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Geological characteristics of unconventional tight oil reservoir (10^9 t): A case study of Upper Cretaceous Qingshankou Formation, northern Songliao Basin, NE China

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A B S T R A C T

The Daqing exploration area in the northern Songliao Basin has great potential for unconventional oil and gas resources, among which the total resources of tight oil alone exceed 10^9 t and is regarded as an important resource base of Daqing oilfield. After years of exploration in the Qijia area, Songliao Basin, NE China, tight oil has been found in the Upper Cretaceous Qingshankou Formation. To work out tight oil's geological characteristics, taking tight oil in Gaotaizi oil layers of the Upper Cretaceous Qingshankou Formation in northern Songliao Basin as an example, this paper systematically analyzed the geological characteristics of unconventional tight oil in Gao3 and Gao4 layers of the Qijia area, based on the data of the geological survey, well drilling journey, well logging, and test. It is that three sets of hydrocarbon source rocks (K_2qn_1, K_2qn_{2+3}, and K_2n_1) develop in the examined area, and exhibit excellent type I and II kerogens, high organic matter abundance, and moderate maturity. The reservoir is generally composed of thin-bedded mudstone, siltstone, and sandstone, and presents poor porosity (average 8.5 vol.%) and air permeability (average 4 mD). The main reservoir space primarily includes intergranular pores, secondary soluble pores, and intergranular soluble pores. Three types of orifice throats were identified, namely fine throat, extra-fine throat, and micro-fine throat. The siltstone is generally oil-bearing, the reservoirs with slime and calcium become worse oil-bearing, and the mudstone has no obvious oil-bearing characteristics. The brittleness indices of the sandstone in the tight oil reservoir range from 40% to 60%, and those of the mudstone range from 40% to 45%, indicating a better brittleness of the tight oil reservoir. Based on the study of typical core hole data, this paper gives a comprehensive evaluation of the properties of the tight oil and establishes a tight oil single well composite bar chart as well as the initial evaluation system with the core of properties in the tight oil reservoir. This study has theoretical guiding significance and practical application value for tight oil exploration and evaluation in the Qijia area.

1. Introduction

The Songliao Basin in NE China, covers an area of 26×10^3 km^2 (Fig. 1), with a total sedimentary thickness exceeding 10 km (Gao RQ and Cai XY, 1997; Wang HJ, 1981; Feng ZQ et al., 2010; Xiang CF et al., 2006; Meng QA et al., 2016; Huang WB et al., 2017; Feng J et al., 2019), represents one of largest Mesozoic–Cenozoic intracontinental sedimentary basins in China (Zhang KJ et al., 2006, 2019; Meng QA et al., 2020). In recent years, great breakthroughs have been made in the field of unconventional tight oil exploration in the northern Songliao Basin. Studies show that the total resource of tight oil exceeds 10^9 t, being regarded as the main target of oil and gas exploration of unconventional reservoir in the basin (Li D et al., 2013; Shi LZ et al., 2015; Gong YJ et al., 2015; Sun Y et al., 2015; Wang Yh et al., 2015; Huang WB et al., 2017; Zhang LC et al., 2017; Cai LX et al., 2019; Sun LD et al., 2019; Gong YJ and Liu KY, 2020; Bai YB et al., 2020; Liu WB et al., 2022). An unconventional oil reservoir of huge potential has been found in the Gao3 and Gao4 oil layer groups of the Gaotaizi oil layer in the Upper Cretaceous Qing$_{2+3}$ member (referred to as K_2qn_{2+3}) of the Qingshankou Formation in Qijia area. But the current exploration and development and related research are still in the preparatory stage (Wang HY and Jin H, 2019). Relevant

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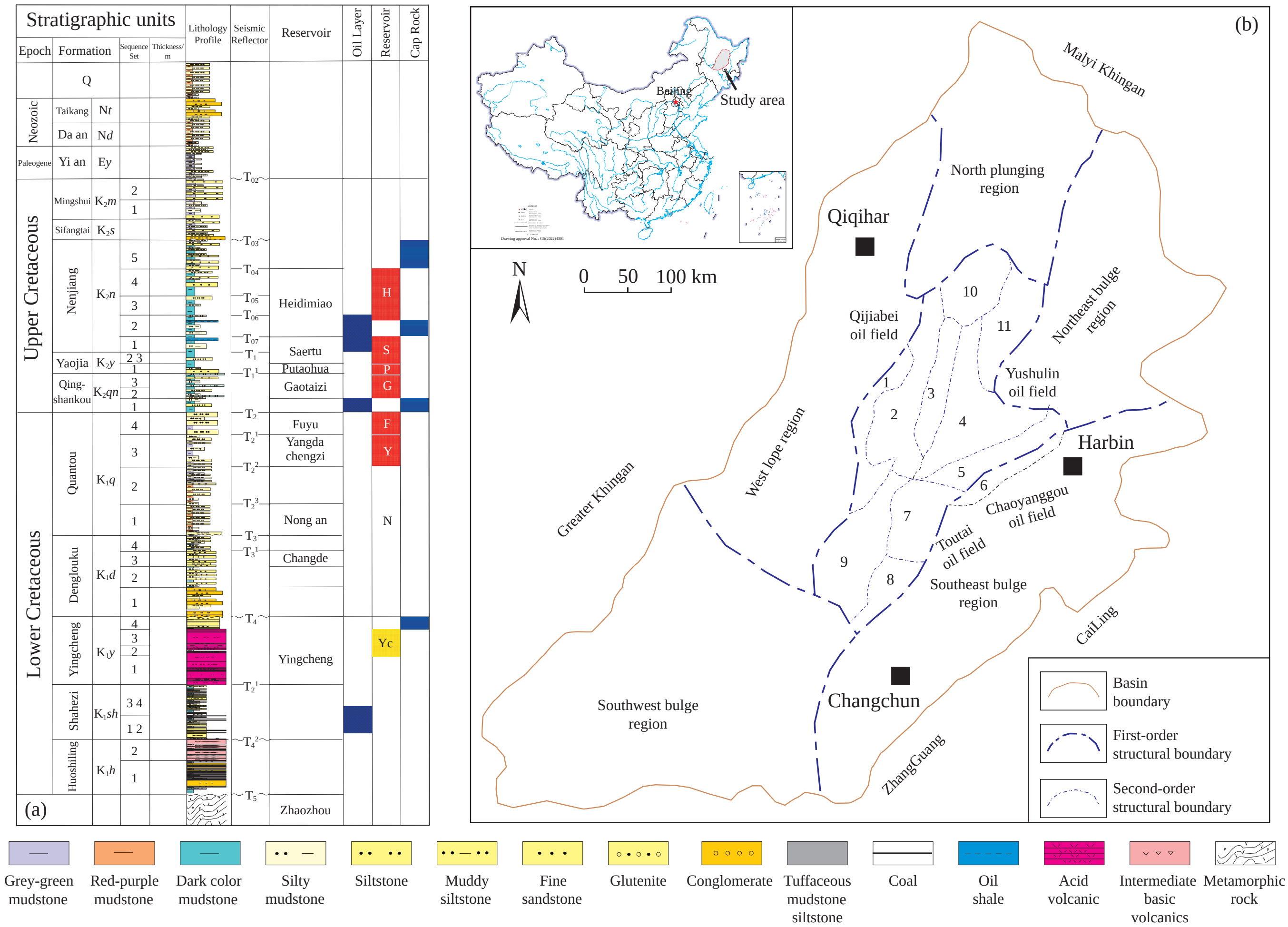

Fig. 1. a–Comprehensive stratigraphic column; b–structural divisions map of Songliao Basin. 1–Longhupao-Daan terrace; 2–Qijia-Gulong sag; 3–Daqing placanticline; 4–Sanzhao sag; 5–Chaoyanggou terrace; 6–Changchunling anticline; 7–Fuxin uplift; 8–Huazijing terrace; 9–Changling sag; 10–Wuyuer sag; 11–Heiyupao sag.

literature mostly discusses the formation conditions of tight oil and analyzes pore-throat structure (Cui BW et al., 2014; Si SH et al., 2018; Ma DH, 2017; Li YL et al., 2020; Zhang JY et al., 2020; Jiang ML et al., 2021). Seldom study the geological characteristics of tight oil. This paper systematically analyzes the geological characteristics of tight oil in the Gao3 and Gao4 layers of the Qijia area. The authors hope this study can provide theoretical and technical support for tight oil exploration and evaluation in the Qijia area, Songliao Basin.

2. Geological setting

The Songliao Basin is located in NE China, offshore the western Pacific (Fig.1), and is characterized by a complex tectonic superimposition involving the latest Permian–Triassic collision between Chinese blocks (Zhang KJ, 1997; Zhang KJ et al., 2006) and the Mesozoic subduction of Mongol-Ohkotsk and Pacific slabs (Zhang KJ, 2014; Zhang KJ et al., 2019). Songliao Basin experienced three stages of tectonic evolution during the Cretaceous: Fault depression, depression, and tectonic inversion (Feng ZQ et al., 2006, 2010; Hou QJ et al., 2009; Zhang S et al., 2011, 2013; Zhang CC et al., 2015; Zhang KJ et al., 2019). Located in the central depression of northern Songliao Basin, the Qijia area is bounded by the Daqing anticline on the east, the western slope on the west, and the Gulong sag on the south, with the whole exploration area of about 3000 km^2 (Fig. 1). The Cenozoic–Mesozoic stratigraphy of the Qijia area from bottom to the top includes the Cretaceous, Paleogene, Neogene and Quaternary layers in ascending order, of which the lower and middle oil and gas assemblages are the main targets, including the following five oil-bearing layers, namely Saertu, Putaohua, Gaotaizi, Fuyu and Yangdachengzi (Gao RQ and Cai XY, 1997; Yang WL et al., 1985; Wang ZW et al., 1993; Shi LZ et al., 2007).

The Gaotaizi oil layer in the Qijia area was a delta-front surface depositional system. During the depositional period of the Gaotaizi oil layer, the study area was mainly controlled by the provenance from the north. Sedimentary facies are mainly delta front surfaces, including inner and outer delta front. The northern part of the delta sedimentary body inserts into favorable source rocks in the Qingshankou Formation from North to South, resulting in a finger-like contact between delta front facies reservoir rock and hydrocarbon source rock (Fig. 2). Hence good configuration relationship including the source rock and oil reservoir developed, and created. It has created a good geological condition for the formation of unconventional tight oil in the source (inside the source rock) of the Gao3 and Gao4 oil layer groups in the Gaotaizi oil layer. The Gao3 and Gao 4 oil layer groups were the main oil-producing layers of the Gaotaizi oil layer, which was the target object of this study.

3. Geological characteristics of tight oil

3.1. Source rock

The study area is located in the center of the Qijia–Gulong depression, the secondary tectonic unit of Songliao Basin, which is one of the most important hydrocarbon-generating sags in this area, and possesses well-developed hydrocarbon source rocks and good oil-generating conditions (Gao RQ and Cai XY, 1997; Yang WL et al., 1985; Hou QJ et al., 2009). At present, the exploration results confirmed that many sets of hydrocarbon source rocks of high quality are widely distributed in the Qijia–Gulong sag and the main hydrocarbon source rocks include a section of the Qingshankou Formation (K_2qn_1), sections two and three of the Qingshankou Formation (K_2qn_{2+3}), and a section of the Nenjiang Formation (K_2n_1). The sedimentary environments of source rocks are mainly lacustrine facies and deep lacustrine facies. All the hydrocarbon source rocks show high organic matter abundance and favorable kerogen types (Type I and II). (Gao RQ and Cai XY, 1997; Yang WL et al., 1985; Wang ZW et al., 1993; Li YJ et al., 1997; Wang ZG et al., 2005). The research shows that two large-scale lake transgression events occurred in the Songliao Basin during the period of the formation of the Qingshankou Formation and the Nenjiang Formation.

The hydrocarbon source rock is relatively thick and it gradually becomes thicker from the North to South in the study area. The thicknesses of K_2qn_1, K_2qn_{2+3}, and K_2n_1 source rocks are 50–250 m,100–450 m, and 60–200 m respectively. As for K_2qn_1, the source rock thickness of larger than 50 m covers the entire Qijia–Gulong area and its vitrinite reflectance ratio (R_o) is generally high. The R_o of the main part of the sag in the Qijia area ranges from 0.51% to 2.02%, Most of the source rocks have reached the mature stage, and more than 1% of them cover an area of 6600 km^2. The average total organic carbon (TOC) reaches 2.13% (Table 1), the average chloroform asphalt A content is 0.43%, the average total hydrocarbon is 4.15×10^{-3}, and the average hydrocarbon generation potential (S_1+S_2) is 18.49 mg/g. According to the evaluation standard of China's continental hydrocarbon source rock organic matter abundance, the hydrocarbon source rock of K_2qn_1 in Qijia–Gulong sag belongs to excellent source rock (Huang DF et al., 1984). and the source rocks of K_2qn_{2+3} and K_2n_1 also meet the standard of good source rock (Table 1).

3.2. Lithology

The Gao3 and Gao4 tight oil reservoirs are s set of interbedded layers of shale, sand, and silstones (which include calcareous siltstone, argilliferous siltstone, and ostracod-bearing siltstone). Some of the reservoirs contain argillaceous

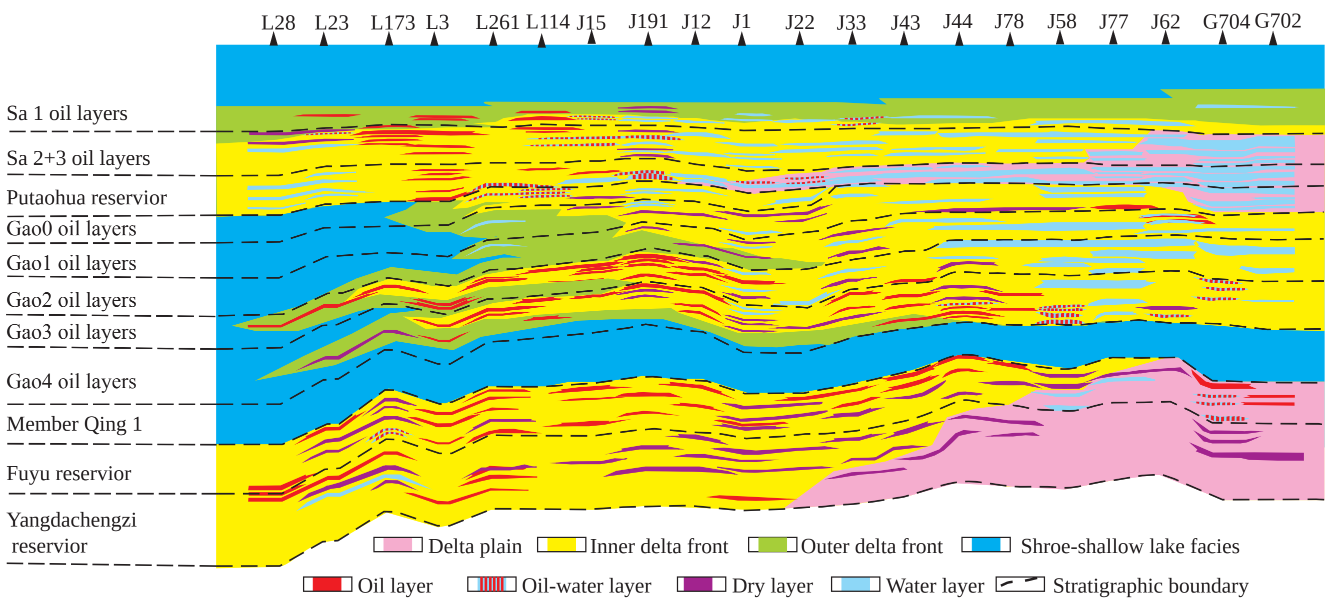

Fig. 2. Sedimentary section of the Gaotaizi reservoir and the upper and lower adjacent layers in Well L28–Well G702 of Qijia area.

Table 1. Organic matter abundance of source rock in the Qijia–Gulong sag.

Formation	Organic carbon/%			Chloroform bitumen"A"/%			Total hydrocarbon/10^{-6}			$(S_1+S_2)/(mg\cdot g^{-1})$			Grade of source rock
	min	max	average	min	max	average	min	max	average	min	max	average	
K_2qn_1	0.22	6.67	2.13(87)	0.016	1.150	0.429(69)	108	10771	4149(105)	0.06	697.00	18.49(190)	Good source rock
K_2qn_{2+3}	0.12	6.56	1.32(536)	0.006	0.904	0.164(146)	55	7412	1866(152)	0.01	719.51	10.41(427)	Good source rock
K_2n_1	0.12	8.59	2.64(186)	0.024	1.351	0.492(38)	144	15643	4023(72)	0.04	420.00	25.15(143)	Good source rock

Note: The values in parentheses are the number of samples.

cements and carbonate components. The main lithologies of the reservoir are lithic arkose, and feldspathic litharenite sandstone (Fig. 3). The content of debris and feldspar in the soluble fraction is relatively high, which provides the material basis for the development of secondary pores.

3.3. Oiliness

Siltstones in the Gao3 and Gao4 oil formations in the Qijia area are generally oil-bearing (Figs. 4a, b), which are independently and uniformly distributed. Reservoirs with mud and calcium weight are relatively poor in oil bearing. The crude oil in mudstone is unevenly distributed and locally enriched in kerogen and other components, inducing an inconspicuous oil-bearing feature (Fig. 4c). It is worth mentioning that the silty bands in mudstone also show good oil-bearing capacity (Fig. 4d).

The study of confocal laser 3D imaging technology shows that light and heavy crude oil is the main component of siltstone in the Gao3 and Gao4 oil layers of the study area, and local enrichment is observed. Kerogen adsorbed oil is the main oil in mudstone, light crude oil, and recombination are evenly distributed in siltstone. But in the mudstone matrix, the light crude oil and recombination are unevenly distributed dispersively, and even rarely seen in some parts (Fig. 5).

3.4. Physical properties of tight oil

3.4.1. Porosity and permeability

Gao3 and Gao4 tight oil reservoirs in the Qijia area are poor in physical properties. The porosity ranges from 4–12 vol.% with an average of 8.5 vol.% and 80% of samples less than 12 vol.%. The air permeability is in the range of 0.1–5 mD with an average of 4 mD, and 93% of samples <1 mD (Fig. 6).

3.4.2. Pore structure

Gao3 and Gao4 tight oil reservoirs have been studied using traditional thin sections, casting thin slices, scanning electron microscope, CT scanning microscopic, and so on. The result shows that reservoir space is composed of primary intergranular pores, secondary dissolved pores, and intragranular dissolved pores, with partial microcracks, melodic pores, and intergranular nano cracks (Fig. 7). Secondary erosion pore is mainly feldspar dissolution pore, rare quartz and calcite dissolution pore, a little bit of detritus dissolution pore. Statistics show that the pore diameter is mainly distributed within 25–1000 μm, and the nanocrystalline pores observed under the microscope are mainly intergranular pores developed in clay minerals and intergranular dissolution pores produced by micro-dissolution of feldspar, which present generally relatively poor in connectivity. According to the statistics from thin section data, pore diameter is 25–1000 μm in general. Under the microscope, the nanopores are mainly intergranular pores developed in clay minerals and intragranular dissolved pores produced by micro dissolution of feldspar. This type of nanopore exhibits poor connectivity.

As shown in Fig. 8, the pore diameter of tight sandstone in

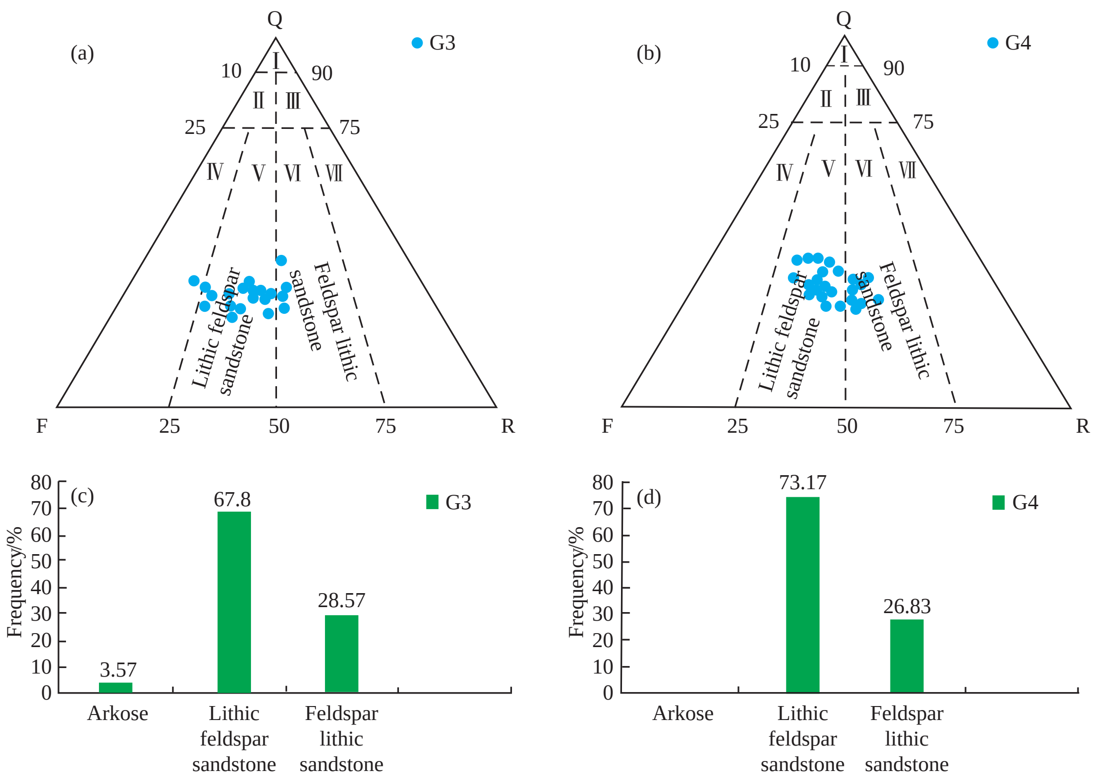

Fig. 3. Rock types and frequency diagram of Gao3 and Gao4 reservoirs in the Qijia area. a–Rock types diagram of Gao3 reservoirs in the Qijia area; b–rock types diagram of Gao4 reservoirs in the Qijia area; c–rock frequency diagram of Gao3 reservoirs in the Qijia area; d–rock frequency diagram of Gao4 reservoirs in the Qijia area.

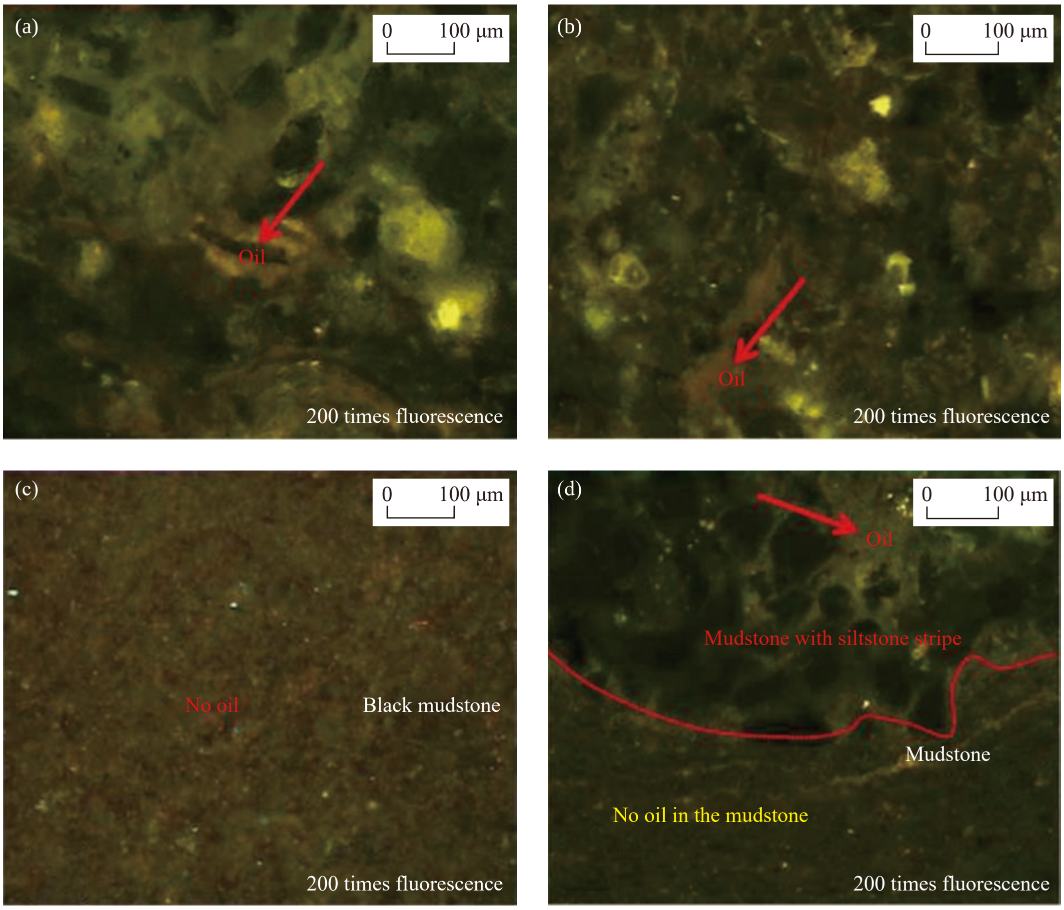

Fig. 4. Microscopic pictures of the tight oil reservoir in the Qipin1 well of the Qijia area. a–Well Qiping 1, mudstone with siltstone stripe, 1982.55 m; b–Well Qiping 1, gray mud-bearing shell siltstone, 1983.59 m; c–Well Qiping 1, mud-bearing siltstone,1986.39 m; d–Well Qiping 1, grey Black mudstone,1981.61 m.

the Gao3 and Gao4 oil reservoirs of the Qiping 1 well is mainly distributed within the range of 25–1000 nm, <25 nm, and relatively few samples >1000 nm.

Three types of pore throats exist in the Gao3 and Gao4 oil reservoirs in the Qijia area, namely fine throat, extra-fine throat, and micro-fine throat. The pore throat is small, resulting in low permeability and difficulty in fluid flow. However, the secondary pore development zone has good potential for stimulation and reconstruction. From the analysis of pore structure characteristics of mercury injection data, the maximum pore throat radius of the Gao3 and Gao4 oil layer groups in the study area is mainly distributed between 0.03–3.50 μm; the average pore throat radius is generally between 0.01 μm and 1.2 μm and mainly <0.2 μm. The pore throat is small (Fig. 9). It can also be concluded from Fig. 9 that the porosity and permeability of a tight reservoir have a poor correlation with pore throats.

3.5. Brittleness

The rock brittleness index, as a reflection of the degree of rock fracturing, refers to the ratio of brittle mineral content and total mineral content. It is an important reference parameter for the fracturing design of a tight oil reservoir.

In the studied area, the basic components of sandstone are lithic sandstone or feldspathic litharenite, and the mineral composition is mainly composed of quartz, feldspar, calcite, and clay. The quartz content in the reservoirs of the Gao3 oil layer group is generally 20–30 vol.%, with an average of 25.8 vol.%. The average of average feldspar content was 34.0 vol.%, mainly for orthoclase, and a little plagioclase. Dissolved fractures and pores are obvious in feldspar, with more formation of dissolution in grains, and dissolution pores, but they are usually filled with calcite or clay minerals. The component of rock debris is single, with a vast majority of igneous rock, and a little bit of metamorphic rock and sedimentary clastic. The average content of debris is 23.3 vol.%. The particle size ranges from 0.04 mm to 0.11mm. The sandstone here is mainly composed of an argillaceous matrix, in which the cement is mainly calcite. The degree of rock sorting is good–medium, degree of rock weathering is medium. The characteristics of rocks in the Gao4 oil layer are similar to the Gao3 oil layer, with quartz content of 25.4%, feldspar content of 32.1%, and rock debris content of 26.7% on average (Table 2).

Analysis of minerals in rocks of Qiping 1 well (Fig. 10) shows that, on average, quartz content is 3–43 vol.%, generally 20–35 vol.%, with an average of 30 vol.%; feldspar content is 16–70 vol.%, generally 20–45 vol.%, with an average of 35 vol.%; carbonate content is 3–97 vol.%,

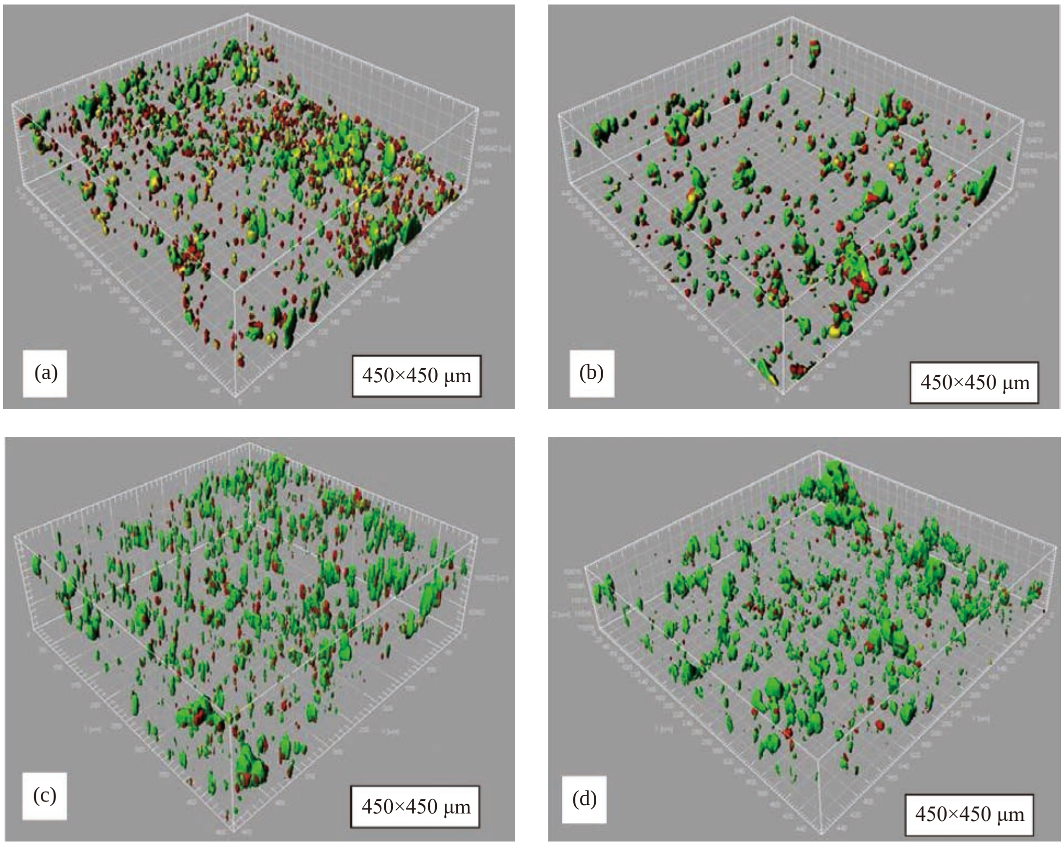

Fig. 5. Representative rocks in the organic components of laser confocal three-dimensional imaging of Qiping1 well in the Qijia area. a–Well Qiping 1, siltstone, 1989.84 m; b–Well Qiping 1, silty mudstone,1991.68 m; c–Well Qiping 1, silty mudstone,1988.8 m; d–Well Qiping 1, mudstone, 1987.52 m. In the figure, yellow represents light organic matter, red represents heavy organic matter, and green represents kerogen + crude oil mixture.

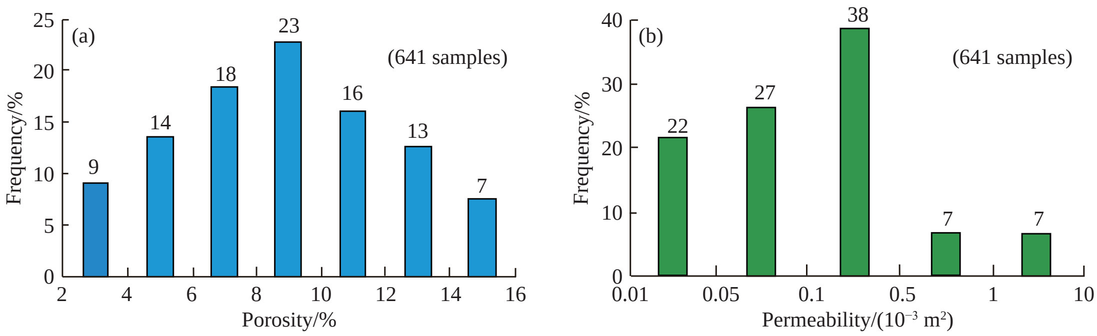

Fig. 6. Frequency distribution histogram of Gao3 and Gao4 reservoirs properties in Qijia area.

generally 3–25 vol.%, with an average of 17.5 vol.%; and the total content of brittle minerals is 40–60% in the sand group and mudstone brittle index is 40–60 vol.% (quartz and carbonate).

In this study, the brittle index of tight oil in Gao3 and Gao4 is calculated by the lithologic component calculation method. The calculation formula is as follows:

$$BI = \frac{Vqa + Vca + Vfs)}{Vqa + Vca + Vfs + Vcl} \tag{1}$$

where, Vqa is quartz, Vca is calcite, Vca is feldspar, Vcl is clay.

Results of lithologic component calculation show that, in the Qijia area, the sandstone brittleness index of tight oil is 40%–60% and the brittleness index of mudstone is 40%–45%. The brittleness condition is favorable to the later fracturing and transformation of tight oil.

4. Discussion

4.1. Relation between oil-bearing, lithology, and physical properties

The results show that the lithology, oil content, and physical properties of the Gao3 and Gao4 oil layers in the study area are better. In the G41 member of the well-developed tight oil formation in well Qiping 1, the well-

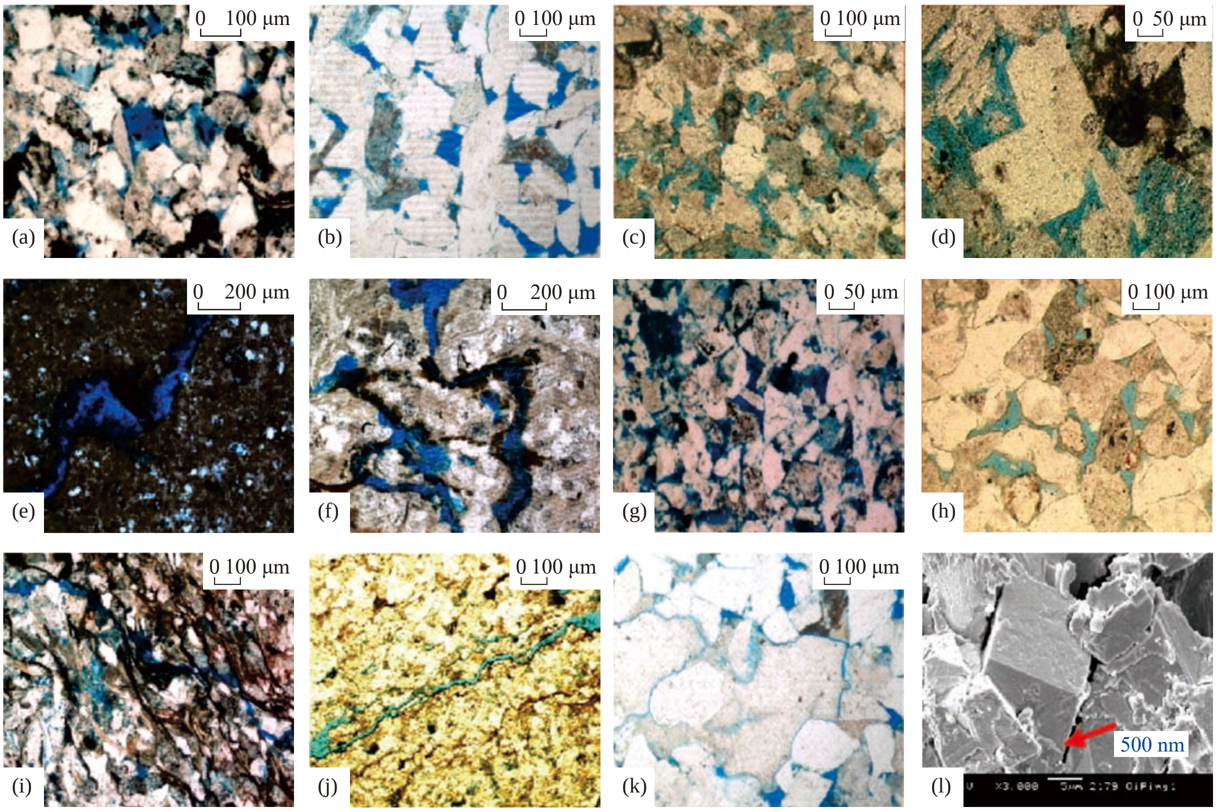

Fig. 7. Tight oil reservoir micropore structure of Gao3 and Gao4 reservoirs in the Qijia area. a–Well Qiping1, 1984 m, intergranular pore, dissolution pore. b–Well Gu433, 2012 m, primary intergranular pore. c–Well Jin57, 1847 m, primary intergranular pore, dissolved pores in rock debris. d–Well Jin51, 1949 m, primary intergranular pore, intergranular dissolution pore in feldspar. e–Well Qiping1, 1981.55 m, dissolved fracture. f–Well Qiping1, 1982 m, dissolved fracture. g–Well Xing 83, 1982 m, primary intergranular pore, intergranular dissolution pore; h–Well Xing 77, 1627 m, primary intergranular pore. i–Well Xing 83, 1957 m, microfracture. j–Well Jin211, 2085 m, microfracture. k–Well Gu433, 2012 m, primary intergranular pore, microfracture. l–Well Qiping1, 1984 m, intergranular nanometer seam.

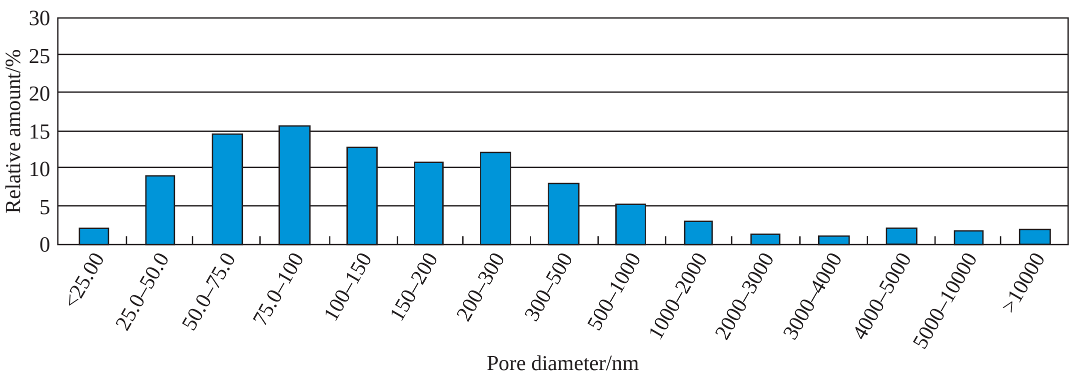

Fig. 8. Diameter distribution of sandstone pores of Gao3 and Gao4 reservoirs in the Qijia area.

formed siltstones (1984–1986 m, 1989–1991 m, and 1994–1995 m) generally contain oil and show good oil and gas display. However, a large number of mudstone sections hardly show good oil and gas display (Fig. 11), which shows an important effect of the reservoir lithology of tight oil on its oiliness.

Studies have shown that physical properties are also one of the important factors affecting oil bearing in tight oil reservoirs. Reservoirs with relatively good physical properties (siltstone, argillaceous siltstone, and sandy bands in mudstone) generally have good oil bearing, while reservoirs with relatively poor physical properties (mudstone) generally have poor oil bearing. Statistics show that the porosity of oil-soaked siltstones in the Gaotaizi oil reservoir in the Qijia area is generally >10%, the oil spot siltstones are generally >8%, and the oil trace siltstones are >3%. It can be seen that the physical properties and oil content is good, and positively correlated with each other (Fig.12).

4.2. Relation between brittleness and oil bearing

The Brittleness index is closely related to oil bearing. Statistics show that the brittleness index increases with the

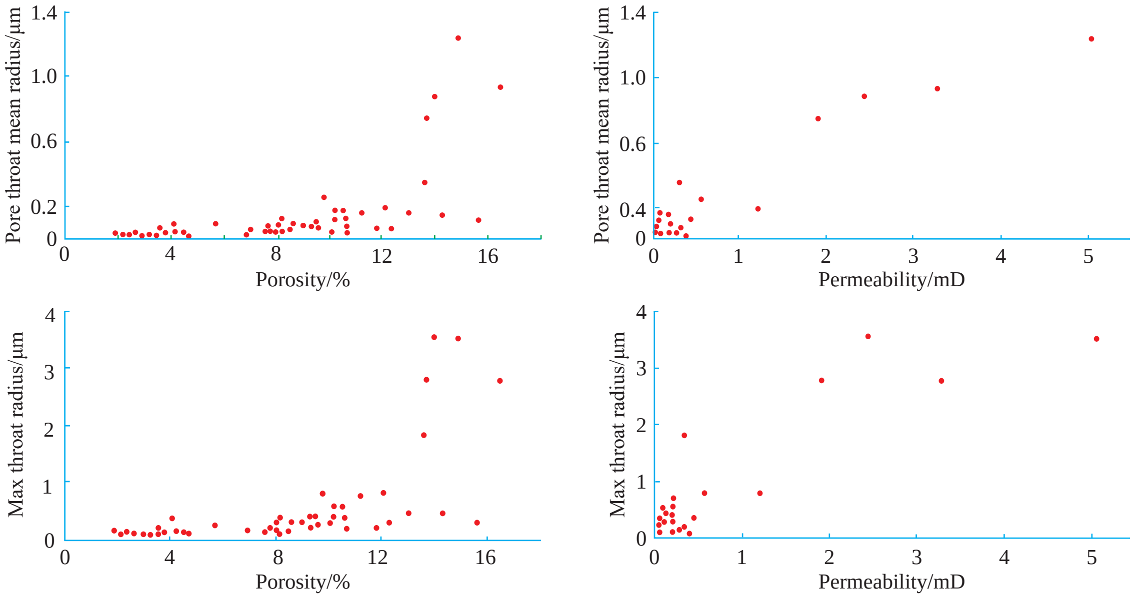

Fig. 9. Pore throat radius and the physical diagram of the Gaotaizi tight oil reservoir in the Qijia area.

Table 2. Statistics of sandstone rock characteristics in the Gaotaizi oil layer, Qijia area.

Oil layer	Content of terrigenous clastic rocks/%				Interstitial matter/%		Size /mm
	Quartz	Feldspar		Lithic-debris	Matrix argillaceous	Calcite	
		Ortho-clase	Plagio-clase				
Gao3	25.8	27.4	6.6	23.3	8.7	16.4	0.04–0.11
Gao4	25.4	26.6	5.5	26.7	6.5	20.2	0.06–0.12

increase of sandstone content, and the brittleness index of siltstones is the highest, generally distributed at 39.5%–67%, with an average index of 50.4%. Siltstone also has the best oil-bearing and oil saturation generally ranges from 3% to 10% (Fig.11). The average distribution of the brittleness index of argillaceous siltstone reservoirs is about 35%, but the oil-bearing of argillaceous siltstone is poor. The brittleness index of mudstone is distributed in 24%–45%, with an average of 32%, and the mudstone has the worst oil bearing. The purer the mudstone is, the lower its brittleness index is, and the lower its oil-bearing is.

5. Classification of tight oil

Based on the comprehensive evaluation and analysis of the properties of tight oil from the typical core hole of the tight oil of well J281 in the Gao3 and Gao4 oil layer groups, the Qijia area, this paper established a tight oil single well composite bar chart (Fig. 13; Table. 3). With the evaluation of properties as its core, it has also set up classification and evaluation criteria for tight oil reservoir.

Gao3 and Gao4 oil layer groups in the Qijia area are mainly composed of tight oils I and II. Tight oil I mainly consists of siltstone, with the total sandstone thickness /Formation thickness >50%. Its oil was soaked, stained, and had high oil saturation. Its porosity is 8%–12%, permeability

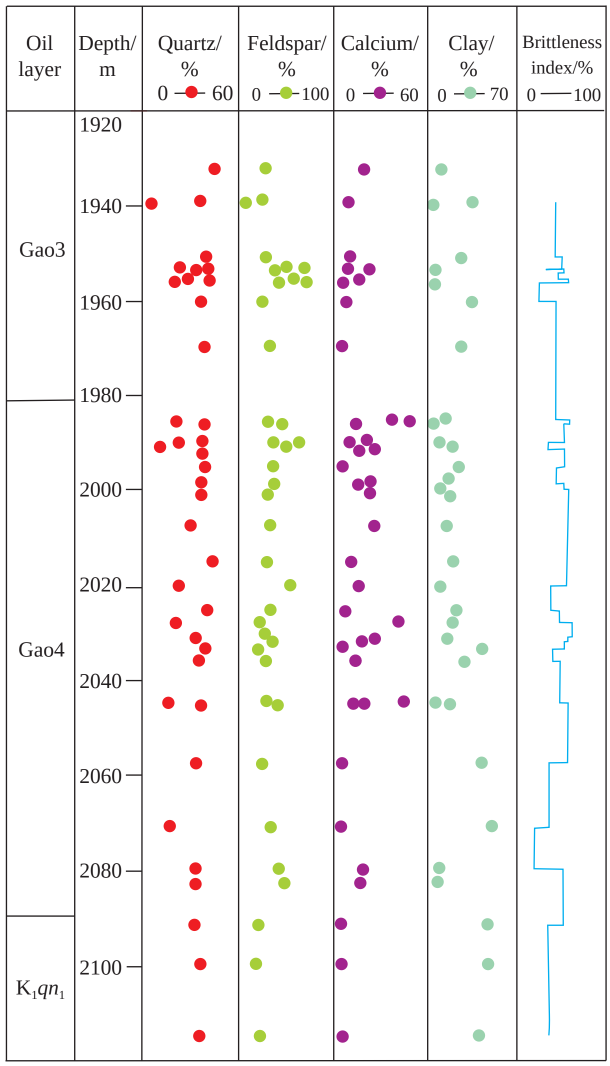

Fig. 10. Rock mineral composition and brittleness index characteristics of Qiping1 well.

is from 0.05 mD to 0.5 mD, and both brittle mineral content and brittleness index are above 50%. Tight oil II mainly

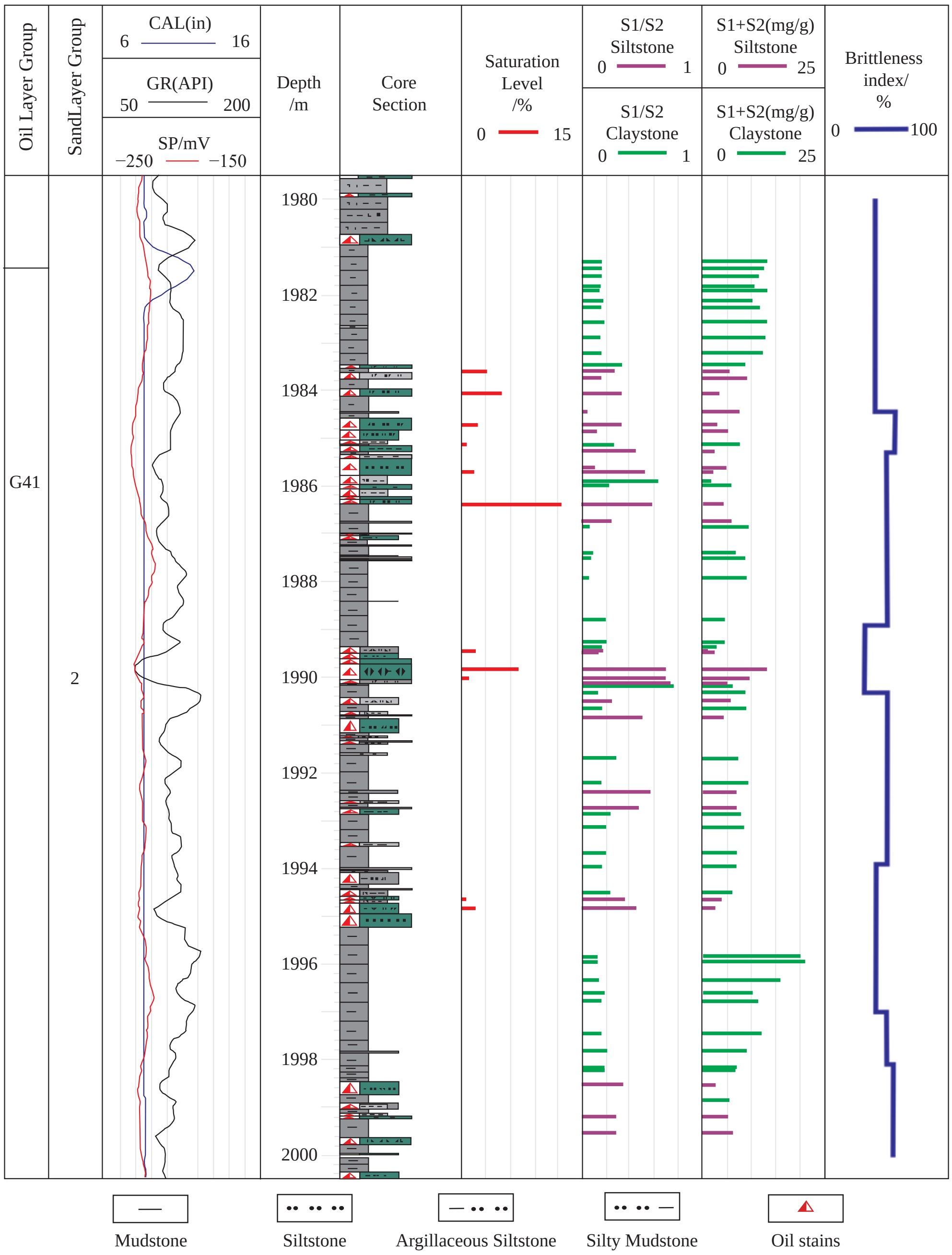

Fig. 11. Comprehensive evaluation of oil-bearing of Qiping1 well.

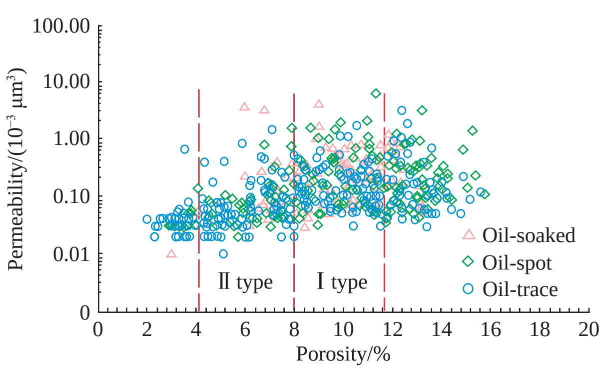

Fig. 12. Tight oil and oil-bearing property and core diagram of Qijia area.

contains muddy siltstone and pelitic siltstone, with a total sandstone thickness and bed thickness ratio of 30%–50%, porosity of 4%–8%, permeability of 0.02–0.05 mD, both brittle mineral content and brittleness index of >40%–50%.

6. Conclusions

(i) Tight oil resources in the northern Songliao Basin have great potential, with the total resources exceeding one billion tons, which is an important resource base for the Daqing oilfield. Qijia area is rich in tight oil and gas resources and has made good breakthroughs in exploration in this area in recent years. Hydrocarbon source rock, lithology, physical property, oiliness, and brittleness, are systematically analyzed in the Gao3 and Gao4 oil layer groups Upper Cretaceous Qingshankou formation, K_2qn_{2+3} member, the Qijia area. There are three series of high-quality source rocks of K_2qn_1, K_2qn_{2+3}, and K_2n_1 in this area, which exhibit excellent type I and II kerogen and have high organic matter abundance mostly in the mature stage. The thin interbeds of sand-shale, and siltstones are the primary locations of tight oil reservoirs.

(ii) The physical property of a tight oil reservoir is relatively poor, with an average porosity of 8.5% and average air permeability of 4 mD. The main reservoir space primarily includes intergranular pores, secondary soluble pores, and intergranular soluble pores. Three types of orifice throats were identified, namely fine throat, extra-fine throat, and micro-fine throat. Siltstone contains oil in general. However, the mudstone has no obvious oil-bearing characteristics. The brittle condition of tight reservoir is good, the sandstone brittleness index is 40%–60%, and the shale brittleness index is 40%–45%, The condition of brittleness in the tight reservoir is good.

(iii) Taking the characteristics of tight oil reservoirs as the

Table 3. Classification and evaluation table of tigh oil layer in Gao3 and Gao4 reservoir, Qijia area.

Classification	Lithology	Physical properties	Oil-bearing property	Brittleness
I	Siltstone Total sandstone thickness /Formation thickness >50%	8% < porosity <12% 0.05 mD< permeability <0.5 mD	Oil patch, oil immersion oil saturation is higher	Contents of brittle minerals >50%, brittleness index >50%
II	Muddy siltstone Argillaceous siltstone Total sandstone thickness /Formation thickness >30%	4%< porosity <8% 0.02 mD < permeability <0.05 mD	Oil patch, oil trace oil saturation is higher	Contents of brittle minerals >40%, brittleness index >40%

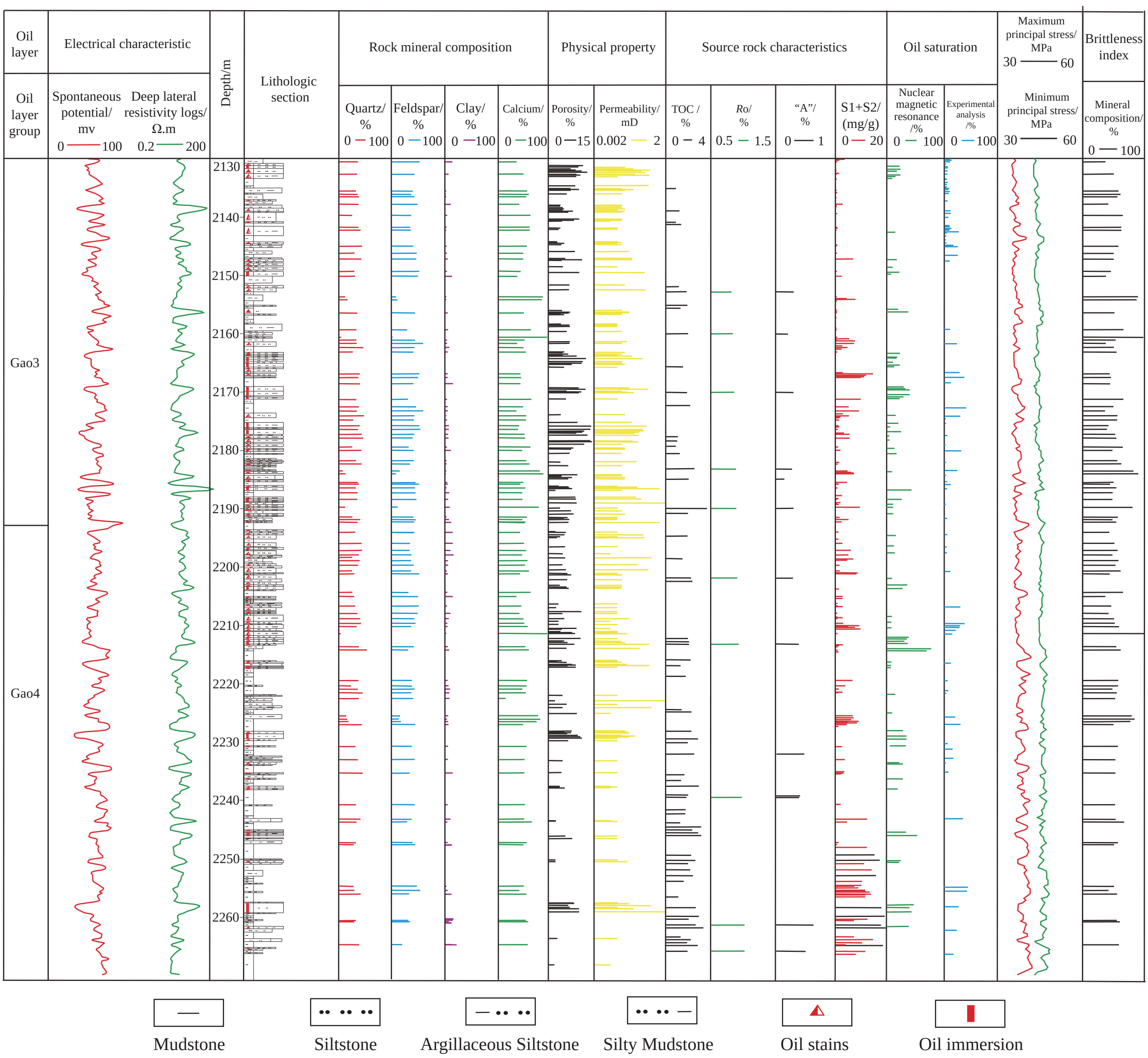

Fig. 13. Single well composite bar chart of tight oil layer in Gao3 and Gao4 reservoir, Qijia area.

core of evaluation, the classification and evaluation criteria of tight oil reservoirs in the Qijia area are preliminarily established. Gao3 and Gao4 oil layer groups in the Qijia area mainly consist of tight oils I and II.

CRediT authorship contribution statement

Li-zhi Shi and Zhuo-zhuo Wang: Conceiving the presented idea, wring-original draft, discussion. Zhan-tao Xing: Collecting data, discussion. Shan Meng and Shuai Guo: discussion. Li-yan Luo and Si-Miao Wu: Editing the geological map. All authors discussed the results and contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflicts of interest.

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