.21μm. The mean value of pore-throat radius ranges from 0.18μm to 0.91μm and the average is 0.46μm. The sorting coefficient changes from 0.16 to 4.37, and the pore-throat distribution is dispersed. This type of reservoir mainly develops in Chang 6_3 and Chang 6_4 oil-bearing layer and secondly develops in Chang 6_2 oil-bearing layer.

Type IV: The rock types are mainly silt to fine arkose and feldspar sandstone, and the main reservoir space is the assemblage of micro-pore. The porosity is less than 6% and permeability less than $0.15\times10^{-3}\mu m^2$. This type of sandstone is primarily the tight interval of the reservoir, the capillary pressure curve is featured by a high slope type, and the displacement pressure is larger than 0.5MPa and medium pressure less than 3.5MPa. The maximum pore-throat radius is less than 1.4μm and medium radius less than 0.2μm, the mean value of pore-throat radius is less than 0.35μm, and the sorting coefficient is less than 0.4, so the pore-throat is featured by relatively good sorting and fine skewness. This type of reservoir mainly develops in Chang 6_4 oil-bearing layer.

Reservoir evaluation of Chang 6 oil-bearing formation indicates that type II is the most developed which accounts for 34.9%, and the secondary developed are type I and type III which account for 27.7% and 24%, respectively.

Tab.3 Evaluation of Chang 6 reservoir in Yuekou area

Reservoir	Type I (%)	Type II (%)	Type III (%)	Type IV (%)
Chang 6_1	27.8	40.1	23.4	8.7
Chang 6_2	15.7	26.0	35.0	22.8
Chang 6_3	14.0	18.9	39.9	27.2
Chang 6	24.0	34.9	27.7	13.4

CONCLUSION

1) High angle inclined or vertical fractures constitute the main core factures, vertical and parallel micro-fractures are discovered under microscope and have the same direction as big fractures.

2) The porosity mainly ranges from 6% to 10%, and the average is 7.95%, the permeability is mostly less than $1.0\times10^{-3}\mu m^2$, and belongs to tight reservoir. With the integration of multiple factors, Chang 6 reservoir types are divided into good, relatively good, relatively poor and poor.

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